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Optimization of biodiesel production and engine performance from high free fatty acid *Calophyllum inophyllum* oil in CI diesel engine

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A B S T R A C T

In the present study, crude *Calophyllum inophyllum* oil (CCIO) has been evaluated as a potential feedstock for biodiesel production. *C. inophyllum* oil has high acid value which is 59.30 mg KOH/g. Therefore, the degumming, esterification, neutralization and transesterification process are carried out to reduce the acid value to 0.34 mg KOH/g. The optimum yield was obtained at 9:1 methanol to oil ratio with 1 wt.%. NaOH catalyst at 50 °C for 2 h. On the other hand, the *C. inophyllum* biodiesel properties fulfilled the specification of ASTM D6751 and EN 14214 biodiesel standards. After that, the *C. inophyllum* biodiesel diesel blends were tested to evaluate the engine performance and emission characteristic. The performance and emission of 10% *C. inophyllum* biodiesel blends (CIB10) give a satisfactory result in diesel engines as the brake thermal increase 2.30% and fuel consumption decrease 3.06% compared to diesel. Besides, CIB10 reduces CO and smoke opacity compared to diesel. In short, *C. inophyllum* biodiesel can become an alternative fuel in the future.

1. Introduction

The fossil fuel resources are dwindling day by day. Biodiesel is one of the possible solutions to overcome oil shortage and environmental issue [1]. Biodiesel have low volatility due to high molecular weight of the triglyceride molecule and have a narrow range of viscosity changes with temperature [2]. Biodiesel is a clean burning alternative fuel was produced from renewable resources like virgin or used vegetable oils, both edible and non-edible [3,4]. Biodiesel is obtained from the chemical transformation of oils (triglycerides) by a transesterification process and many oleaginous vegetable species [5]. However, biodiesel produced from edible oils raised the concerns of feedstock competing with food supply in the long-term [6]. Therefore, non-edible oils resources are gaining worldwide attention as it is easily available in many parts of the world especially wastelands that are not suitable for food crops [7]. Besides, the use of biodiesel in diesel engines results in substantial reduction of harmful emission such as unburned hydrocarbons, carbon monoxide and particulate matters [8,9].

There are many ways and procedures to biodiesel fuel from vegetable oil such as pyrolysis, dilution, microemulsion and transesterification [10]. The transesterification process is the most viable and economical process [11]. Transesterification process is using an alcohol (methanol, ethanol or propanol) with the presence of alkali catalyst (sodium hydroxide or potassium hydroxide) to break the molecule of the vegetable oil into methyl or ethyl esters chemically with glycerol as a byproduct [12]. Biodiesel produced via transesterification process has proven to be a viable alternative fuel with similar characteristics to diesel fuel [13]. Besides, some researchers are using two-step esterification and transesterification processes in producing biodiesel from crude oils with high free fatty acid (FFA) [14]. Dhar et al. [15] reported that high FFA of neem oil (20.3%) was converted to methyl ester using two-step esterification and transesterification process. As a result, the important properties of the biodiesel were within the ASTM biodiesel specification. Jena et al. [16] investigated that acid pretreatment and base transesterification reaction process

Abbreviations: ASTM, American society for testing and materials; Bsfc, brake specific fuel consumption; BTE, brake thermal efficiency; CCIO, crude *Calophyllum inophyllum* oil; CI, compression ignition; CIB, *Calophyllum inophyllum* biodiesel blends; CIB10, *Calophyllum inophyllum* blending 10%; CIB20, *Calophyllum inophyllum* blending 20%; CIB30, *Calophyllum inophyllum* blending 30%; CIB50, *Calophyllum inophyllum* blending 50%; CIME, *Calophyllum inophyllum* methyl ester; CO, carbon monoxide; DOE, design of experiment; EN, European standard; EGT, exhaust gas temperature; FFA, free fatty acid; FAME, fatty acid methyl ester; H_2SO_4, sulfuric acid; H_3PO_4, phosphoric acid; HSU, Hartridge smoke units; NaOH, sodium hydroxide; $NaHCO_3$, sodium bicarbonate; NO_x, nitrogen oxide; ppm, parts per million.

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is suitable for biodiesel production from mixture of mahua and simarouba oils with high FFA. The yield of biodiesel and ester conversion was around 98% and 90% respectively.

In this study, non-edible "*Calophyllum inophyllum*" oil was investigated as a potential feedstock for biodiesel production. *C. inophyllum* is a multipurpose tree belonging to the family *Clusiaceae*, commonly known as mangosteen family [17]. This plant has multiple origins including East Africa, India, South East Asia, Australia, and the South Pacific [18]. Fig. 1 shows the distribution map of *C. inophyllum* around the world. It grows in areas with an annual rain of 1000–5000 mm at altitudes from 0 to 200 m. *C. inophyllum* is a low-branching and slow-growing tree which grows best in sandy and well drained soils. Its sizes typically ranges between 8 and 20 m (25–65 ft) tall at maturity, sometimes reaching up to 35 m (115 ft) [19]. In each fruit, it consists one large brown seed with 2–4 cm (0.8–1.6 in.) in diameter [20]. *C. inophyllum* tree can be planted at a density of 400 tree/ha with an average oil yield of 11.7 kg/tree or 4680 kg/ha [11]. Traditionally, its oil has been used as a medicine, soap, lamp oil, hair grease and cosmetic in different parts of the world [21]. Fig. 2 shows *C. inophyllum* tree, fruit, seeds and kernels.

The objective of this study is to produce biodiesel from crude *C. inophyllum* oil using H_2SO_4 as acid catalyst and NaOH as alkaline catalyst. After that, the optimization of *C. inophyllum* methyl ester production was studied and its properties as biofuel were analyzed based on ASTM D6751 and EN 14214 biodiesel standards. On top of that, a *C. inophyllum* biodiesel diesel blend properties were tested and the performance and emission characteristic were conducted in a direct injection diesel engine. It is notable that this study suggests a novel alternative biodiesel feedstock as energy source in compression ignition engine.

2. Methodology

2.1. Extraction of C. inophyllum seed oil

C. inophyllum seeds were collected from Kebumen, Center Java, Indonesia. After that, the seeds were dried under sunlight until the color of the seeds turn into red-brown. The ideal conditions to preserve the kernel are 26–27 °C and 60–70% humidity. Hydraulic machine is used to extract the oil from *C. inophyllum* kernel seed. The remaining seed cake after extraction has high commercial value and can be used either for agricultural or industrial applications. The *C. inophyllum* oil extracted was found to contain many impurities and chemical compound. Therefore, it is important to undergo a degumming process before converting crude *C. inophyllum* oil to biodiesel. The flow chart shown in Fig. 3 is the methodology applied for *C. inophyllum* biodiesel production process.

2.2. Degumming process

Gum contains phosphate, protein, carbohydrate, water residue and resin. In order to improve the oxidization stability of the final product, the oil is separated from the gums through the degumming process. In this process, the crude oil was heated at a temperature of 60 °C and stirring speed of 1000 rpm. Then, 0.5 vol.% of phosphoric acid (H_3PO_4, 20% concentration) was added to the preheated crude oil. The process was continued with stirring and the temperature maintained at 60 °C for 30 min. After that, this mixture was separated by density separation process using a separating funnel for at least 4 h in which the phosphate compounds resided at the bottom. These gums were separated from the oil and washed several times with distilled water at 40 °C. After washing, water was evaporated with vacuum pump for 30 min to avoid the oxidization of oil.

2.3. Esterification process

The degummed *C. inophyllum* oil has high content of FFA and viscosity. The maximum limit of FFA amount is 2 wt.%. and below. Therefore, a pretreatment process using acid catalyzed esterification is required for the crude oil with high FFA content before the transesterification process. Thus, sulfuric acid (H_2SO_4) is used to convert and reduce the FFA content to below 2 wt.%. in the oil. Therefore, two step processes of acid catalyzed esterification

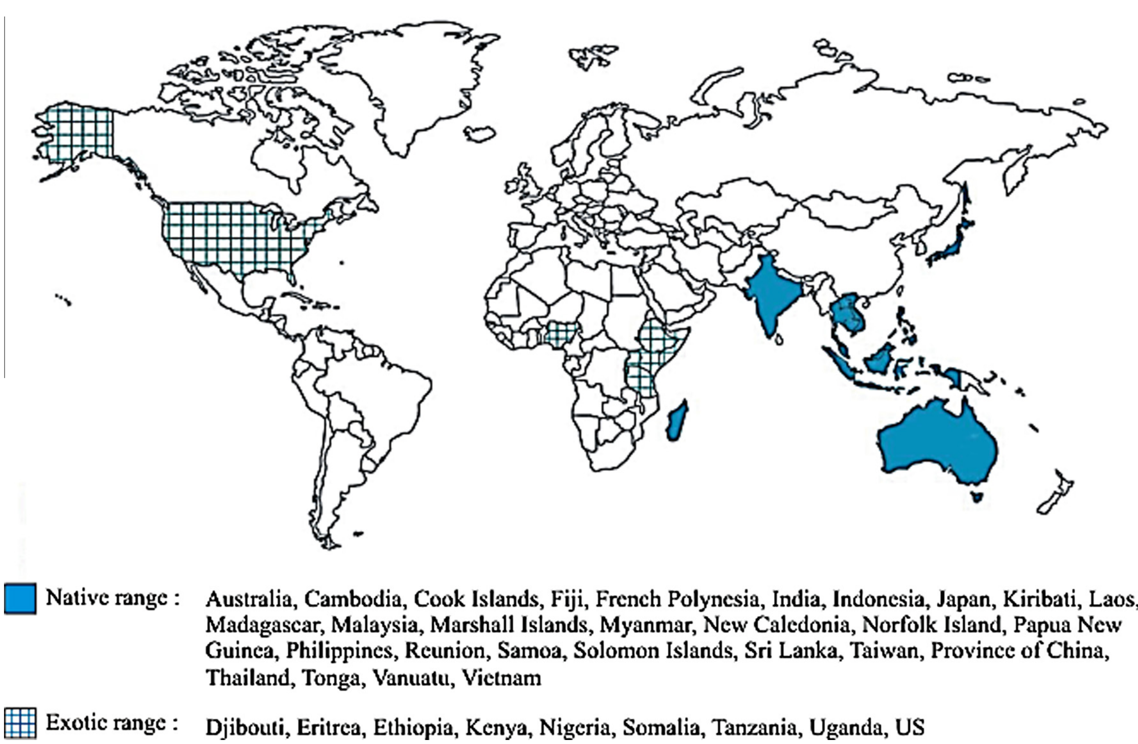

Fig. 1. Distribution of *Calophyllum inophyllum* tree around the world.