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Investigations of red mud as a catalyst in Mahua oil biodiesel production and its engine performance

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ABSTRACT

Biodiesel productions from Mahua oil using two different catalysts, including KOH and activated red mud by catalytic cracking (waste from aluminum industry) were compared in distinctive blends of diesel fuel. Red mud was subjected to characterization studies to find the mechanism of red mud during catalytic cracking using Energy Dispersive Spectroscopy (EDS) and Scanning Electron Microscope (SEM). The cracking process was carried at 300 °C for 2 h and different blends of biodiesel (B25, B50, B75, and B100) were examined for physical properties. Furthermore, the different blends were subjected to a four-stroke diesel engine to study its engine performance. The results showed that the changes in elemental composition during EDS analysis could be an important reason for red mud to have a better calorific value (10,601 kcal/kg) compared to KOH as a catalyst. The NO_x emission from KOH biodiesel was 7.5% higher compared to red mud biodiesel when it was blended 100% at 1500 RPM at a maximum brake power (5.2 kW). From the findings of this study, it was evident that using red mud as a catalyst not just increases most of the properties of the fuel, but also reduces the stress on the environment in the form of less emission and fuel consumption. Since red mud was a hazardous waste from aluminum industry, utilizing it for biodiesel productions could also be an economically viable option.

1. Introduction

In India, diesel was mainly consumed as oil in 2013. It accounts for 42% of the total petroleum consumption in the country. During the same period, per day petroleum consumption was 418,414 m^3/day placed after China and Japan in Asia. The petroleum products' consumption has increased to more than 14% over the last five years [1]. While the need for the consumption is steadily increasing as witnessed, the fossil-fuel depletion poses an alarming question on sustainability and the need for the future.

Some of the possible alternative fuels include biogas, ethanol, and biodiesel of which the latter two are mainly used in the transportation sector [2]. Both fuels have been produced from energy crops, such as jatropha, maize, and vegetable oils (soybean oil, Mahua oil). [3] Biodiesel production in India was 268-m^3/day in 2012, accounting for 0.06% share of the total petroleum consumed during the same period [4,5]. The share of renewable is negligible, due to the reason which concerns over its profitability. The sustainability aspect of biodiesel depends on how economic and environmental friendly a process is.

Biodiesel is produced by the transesterification of fats and oil composed of triglycerides. During the transesterification process, an alcohol is added to fats and oil for the production of mono-alkyl ester and crude glycerol [6,7]. The mono-alkyl ester possesses the physical properties equivalent to fossil-fuel diesel. However, this reaction is not a spontaneous reaction and requires the addition of catalysts such as sodium hydroxide, potassium hydroxide, and sodium methoxide [8]. The cost of the catalyst plays an important role in the overall economy of the process. Reducing the cost of the catalyst thus, can increase the commercial acceptance of biodiesel globally. For that reason, the needs for alternative catalysts are inevitable.

The catalyst for biodiesel production should either be an alkali or acid [9,10]. One such alkali is red mud, which is the solid waste formed after the digestion of bauxite for the production of alumina [11,12]. About 90 million tons of red mud is produced globally, leaving an impact that utilizing the waste from one process and improving another process could lead an example to a better and efficient environment. Red mud has an alkaline pH in the range of 10–13, which is mainly due to the sodium hydroxide used in the processing of alumina [11,13]. It has aluminum, iron, silicon, titanium oxide and hydroxides, and it is regarded as a hazardous waste [14,15]. The alkalinity in red mud can be used as a catalyst for biodiesel production [15]. Previously, Liu et al. [11] has mentioned the application of red mud as a catalyst for biodiesel production from soybean oil.

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Table 1
Specifications of the diesel engine used in this study.

Specification	Description
Type	Single cylinder, vertical, water cooled, 4 stroke diesel engine
Bore	87.5
Compression ratio	17.5:1
Orifice diameter	20 mm
Dynamometer arm length	0.195 m
Power	5.2 kw (7 HP)
Speed	1500 rpm
Bore × Stroke	87.5 mm × 110 mm

In this work, biodiesel production from Mahua oil was explored with the addition of red mud as a catalyst. According to the author's knowledge, no earlier works have been reported in the literature on testing the engine performance using red mud as a catalyst for Mahua-oil biodiesel production. In addition, the effect of different percentages of blending red-mud activated Mahua oil biodiesel with fossil-fuel diesel was investigated.

2. Materials and methods

2.1. Materials and chemicals

In this work, Mahua oil was used to produce biodiesel. Mahua oil was obtained from a local Ayurveda shop. Red mud was collected from an aluminum industry in Salem, India. Methanol was used as an alcohol source and potassium hydroxide was used as one of the catalysts in biodiesel productions. For activating the red mud, it was sieved first to a size less than 10 mm and was kept in an oven at a temperature range of 100–150 °C for 12 h.

2.2. Biodiesel preparations

Two different types of biodiesel were prepared in this study, which compare the effect of the conventional catalyst, i.e., potassium hydroxide and the cracked red mud. The red mud should be catalytically cracked or calcinated i.e., heating it at higher temperatures (200–1000 °C) with the presence of oxygen, in order to remove water or carbon dioxide or to oxidize a substance either partly/fully [11]. The calcination or catalytic cracking process changes the physical and chemical composition of the substance, which might be used as a catalyst. The possible changes that could occur during catalytic cracking include increase in surface area, pore volume and average pore diameter. Previously, it was reported that reduction of iron oxides in red mud could be used as an active catalyst for hydrocarbon decomposition [16]. During the cracking of red mud, it is expected that the available carbon increases due to the breakdown [11,17].

The catalytic cracking was performed using a catalytic reactor at temperature 300 °C for 2 h. For the biodiesel preparation, 1 L of Mahua oil was mixed with 0.2 L of methanol and transesterification reaction was carried out in a catalytic reactor at 60 °C for 30 min. The catalysts used were KOH and cracked red mud, respectively, which was used in the concentrations of 15 g/L of Mahua oil. Post to the transesterification reaction, the vapors were condensed and collected in a fuel collection tank. The collected biodiesel mixture was subjected to further analysis as described later. For every liter of Mahua oil used, about 0.8 L biodiesel was collected as a final product.

2.3. Red mud characterization studies

This main objective of this study was to show the use of red mud as a catalyst. For this purpose, it was necessary to study its characterization before and after activation of red mud at elevated temperatures. This could help to identify the importance of structural and chemical

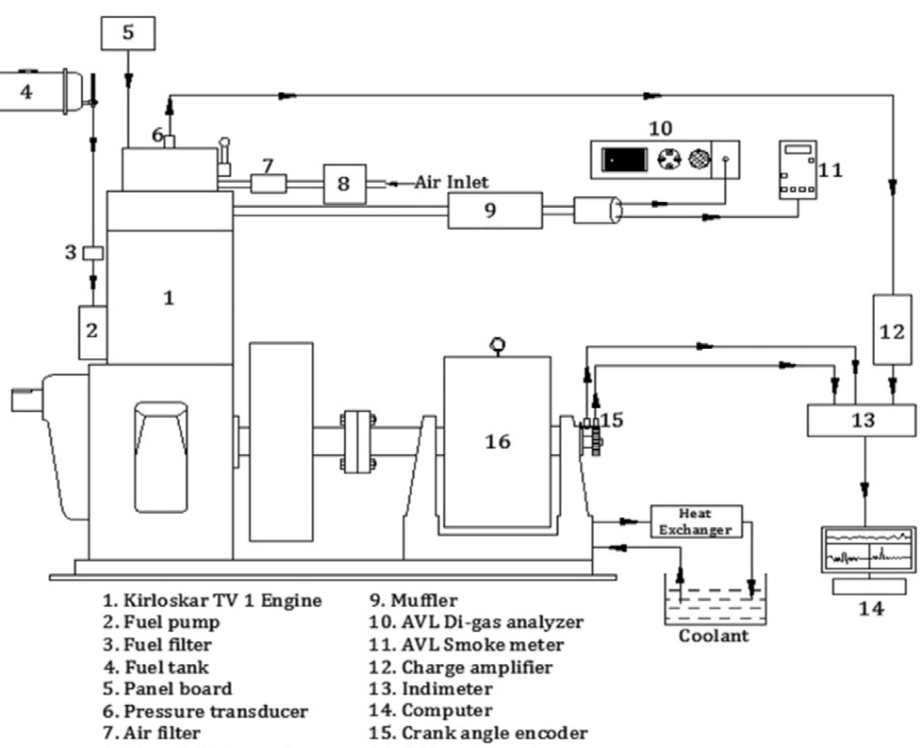

Fig. 1. Experimental setup of the diesel engine used.