Engineering Science and Technology, an International Journal 19 (2016) 1018–1026

HOSTED BY

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

journal homepage: http://www.elsevier.com/locate/jestch

Review

# Exploration of waste cooking oil methyl esters (WCOME) as fuel in compression ignition engines: A critical review

S. Kathirvel [a,*], Apurba Layek [a], S. Muthuraman [b]

[a] Department of Mechanical Engineering, National Institute of Technology Durgapur, Durgapur, West Bengal, India
[b] Department of Mechanical Engineering, Higher College of Technology, Muscat, Oman

ARTICLE INFO

*Article history:*
Received 25 September 2015
Received in revised form
30 December 2015
Accepted 12 January 2016
Available online 4 February 2016

*Keywords:*
WCOME
Biodiesel
Compression ignition engines
Performance
Combustion and emission parameters

ABSTRACT

The ever growing human population and the corresponding economic development of mankind have caused a relentless surge in the energy demand of the world. The fast diminishing fossil fuel reserves and the overdependence of petroleum based fuels have already prompted the world to look for alternate sources of energy to offset the fuel crisis in the future. Waste Cooking Oil Methyl Ester (WCOME) has proven itself as a viable alternate fuel that can be used in Compression Ignition (CI) engines due to its low cost, non-toxicity, biodegradability and renewable nature. It also contributes a minimum amount of net greenhouse gases, such as $CO_2$, $SO_2$ and NO emissions to the atmosphere. The main objective of this paper is to focus on the study of the performance, combustion and emission parameters of CI engines using WCOME and to explore the possibility of utilizing WCOME blends with diesel extensively in place of diesel. The production methods used for transesterification play a vital role in the physiochemical properties of the methyl esters produced. Various production intensification technologies such as hydrodynamic cavitation and ultrasonic cavitation were employed to improve the yield of the methyl esters during transesterification. This review includes the study of WCOME from different origins in various types of diesel engines. Most of the studies comply with the decrease in carbon monoxide (CO) emissions and the increase in brake thermal efficiency while using WCOME in CI engines. Many researchers reported slight increase in the emissions of oxides of nitrogen. ANN modeling has been widely used to predict the process variables of the diesel engine while using WCOME. The versatility of ANN modeling was proven by the minimum error percentages of the actual and predicted values of the performance and emission characteristics.



## 1. Introduction

The search for useful energy and the desire to have a clean and green environment remain always a vital point of interest for any researcher. The fast depleting petroleum reserves have already waved a warning signal all around the globe to look for alternate means to cater to the ever increasing needs of energy. Further, the harmful emissions of fossil fuels also need to be taken care of. Biodiesel made from different renewable sources has become a viable alternative for use as a fuel in Compression Ignition (CI) engines. Biodiesel is referred to as mono-alkyl esters of long chain fatty acids. With the help of a chemical process known as transesterification, the biodiesel is produced from vegetable oils and is used on unmodified compression ignition (CI) engines [1–3]. The variation of the percentage concentration of methyl esters in the biodiesel from different sources leads to considerable changes in the physical and chemical properties of the biodiesel which in turn affects the characteristics of the engine used [4].

Biodiesels from various feedstocks have been tried by different researchers [2,5–12] to study and analyze the performance, emission and combustion characteristics of the CI engine. Encouraging results such as decrease in hydrocarbon (HC) emissions, less pronounced decrease in brake power (BP) and increase in brake specific fuel consumption (BSFC) have been reported. However, the major obstacle in commercializing biodiesel produced from vegetable oil and animal fat is the cost of its production.

Meanwhile, an enormous quantity of used cooking oil is being wasted around the world. Disposal of such oil remains again a matter of concern as many pollution-related problems arise while dumping such stuff in rivers and landfills. This also leads to issues in the maintenance of the ecological balance. The best way to avoid contamination of the waste cooking oil (WCO) is to produce waste cooking oil methyl esters (WCOME) [13–15] and use it as biodiesel in CI engines. Hence, biodiesel produced from waste fried oil or the waste cooking oil is gaining momentum in most parts of the world as a cheaper alternative for pure diesel.

* Corresponding author. Tel.: +919488726288; fax: +919600902364.
*E-mail address:* kathirnitd@gmail.com (S. Kathirvel).
Peer review under responsibility of Karabuk University.

http://dx.doi.org/10.1016/j.jestch.2016.01.007
2215-0986/

Several works using WCOME as the fuel in CI engines have been reported in the literature. Waste cooking oil methyl esters from different origins were used as fuel for diesel engines to study their effects. Kalam et al. [14] experimented with waste cooking oil from two different origins like palm oil and coconut oil with blends of 5% of waste oil and 95% of pure diesel and analyzed the emission and performance characteristics of a 4 cylinder, four stroke, naturally aspirated, indirect ignition diesel engine. Ahmed et al. [16] used Mustard Biodiesel (MB) extracted from waste mustard oil in an inline four-cylinder, Mitsubishi Pajero engine and explored the performance, emission and noise characteristics. Different production technologies employed for methyl ester extraction from the waste oils also influence the performance and emission characteristics of the engines used. Chuah et al. [17] used hydrodynamic cavitation technology to extract methyl esters from palm olein with a high percentage of extraction of more than 96.5% and showed that such intensification technologies make a greater impact in the fuel properties thereby affecting the performance and emission characteristics of the diesel engines.

Even though many reviews [1,18–22] based on the use of biodiesel as a fuel are in existence, a specific review focusing on the use of biodiesel originated from waste cooking oil as the fuel is still missing. This paper is a serious attempt to fill such a gap by critically reviewing the major results of the recent works available in the literature.

## 2. Waste Cooking Oil Biodiesel

Waste cooking Biodiesel or Waste cooking oil Methyl Ester (WCOME) has all the making of a viable alternate for use in CI engines due to its characteristic to reduce emissions and the scope it extends to alleviate the overdependence on fossil fuels. The physiochemical properties of WCOME are tabulated in Table 1 for comparison. Even though there are many existing methods of producing biodiesel from WCO, Transesterification remains as a popular choice for many researchers. Transesterification is a chemical process in which organically derived oils (vegetable oils, animal fats and recycled waste cooking or frying oils) are combined with alcohol to form fatty esters such as methyl/ethyl esters. Transesterification reaction, also known as alcoholysis, is based on one mole of triglyceride reacting with three moles of methanol to produce three moles of methyl ester, which is known as biodiesel. The Transesterification process is normally carried out with some catalysts to improve the reaction rate and yield. In some cases, catalyst free process is also employed. The catalyst can be alkaline or acidic or may be homogeneous or heterogeneous based on its nature. Problems like separation of products from reactants and formation of soap that shoot up the operating cost of the process are some facts that act against using homogenous catalysts, whereas nonformation of soap and easier separation methods help heterogeneous catalysts to become more popular for the transesterification process [23,24].

Alkali metals supported by the silica of Rice Husk Ash (RHA) can also be used as catalysts for the transesterification process.

**Table 1**
Comparison of WCOME properties with diesel.

| Sl no. | Fuel properties | Diesel | Biodiesel |
|---|---|---|---|
| 1 | Fuel standard | ASTM D 975 | ASTM D 6751 |
| 2 | Fuel composition | $C_{10-21}$ HC | $C_{12-22}$FAME |
| 3 | Lower heating value (MJ/kg) | 42.49 | 39.6 |
| 4 | Kinematic viscosity(CST) at 30 °C | 4.59 | 1.9–6.0 |
| 5 | Density at 15 °C (kg/m$^3$) | 840 | 880 |
| 6 | Flash point (°C) | 52–96 | 273 |
| 7 | Cetane number | 45 | 37 |
| 8 | Auto ignition temperature (°C) | 260 | 300 |

Hindryawati et al. [25] used silica of rice husk ash as a supporting material for alkali metals such as Lithium (Li), Sodium (Na) and Potassium (K) to examine the reaction parameters like the amount of catalyst added, duration of reaction, molar ratio of methanol to oil and the reaction temperature. The author successfully applied the impregnation of alkali metals in silica and reported that the catalyst can be reused again for six times as it was proven very easy to separate the catalyst from the reaction solution.

A lot of researchers have explored different production methods to study the impact of different critical parameters of the reaction. Amani et al. [26] investigated the potential of using Cesium impregnated silica as the heterogeneous catalyst for the transesterification reaction of waste cooking palm oil (WCPO) and palm oil (PO). The author used various combinations of Cesium loadings, the methanol-to-oil molar ratios, catalyst loading, reaction time and water content to study their influence on the process variables of the reaction. Detailed characterization of the catalyst was carried out by the authors and 25% of cesium on silica was reported to result in a maximum yield of 90% within a short reaction time of 3 hours at 65 °C with 3 wt % of catalyst loading.

Sneha et al. [27] synthesized a heterogeneous catalyst of 25% Potassium Bromide impregnated in CaO using wet impregnation method for the transesterification process. Fourier Transform Infrared spectrometry (FTIR), X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) techniques were used for the characterization of the catalyst, and Gas Chromatography–Mass Spectrometry (GC–MS) was used to ascertain the composition of the methyl esters formed. The author varied the process parameters of the transesterification method like catalyst loading, reaction time, and methanol to oil molar ratio to analyze their effect in the yield of the methyl esters with the help of Response Surface Modeling (RSM). The transesterified biodiesel was used in a four stroke, direct injection diesel engine with different blends. Less emission was observed for B10 and B20 blends while the brake thermal efficiency increased compared to the pure diesel.

Mechanical stirring methods are handicapped by the long reaction time and lower yield efficiency due to the mass transfer resistance of the immiscible reactants. Hence, many intensification technologies were experimented in the conversion of methyl esters from waste oils of different origins. Microwave assisted intensification [28], hydrodynamic cavitation (HC) [17], ultrasonic cavitation [29] etc., are some of the methods tried by various researchers. Gupta et al. [30] explored the impact of the process parameters of the transesterification reaction using calcium diglyceroxide (CaDG) as a heterogeneous catalyst. The ultrasonic irradiation was used to intensify the reaction, and the parameters like reaction temperature, catalyst loading, methanol to oil molar ratio, ultrasonic and duty cycle on the progress of the reaction were varied to determine the optimum set of variables. Methanol to oil molar ratio of 9:1, catalyst loading of 1% (w/w) of waste cooking oil, reaction temperature of 60 °C, low intensity ultrasonic power of 120 W and 50% duty cycle were found as optimal conditions for the reaction and a maximum biodiesel yield of 93.5% was reported. The conventional stirring method was also compared with the ultrasonic assisted reaction process, and the improvement of the resultant biodiesel properties was highlighted.

Chuah et al. [31] examined the conversion of methyl esters from waste cooking oil from palm olein and refined cooking oil using hydrodynamic cavitation technology. The author studied the impact of the inlet pressure and the geometry of the orifice plate on the yield % and the reaction time of the conversion process. It was reported that 8 times more energy efficiency and 6 times less reaction time were achieved with the optimized orifice plate geometry that had 21 holes for each 1 mm diameter.

The effect of the major operating parameters in methyl ester conversion with hydrodynamic cavitation was further analyzed by Chuah