Energy Conversion and Management 156 (2018) 337–357

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

A comparative assessment of ternary blends of three bio-alcohols with waste cooking oil and diesel for optimum emissions and performance in a CI engine using response surface methodology

V. Krishnamoorthy[a], R. Dhanasekaran[a,b,*], D. Rana[c], S. Saravanan[d], B. Rajesh Kumar[d,*]

[a] Department of Mechanical Engineering, Jeppiaar Maamallan Engineering College, Chennai, TN, India
[b] Centre for Research, Sathyabama University, Chennai, TN, India
[c] Department of Chemical and Biological Engineering, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada
[d] Department of Mechanical Engineering, Sri Venkateswara College of Engineering, Chennai, TN, India

ARTICLE INFO

Keywords:
Exhaust emissions
Engine optimization
Waste cooking oil
Yellow grease
Ternary blend
Butanol

ABSTRACT

Recycling waste cooking oil (WCO) for use in diesel engines offers a sustainable solution for ecological wellbeing and energy security. Diesel-WCO-alcohol ternary blends provide a straightforward and cost-effective opportunity to utilise both a bio-component & a recycled component to partially replace diesel and to reduce viscosity of WCO instead of expensive pre-heating and trans-esterification. Three bio-alcohols, *n*-propanol (Pr), *n*-butanol (Bu) and *n*-pentanol (Pe) were chosen for this purpose. An investigation was carried out to compare the effects of adding three bio-alcohols to form ternary blends with WCO and diesel (D) individually (D50-WCO30-Pr20, D50-WCO30-Bu20 and D50-WCO30-Pe20) for optimum engine characteristics by employing a response surface methodology (RSM) based optimization using a 3-factor × 3-level full factorial experimental design. Three alcohols, three injection timings (23°, 25° and 27°CA bTDC) and three EGR rates (10, 20 and 30%) were chosen as factors and their levels. Regression models were developed for NOx, smoke, HC, CO, BTE and BSFC and were found to be statistically significant. Interactive effects between injection timing and EGR for all blends were presented. Pentanol was found to be a suitable alcohol for this purpose as the ternary blend D50-WCO30-Pe20 injected at 23°CA bTDC at 15% EGR had the highest desirability. Confirmatory tests validated that the models developed were adequate and the error in prediction is within 6%.

1. Introduction

Despite proven as 'workhorses' that deliver high fuel conversion efficiency with unmatched torque capability and durability, diesel engines were dubbed as 'dirty' as they produce high NOx and particulate emissions that were perilous to both human health and ecosystem when fueled with fossil diesel [1]. According to an estimate, crude oil reserves are depleting at a rate of 2.1% every year [2], and hence researchers are in pursuit of alternative sources for powering diesel engines that play a vital role in transportation, power generation and heavy duty machinery.

Recycling is one of the key aspects for achieving environmental sustainability. Several billion gallons of waste cooking oil (WCO) were discarded every year globally [3]. Nevertheless WCO poses a serious hazard to the environment when it is not disposed properly. WCO can congest and contaminate water passages. It poses a potential health hazard by re-entering into human food-chain via edible aquatic life. WCO disposed in drainage can complicate the normal processing in waste water treatment plants [4]. Treating and recycling WCO for use in diesel engines offers a sustainable solution for ecological wellbeing and energy security [5]. As an additional benefit, WCO is inexpensive and all the costs incurred would be in collecting and treating only [6]. Recycling WCO as an alternative fuel for diesel engines also presents a promising avenue to reduce dependency on depleting fossil oil reserves. Though diesel engine was originally conceived to be run in vegetable oils by its inventor Rudolf Diesel [7], direct use of vegetable oil in modern diesel engines presents some complications like fuel filter clogging, injector coking, heavy carbon deposits in engine parts, piston-ring sticking, lubrication oil gelling and excessive engine wear [3,5,6,8]. WCO has high viscosity and low volatility which results in poor atomization, vaporisation, and fuel-air mixing causing high particulates in diesel engines [3]. Methods like pre-heating WCO or trans-esterifying WCO to biodiesel were popularly used to manage these problems [9]. Preheating involves extra energy expenditure that lowers

* Corresponding authors at: Department of Mechanical Engineering, Jeppiaar Maamallan Engineering College, Chennai, TN, India (R. Dhanasekaran).
E-mail addresses: dhan_mit@rediffmail.com (R. Dhanasekaran), rajeshb@mail.fresnostate.edu (B. Rajesh Kumar).

https://doi.org/10.1016/j.enconman.2017.10.087
Received 10 September 2017; Received in revised form 27 October 2017; Accepted 28 October 2017
0196-8904/ © 2017 Elsevier Ltd. All rights reserved.

Table 1
Fuel properties [22].

Properties	Diesel	*n*-Propanol	*n*-Butanol	*n*-Pentanol
Molecular formula	C_XH_Y	C_3H_7-OH	C_4H_9-OH	C_5H_{11}-OH
Molecular weight (kg/kmol)	190–211.7	60.9	74.12	88.15
C (%wt)	86.13	59.96	64.82	68.13
H (%wt)	13.87	13.31	13.49	13.61
O (%wt)	0	26.62	21.59	18.15
Cetane number	≈ 50	12	17	20
Self-ignition temperature (°C)	≈ 300	350	345	320
Density (kg/m^3) at 15 °C	835	803.7	809.7	814.8
Viscosity at 25 °C m·Pa·s	1.9–4.1	1.74	2.22	2.89
Lower heating value (MJ/kg)	42.49	30.63	33.09	34.65
Latent heat of evaporation (kJ/kg)	256	727.88	684	308.05
Vapor pressure (mmHg)	0.4	20	7	6
Boiling point (°C)	180–360	97.1	117.5	137.9
Flash point (°C)	> 55	11.7	36	49

Table 2
Chemical properties of WCO.

C (%wt)	78.57%
H (%wt)	12.96%
O (%wt)	8.47%
Iodine value (IV) in g/100 g of oil	55
Saponification number (SN) in mg of KOH/g of oil	261.092
Acid value (AV) in mg of KOH/g of oil	3.5432
Free fatty acid (FFA) content in %	2.127
Moisture content in %	0.3237
Lower heating value (LHV) in MJ/kg	37.68
Kinematic viscosity (ν) at 30 °C in mm^2/s	52
Density (ρ) in kg/m^3	900
CN	54.8
Flash point in °C	271

the gross efficiency of the system. Trans-esterification of WCO to biodiesel is a time consuming, complex and expensive process that also produces glycerine as a by-product which has to be again disposed carefully [10].

Recently reformulating WCO with alcohols has gained interest among researchers as it is a simple, straightforward and inexpensive method to reduce the viscosity of vegetable oils [11–18]. Studies have shown that ternary blends of waste cooking oil with diesel and alcohol have low viscosity, better cetane number and density closer to diesel [14–18]. The significance of ternary blends lies in the fact that it improves environmental safety and energy security by partially replacing diesel with a recycled component like WCO and a renewable bio-derived component like alcohol. Some properties of the alcohol are listed in Table 1 in comparison with diesel. Syntheses of alcohols by sustainable means are devised using biochemical, genetic, and metabolic engineering strategies utilising a novel engineered micro-organism *Escherichia coli* [19–21].

Several studies have analysed virgin vegetable oil as a ternary blend component with diesel and alcohol. Lujaji et al. [13] reported higher cylinder, higher heat release rates, higher energy consumption, lower BTE, lower NOx and lower smoke emissions with croton-oil, butanol and diesel ternary blends when compared to diesel. Atmanli et al. [11] suggested that a ternary blend consisting of 70% diesel fuel, 20% cotton oil and 10% *n*-butanol has satisfactory fuel properties with low engine emissions in a four-cylinder, turbo-charged direct-injection diesel engine. Atmanli et al. [15] also affirmed that NOx emissions increased with high volume butanol addition to vegetable oil/diesel blends. Later Atmanli et al. [16] evaluated six ternary blends of canola oil/*n*-butanol/diesel, soybean oil/*n*-butanol/diesel, sunflower oil/*n*-butanol/diesel, corn oil/*n*-butanol/diesel, olive oil/*n*-butanol/diesel, and hazelnut oil/*n*-butanol/diesel in the same engine and recorded loss in efficiency and fuel consumption of the engine.

The concept of ternary blend formulation was not only attempted with vegetable oils but also extended to biodiesels derived from them and favourable results have been reported [23,24]. Li et al. [23] showed that addition of pentanol to biodiesel/diesel improved emissions and performance especially at low/medium loads. A ternary blend containing diesel (40%), biodiesel (30%) and pentanol (30%) delivered good combustion, performance and emissions. Imdadul et al. [24] obtained optimum emissions and performance with 15–20% addition of *n*-pentanol with Calophyllum biodiesel/diesel blends in a DI diesel engine. Later, Atmanli [17] used a cetane improver with ternary blends of n-butanol/hazelnut-oil/diesel & *n*-pentanol/hazelnut-oil/diesel and obtained less NOx and fuel consumption. Atmanli et al. [25] employed a response surface methodology based optimization for determining an

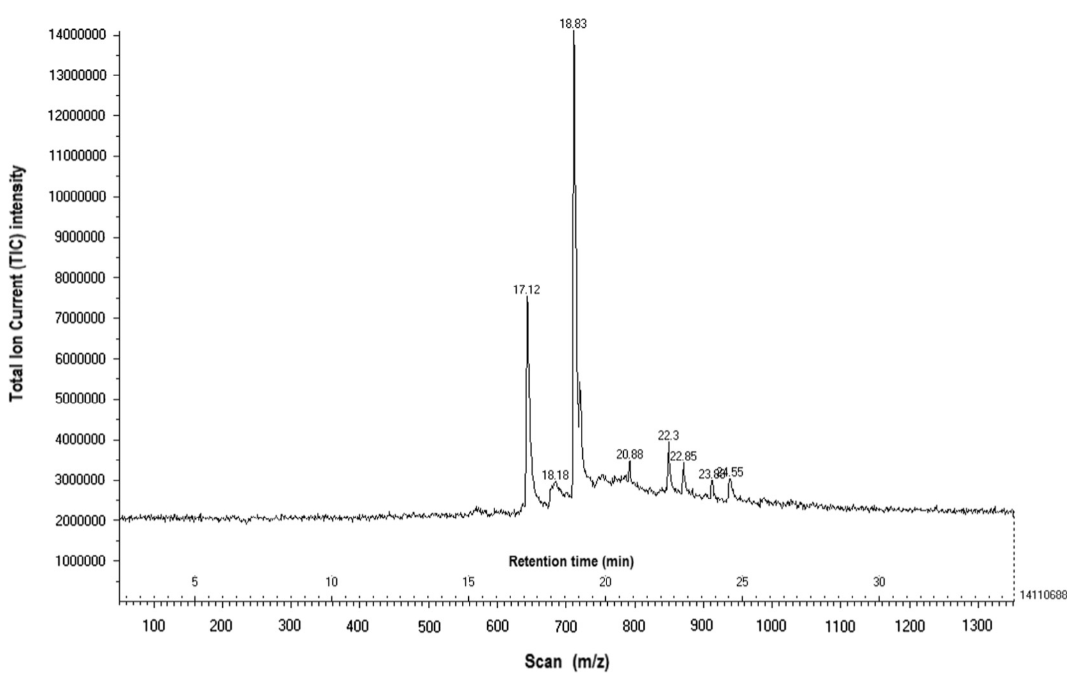

Fig. 1. Total Ion Current (TIC) Chromatogram of a GC–MS analysis for waste cooking oil.

Download English Version:

https://daneshyari.com/en/article/7159493

Download Persian Version:

https://daneshyari.com/article/7159493

Daneshyari.com