Energy Conversion and Management 169 (2018) 291–314

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Nano-additives incorporated water in diesel emulsion fuel: Fuel properties, performance and emission characteristics assessment

A.K. Hasannuddin[a], W.J. Yahya[a,*], S. Sarah[a], A.M. Ithnin[a], S. Syahrullail[b], N.A.C. Sidik[c], K.A. Abu Kassim[d], Y. Ahmad[d], N. Hirofumi[e], M.A. Ahmad[a], D.A. Sugeng[a], M.A. Zuber[a], N.A. Ramlan[a]

[a] Vehicle System Engineering, Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Semarak, 54100 Kuala Lumpur, Malaysia

[b] Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

[c] Malaysia-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Jalan Semarak, 54100 Kuala Lumpur, Malaysia

[d] Malaysia Institute of Road Safety Research, Lot 125-135, Jalan TKS 1, Taman Kajang Sentral, 43000 Kajang, Selangor Malaysia

[e] Mechanical Engineering, Maizuru National College of Technology, 234 Aza Shiroya, Maizuru, Kyoto 625-8511, Japan

ARTICLE INFO

Keywords:
Diesel engine
Emulsion fuel
Nano-additives
Thermogravimetric analysis
Carbon monoxide

ABSTRACT

The main objective of the study was to improve the fuel properties, performance and reduce the level of hydrocarbon (HC) and carbon monoxide (CO) when running with water in diesel emulsion fuel (W/D) by adding various nano-additives. Aluminium Oxide (Al_2O_3), Copper(II) Oxide (CuO), Magnesium Oxide (MgO), Manganese(IV) Oxide (MnO) and Zinc Oxide (ZnO) nano-additives were selected for W/D with 10% water (E10). Each nano-additive was added to E10 at a dosage of 50 ppm and further denoted as nano-additive emulsion fuel: $E10Al_2O_3$, E10CuO, E10MgO, E10MnO and E10ZnO. The properties (density, viscosity, water droplet size, stability period and oxidative thermokinetics), performance (torque, brake power, brake specific fuel consumption (BSFC), and emission (nitrogen oxides (NO_x), particulate matter (PM), carbon dioxide (CO_2), CO and HC) of each test fuel were investigated. Overall, nano-additives tended to increase density, viscosity, water droplet size and oxidative thermokinetics but decrease the stability period. The nano-additives resulted in a marginal increase of performance with the $E10Al_2O_3$ yielding the highest reduction in BSFC. The nano-additives also lowered the brake specific CO (BSCO) emissions compared to Euro 2 standard diesel (D2) by up to 17% with E10ZnO. Nano-additives produced from different metals impact the fuel properties, performance and emissions differently. Al_2O_3 is nominated as the best nano-additive due to the smallest water droplet size, highest DTG_{max} and its consistency in increasing the torque and reducing the BSFC, brake specific NO_x ($BSNO_x$), BSCO compared to other nano-additives. That is to say, nano-additives coupled with a W/D has the potential to reduce BSFC and BSCO simultaneously.

1. Introduction

Rudolf Diesel invented the engine with better fuel efficiency, higher thermal efficiency, larger torque power output, lower carbon dioxide (CO_2) emissions and extended durability in comparison to Nicolaus Otto. This made the diesel engine the ultimate choice for on-road and off-road operations. Due to the operation characteristics of a diesel engine, the nitrogen oxides (NO_x) and particulate matter (PM) emissions are higher than spark ignition engine [1]. The formation regions of NO_x and PM emissions are quite different, and they have a trade-off relationship. Lately, simultaneous NO_x and PM emissions reductions for diesel engines received growing attention. Nevertheless, due to the trade-off between the NO_x and PM emissions, it is of great challenge to meet both emission standards via in-cylinder techniques only without significantly sacrificing the engine fuel economy [2,3]. The in-cylinder method such as exhaust gas recirculation (EGR) focuses on reducing NO_x emissions [4], but the PM emission increases and to keep the suitable air-fuel ratio this method demands extra pressure at medium and high loads. Moreover, EGR can affect the quality of the lubricant oil and engine durability due to the higher wear in the piston rings and cylinder liner [5]. A less demanding NO_x reduction technique is by introducing water into the combustion process, which includes the use of water-diesel emulsion fuel (W/D) [6,7], water injection in combustion chamber [8] and water fumigation on intake manifold [9].

* Corresponding author.
E-mail address: wira@utm.my (W.J. Yahya).

https://doi.org/10.1016/j.enconman.2018.05.070
Received 1 February 2018; Received in revised form 18 May 2018; Accepted 19 May 2018

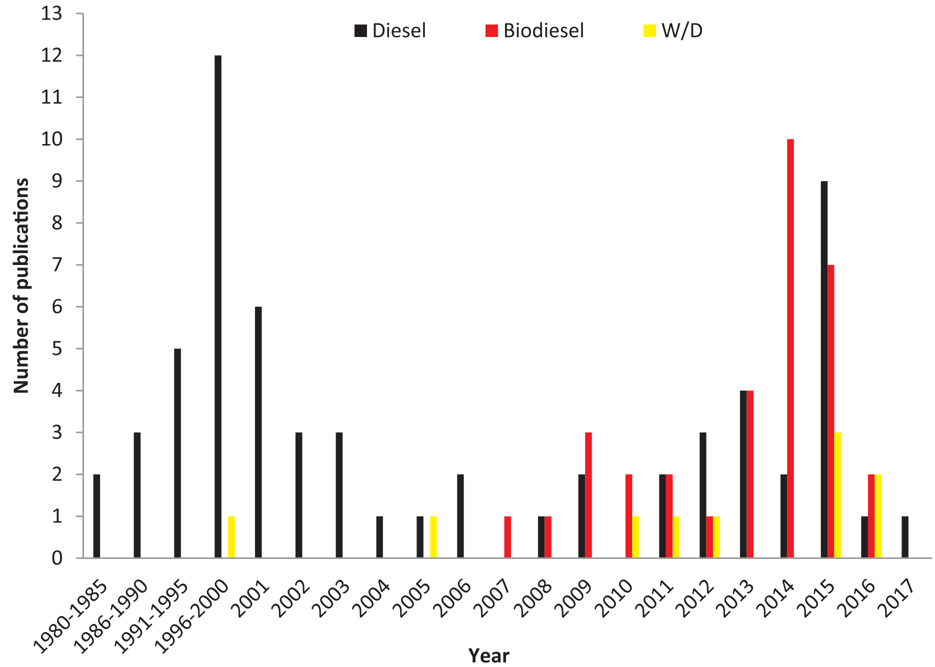

Fig. 1. Publications during 1980–2017 about the use of nano-additives in diesel, biodiesel and W/D for diesel engine. *Google Scholar search keywords: nano-additives, diesel, biodiesel and emulsion fuel.

Overall, W/D is a widely studied method to reduce both NO_x and PM emissions simultaneously without engine modification [10]. The rapid and intense water vaporisation called as micro-explosions improves the mixing between air and fuel by producing smaller fuel droplets. The water reduces the temperatures in the core spray where soot is formed, hence the reduction in soot creation rate. However, the major problem with W/D is higher carbon monoxide (CO), hydrocarbon (HC) emissions and rate of pressure rise because of long ignition delay [11]. The water content lowers the combustion temperature due to longer ignition delay and causes rough engine operation. The ignition delay is equivalent to the activation energy, fuel with better ignition will have lower activation energy. Recent studies showed that nano-additives possess desirable characteristics to improve the combustion characteristics [12]. Nano-additives improve the surface-area-to-volume ratio which will consequently increase the distribution of the fuel and oxidizer [13]. By using Google Scholar search keywords: nano-additives, diesel, biodiesel and emulsion fuel, a list in Fig. 1 is obtained. It shows publications during 1980–2017 on the use of nano-additives in diesel, biodiesel and W/D in the diesel engine.

In 2011, Kannan et al. investigate the use of ferric chloride as nano-additives for biodiesel derived from palm-based waste cooking oil by 20 µmol/L. The results showed a reduction in brake specific fuel consumption (BSFC) of 8.6%, an increase in brake thermal efficiency (BTE) of 6.3%, lower nitrogen oxide (NO) emission and slightly higher CO_2. The CO, HC and smoke emission decreased by 52.6%, 26.6% and 6.9% while cylinder gas pressure increased, heat release rate improved and ignition delay shortened [14]. In 2013, Ma et al. used a Fe-based a nano-additive and achieved a reduction in the BSFC of up to 3.7%, and reductions in PM, CO and HC emissions of up to 39.5%, 21.1% and 13.1% but the NO_x emission rise by 6% [15]. In 2014, Ma et al. again used Fe-based nano-additive to study the chemical characteristics of soot in detail. Soot presented same fractal dimensions that claim no apparent changes in the creation mechanisms. Also, the nano-additive improved the combustion process, leaving fewer soot precursors and helped the oxidation of soot particles [16]. Tables 1 and 2 summarise the impact of nano-additives on performance, combustion characteristics and emissions for diesel and W/D. From the Tables 1 and 2, it can be concluded that the use of nano-additives has a potential to reduce CO, HC and PM simultaneously.

The novelty of this study include, first by multiple types of nano-additives. Research in the use of nano-additives in W/D is gaining interests, where sometimes one or two types of nano-additive are added to a W/D by varying mass fractions. However, no work is found on the comparison of W/D with multiple types of nano-additives. This study emphasises on the use of Aluminum Oxide (Al_2O_3), Copper(II) Oxide (CuO), Magnesium Oxide (MgO), Manganese(IV) Oxide (MnO) and Zinc Oxide (ZnO). Second, to the best of our knowledge, there is little information about oxidative thermokinetics of W/D and nano-additives emulsion fuel. The long ignition delay of W/D was reported to have negative effect on CO emission reduction due to the incomplete combustion. The data from oxidative thermokinetics will include the initial decomposition temperature, the temperature when the sample burns out and the temperature at the maximum decomposition rate that will determine the reactivity of the fuel to lower the CO emissions. The first part of the study covers W/D preparation, incorporation of the nano-additives with W/D, physiochemical properties, water droplet size, stability period and oxidative thermokinetics of the tested fuels. In the second part, the performance and emission characteristics of tested fuel will be evaluated. Then the analysis on PM by using SEM with EDX.

2. Experiment details

For the preparation of W/D (E10), 10% water, 89% low-grade diesel fuel (D2) and 1% SPAN 80 as a surfactant (all volumetric%) were mixed using a electrical mixer at a speed of 2500 rpm at a temperature of 27 °C and atmospheric pressure for 5 min. The specifications of D2 are shown in [44]. 50 ppm of nano-additives was added to be dispersed during E10 formation. The basic properties of nano-additives are listed in Table 3. The W/D with Al_2O_3, CuO, MgO, MnO and ZnO nano-additives are further denoted as E10Al_2O_3, E10CuO, E10MgO, E10MnO and E10ZnO respectively. The viscosity and density of the tested fuels were measured at 26 °C. Expert Series Fungi Lab-Viscometer were used to measure the viscosity. The analysis of the water droplets was performed by using a digital microscope (Keyence VHX 2000). For the stability period, tested fuel was filled into 50 ml vessels. The time elapsed until the water layer created reaches 5 ml marking is defined as stability