ARTICLE IN PRESS

Atmospheric Pollution Research xxx (2017) 1–6

HOSTED BY

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine

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ARTICLE INFO

Article history:
Received 16 February 2017
Received in revised form
22 April 2017
Accepted 4 June 2017
Available online xxx

Keywords:
Biodiesel
Mustard oil
Nano additive
TiO_2 nano-fluid

ABSTRACT

The present study investigates the effect of the TiO_2 nanofluid on the formation of hydrocarbon, carbon-monoxide, nitrogen oxide and smoke emission from a neat mustard oil methyl ester fueled diesel engine. TiO_2 nano particle with an average size of 50 nm was synthesized by sol-gel route. The synthesized particles are dispersed with mustard oil methyl ester at various concentrations (100 and 200 ppm) by the means of a mechanical homogenizer and an ultrasonicator. Experiments were conducted in a four-stroke, single-cylinder, diesel-engine, fuelled with diesel, neat mustard oil methyl ester and nanofluid incorporated methyl ester. From the obtained results, it can be recognized that methyl ester from mustard oil is potential candidate as an alternative fuel in existing diesel engine. Further, it is also observed that TiO_2 nanofluid associated to mustard oil methyl ester reduced various emissions over neat mustard oil methyl ester.

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1. Introduction

Biodiesels from vegetable oils are bio degradable and renewable in nature (Kegl et al., 2013; Kegl, 2011). It is obtained from a many natural feedstock sources and totally around 300 crops are found and recognized as the potential feedstock for biodiesel production (Lesnik and Bilus, 2016). Many types of seed from the plants which are non-edible in nature such as neem, jatropha, pongamia, mahua, and castor are employed to obtain the biodiesel oil (Lahane and Subramanian (2015); Gnanasekaran et al., 2016). These non-edible oil plants are distinguished as second generation feedstock which are economical and are cultivated across the globe (Mohamed Ismail et al., 2013; Lahane and Subramanian, 2015). There are many drawbacks associated with vegetable oils when compared to petroleum diesel. High free fatty acid, poor volatility, lower energy content, higher density, higher NO_x emissions, increased delay period and inferior combustion rate (Anon, 2015; Verma and Sharma, 2016). High free fatty acid of Vegetable oils requires a chemical process called trans-esterification (Shirneshan and Nedayali (2016); Calay and Pisac 2013). Through this process glycerol is removed from the oil and can be used in existing engines. Further, by this process the oil properties are made closer to fossil fuel. Transesterified vegetable oil is called as biodiesel. By this process the drawbacks such as higher viscosity, density and longer delay period is reduced (Schroder et al., 2013; McCormick, 2007).

Biodiesel after transesterification process has comparatively higher kinematic viscosity and oxygen content than diesel which results in increase in nitrous oxide (NOx) emission during the combustion process in diesel engine (Issariyakul and Dalai (2012); Alam and Rahman (2013); Tabtabaei et al., 2015). Many works have been reported in the engine operation of biodiesel for its effective usage in the CI engine application (Yuvarajan and Venkata Ramanan, 2016a,b; Singh et al., 2010) Yuvarajan and Venkata Ramanan (2016a,b) studied the working of diesel engine fuelled with neat biodiesel and found reduction in brake thermal efficiency and significant increase in NOx emission when compared with diesel. However HC and CO emission was found to be lesser for biodiesel as compare to diesel. Singh et al. (2010) investigated the biodiesel in a CI engine and found 3.1% increase in NO_x emissions

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2017.06.003
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Please cite this article in press as: Yuvarajan, D., et al., Experimental investigation on the influence of titanium dioxide nanofluid on emission pattern of biodiesel in a diesel engine, Atmospheric Pollution Research (2017), http://dx.doi.org/10.1016/j.apr.2017.06.003

with reduction in 2.1% of CO emissions. Venkata Ramanan and Yuvarajan (2015) studied the effect of preheating the biodiesel to reduce the viscosity in diesel engine and found 4.1% increase in NO_x emissions at all loads. Issariyakul and Dalai (2011) employed biodiesel in constant speed diesel engine and 1.7% reduction in CO and 2.5% reduction in smoke emission when compared to diesel. However, 4.2% of NO_x emissions were found to increase with increase in biodiesel content.

In order to reduce the drawbacks of neat biodiesel metal oxide nano particle is added to it. Adding nano particle to the biodiesel results in higher evaporation rate, shortened delay period, and promotes secondary atomization which results in lower engine emissions. It also provides the catalytic activity during combustion process (Keskin et al., 2007). Nano sized metallic particle has an ability to hold energy within which results in improved reactivity. Further it also has larger specific surface area which improves the combustion. Nano fluid improves the reaction between fuel and oxygen present in the cylinder owing to high surface to volume ratio to improve the combustion (Khond and Kriplani, 2016). In addition Nano sized metallic particle produces hydroxyl radicals during the reaction between metal and water which in turn improves the oxidation of soot and thereby reducing oxidation temperature (Keskin et al., 2007). Due to many inbuilt features, many metal oxides namely MnO, ZnO, CuO and TiO_2 are used as an additive in diesel engines.

Many research works has been carried out to reduce emissions in biodiesel operation by adding Nano sized metallic particle at different proportions. Keskin et al. (2007) investigated the effect of doping synthesized Mn and Ni nano metal as a metal based additive in diesel fuel. They found improvement in fire point, flash point and viscosity. Further manganese oxide additive reduced CO emission by 37%, NO_x by 4% as compared to the diesel fuel. Sadhik Basha and Anand (2012) studied the effect of nanofluid additives on performances and emissions characteristics of emulsified diesel and biodiesel fueled in stationary CI engine. They found nanofluid reduces NO_x emissions by 6.7%. Venkateswara Rao (2012) investigated the influence of oxygenated Additive at many proportions with coconut oil methyl ester and found 6%, 3.2%, 3.3% and 3.2% reduction in CO, Smoke, HC and NO_x emissions. Ganesh and Gowrishankar (2011) investigated the effect of nano-fuel in biodiesel and diesel blends and reported that by adding nano-fuel with fuel blend results in reduced emissions. Balamurugan et al. (2013) investigated the impact of Nano-Copper in soya bean biodiesel. They concluded that the NO_x emission of soya bean biodiesel was found to be decreased by adding copper nano particle. Kasireddy Sravani and Ravindra Reddy (2016) investigated the effect of Zinc Oxide Nano Fluid with Pongamia biodiesel and reported in the considerable reduction of emissions with slight increase in NO_x at exhaust. Yang et al. (2013) studied the effect of novel nano-organic additives in biodiesel and found 4%, 9.2% and 8.2% reduction in NOx, CO and smoke emissions respectively. Sadhik Basha (2014) employed Alumina oxide nano particle as an additive in neat Water-biodiesel emulsion fuels and found significant reduction in CO and HC emission when compared to neat diesel.

Hence, this work investigates the influence of adding titanium dioxide nanofluid at various concentrations on emission pattern of mustard oil biodiesel in a diesel engine. TiO_2 nano particle with an average size of 50 nm was synthesized by sol-gel route. The synthesized particles are dispersed with mustard oil methyl ester at various concentrations (100 and 200 ppm) by the means of a mechanical homogenizer and an ultrasonicator. MOME dozed with TiO_2 nanofluid at 100 and 200 ppm are called as MOMET100 and MOMET200. From the prepared fuel blends the CI engine operated to evaluate the emission characteristics and the results are compared with neat diesel fuel.

2. Materials & methods

2.1. Biodiesel synthesis

MOME is synthesized from the mustard oil through esterification process. Methoxide solution comprises of 95 ml of methanol and 5 ml of sulphuric acid which is added at a molar ratio of 15:1 to the mustard oil. This sample mixture is heated at a temperature below 60 °C for 60 min at constant stirring rate. In the second step, the resultant mustard oil is mixed with alkali catalyst (potassium hydroxide) to reduce the free fatty acid content present in the mustard oil. The optimum conditions based on the literature for the alkali trans-esterification process is found for methanol oil molar ratio of 6:1, 1% weight concentration of potassium hydroxide and a reaction temperature of 60 °C. This mixture has to be stirred at a constant rate for a reaction time of 60 min. By this method, methyl ester is produced as an outcome of reaction between alcohol and vegetable oil by alkyl catalyst. Glycerin is obtained as a by-product of this process. 85% of conversion rate is achieved during synthesis. The obtained oil consists of MOME and methanol. The obtained mixture is preheated to 80 °C for more yield of methyl ester by removing methanol present in it. Fig. 1 shows the photography of MOME.

2.2. TiO_2 nanofluid preparation

Titanium dioxide nano-particles are utilized to prepare the nano emulsion with MOME. TiO_2 is characterized via X-ray diffraction technique and found with the crystalline structure of Anatase/Rutile mixture. Fig. 2 a) shows the SEM image of TiO_2 nanofluid and b) shows the TEM image of TiO_2 nanofluid. From these images it is found that TiO_2 nanofluid are clustered and having average particle size of 50 nm which are lesser than the diameter of fuel injector nozzle. Hence it does not provide any obstacle during its flow in the fuel injector. TiO_2 nanofluid is prepared by adding TiO_2 at 100 and 200 ppm to distilled water. TiO_2 is dispersed into distilled water by using ultra sonication process. Ultrasonicator having a frequency of 60–100 kHz is employed for dispersion of TiO_2 to distilled water. TiO_2 nanofluid is milky white in color. Fig. 3 shows the Photography of nanofluid water-TiO2.

2.3. Emulsion- preparation

TiO_2 nanofluid acts as an oxygen buffer during combustion which contributes to the catalytic effect. TiO_2 nanofluid also provides high surface energy due to its large surface to volume ratio

Fig. 1. Photography of Mustard oil methyl ester.

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