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Investigation on the combustion characteristics of alumina nanoparticles dispersed longer term stable biodiesel nanofluids

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ABSTRACT

In this paper, the combustion characteristics of alumina nanoparticles dispersed jatropha biodiesel based nanofluids were investigated by dispersing the alumina nanoparticles having average size of ~13 nm in jatropha biodiesel with 0.1 volume fraction. Only longer duration having more than one year stable nanofluids were tested for the combustion characteristics such as evaporation time on a hot-plate test in the temperature range of 300 ^{0}C to 600 ^{0}C. The preliminary evaporation test results revealed that the evaporation time of one year older stable ~13 nm alumina nanoparticles dispersed nanofluids significantly improved and were comparable to that of the commercially available diesel fuel beyond 450 ^{0}C. Such type of biofuel based nanofluids having longer term stability and improved combustion characteristics can be utilized directly as an alternate fuel for the future diesel engines. Copyright © 2016 VBRI Press.

Keywords: Nanofluids; alumina nanoparticles; jatropha biodiesel; combustion characteristics; alternative fuel.

Introduction

Automobile sectors are playing vital role in the development of present civilization and the main requirements of automobiles are the availability of fossil fuel. However, due to the future shortage of these fossil fuels, alternative fuels such as biofuel and biodiesel are considered as the alternative substitute to overcome the current energy crisis in automobile sectors. Therefore, the thrust for developing alternate fuels such as biodiesel and the need to improve its efficiency on the diesel engine has attracted much attention worldwide. However, the direct utilization of such biodiesel is not possible due to several drawbacks such as low calorific value, poor atomization, high ignition delay, low cetane number [**1**]. In this context, several researchers recently reported that such drawbacks of biodiesel can be improved by dispersing different types of nanomaterials such as alumina, copper oxide, multi-walled carbon nanotubes (MWCNT's) into the biodiesel as the basefluids[**2-6**]. Since, dispersing such nanomaterials can enhance the thermo-physical properties of the biodiesel as compared to the basefluids due to the unique physical, thermal, and catalyst properties of the nanomaterials. Furthermore, such nanomaterials have high surface to volume ratio and hence larger surface contact area during the rapid oxidation process. Also, due to size dependent properties they can have the potential to release higher energy and hence can improve the fuel characteristics of the diesel engines. It was reported that metal and metal-oxide nanoparticles dispersed in diesel and ethanol showed improved properties of such fuels as compared to the fuel without the dispersion of nanoparticles [**7, 9**].Tyagi *et al.* investigated the ignition probability tests on the neat diesel and also with aluminum nanoparticles dispersed in diesel and concluded that the ignition probability of aluminum nanoparticles dispersed in diesel was improved as compared to that of neat diesel [**6**]. Nasrin *et al.* [**15**] reported that even at very lower concentrations of nanomaterials, the performance of the diesel engine can be improved with the reduction of harmful pollutants like NOx and SO_2. Sadhik *et al.* [**13**] conducted the fuel tests of the CNT's dispersed in Jatropha Methyl Ester (JME) on a diesel engine and concluded that the brake thermal efficiency for CNT's blended JME was higher with reduction in the smoke as compared to the neat JME. Quiao *et al.* [**10,11,12**] investigated on the fuel characteristics of boron and iron nanoparticles dispersion in n-decane and ethanol as the base fuel by considering both the lower and higher concentration and reported that for the lower concentrations, the nanoparticles burn quickly and faster than the fluid droplet associated with it while in the case of dense concentrations, the nanoparticles forms an aggregated cluster and hence, as a result, this aggregated cluster begins to burn after the burning of the liquid droplet associated with it. In this manner, though several investigations were carried out for the different nanoparticles/nanomaterials dispersions in the different biofuels as the basefluids, the stability of nanofluids was considered only for few weeks. Since, the major issues associated with the nanoparticles dispersed biofuels were the long term stability as with time the nanoparticles/nanomaterials start to coagulate with each other in the nanofluids and degrade the properties of the fuels. Hence, long term stable biodiesel based nanofluids are still required to be investigated for improving the combustion characteristics and such nanofluids can have the potential to be utilized commercially as alternative fuel for diesel engines. Therefore, the main objective of this work is to investigate the combustion characteristics of the alumina nanoparticles dispersed Jatropha biodiesel having longer term stability by using the hot-plate evaporation test. In this work, the effect of alumina nanoparticles having size of ~13 nm with 0.1vol % on the evaporation time of the nanofluids is reported. Such size and vol. fraction of alumina nanoparticles were considered in this work as recently it was reported [**14**] that such size and vol. fraction are the optimum parameters for achieving the longer duration more than one year stable nanofluids.

Experimental

Material

Alumina nanoparticles having ~13 nm average sizes with 99 % purity was purchased as dry powder from the Sigma Aldrich Company, USA. Jatropha raw oil was purchased from the commercially available dealers (India). Surfactants Span^{80} and Tween^{80} with 99.5 % purity were purchased from Hychem Laboratories, India. Acids and alcohols such as sulphuric acid and methanol were also purchased from the Hychem Laboratories, India.

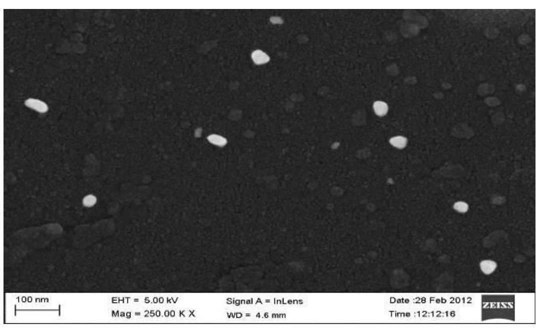

Fig.1. FESEM image of alumina nanoparticles of average size 13 nm size.

Characterizations

Alumina nanoparticles were characterized by X-ray diffraction (XRD) as reported earlier [**14**] and it was found to be the mixed phases of δ and γ having crystalline structure. The morphology of the alumina nanoparticles were studied by dispersing the alumina nanoparticles in de-ionized water and sonicating it for about 30 minutes. A droplet of this sample was casted on a pre-cleaned silicon substrate. The fluid content on the silicon substrate was evaporated by employing a hot-plate and finally the silicon substrate containing the nanoparticles was loaded in Zeiss FESEM apparatus for analysis. **Fig. 1** shows the FESEM image of the alumina nanoparticles having nearly spherical shape and the average size was found to be ~13 nm.

Alumina nanofluids preparation

Alumina nanofluids were prepared by dispersing the alumina nanoparticles (~13 nm sizes) in the Jatropha biodiesel by two-step process. First of all, Jatropha raw oil was synthesized by using the "transesterification" process as reported earlier [**14**] and then alumina nanoparticles were dispersed in the Jatropha biodiesel by using the ultrasonication at 40 kHz frequency. The surfactant Span80 and Tween80 was also used while dispersing the alumina nanoparticles in the jatropha biodiesel for better stability as reported earlier [**14**]. The prepared alumina nanofluids were evaluated for their stability by different characterization techniques such as sedimentation, TEM, and also by UV-Vis spectroscopy.

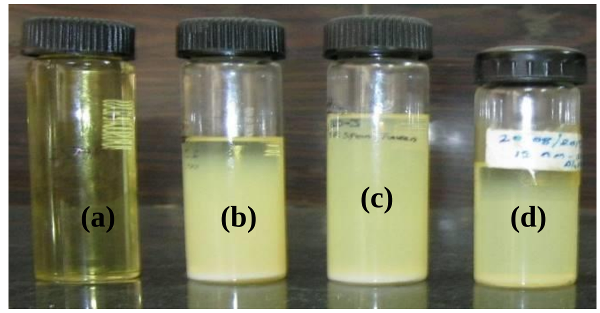

Fig. 2. Photographic images of the alumina nanofluids (a) Raw Jatropha Biodiesel (b) one Year old Sample(c) One month old sample and (d) As-prepared sample.

Fig. 2 shows the photographic images of the stable nanofluids of alumina nanoparticles (~13 nm) dispersed in jatropha biodiesel based nanofluids having 0.1 % volume fractions for different stability time durations such as pure jatropha biodiesel, as-prepared, one month older and 1year older sample.

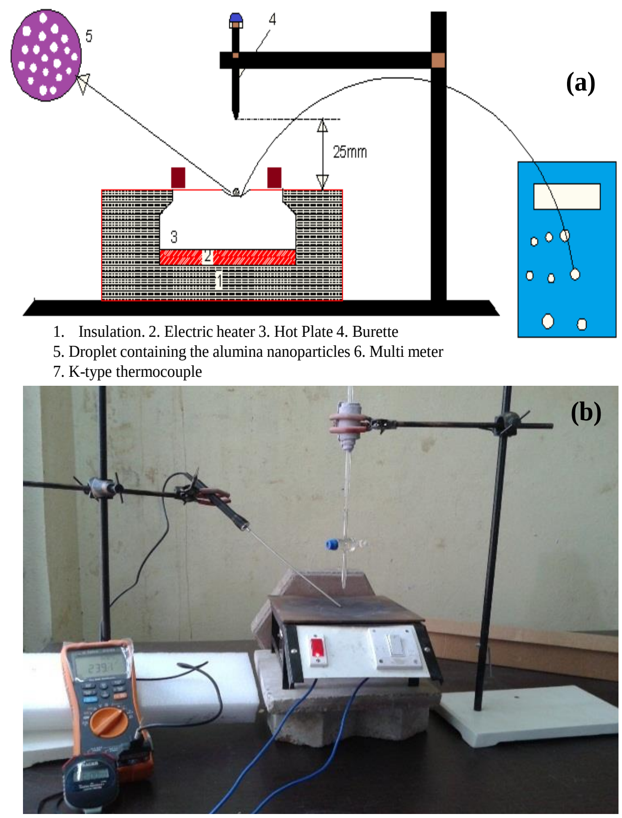

Fig. 3. Set up for the Hot-Plate combustion test of the nanofluids (a) Block diagram (b) Experimental set up.

Experimental set-up

Fig. 3(a) shows the block diagram of the hot-plate evaporation set-up for carrying out the combustion characteristics test and **Fig. 3(b)** shows the experimental set-up as designed in-house in our laboratory. The experimental set-up consists of a hot-plate of 100 mm x 100 mm x 4 mm, an electric heater, one burette of 1 mm diameter, multi-meter, K-Type thermocouple, and stop-watch. The hot-plate has a curvature of 5mm diameter at its center so as to hold the fuel droplets and prevent it from falling down from the hot plate. The distance between the burette and hot plate is 25 mm which is generally mentioned in diesel engine. The average droplet size was calculated by measuring the total volume of the nanofluid with number of droplets fallen down and found to be approximately 3.74 mm. The same burette was considered for all the evaporation tests for all the test samples which include alumina dispersed nanofluids, the biodiesel and also the commercial diesel.

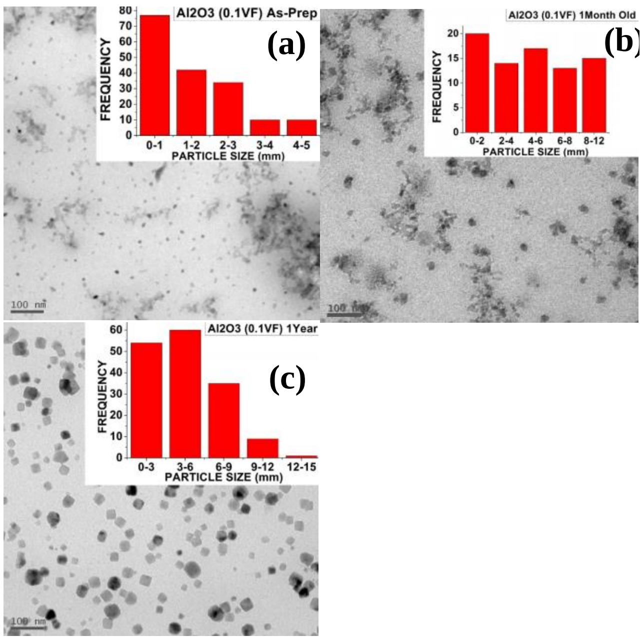

Fig. 4. TEM micrographs of ~13 nm size alumina nano-particles having 0.1 % VF with different stability time (a) as–prepared sample (b) 1 month older sample and (c) 1 year older sample.

In the above experimental work, the droplets of alumina nanofluids were made to fall down on the curvature of the hot-plate, and the time taken to evaporate the droptlets completely were noted down by using the stop-watch. This procedure was followed for the above mentioned set-up for different hot-plate temperatures in the range of 300 ^{o}C to 600 ^{o}C for every 30 ^{o}C rise in temperature. The temperature difference of 30 ^{o}C interval was given so that when the first droplet was tested for the evaporation time by allowing it to fall on the surface of the hot-plate, it was observed that the temperature of the hot-plate instantly decreased by ~30 ^{o}C. Therefore this time interval was to be considered for maintaining uniformity in rise of hot-plate temperature before the testing of the subsequent fuel droplets on the hot-plate. In this way the hot-plate evaporation tests were conducted for five different samples which includes three samples of alumina nanoparticles dispersed nanofluids having different stability time durations (as-prepared, 1month old and 1year old samples) and the results were compared with the pure diesel oil, and also with pure Jatropha biodiesel.

Results and discussion

Fig. 4(**a-c**) show the Transmission Electron Microscopy (TEM) images of the alumina nanoparticles (having average size ~13 nm) dispersed in the Jatropha biodiesel for 0.1 %VF of as-prepared, 1month older and 1Year older samples respectively. The sample preparation for the TEM analysis was same as reported earlier in our earlier work [**14**]. The TEM images of **Fig. 4**(**a**, **b**, **c**) confrim the dispersion stability of alumina nanoparticels in jatropha biodiesel as the basefluids for as-prepared samples, 1month old and 1year old samples respectively. However, it is also seen that agglomeration of the nanoparticles was initiated from the 1 month older sample as seen from the from **Fig. 4**(**b**) and hence nanopartciels clustering is also noted. Thefore, the concentration of the nanofluids starts to decrease as compared to the as-prepared sample which is further confirmed from the UV-Vis spectroscopy. This may be due to the fact that bigger sizes of nanoclustres start to settle down with the time. Futhermore, with increasing the time such as for 1 year older sample, it is observed that from **Fig. 4**(**c**), the alumina nanopartciels were forming different sizes and morphology [**14**] and no clustering is observed as most of the large size aggregates were already setteled down at this point of time. This variation in sizes of nanopartciels due to the growth of the alumina nanoparticles in the Jatropha biodiesel as the basefluid and may be due to the effect of the growth of nanoparticles when diffused in suitable basefluids with suitable surfactant.

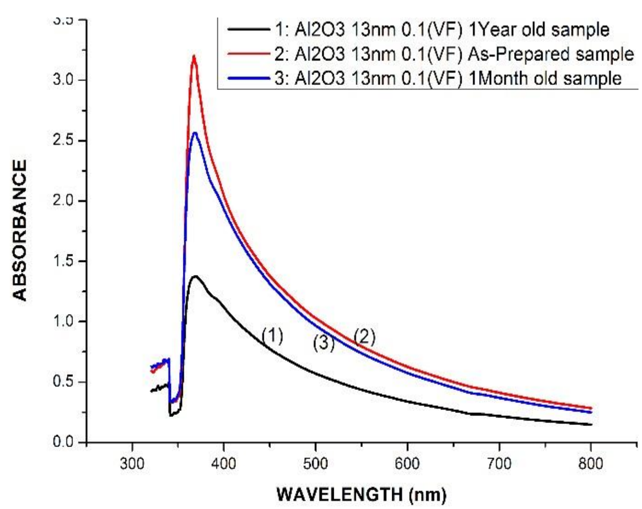

Fig. 5. UV-Vis spectroscopy plots of the alumina based biodiesel nanofluids having different stability time.

Fig. 5 shows the UV-Vis spectra of the alumina nanoparticles of ~13 nm dispersed in the Jatropha biodiesel having different stability durations for 0.1volume fraction. It is clearly observed from the **Fig. 5** that the absorbance peak intensity is decreasing with the increase in the sedimentation time, as the number of alumina nanoparticles dispersed in the Jatropha biodiesel were aggregated and setteled down at the bottom of the glass tube and therefore the concentartion was decreasing with te sedimentation time. **Fig. 6** shows the evaporation time with the temparture for all the alumina nanofluids having ~13 nm size with 0.1 % volume fraction for different sedimentation time periods. As shown in **Fig. 6**, the evaporation time is lower for the alumina nanoparticles dispersed biodiesel as compared to the raw biodiesel and then gradually decerased from as-prepared to 1 year older sample. Therfore, the evaporation time can be improved by dispersing the alumina nanopartciels, however as the sedimentation time incereases, lagrer sizes nanopartciels and nano-aggregates start to settle down with time and can form the nanoparticles which are of more uniform in sizes and morphology. Hence more uniform dispersion can be achiewed as compared to the as-prepared and 1 month older smaple. That may be the reason that 1 year older sample evaporation time is lower as compared to the as-prepared and 1 month older sample.

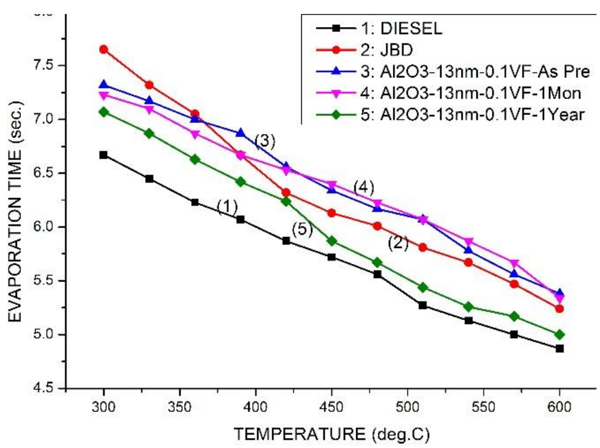

Fig. 6. Hot-Plate evaporation test of the alumina nanoparticles based biodiesel nanofluids for temperature range of 300.– 600 ^{o}C having different stability durations.

Further, it is also observed from the **Fig. 6** that beyond 450 ^{0}C, the combustion characteristic such as evaporation time was very close to that of commercial diesel for the one year older sample. This may be due the fact that the alumina nanoparticles at higher temperatures impart its energy during the combustion process when compared to the lower temperature. However, for the as –prepared and one month older samples, the combustion characteristic is not much improved even at higher temperature as it is clear from the TEM images that the nanoparticles sizes are not uniform (referring to **Fig. 4**(**a**) and (**b**) of TEM images). Also, agglomerations are observed in such samples which may be the reason that combustion characteristics are not much improved as compared to that one year older sample. On the basis of the results obtained on this study, several conclusions can be made about the effect of parameters such as nanomaterials type and size on the combustion characteristics of the biodiesel based nanofluids. Hence, investigations on different types of nanomaterials and their effects on the combustion characteristics are still underway in our research group to compare these results with different type nanomaterials dispersed biodiesel nanofluids.

Conclusion

The combustion characteristics of the alumina nanoparticles dispersed in biodiesel based nanofluids on a hot-plate evaporation tests were carried out for a longer duration of stable alumina nanofluids. It was observed that alumina nanoparticles dispersed biodiesel, significantly improved the combustion characteristic such as evaporation time as compared to that of the raw biodiesel. Also, at the higher temperature beyond 450 ^{0}C, the combustion characteristic of the one year older biodiesel based alumina nanofluid was comparable to that of the commercial diesel. Therefore, the biodiesel combustion characteristics can be improved by adding the nanomaterials such as alumina as the radiative and heat transfer properties of the biofuel can be enhanced and hence droplets would be ignited at much lower temperature. Such longer duration stable biodiesel based nanofluids having improved combustion characteristics can be directly used in the diesel engine for transportation sectors.

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Author Contributions

RD, DR; Performed the expeirments:RD,DR; Data analysis: RD,DR; Wrote the paper: RD,DR. Authors have no competing financial interests.

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