I&EC research
Industrial & Engineering Chemistry Research

Article

pubs.acs.org/IECR

Evaluation of Additive Effects on Oxidation Stability of *Jatropha Curcas* Biodiesel Blends with Conventional Diesel Sold at Retail Outlets

Girdhar Joshi,* Bhawna Y. Lamba, Devendra S. Rawat, Sudesh Mallick, and K. S. R. Murthy

Department of Chemistry, University of Petroleum & Energy Studies, Dehradun, 248007, India

ABSTRACT: This study investigates the effect of antioxidant additives on oxidation stability of neat biodiesel and its diesel blends. Biodiesel was prepared by methanolic KOH catalyzed transesterification of *Jatropha curcas* oil. Various diesel-biodiesel blends (B10, B15, B20, and B25) were prepared with conventional diesel sold at retail outlets of Northern India. Butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT), pyrogallol (PL), propyl-gallate (PG), *tert*-butylhydroxyquinone (TBHQ), and diphenylamine (DPA) additives were selected for this study. Significant improvement in oxidation stability as well as in density and kinematic viscosity of diesel−biodiesel blends was obtained with all antioxidants studied. TBHQ, PG, and PL were found to be the most effective among all antioxidants tested, and their use in diesel−biodiesel blends showed a greater stabilizing potential. The properties of the blended fuel were not found consistent during the study. It may be due to composition of biodiesel, nature of antioxidant additives, and quality of diesel fuel.

1. INTRODUCTION

Diesel is the major fuel source for transport and heavy-duty engines due to high combustion efficiency, reliability, and cost effectiveness. However, in respect of environmental concerns, emission of pollutants is the major problem associated with the diesel fuel. It is well accepted that in diesel engines, clean combustion can be fulfilled only by engine development coupled with diesel fuel formulation.[1,2] Due to increase in demand, depletion of petroleum reserves as well as increasing environmental concerns, there is an urgent need for the search of renewable energy, hydroelectricity, or nuclear energy resources as alternative has been raised in recent years.[3,4] One of the environmental friendly renewable energy sources is biodiesel.[5] Biodiesel is a mixture of methyl esters of long chain fatty acids derived from vegetable oil and animal fats, and is similar to the commercial diesel in terms of fuel quality and combustion properties.[6,7] The biodiesel production from edible oil resources in India is very less, as the indigenous edible oil production is much less than its actual demand. Therefore nonedible oils (e.g., *Jatropha*, *Pongamia*(*Karanja*), *Mahua*, and *Sal*) seem to be the only possible source of biodiesel in India.[7] Biodiesel is a fuel source that is nonflammable, nonexplosive, biodegradable, nontoxic, and free from sulfur and aromatics. Biodiesel also provides less harmful emissions compared to petroleum diesel fuel,[9,10] which makes biodiesel a good alternative to substitute for petroleum diesel.[11] However, the long-term storage of biodiesel is a problem. The presence of unsaturated fatty acid esters in biodiesel makes it more susceptible to oxidation or autoxidation during long-term storage.[12,13] It is well reported in the literature that oxidation stability does not correlate with the total number of double bonds but with the total number and position of allylic and bis-allylic carbons that are adjacent to double bonds.[14] These oxidation processes are less pronounced in the parent oil due to the presence of natural antioxidants which get partially lost during refining.[15] Reports have been found stating that, after oxidation of biodiesel and its diesel blends, the acid value, density, and viscosity increased, while iodine value decreased with increasing storage time.[16] Thus biodiesel instability results in the formation of sediment and gum along with fuel darkening, which causes filter plugging, injector fouling, deposition in the engine combustion chamber, and malfunction in various components of the fuel system.[17,18] The use of antioxidant additives not only slows down the oxidation processes but also improves the fuel stability up to a certain extent.[19] Several reports have been found on the stabilities of diesel biodiesel blends.[19−27] However, very limited reports are available on the impact of antioxidant additives on oxidation behavior of biodiesel/diesel blends, especially when biodiesel is derived from a nonedible oil source.[8,28−46] The aim of this study is to provide the experimental results on the effects of antioxidant additives on *Jatropha* biodiesel and its blends with diesel fuel sold in Northern India. The effectiveness of selected antioxidants on oxidation stability, kinematic viscosity, and density of the neat biodiesel and its diesel blends was investigated. The goal was to find out the optimum additive which could significantly improve the storage stability of both the neat biodiesel and its diesel blends. These results will help to support the development of biodiesel specification and technology.

2. EXPERIMENTAL SECTION

2.1. Base Diesel Fuel. Three commercial diesel fuel samples (D1, D2, and D3) were selected as base fuel. These diesel samples were purchased from the retail outlets of different oil companies in Northern India. The diesel was sold by these outlets, received from respective refineries, and was

Received: March 12, 2013
Revised: May 6, 2013
Accepted: May 16, 2013
Published: May 16, 2013

dx.doi.org/10.1021/ie400801h | *Ind. Eng. Chem. Res.* 2013, 52, 7586−7592

Table 1. General Properties of Base Diesel and Biodiesel

s. no.	property (unit)	D1	D2	D3	*Jatropha Curcas* biodiesel	std. limits: diesel	std. limits: *Jatropha* biodiesel	test method
1	flash point (°C)	68.0	79.0	84.0	161.5	55 min	100 min	ASTM D 93
2	moisture content (mg/kg)	0.004%	0.010%	0.011%	0.041%	Max. 0.02%	Max. 0.05%	ASTM-D 2709
3	cloud point (°C)	+3	0	0	+12			ASTM-D 2500
4	pour point (°C)	0	−3	−3	+3			ASTM-D 97
5	total sulfur (ppm)	310 (±2)	336 (±2)	340 (±2)		350 max		ASTM D 1266 and IP 336
6	calorific value (kJ/kg)	43358	41929	42848	39071			
7	density (g/cm^3) at 15 °C	0.8309	0.8288	0.8373	0.8811	0.820−0.845	0.880−0.890	ASTM-D 4052
8	kinemetic viscosity (mm^2/s) at 40 °C	3.07	2.88	2.82	4.71	2.00−4.50	1.90−6.00	ASTM-D 445
9	oxidation stability (IP, at 140 °C, h)				4.21		3 (min)	ASTM-D 7545 and prEN16091

not known to contain cold flow or lubricity additives. The difference in their properties (Table 1) may be because of the difference in origin of crude oil and its processing and quality control.

2.2. *Jatropha Curcas* Biodiesel. *Jatropha curcas* biodiesel was used as blending stock for collected diesel samples and was prepared from the base catalyzed transesterification of *Jatropha curcas* oil. The main physical properties of biodiesel are listed in Table 1. The GC-MS analysis of fatty acid methyl ester (FAME; biodiesel sample) was carried out on a QP2010 gas chromatography mass spectrometer (GC-2010 coupled with GC-MS QP-2010) equipped with an auto sampler (AOC-5000) from Shimadzu (Japan) using a RTX-5 fused silica capillary column, 30 m × 0.25 mm × 0.25 μm (Rastek).

Helium (99.9% purity) was used as the carrier gas with a column flow rate of 1 mL/min and a precolumn pressure of 49.7 kPa. The column temperature regime was 40 °C for 3 min, followed by a 5 °C/min ramp up to 230 °C, followed by 40 min at 230 °C. The injection volume and temperature were 0.2 μL and 240 °C, and the split ratio was 1/30. The mass spectrometer was operated in electron compact mode with electron energy of 70 eV. Both the ion source temperature and the interface temperature were set at 200 °C. FAME peaks were identified by comparison of their retention times with authentic standards by GC-MS post run analysis and quantified by area normalization. Analysis revealed that the prepared *Jatropha curcas* biodiesel contains methyl esters of palmitic acid (16:0) [17.52%], palmitoleic acid (16:1) [0.74%], stearic acid (18:0) [8.62%], oleic acid (18:1) [41.78%], and linoleic acid (18:2) [31.12%]. Linolenic methyl ester (18:3) was not observed at all by GC-MS analysis. The GC-MS results obtained were also supported by the existing literature where the composition of biodiesel from *Jatropha curcas* has been reported.[37,47] The prepared biodiesel was used to constitute the diesel−biodiesel blends with B10, B15, B20, and B25 (volume/volume) with diesel fuel to study their physicochemical properties (oxidation stability, viscosity, and density) during long-term storage.

2.3. Antioxidants Additives. Butylated hydroxy anisole (BHA), butylated hydroxy toluene (BHT), pyrogallol (PL), propyl-gallate (PG), *tert*-butylhydroxyquinone (TBHQ), and diphenylamine (DPA) were used as antioxidant additives. All additives were analytical grade and procured from Sigma Aldrich, India, and used as received.

2.4. Storage Conditions. Biodiesel and its diesel blend samples of volume 500 mL were stored in closed Borosil glass bottles of 1 L capacity for 90 days and were kept indoors, at a room temperature of 18 and 28 °C. A 500 mL space in the bottle was occupied by air. Samples were taken out periodically every 15 days to study the additive effects.

2.5. Oxidation Stability Measurements. The oxidation stability (induction period, i.e., IP) of neat *Jatropha* biodiesel and its diesel blends were investigated by Petrotest "PetroOXY-(e)-VERSION: 10.08.2011" instrument made in Germany. The IP of biodiesel and its diesel blends was estimated according to the ASTM-D 7545-09 and prEN 16091 "Oxidation stability of fuel". IP was calculated for 5 mL fuel sample in hermetically sealed test chamber. The chamber was automatically pressurized with oxygen up to 700 kPa (∼7 bar/101.5 psi) and heated to a temperature of 140 °C. This initiates a very fast oxidation process. As the fuel oxidizes, it consumes the oxygen in the sealed test chamber resulting in a 10% pressure drop that is displayed. The length of the induction period is a measure of how long the antioxidant will protect the biodiesel and its diesel blends from oxidation. The obtained IP values were converted to their corresponding Rancimate time by multiplying the Petrotest time with a correction factor 20 (as recommended by the test method and was automatically displayed). All determinations were performed in duplicate and the mean value is reported.

2.6. Density, Kinematic Viscosity, Flash Point, and Sulfur Content Measurements. Density of biodiesel and diesel blends were analyzed at 15 °C by Anton Paar density meter DMA-35 Version 3, according to ASTM-D 4052 method while as the kinematic viscosity of the biodiesel and its diesel blends were analyzed at 40 °C temperature and 50% Torque by Fungi-lab expert series viscometer, according to ASTM-D 445 method. Flash point of the diesel and *Jatropha* biodiesel samples were analyzed by Penske Martene Flash point apparatus with close cup, according to ASTM-D 93 method. Total sulfur content of diesel fuel samples were estimated by Lamp method for sulfur determination in petroleum products according to ASTM D 1266-107 and IP 336. All the data obtained were well supported by the reported/standard values.

3. RESULT AND DISCUSSION

3.1. Effect of Antioxidants on the Oxidation Stability of Biodiesel Samples. The effects of additives on the oxidation stability of the neat *Jatropha* biodiesel samples were investigated for 90 days indoor storage conditions. The antioxidants were screened by adding 300, 400, and 500 ppm concentration of each antioxidant in 500 mL of neat *Jatropha* biodiesel. The results are shown in Figure 1. A significant

dx.doi.org/10.1021/ie400801h | *Ind. Eng. Chem. Res.* 2013, 52, 7586−7592

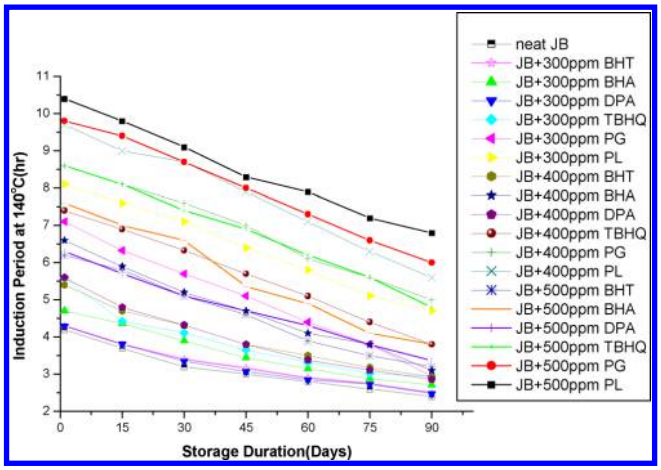

Figure 1. Oxidation stability of *Jatropha* biodiesel with additives.

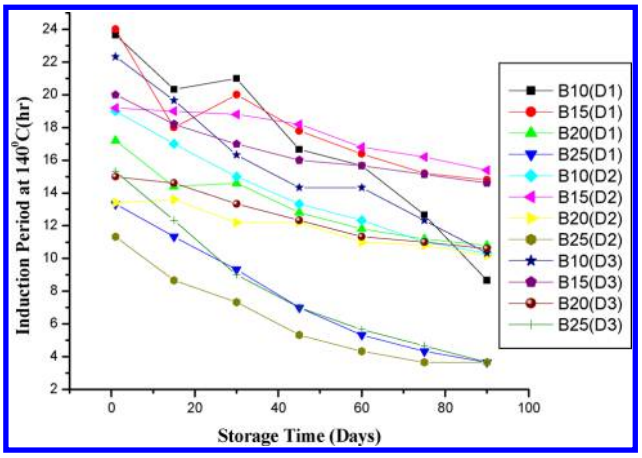

Figure 2. Oxidation stability of diesel−biodiesel blends without antioxidants.

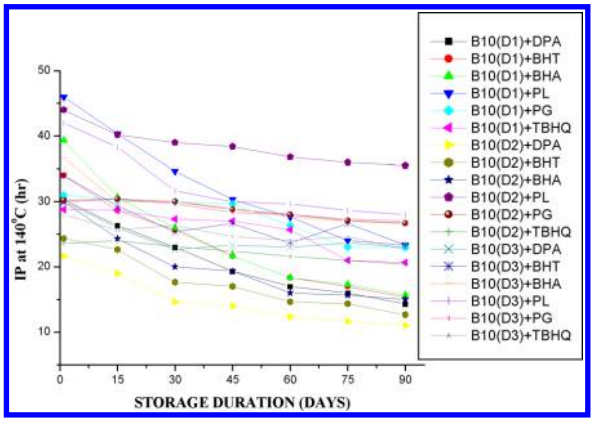

Figure 3. Oxidation stability of biodiesel blends of D1, D2, and D3 with different antioxidants [B10].

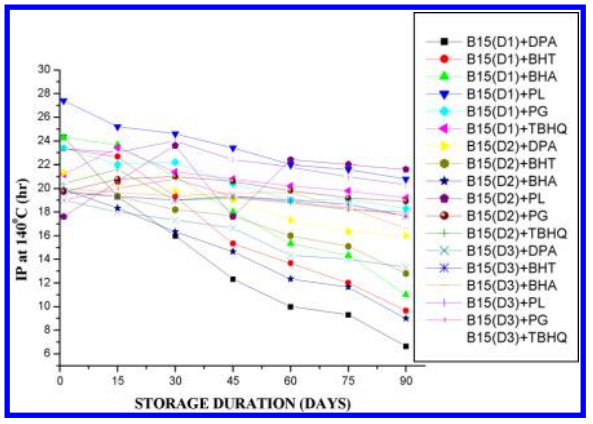

Figure 4. Oxidation stability of biodiesel blends of D1, D2, and D3 with different antioxidants [B15].

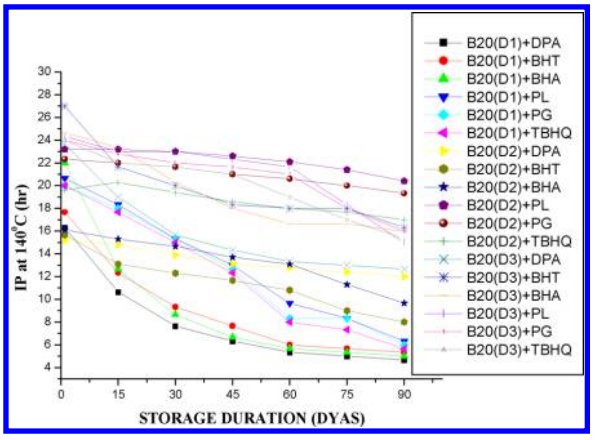

Figure 5. Oxidation stability of biodiesel blends of D1, D2, and D3 with different antioxidants [B20].

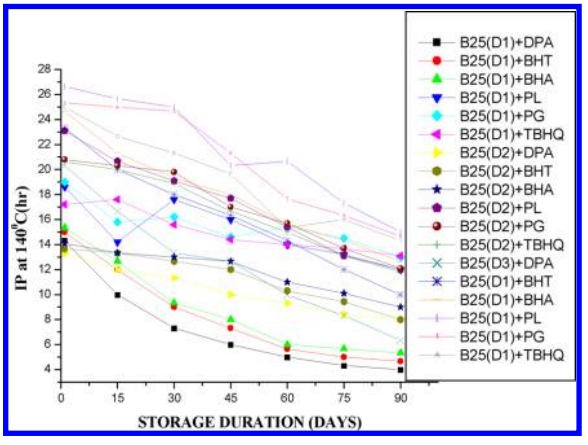

Figure 6. Oxidation stability of biodiesel blends of D1, D2, and D3 with different antioxidants [B25].

difference in the efficiencies of tested antioxidants was observed. It is clear from Figure 1 that the induction period of biodiesel with additives was improved significantly. A screening study of antioxidant additive also reveled that the 500 ppm concentration of additive was the optimum concentration at which maximum stability was obtained. Therefore 500 ppm additive concentration was used for further studies of oxidation stability of diesel/biodiesel blends. Pyrogallol (PL) was found to be the most effective antioxidant with maximum IP of 10.4 h whereas diphenylamine (DPA) was found to be least effective during the course of study. On the basis of screening data, the effectiveness of antioxidants used was observed in order of PL > PG > TBHQ > BHA > BHT > DPA. Study revealed that the phenolic antioxidants were found more effective. As the active hydroxyl group provides a free proton easily to inhibit the formation of free radicals or interrupt the propagation of free radical and thus slow down the rate of oxidation, also the phenolic additives offer more sites for the formation of the complex between the free radical and

dx.doi.org/10.1021/ie400801h | Ind. Eng. Chem. Res. 2013, 52, 7586−7592

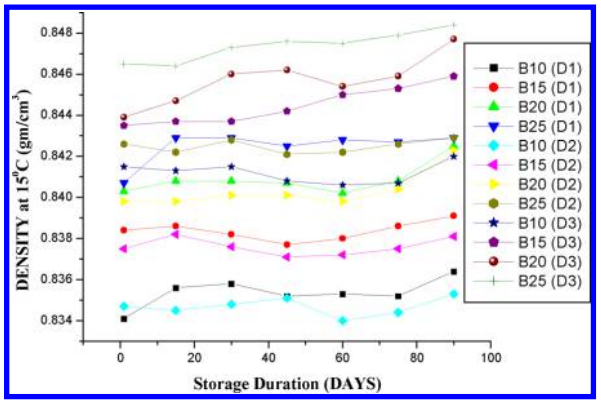

Figure 7. Density of diesel/biodiesel blends without antioxidants.

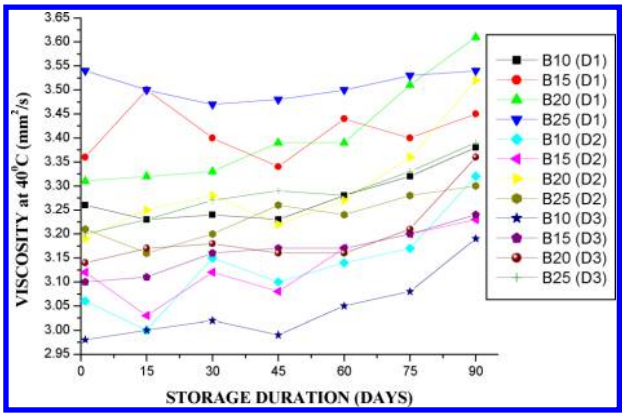

Figure 9. Kinematic viscosity of diesel/biodiesel blends without antioxidants.

antioxidant radical for the stabilization of the ester chain.[42,48,49] It can also be stated that the stability of prepared *Jatropha* biodiesel is lower due to the presence of ∼84% of unsaturated fatty acid.

3.2. Effects of Antioxidants on the Oxidation Stability of Diesel−Biodiesel Blends. Oxidation stability of neat diesel biodiesel blends (B10, B15, B20, and B25) was investigated under storage conditions, and the results obtained are shown in Figure 2.

Results from Figure 2 revealed that only B10 blends with all diesel samples and B15 blends with D1 and D3 were stable for an induction period of 20 h or more than this (at day 1) and the rest failed to meet the minimum induction period. The oxidation stability was further decreased for the next 15, 30, ..., 90 days of storage duration, due to the decomposition of unsaturated fatty acids present in of biodiesel. Whereas Figures 3, 4, 5, and 6 shows the oxidation stability of B10, B15, B20,

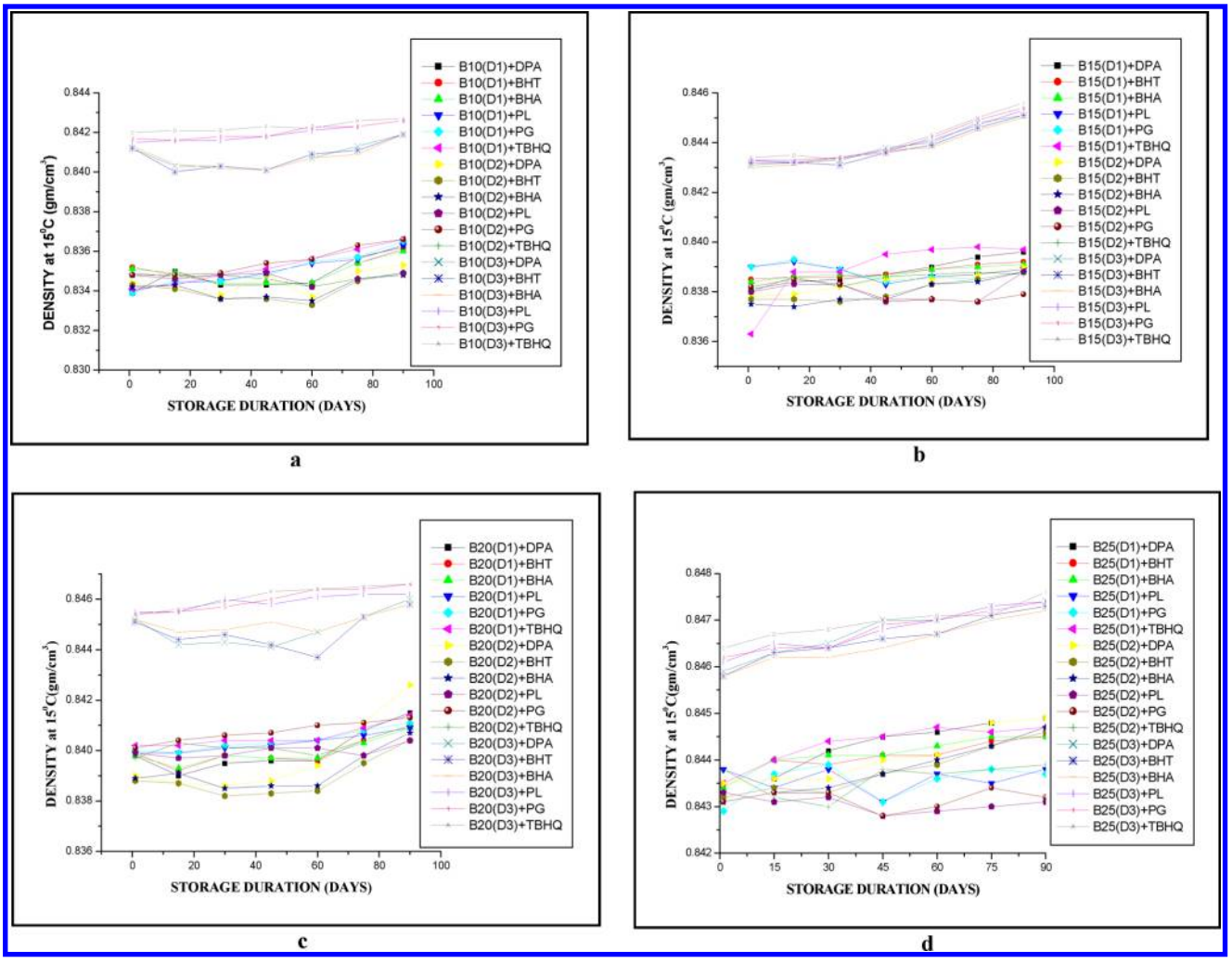

Figure 8. Effect of antioxidant additives on density of blends of *Jatropha* biodiesel with D1, D2, and D3: (a) B10, (b) B15, (c) B20, and (d) B25.

dx.doi.org/10.1021/ie400801h | *Ind. Eng. Chem. Res.* 2013, 52, 7586−7592

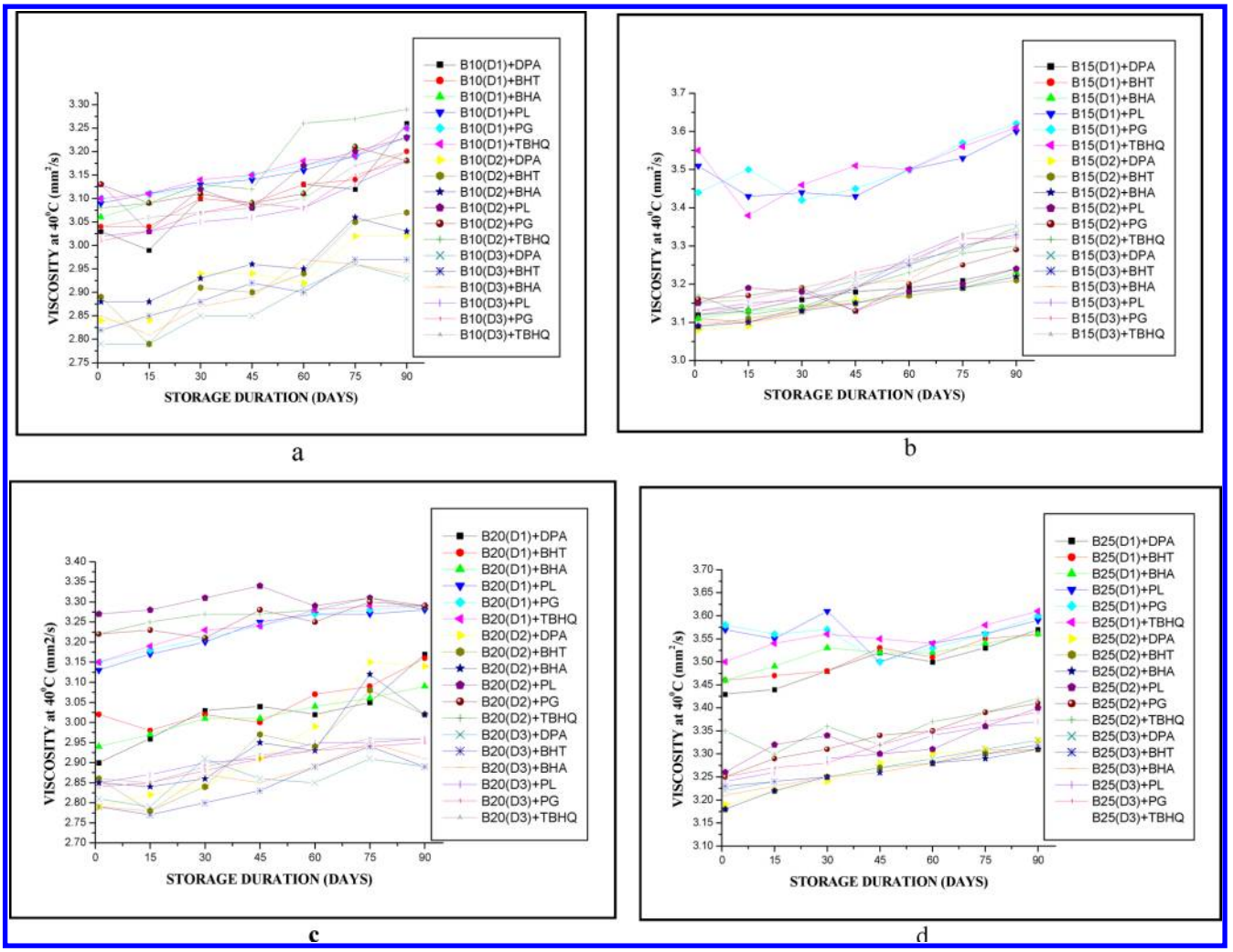

Figure 10. Effect of antioxidant additives on kinematic viscosity of blends of *Jatropha* biodiesel with D1, D2, and D3: (a) B10, (b) B15, (c) B20, and (d) B25.

and B25 diesel biodiesel blends after the addition of optimized concentration of each antioxidant additives separately in 500 mL test solution of these blends.

Figure 3 shows the effect of antioxidant additives of oxidation stability of B10 blends of D1, D2, and D3 diesel samples. It is clear from the study that all the B10 blends of D3 diesel sample were stable during the 90 days storage time with all additives. However, B10 blends of D1 and D2 were stable up to 90 days only with PL, PG, and TBHQ. The B15 blends of D1, D2, and D3 using additive PL were found stable up to 90 days whereas these blends could be stored up to maximum 60 days with PG and TBHQ (Figure 4). The rest of the additives were not shown their effectiveness on long-term storage of B15 blends. When similar study was performed for B20 blends of D1, D2, and D3 (Figure 5) using antioxidant additives, it was observed that B20 blends of D1 could not give satisfactory results, whereas B20 blends of D2 with additives PL and PG were found stable up to 90 days. B20 blends of D3 with antioxidants PL and PG were stable up to 60 days only. Finally, oxidation stability of B25 blends of D1, D2, and D3 (Figure 6) were also investigated, and it was observed that only B25 blend of D3 using additive PL was stable for 60 days. Among the antioxidants investigated PL and PG shown a greater effect on the stability of diesel biodiesel blends of D1, D2, and D3. This was expected because both the additives have shown good stabilizing potential with neat *Jatropha* biodiesel sample. Although the use of TBHQ showed good performance in neat *Jatropha* biodiesel, undesirable results were obtained with the biodiesel blends which may be due to a *pro-oxidant interaction*[48] of TBHQ. On the other hand, BHA, BHT, and DPA were found to be the least effective. Since the properties of diesel fuel samples were not found to be the same (Table 1), which may be the reason for the variation in oxidation stabilities of similar blends. Further research is needed to know the effect of diesel fuel properties on the oxidation stability of its biodiesel blends.

3.3. Density Measurement of Diesel Biodiesel Blends.

A density measurement reflects stability and consistency of a fuel sample. It is a property for developing adequate storage methods for diesel−biodiesel blends.[50,51] In diesel−biodiesel blends the density of fuel increases with the increase of amount of biodiesel in the mixture. The density of all the blends was observed within the range mentioned by standard ASTM-D 445.

The initial density value for neat blends (B10, B15, B20, and B25) of D1, D2, and D3 ranged from 0.834 to 0.846 g/cm^3 with an average density value of 0.8399 g/cm^3 while the final density value for the same ranged from 0.835 to 0.848 g/cm^3

dx.doi.org/10.1021/ie400801h | *Ind. Eng. Chem. Res.* 2013, 52, 7586−7592

with an average of 0.841 g/cm^3 (Figure 7). Similarly, densities of all the blends were also investigated with antioxidant additives, and the results are shown in Figure 8. The average density of B10 blends (Figure 8a) with additives ranged from 0.834−0.842 g/cm^3. Whereas, the average density of B15 and B20 blends with additives ranged between 0.838 and 0.846 g/cm^3 (Figure 8b and c).

3.4. Kinematic Viscosity Measurement of Diesel−Biodiesel Blends. The kinematic viscosity of all the blends was also investigated with and without antioxidant additives, and the results are summarized in Figures 9 and 10, respectively. As during oxidation of biodiesel the viscosity starts to increase due to the formation of oxidized products which lead to the formation of sediments and gum.[32]

The initial kinematic viscosity of neat diesel biodiesel blends ranged from 2.98 to 3.54 mm^2/s with an average value of 3.20 mm^2/s whereas the final values ranged from 3.19 to 3.61 mm^2/s with an average of 3.37 mm^2/s (Figure 9). The initial and final average kinematic viscosity of B10 blends with additives (Figure 10a) ranged from 3.03 to 3.29 mm^2/s, whereas the same value for B15 and B20 blends with additives (Figure 10b and c) ranged between 3.02 and 3.62 mm^2/s over the course of storage. The viscosity of blends was within the range of standard ASTM-D 445.

4. CONCLUSION

In present work the *Jatropha* biodiesel was blended with diesel obtained from the retail outlets of three different oil companies in northern India, and the effectiveness of six antioxidants on the storage stability (oxidation stability, density, and viscosity) of these blends were studied over a period of 90 days. B10, B15, B20, and B25 diesel−biodiesel blends were tested in present study. The experimental results revealed that PL, PG, and TBHQ were most effective in neat biodiesel as well as its diesel blends, whereas BHA, BHT, and DPA were found less effective. It was also observed that with increasing the concentration of biodiesel the oxidation stability decreases. The increase in density and viscosity of diesel biodiesel blends revealed that storage stability can be affected by the storage condition and time. Study showed that the tested physicochemical properties of blended fuel were not consistent. These variations may be due the composition of biodiesel, nature of antioxidant additives, and quality of diesel fuel. However, further study is required to understand the role of the diesel fuel in the oxidation stability of diesel biodiesel blends, especially when there is a difference in the physical properties of the diesel fuel used for the blend preparation.

AUTHOR INFORMATION

Corresponding Author

*E-mail: drgirdharjoshi@yahoo.in. Tele Fax: 0135-2776090, ext 412.

Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors are highly thankful to the Chancellor Prof. S. J. Chopra, University of Petroleum and Energy Studies, Dehradun, and Dr. P. Kumar, Department of Chemistry, for their continuous encouragement. The Department of Science and Technology (Govt. of India) is gratefully acknowledged for providing financial support under sanctioned project DST/TSG/AF/2011/104.

REFERENCES

(1) Ulrich, A.; Wichser, A. Analysis of additive metals in fuel and emission aerosols of diesel vehicles with and without particle traps. *Anal. Bioanal. Chem.* **2003**, *377*, 71−81.

(2) He, B. Q.; Shuai, S. J.; Wang, J. X.; He, H. The effect of ethanol blended diesel fuels on emissions from a diesel engine. *Atmos. Environ.* **2003**, *37*, 4965−4971.

(3) Mori, S. Development of utilization technologies of biomass energy. *J. Environ. Eng. Manage.* **2009**, *19*, 67−72.

(4) Werther, J. Sustainable and energy-efficient utilization of biomass by co-combustion in large-scale power stations. *J. Environ. Eng. Manage.* **2009**, *19*, 135−144.

(5) Chen, K. S.; Lin, Y. C.; Hsieh, L. T.; Lin, L. F.; Wu, C. C. Saving energy and reducing pollution by use of emulsified palm-biodiesel blends with bio-solution additive. *Energy* **2010**, *36*, 2043−2048.

(6) Banerjee, A.; Chakraborty, R. Parametric sensitivity in trans-esterification of waste cooking oil for biodiesel production—A review. *Resour. Conserv. Recy.* **2009**, *53* (9), 490−497.

(7) Meng, X.; Chen, G.; Wang, Y. Biodiesel production from waste cooking oil via alkali catalyst and its engine test. *Fuel Process. Technol.* **2008**, *89* (9), 851−857.

(8) Jain, S.; Sharma, M. P. Prospects of biodiesel from Jatropha in India: A review. *Renewable Sustainable Energy Rev.* **2010**, *14* (2), 763−771.

(9) Leung, D. Y. C.; Wu, X.; Leung, M. K. H. A review on biodiesel production using catalyzed transesterification. *Appl. Energy* **2010**, *87* (4), 1083−1095.

(10) Zheng, S.; Kates, M.; Dube, M. A.; McLean, D. D. Acid-catalyzed production of biodiesel from waste frying oil. *Biomass Bioenergy* **2006**, *30* (3), 267−272.

(11) Patil, P. D.; Deng, S. Optimization of biodiesel production from edible and non-edible vegetable oils. *Fuel* **2009**, *88* (7), 1302−1306.

(12) Tang, H.; Wang, A.; Salley, S. O.; Simon Ng, K. Y. The effect of natural and synthetic antioxidants on the oxidative stability of biodiesel. *J. Am. Oil Chem. Soc.* **2008**, *85*, 373−382.

(13) Bouaid, A.; Martinez, M.; Aracil, J. Long storage stability of biodiesel from vegetable and used frying oils. *Fuel* **2007**, *86*, 2596−2602.

(14) Fang, H. L.; McCormick, R. L. *Spectroscopic study of biodiesel degradation pathways*; SAE Technical Paper, Society of Automotive Engineers: Warrendale, PA, 2006; 2006-01-3300.

(15) Lamba, Y. B.; Singh, H.; Rawat, M. S. M. Oxidation stability of methyl ester and diesel fuel blends. *Erdol Erdgas Kohle* **2011**, *127*, 91−93.

(16) McCormick, R. L.; Ratcliff, M.; Moens, L.; Lawrence, R. Several factors affecting the stability of biodiesel in standard accelerated tests. *Fuel Process. Technol.* **2007**, *88*, 651−657.

(17) Monyem, A.; VanGerpen, J. H. The effect of biodiesel oxidation on engine performance and emissions. *J. Biomass Bioenergy* **2001**, *20*, 317−325.

(18) Kapilan, N.; Ashok Babu, T. P.; Reddy, R. P. Technical aspects of biodiesel and its oxidation stability. *Int. J. Chem. Tech. Res.* **2009**, *1*, 278−282.

(19) Schober, S.; Mittelbach, M. The impact of antioxidants on biodiesel oxidation stability. *Eur. J. Lipid Sci. Technol.* **2004**, *106*, 382−389.

(20) Dunn, O. Effect of antioxidants on the oxidative stability of methyl soyate (biodiesel). *Fuel Process. Technol.* **2005**, *86*, 1071−1085.

(21) Ryu, K. The characteristics of performance and exhaust emissions of a diesel engine using a biodiesel with antioxidants. *Bioresour. Technol.* **2010**, *101*, 578−582.

(22) Tang, H.; De Guzman, R. C.; Salley, S. O.; Simon Ng, K. Y. The oxidative stability of biodiesel: Effects of FAME composition and antioxidant. *Lipid Technol.* **2008**, *20*, 249−252.

(23) Mushrush, G. W.; Hughes, J. M.; Willauer, H. D. Blends of soybean biodiesel with petroleum diesel: advantages. *Ind. Eng. Chem. Res.* **2013**, *52*, 1764−1768.
(24) Mushrush, G. W.; Wynne, J. H.; Hughes, J. M.; Beal, E. J.; Lloyd, C. T. Soybean-derived fuel liquids from different sources as blending stocks for middle distillate ground transportation fuels. *Ind. Eng. Chem. Res.* **2003**, *42*, 2387−2389.
(25) Altun, S.; Oner, C.; Yasar, F.; Adin, H. Effect of n-butanol blending with a blend of diesel and biodiesel on performance and exhaust emissions of a diesel engine. *Ind. Eng. Chem. Res.* **2011**, *50*, 9425−9430.
(26) Mushrush, G. W.; Wynne, J. H.; Willauer, J. M.; Lloyd, C. T. J. H.; Hughes, J. M. Beal, Recycled soybean cooking oils as blending stocks for diesel fuels. *Ind. Eng. Chem. Res.* **2004**, *43*, 4944−4946.
(27) Karavalakis, G.; Hilari, D.; Givalou, L.; Karonis, D.; Stournas, S. Storage stability and ageing effect of biodiesel blends treated with different antioxidants. *Energy* **2011**, *36*, 369−374.
(28) Karavalakis, G.; Karonis, D.; Stournas, S. Evaluation of the oxidation stability of diesel/biodiesel blends using the modified Rancimat method. *SAE Int. J. Fuels Lubr.* **2009**, *2*, 839−849.
(29) Knothe, G. Some aspects of biodiesel oxidative stability. *Fuel Process. Technol.* **2007**, *88*, 669−677.
(30) Lin, C.-Y.; Chiu, C. C. Effects of oxidation during long-term storage on the fuel properties of palm oil-based biodiesel. *Energy Fuels* **2009**, *23*, 3285−3289.
(31) Domingos, A. K.; Saad, E. B.; Vechiatto, W. W. D.; Wilhelmc, H. M.; Ramos, L. P. Kinetics of oxidation of biodiesel from soybean oil mixed with TBHQ: determination of storage time. *J. Braz. Chem. Soc.* **2007**, *18*, 416−423.
(32) Das, L. M.; Bora, D. K.; Pradhan, S.; Naik, M. K.; Naik, S. N. Long-term storage stability of biodiesel produced from Karanja oil. *Fuel* **2009**, *88*, 2315−2318.
(33) Xin, J.; Imahara, H.; Saka, S. Kinetics on the oxidation of biodiesel stabilized with antioxidant. *Fuel* **2009**, *88*, 282−286.
(34) Paligova, J.; Jorikova, L.; Cvengros, J. Study of FAME stability. *Energy Fuels* **2008**, *22*, 1991−1996.
(35) Dantas, M. S. G.; Castro Dantas, T. N.; Dantas Neto, A. A.; D'Ornellas, C. V. Antioxidative efficiency of novel β-naphthol derivatives in storage assays of cracked naphtha. *Fuel* **2008**, *87*, 3445−3454.
(36) Ribeiro, N. M.; Pinto, A. C.; Quintella, C. M.; da Rocha, G. O.; Teixeira, L. S. G.; Guarieiro, L. L. N.; Rangel, M. C.; Veloso, M. C. C.; Rezende, M. J. C.; da Cruz, R. S.; de Oliveira, A. M.; Torresr, E. A.; de Andrade, J. B. The Role of additives for diesel and diesel blended (ethanol or biodiesel) fuels: a review. *Energy Fuels* **2007**, *21*, 2433−2445.
(37) Singh, S. P.; Singh, D. Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: A review. *Renewable Sustainable Energy Rev.* **2010**, *14*, 200−216.
(38) Jain, S.; Sharma, M. P. Study of oxidation stability of Jatropha *curcas* biodiesel/diesel blends. *Int. J. Energy Environ. (IJEE)* **2011**, *2*, 533−542.
(39) Sarin, R.; Sharma, M.; Sinharay, S.; Malhotra, R. K. Jatropha−palm biodiesel blends: an optimum mix for Asia. *Fuel* **2007**, *86*, 1365−1371.
(40) Jain, S.; Sharma, M. P. Stability of biodiesel and its blends: A review. *Renewable Sustainable Energy Rev.* **2010**, *14*, 667−678.
(41) Liang, Y. C.; May, C. Y.; Foon, C. S.; Ngan, M. A.; Hock, C. C.; Basiron, Y. The effect of natural and synthetic antioxidants on the oxidative stability of palm diesel. *Fuel* **2006**, *85*, 867−870.
(42) Sarin, A.; Arora, R.; Singh, N. P.; Sharma, M.; Malhotra, R. K. Influence of metal contaminants on oxidation stability of Jatropha biodiesel. *Energy* **2009**, *34*, 1271−1275.
(43) McCormick, R. L.; Westbrook, S. R. Storage Stability of biodiesel and biodiesel blends. *Energy Fuels* **2010**, *24*, 690−698.
(44) Dunn, R. O. Antioxidants for improving storage stability of biodiesel. *Biofuels, Bioprod. Biorefin.* **2008**, *2*, 304−318.
(45) Rosen, D.; Georgi, H.; Dicho, S.; Violeta, B. A. Effect of commercially available antioxidants over biodiesel/diesel blends stability. *Fuel* **2009**, *88*, 732−737.
(46) Focke, W. W.; van der Westhuizen, I.; Grobler, A. B. L.; Nshoane, K. T.; Reddy, J. K.; Luyt, A. S. The effect of synthetic antioxidants on the oxidative stability of biodiesel. *Fuel* **2012**, *94*, 227−233.
(47) De-Oliveira, J. S.; Leite, P. M.; de Souza, L. B.; Mello, V. M.; Silva, E. C.; Rubim, J. C.; Simoni Meneghetti, M. P.; Paulo Suarez, A. Z. Characteristics and composition of Jatropha *gossypiifolia*and Jatropha *curcas* L. oils and application for biodiesel production. *Biomass Bioenergy* **2009**, *33*, 449−453.
(48) DeGuzman, R.; Tang, H.; Salley, S.; Simon Ng, K. Y. Synergistic effect of antioxidants on the oxidative stability of soybean oil and poultry fat-based biodiesel. *J. Am. Oil Chem. Soc.* **2009**, *86*, 459−467.
(49) Karavalakis, G.; Stournas, S. Impact of antioxidant additives on the oxidation stability of Diesel/Biodiesel Blends. *Energy Fuel* **2010**, *24*, 3682−3686.
(50) Alptekin, E.; Canakci, M. Determination of the density and the viscosities of biodiesel-diesel fuel blends. *Renewable Energy* **2008**, *13*, 2623−2630.
(51) Geller, D. P.; Adams, T. T.; Goodrum, W. J.; Pendergrass, J. Storage stability of poultry fat and diesel fuel mixture: Specific gravity and viscosity. *Fuel* **2008**, *87*, 92−102.