

Storage stability of poultry fat and diesel fuel mixtures: Specific gravity and viscosity

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Abstract

Poultry fat (biofuel) and its 20%, 40%, 60% and 80% mixtures with #2 pump diesel fuel were stored for 1 year at bench scale (1 L) under controlled laboratory conditions at 4, 38, 54.4 °C and at ambient room temperature. Poultry fat (100%) was studied under these same conditions with and without an antioxidant additive. Poultry fat mixtures (20% and 80%) were also stored at pilot scale (250 gallons) under outdoor, ambient conditions. Physical properties and phenomenon relevant to the use of these mixtures as biofuels for industrial boilers were studied and tracked. These properties include specific gravity, dynamic viscosity, sedimentation accumulation and separation (layering). Corrosive effects of these fuels on various metals were also examined. Viscosity and specific gravity of these biofuels changed very little over the course of the 1 year storage period. Sediment accumulation was present in all treatments, with increasing sedimentation correlating with increasing biofuel concentrations. The addition of antioxidant to 100% biofuel minimized changes in physical properties and sedimentation over the course of this study. Layering occurred in all mixtures of poultry fat and diesel fuel. Results also include the approximate amount of energy required to insure proper mixing of each treatment. After mixing, homogenization was maintained for considerable time periods. This suggests that mixing should only be performed immediately before the fuels are utilized. Corrosive properties of these biofuels were generally as expected; brass and copper were susceptible to attack by these fuels where as 316 stainless steel and carbon steel were not.

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1. Introduction

The development of novel uses for agriculturally based fats and oils provides expanded markets for producers of these byproducts. One such value-added use for these oils is their implementation as biofuels or fuel extenders in traditional liquid fuel systems such as oil heaters. The use of agricultural fats and oils as alternate fuel sources or fuel extenders may provide an inexpensive fuel source while increasing the value of these byproducts. In addition, the renewability of this biofuel gives it a competitive advantage

over fossil fuels. Furthermore, these oils are sulfur-free and exhibit much lower particulate matter and CO emissions than petroleum based fuels [1].

Use of these fats and their mixtures with petroleum fuels as alternative energy sources will require their stability during storage periods when the biofuels are not being used. For example, poultry fat collected in warm summer months may be stored until needed to heat broiler houses in colder winter months. While these fats are being stored, they must be relatively stable so that fuel properties will not deteriorate before the biofuel is used. Previous work has examined the stability of Biodiesel; a fuel derived from triglyceride based oils [2–5] and found that this form of fuel is quite stable during long-term storage. Stability of stored vegetable oils has also been examined [6–8]. Most of these studies find adequate stability after six months storage.

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This study intended to gather similar information for the storage of unmodified poultry fat.

Physical changes during storage of these fat and diesel mixtures may cause undesired effects on the use of these fuels. Changes in viscosity or specific gravity could have detrimental effects on their transport and eventual use. Separation of fat and fuel layers could affect the overall fuel properties of these mixtures since systems for their use may be designed around specific biofuel concentrations which change if layering occurs. Sedimentation could cause complication by accumulating on vital parts of the fuel system. Corrosive properties of these fats and oils could cause problems if compatible materials are not used in fuel system designs.

This study was designed to study the effects of long-term storage on the physical properties of poultry fat and its mixtures with No. 2 petroleum diesel fuel. This work examines dynamic viscosity, specific gravity, sedimentation accumulation, separation (layering) and corrosive properties. Fuel mixtures of petroleum diesel and increasing poultry fat concentrations of 20%, 40%, 60%, 80% and 100%, were stored for one year in small scale (1 L), controlled, laboratory conditions (4, 38, 54.4 °C and room temperature) while 20% and 80% biofuel mixtures were also subjected to outdoor ambient conditions in a pilot scale (250 gallon) storage study. Monthly measurements of viscosity and specific gravity were recorded. A study of the sedimentation and layering of these fuels was conducted as well as a 10 month corrosion study using corrosion coupons in 20% and 80% biofuel mixtures. Additionally, the effect of antioxidants on these fuels was also studied. It has been shown that antioxidants increase oxidative stability of stored animal fats [9]. This study also sought to explore the stabilizing effect of antioxidant on relative fuel properties of stored poultry fat. Antioxidants inhibit the formation of free fatty acids in triglycerides; the effect of this inhibition on relevant fuel properties of poultry fat was studied here. This data was used to determine the utility of antioxidant as a stabilizer in stored poultry fat and its mixtures with No. 2 petroleum diesel.

2. Experimental procedures

The storage study was conducted using poultry fat provided by American Protein, Inc. (Cumming, GA) mixed with common #2 pump diesel fuel (D2) provided by the University of Georgia. The biofuels were stored on two scales; laboratory scale in which individual samples were stored in 1 L inert bottles and pilot scale in which samples were stored at outdoor ambient temperature in 250 gallon steel tanks. The entire treatment schedule is available in Table 1. Laboratory studies were conducted at 4 different temperatures: 4, 25, 38 and 54.4 °C (39.2, 77.0, 100.4 and 129.9 °F) and at five different concentrations of 20%, 40%, 60%, 80% and 100% chicken fat. Additionally, another set of 100% chicken fat samples was studied that had 10 mL (1.0%) of Rendox AT20 Liquid added. Rendox is an antioxidant provided by Kemin Industries (Des

Moines, IA) which contains Soybean Oil, Butylated Hydroxyanisole and Butylated Hydroxytoluene. Each of the laboratory scale studies were conducted in triplicate and stored in temperature controlled incubators. Pilot scale storage of the biofuels was conducted at two different concentrations of 20% and 80% chicken fat. Tanks were stored outside in Athens, GA and were subject to ambient temperatures and conditions over the 12 month study. No antioxidant was added to the pilot scale biofuels. Laboratory samples (1 L) were stored under controlled conditions.

2.1. Sample collection

Laboratory samples were collected from each treatment on a monthly basis and analyzed for specific gravity and viscosity. This required a relatively small volume sample loss (~10 mL) each month. For samples stored at 4 °C, a fast heating was performed by immersing sample bottles in warm tap water. This was done to insure fluidity necessary for analysis. This did not effect the outcome of analyses as viscosity testing was carried out at controlled temperatures and all specific gravity analyses were performed at room temperature.

Outdoor pilot scale samples were collected monthly using an electric drum pump. Biofuel was circulated for 1 h by the pump before samples were collected and circulation continued for 5 min between each of three samples collected per month. Approximately 1–3 L of sample was removed from each tank every month.

2.2. Specific gravity analysis

Specific gravity was measured using two compatible methods depending upon the specific gravity of the sample being measured. Most specific gravity data was obtained using a Fisherbrand 150 mm long precision specific gravity hydrometer (Fisher Scientific, Pittsburgh, PA). Hydrometer data was not obtainable for some density ranges or viscosities at specific temperatures. For these cases, a densitometer method using a Moore–Van Slyke Specific Gravity Bottle (Fisher Scientific, Pittsburgh, PA) was employed to measure density. The densitometer method required a small amount of sample loss and two weighing steps using an electronic balance. Individual observations that varied beyond 20% of the mean for the current treatment were omitted as random outliers. Statistical comparison of the two methods showed they were in close agreement with each other and results from both tests are considered compatible.

2.3. Viscosity analysis

Viscosity was measured for each liquid sample in triplicate by using a Brookfield Synchro-metric LVT viscometer with UL adapter (Stoughton, MA). This immersion-type concentric cylinder viscometer was operated at three discrete shear rates: 0.32, 32.34 and 64.69 s⁻¹. The instrument's accuracy and reproducibility were 1% and 0.2% of

Table 1
Treatment schedule

Sample no.	Sample composition			Sample size		Sample temperature				
	% Biofuel	% Fuel oil	Antioxidant	1.0 L	250 gal.	4 ° C	Room temperature	38 °C	54 °C	Outdoor (ambient)
10-B-S-A	100	0		×		×				
80-B-S-A	80	20		×		×				
60-B-S-A	60	40		×		×				
40-B-S-A	40	60		×		×				
20-B-S-A	20	80		×		×				
10-A-S-A	100	0	Yes	×		×				
10-B-S-B	100	0		×			×			
80-B-S-B	80	20		×			×			
60-B-S-B	60	40		×			×			
40-B-S-B	40	60		×			×			
20-B-S-B	20	80		×			×			
10-A-S-B	100	0	Yes	×			×			
10-B-S-C	100	0		×				×		
80-B-S-C	80	20		×				×		
60-B-S-C	60	40		×				×		
40-B-S-C	40	60		×				×		
20-B-S-C	20	80		×				×		
10-A-S-C	100	0	Yes	×				×		
10-B-S-D	100	0		×					×	
80-B-S-D	80	20		×					×	
60-B-S-D	60	40		×					×	
40-B-S-D	40	60		×					×	
20-B-S-D	20	80		×					×	
10-A-S-D	100	0	Yes	×					×	
80-B-L-E	80	20			×					×
20-B-L-E	20	80			×					×

Sample code: ZZ-Y-X-W.

ZZ signifies % biofuel (20, 40, 60, 80, or 10, for 100%).

Y signifies antioxidant addition to sample, either A for antioxidant or B for no antioxidant.

X signifies sample size, either S for small (1.0 L) or L for large (250 gallon).

W signifies sample temperature: A for 4 °C, B for room temperature, C for 38 °C, D for 54.4 °C, and E for outdoor ambient.

full-scale, respectively. Observations that fell below 5% of full-scale at a given shear rate were not within the instrument's range and, therefore, were not recorded. Individual observations that varied beyond 20% of the mean for the current treatment were omitted as random outliers. A circulating temperature bath provided two constant temperatures for experimentation: 54.4 and 85 °C maintained to an accuracy of ± 0.5 °C.

2.4. Sediment accumulation

Samples of all treatments (20%, 40%, 60%, 80%, 100% biofuels) stored at 38 °C and 54.4 °C for one year were isolated and left undisturbed for 2 weeks at their respective storage temperatures before sediment measurements were taken. Samples were removed from the oven and the depth of sediment was measured along with the total depth of the sample. Volumes were calculated for each component and a sediment as a percent of total volume was calculated.

2.5. Layering time line

Layer formation between biofuel and #2 diesel fuel was measured as a function of time. Initial 1 L sample bottles

were filled 5 in. with appropriate fuel mixtures and were then shaken until homogenous. Bottles were then placed in an undisturbed location at room temperature and bottom (biofuel) layer height was measured at increasing intervals over the course of 936 h (39 days).

2.6. Mixing energy determination

Samples stored at 20 °C were heated at increments of 1 °C over the course of 29 h. Chicken fat mixture (20%) was mixed at starting temperature. Mixing temperature was taken as the temperature when layers were no longer visible to the eye. This method was only intended to provide a rough estimate of the mixing temperature sufficient to allow prediction of effective energy input for homogenization of these fuel mixtures.

2.7. Corrosion study

Corrosion studies commenced on September 5, 2003 at 2:00 pm and terminated on July 2, 2004 at 12:00 pm (10 months/7342 h). Carbon Steel, Admiralty Brass, Copper, Grey Cast Iron and 316 Stainless Steel corrosion coupons were obtained from Enviro Sciences, Inc. (Carrollton,

TX). Coupons were weighed and then suspended in 1 L bottles of 20% and 80% biofuel samples. Three replicates of each sample metal were tested in both 20% and 80% biofuel. The samples were stored in a climate controlled oven at 38 °C (100.4 °F). At the end of the study, coupons were cleaned and reweighed using guidelines outlined in ASTM designation G21-72 [10]. The final weight was measured and total weight loss and loss rates were calculated using formulas from the ASTM method. The appearance of the coupons at the end of the study was recorded using digital photography and photo microscopy.

2.8. Statistical analysis

All Analysis of Variance (ANOVA) analyses were performed using Microsoft Excel. All ANOVA tests used $\alpha = 0.05$ to determine statistical significance.

3. Results and discussion

The overall results of this study suggest that these biofuels are relatively stable for up to one year under both controlled conditions and naturally variable environmental conditions. The properties most relevant to practical application which were studied here: specific gravity and viscosity, show relative stability in all samples examined in this study. The other properties studied here; layer formation and sediment accumulation presented complicating factors to storage for fuel use. These complications are overcome by simple methods which will not complicate the use of these fuels and their mixtures as fuels. Layer formation is overcome by the input of energy to assure mixing of components at time of use, after this energy is added and mixing is complete; the mixtures remain homogenous for extended periods of time. Sediment accumulation was shown to be significantly reduced by the addition of antioxidant. Metal corrosion effects of these fuel mixtures were generally as predicted from previous studies on Biodiesel [11] and can be avoided by the use of proper materials (steel, plastic) in storage and transport systems.

3.1. Specific gravity analysis

Specific gravity measurements reflected stability and consistency. In almost all of the samples studied, the specific gravity of the biofuels increased slightly over the course of storage. Interestingly, only in a few of the 40% and 80% biofuel samples did we observe a decrease in specific gravity from the beginning to the end of the study. The results of the specific gravity analysis on the studied biofuels are shown in Fig. 1. ANOVA analysis showed none of the treatments had a P -value of less than .05. This indicates no significant variation between initial and final specific gravity values thus suggesting no significant impact on volume will be observed when storing these biofuels.

There was very little variation in specific gravity between the temperature treatments studied. Analysis of variance

did not show significant variance between temperature treatments suggesting temperature dependent volume changes are not significant. Initial specific gravity values ranged from 0.8758 g/mL to 0.8927 g/mL with an average of 0.8831 g/mL. Final average specific gravity values independent of temperature ranged from 0.8650 g/mL for 20% biofuel at 25 °C to 0.9260 g/mL for 100% biofuel stored at 4 °C, with an average of 0.8953 g/mL. The difference between the highest and lowest observed specific gravity values at the end of the study is only 0.0353 g/mL. This is a variation of only 4.08% amongst the samples. Similarly, initial variation was only 3.37%. Throughout the entire study specific gravity peaked at 0.9453 g/mL for 100% biofuel at 4 °C; while the lowest observed value was 0.8454 for 60% biofuel at 54.4 °C. This is a maximum variation of 0.0999 g/mL or about 10.0%. While variation increased slightly due to long-term storage conditions, the overall variation was determined to be statistically insignificant. The use of various mixtures of biofuel and diesel could be easily accommodated in storage systems by the incorporation of minimal compensatory volume (<10%) especially at elevated temperatures.

3.2. Viscosity analysis

Viscosity was relatively stable for the biofuel blends studied here. In most cases, viscosity dropped slightly or held steady during the course of the study. However, due to the large viscosity difference between diesel fuel and biofuels, viscosity was not consistent between the different fuel blends. Analysis of Variance confirmed that the difference between all treatments and initial and final values were statistically significant. This was as expected and should be considered in the design of storage systems that may use more than one blend of biofuel.

In general, viscosity changed very little during the course of the study. As there were over 2700 individual viscosity measurements taken during the course of the study, we chose to present representative viscosity data as shown in Fig. 2. These figures reflect the results of viscosity analysis at 30 rpm and 85 °C. This data set provided the most complete results of the six shear rate and temperature combinations and is representative of the entire range of viscosity analyses. All storage temperatures caused the viscosity of 100% biofuel with and without antioxidant to drop slightly during the study. Two storage temperatures, outdoor ambient and the lowest temperature of 4.0 °C also showed a viscosity drop for 80% biofuel at 30 rpm (32.34 s^{-1} shear rate) and 85 °C. The data presented here is generally representative of each treatment's viscosity behavior in terms of effect of relative storage temperature. The variation within treatments observed in Fig. 2 is the error inherent in viscosity testing (<5.0%). One significant trend observed here is the slightly higher viscosity maintained by samples stored at 54.4 °C. This trend is observed throughout the variable concentrations in all six plots. Additionally, as biofuel

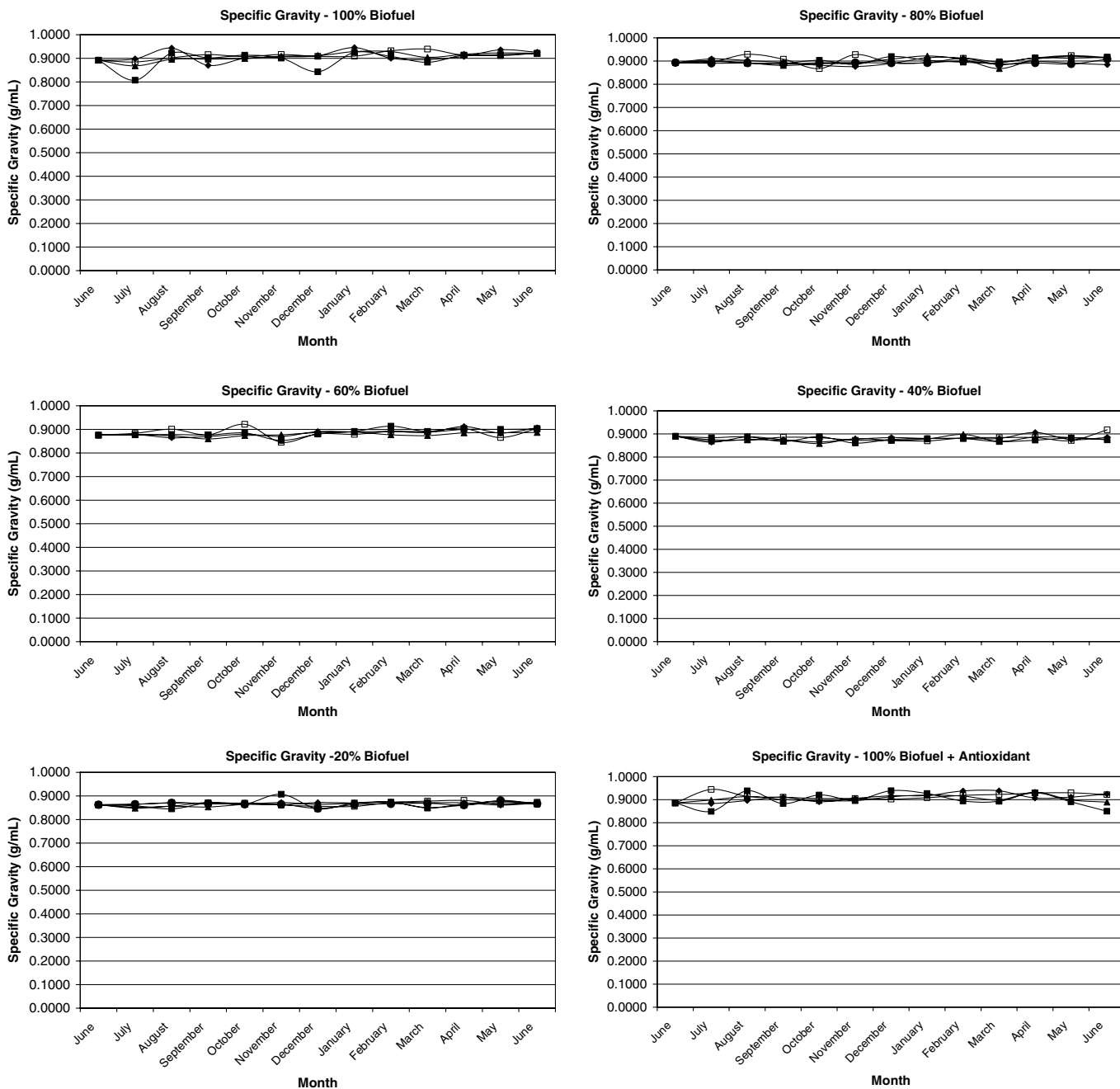


Fig. 1. Specific gravity versus storage month for six biofuel concentrations. ◆ – 4 °C storage, ■ – 25 °C storage, ▲ – 38 °C storage, □ – 54.4 °C storage, ● – Outdoor ambient storage.

concentration increases, we see more dramatic viscosity variation within the sample sets.

One unexpected trend observed in the viscosity data was not related to time or temperature, but to biofuel concentration. This trend can be best seen by in our initial viscosity data at 30 rpm and 85 °C. A non-linear increase in viscosity accompanying increasing concentrations of poultry fat can be observed. The initial viscosities of each treatment are shown in Fig. 3; this figure includes the difference between each subsequent biofuel concentration. These differences are plotted in Fig. 4 and a regression

equation is presented here representing the behavior of this viscosity change versus concentration. Similar behavior has been noted in previous studies on peanut oil/diesel fuel blends [12] suggesting this behavior extends beyond animal fats and can be seen in other triglyceride based oils.

3.3. Sediment accumulation

Throughout the study it was noticed that a loose accumulation of sediment had formed in all 1 L (small) treat-

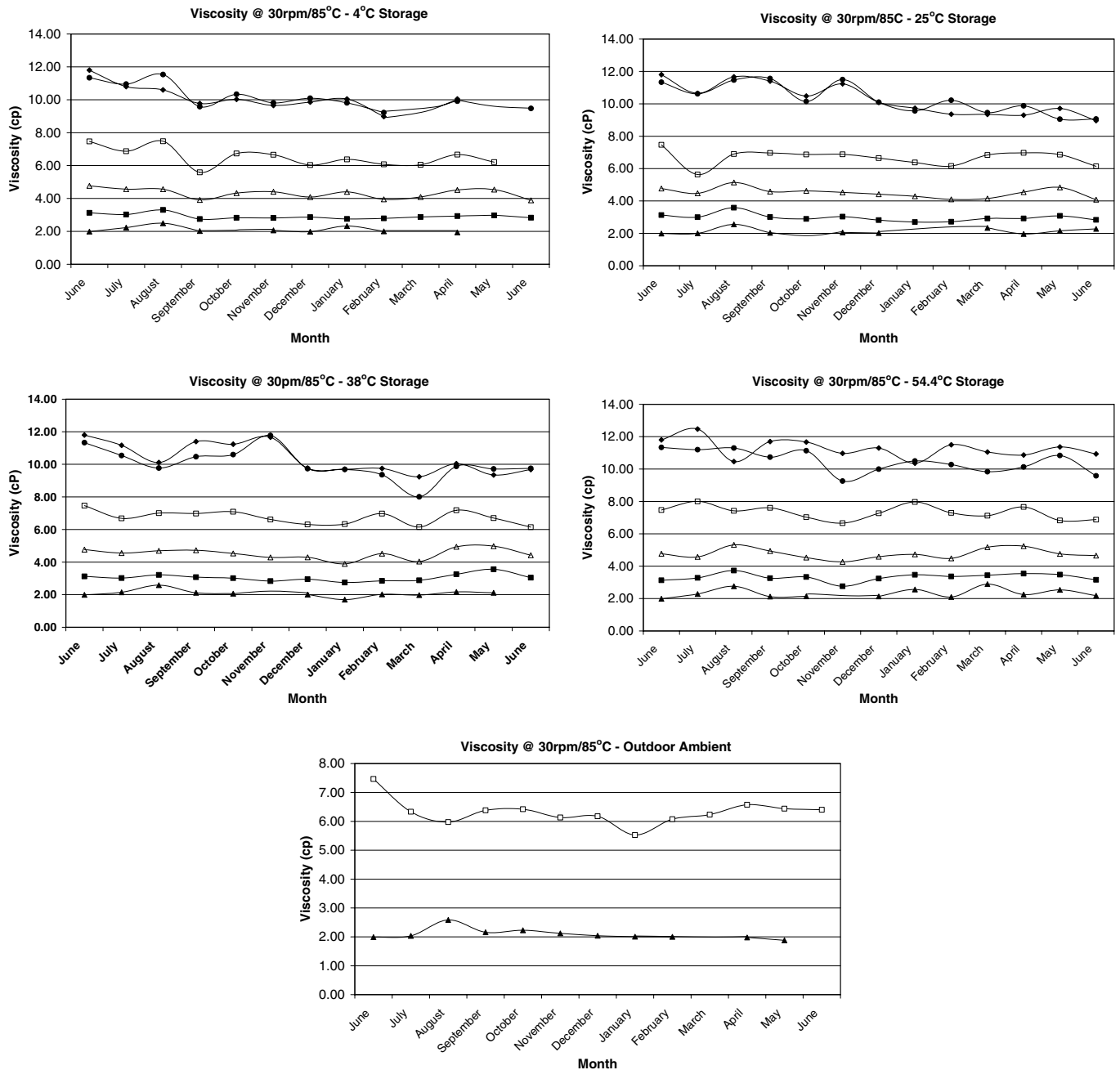


Fig. 2. Viscosity at 30 rpm/85 °C (32.34 s⁻¹ shear rate) versus storage month for five storage temperature treatments. ◆ – 100% biofuel, □ – 80% biofuel, △ – 60% biofuel, ■ – 40% biofuel, ▲ – 20% biofuel, ● – 100% biofuel with antioxidant.

ments that were liquid at treatment temperature (38 °C and 54.4 °C). Attempts were made to quantify this material. Due to its tendency to dissolve in the liquid phase of fuel samples upon agitation, it was difficult to isolate these sediments for weight and volume quantification. The tendency of this sediment to stick to the side of storage vessels made it challenging to get an accurate measurement of their actual depth and volume. The method described above was used to roughly quantify this material on a volume percentage basis. The results of these measurements are shown in Fig. 5.

Storage at elevated temperature clearly allows differentiation of sediment levels between treatments. 38 °C storage resulted in somewhat consistent sedimentation for biofuel concentrations between 20% and 80%. Hundred percent biofuel showed a slightly higher sediment level which was reduced slightly by the addition of antioxidant. When the temperature was elevated to 54.4 °C sedimentation became much more dependent on biofuel concentration. A definite increase in sedimentation accompanied increases in biofuel levels. In this case, addition of antioxidant to 100% biofuel led to a significant reduction in

sediment accumulation in this treatment. Antioxidant addition brought the sediment level down below that which is seen for 80% biofuel. From this observation it

can be postulated that sediment formation may be linked to oxidative degradation.

3.4. Separation of fuel layers

Separation of fuel oil and poultry fat occurred in samples stored at or below room temperature. Samples stored at 38 and 54.4 °C showed no layering of fuels. An experiment to track the rate of separation of these fuels was carried out on all five poultry fat concentrations: 20%, 40%, 60%, 60% and 100%. Bottles were initially shaken until the mixture was uniform and then left to settle. Layer depths were then recorded at regular intervals. The results of this experiment are shown in Fig. 6. Biofuel mixtures (20% and 40%) began separating within 15 min of the initial homogenization. 60% biofuel took 312 h (13 days) to begin separation and 80% biofuel took 336 h (2 weeks) before any separation was visible. Fluctuations in layer volumes occurred in these samples while settling occurred. Ultimately, 40% biofuel was completely separated in

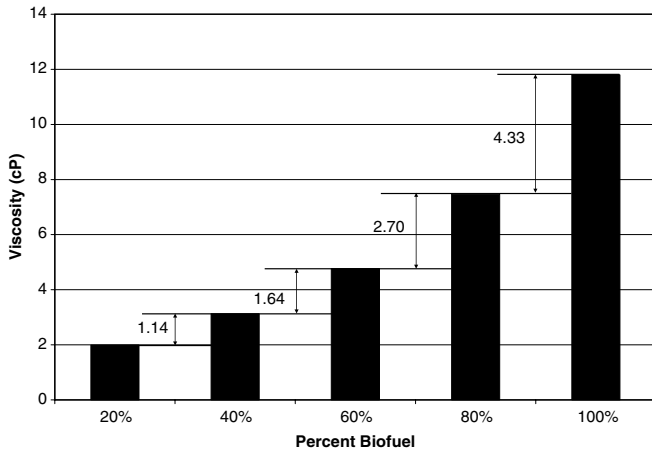


Fig. 3. Baseline viscosity versus percent biofuel. Arrows and numbers indicate viscosity changes between subsequent treatments in cP.

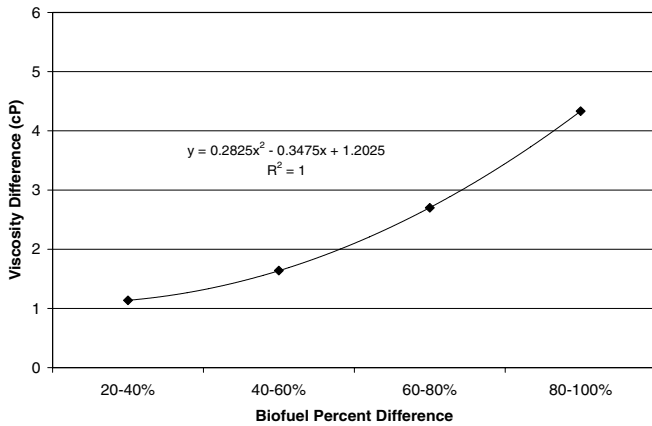


Fig. 4. Baseline viscosity difference versus change in biofuel concentration.

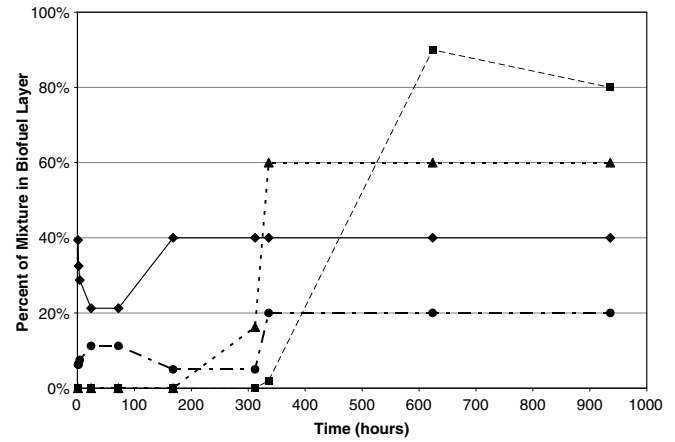


Fig. 6. Layering of #2 diesel fuel and poultry fat mixtures versus time. ■ – 80% biofuel, ▲ – 60% biofuel, ◆ – 40% biofuel, ● – 20% biofuel.

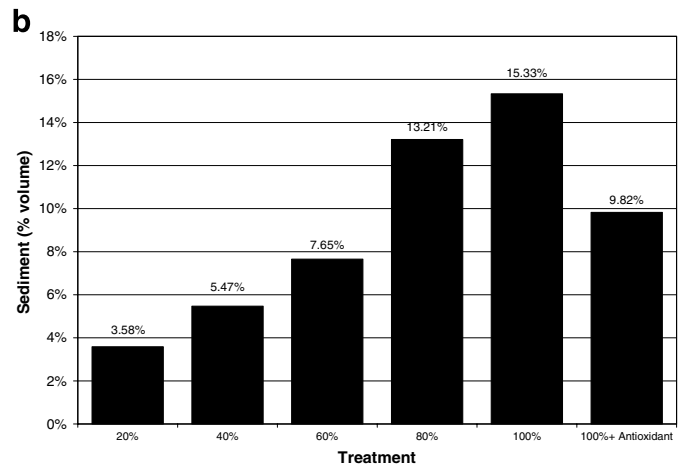
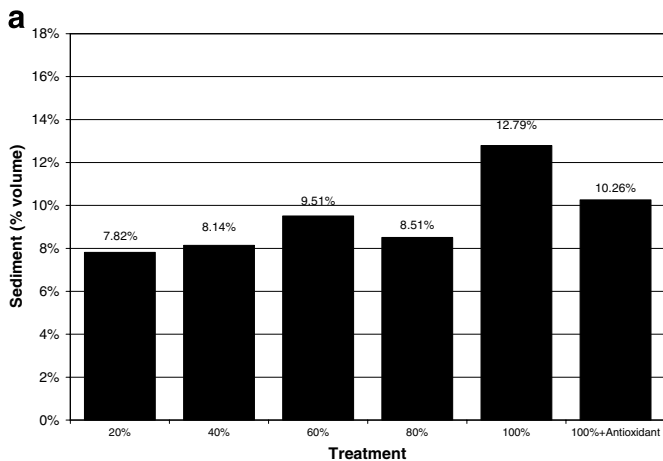


Fig. 5. Sediment accumulation in undisturbed 1 L bottles of biofuel/diesel mixtures after 2 weeks. Treatment labels refer to biofuel concentrations. (a) 38 °C storage and (b) 54.4 °C storage.

168 h (1 week) while 20% and 60% biofuel mixtures took twice as long with a complete separation time of 336 h (2 weeks). Biofuel mixtures (80%) took considerably longer to settle and separate with a total separation time of 936 h (39 days).

3.5. Mixing

In order to deal with the natural tendency of these biofuel and diesel fuel mixtures to separate, we examined the energy input required to keep the fuels homogenous. The energy required to homogenize these fuels was determined by measuring the temperature required to mix the layers present in combination fuel samples. The temperature at which each treatment becomes homogenous is shown in Table 2. Note that the 20% poultry fat mixture was already mixed at the initial temperature of 20 °C (68 °F). The specific heat capacity (c) of animal fat = 0.5 BTU/lb °F = 0.5 cal/g K [13] is very close to the specific heat of diesel fuel = 0.45 BTU/lb °F = 0.45 cal/g K. Therefore, we assume the specific heat capacity of the system to be proportionate to the percent composition of each component. These proportionate specific heat capacity values are also presented in Table 2.

A rough estimate of energy required to mix these fuels can then be determined using Eq. (1).

$$\Delta Q = mc\Delta T \quad (1)$$

The most direct method for applying this data to real world storage situations is to simply heat the stored biofuels to the indicated temperatures. However, energy may be applied by other means such as mixing or pumping. The en-

Table 2
Mixing temperatures and specific heat values of various poultry fat and diesel fuel mixtures

Poultry fat (%)	Diesel fuel (%)	Mixing temperature (°C)	Mixing temperature (°F)	c (BTU/lb °F)	c (cal/g K)
20	80	20	68.0	0.46	0.46
40	60	23	73.4	0.47	0.47
60	40	32	89.6	0.48	0.48
80	20	34	93.2	0.49	0.49

ergy required (ΔQ) can be determined by simply calculating the difference between ambient and mixing temperatures ($\Delta T = T_{\text{mix}} - T_{\text{amb}}$) and using the appropriate, proportionate specific heat (c). The mass (m) is simply the mass of the entire mixture to be homogenized and will be different for each application.

As explained above, once mixed, these fuels maintain homogeneity for extended periods. Therefore, once an appropriate amount of energy is added either mechanically or thermally, the mixture will maintain its uniformity for immediate use. To insure full mixing it would be wise to overestimate the amount of energy required for homogenization by at least 10%.

3.6. Corrosion

Results of the corrosion study are presented in Table 3. Carbon Steel and 316 Stainless Steel showed no weight loss or visible corrosion when exposed to these fuels in 20:80, and 80:20 concentrations for 10 months at 38 °C. The condition of these exposed coupons after cleaning can be observed in Fig. 7. Light micrographs of the coupon surfaces are shown in Fig. 8. These micrographs show very

Table 3
Corrosion coupon data

Metal	Percent biofuel	Initial weight (g)	Final weight (g)	Weight change (g)	Percent change	Rate (g/m ² h)
Carbon steel	20	10.4172	10.4171	0.0000	0.00%	0.0000
Carbon steel	80	10.3847	10.3849	0.0001	0.00%	0.0000
316 SS	20	10.8978	10.8976	-0.0001	0.00%	0.0000
316 SS	80	10.9421	10.9420	0.0000	0.00%	0.0000
Copper	20	13.1592	13.0669	-0.0923	-0.71%	-0.0130
Copper	80	13.1625	13.0606	-0.1020	-0.78%	-0.0144
Admiralty brass	20	12.5028	12.4459	-0.0569	-0.46%	-0.0080
Admiralty brass	80	12.5398	12.4471	-0.0926	-0.74%	-0.0130
Grey cast iron	20	10.6468	10.6468	0.0000	0.00%	0.0000
Grey cast iron	80	10.6252	10.6224	-0.0028	-0.03%	-0.0004

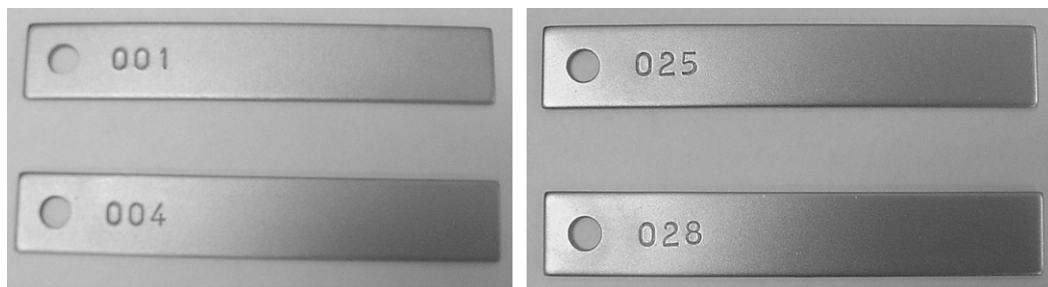


Fig. 7. Carbon steel and 316 stainless steel corrosion coupons after exposure to 80% and 20% biofuel for 10 months (7342 h). 001 = Carbon steel stored in 20% biofuel, 004 = carbon steel stored in 80% biofuel, 025 = 316 SS stored in 20% biofuel, 028 = 316 SS stored in 80% biofuel.

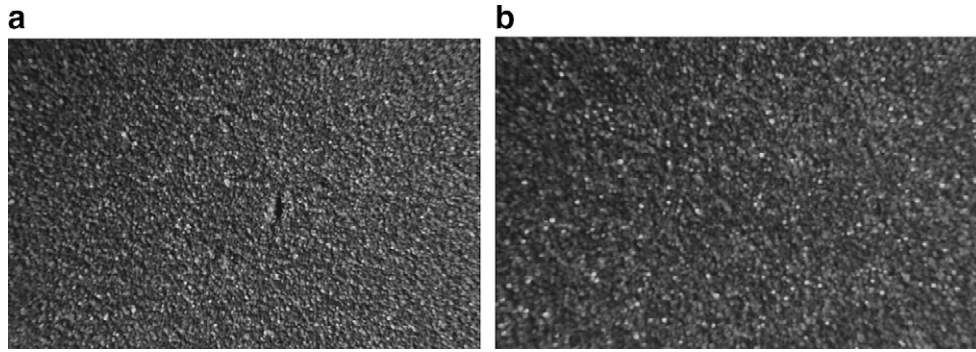


Fig. 8. 8× light micrographs of a. carbon steel after exposure to 80% biofuel for 10 months (7342 h) and b. 316 stainless steel after exposure to 20% biofuel for 7342 h.

little damage to coupon surfaces other than occasional pitting likely attributed to rough handling. The absence of corrosion was as expected as general industry practices use steel containers for storage of animal fats and vegetable oils. Such storage containers are stable and effective for use with these triglyceride based oils. Likewise, diesel fuel oil can be successfully stored in such containers as well, making them adequate for storage of biofuel/fuel oil mixtures.

Copper showed the greatest weight loss and susceptibility to the fuels of the metals studied, a photograph of this damage on cleaned corrosion coupons is shown in Fig. 9. This damage is magnified to 8× in the micrographs in

Fig. 10. Twenty percent biofuel resulted in a weight loss of 0.71% and 80% biofuel caused a slightly higher weight loss of 0.74%. Visibly, the copper sample coupons were covered in dark deposits which required detergent and slight physical abrasion for removal. The resulting, cleaned coupon had a smooth, pink, matte finish in contrast to the metallic copper finish with which they began. Copper exposed to 20% biofuel showed more visible corrosion and had a streaked appearance which carries remnants of its original finish. In contrast, 80% biofuel completely removed the original finish and produced a coupon with a uniformly pink surface with random pitting present.

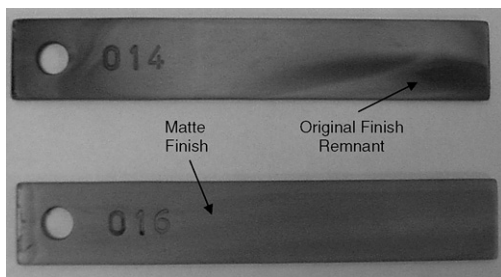


Fig. 9. Copper corrosion coupons after exposure to 80% and 20% biofuel for 10 months (7342 h). 014 (top) = Copper stored in 20% biofuel, 016 (bottom) = copper stored in 80% biofuel.

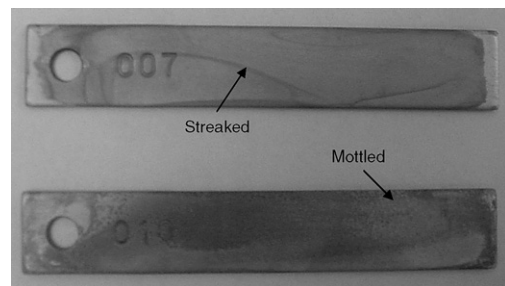


Fig. 11. Brass corrosion coupons after exposure to 80% and 20% biofuel for 10 months (7342 h). 007 (top) = Brass stored in 20% biofuel and 010 (bottom) = brass stored in 80% biofuel.

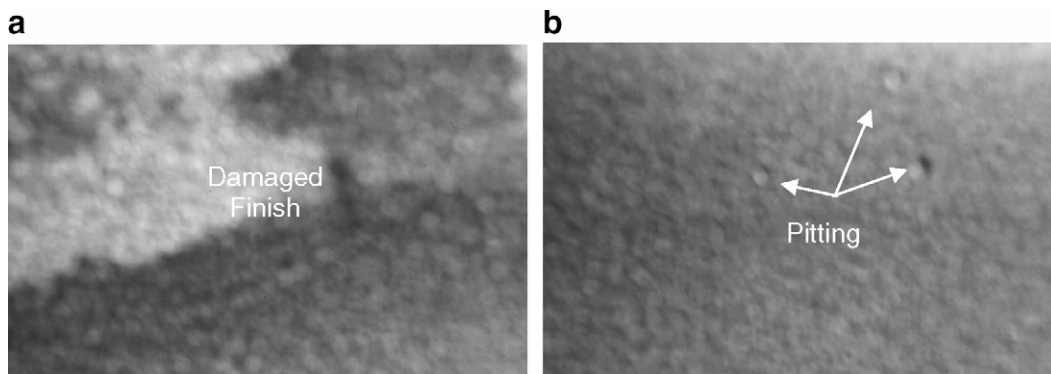


Fig. 10. 8× light micrograph of copper coupon surface: (a) after exposure to 20% biofuel for 10 months (7342 h) and (b) after exposure to 80% biofuel for 7342 h.

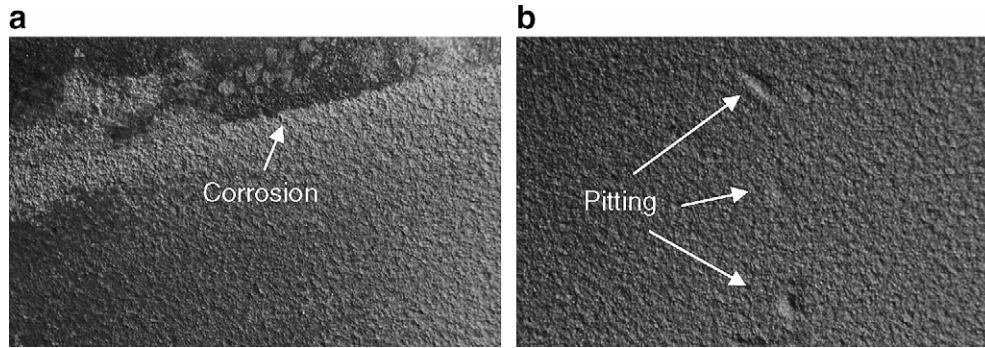


Fig. 12. 8× light micrograph of brass coupon surface: (a) after exposure to 20% biofuel for 10 months (7342 h) and (b) after exposure to 80% biofuel for 10 months (7342 h).

The micrographs shown in Fig. 10 reveal a clearer picture of the damage as the differentiation in finishes in 20% biofuel exposed samples is amplified as is the damage to the surface of the coupon exposed to 80% biofuel.

Brass coupons showed similar corrosion patterns to copper but to a lesser extent. This corrosion can be seen in Fig. 11. A magnification of coupon surfaces can be seen in Fig. 12. Brass coupons showed more resistance to lower concentrations of biofuels as the weight loss in the samples exposed to 20% biofuel only lost an average of 0.46% while those exposed to 80% biofuel lost 0.74%, a figure on par with that observed for copper at both concentrations. Both concentrations left initial dark, streaked deposits on the surface of the corrosion coupons which was easily removed with water, minimal detergent and minimal mechanical scrubbing. Once clean the coupons exposed to the two concentrations of biofuel had very different appearances. The surface of the 80% biofuel coupons were completely mottled with a matte finish. Twenty percent biofuel coupons were only partially matte and lacked the extremely mottled appearance of the 80% coupons. In addition, 20% coupons showed dramatic streaks but lacked the severe pitting damage seen at higher fat concentration.

Grey cast iron corrosion studies provided interesting results. In 20% biofuel, these coupons showed no weight loss. However, upon microscopic examination, random pitting was observable. The pitting was rare and dispersed suggesting possible outside influence from sample han-

dling. 80% biofuel produced a very different coupon. This phenomenon is illustrated in Fig. 13. Amplification of coupon surfaces in Fig. 14 also shows this increase in corrosive properties of higher biofuel mixtures. An initially uniform sample was cleaned to reveal faint streaking across the surface of the coupon. No physical deposits had to be removed but the surface of the samples had definitely changed over the course of the study. Additionally, the streaks were accompanied by a weight loss of 0.03%. While this is a relatively small number, it is significant in that no loss was expected and even small losses due to corrosion can be a sign of possible complications in application leading to possible failure and eventual replacement. The grey cast iron coupon stored in 80% biofuel also showed the dispersed pitting observed in 20% biofuel.



Fig. 13. Grey cast iron corrosion coupons after exposure to 80% and 20% biofuel for 10 months (7342 h). 021 = Grey cast iron stored in 20% biofuel and 022 = grey cast iron stored in 80% biofuel.

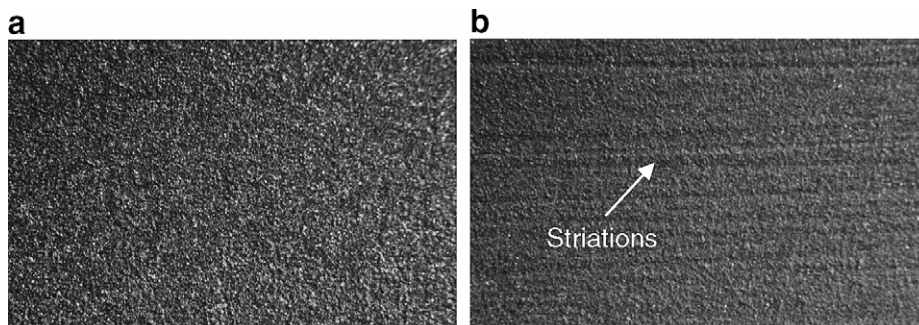


Fig. 14. 8× light micrograph of cast iron coupon surface: (a) after exposure to 20% biofuel for 7342 h and (b) after exposure to 80% biofuel for 10 months (7342 h).

4. Conclusions

Physical properties and phenomenon critical to fuel applications were studied for mixtures of poultry fat and petroleum diesel for up to one year of storage under variable conditions. Specific gravity, a property critical for developing adequate storage methods for these fuels was statistically unchanged during the 1 year study. This suggests volume changes associated with long-term storage will be minimal and only a small compensatory volume need be included in storage systems. Viscosity for 100% and 80% biofuel mixtures showed a slight and gradual, yet statistically significant decrease throughout the study. Other mixtures showed no statistically significant changes in viscosity throughout the study. The relative stability of these key physical fuel properties suggest storage and transport systems for these fuels will not require major modifications when fuels are stored for up to 1 year.

The presence of sediment and gums can complicate the use of fuels and require the use of filtering systems to avoid damage to vital components. Up to 15% of the stored fuels converted to sediment over the one year storage period. It is important to recognize this problem when storing these fuels for extended periods of time. In general, higher biofuel concentrations lead to increased sediment accumulation. The addition of antioxidants clearly reduced the accumulation of sediment in 100% biofuel and their use is recommended when storing these biofuels for extended periods of time. The inclusion of petroleum diesel also reduces the formation of sediment as well as enhancing other physical properties such as a reduction and stabilization of viscosity. It would appear that mixtures of diesel and biofuel may provide a good combination of stability and renewability when considering fuels for heating and other non-motive systems.

Separation of biofuel and petroleum fuel layers during storage was evident in this study but poses no real complications when simply storing these fuels. However, before utilizing these fuels it is necessary to homogenize the mixtures. Ideally this will be accomplished through the addition of heat, the value of which can be determined by the use of Eq. (1). This heat not only insures mixing but will also result in reduced viscosity of the biofuels insuring smooth operation of systems which will use these fuels. The layering time line in Fig. 6 shows that mixtures remain relatively homogenous for extended periods after mixing suggesting energy only need be added immediately before the use or transport of these fuel mixtures.

Corrosive effects of the biofuel component of these fuels necessitate the use of resistant materials in systems designed to store, transport and utilize these fuels. Specifically any copper and/or brass containing components must

be replaced with steel. Grey cast iron showed slight corrosion and is better avoided when designing systems that utilize these biofuels.

In general very little retrofitting is necessary to compensate for physical differences between fuels when switching to biofuels in systems designed to store, transport and utilize petroleum fuels. Ongoing studies are addressing changes and differences in chemical properties and the actual application of these fuels in pilot scale studies.

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