The Specific Gravity of Biodiesel and Its Blends with Diesel Fuel

Mustafa E. Tat and Jon H. Van Gerpen*

Iowa State University, Ames, Iowa 50011

ABSTRACT: The specific gravities of biodiesel and 75, 50, and 20% blends with No. 1 and No. 2 diesel fuels were measured as a function of temperature from the onset of crystallization to 100°C. The results indicate that biodiesel and its blends demonstrate temperature-dependent behavior that is qualitatively similar to the diesel fuels. The temperature dependence of the specific gravity for biodiesel and its blends was compared with the ASTM D 1250-80 procedure for the temperature correction of hydrocarbon fuels, and the procedure was found to provide accurate corrections. A blending equation was developed that allows the specific gravity of blends to be calculated from the specific gravities of the biodiesel and diesel fuels.

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KEY WORDS: Biodiesel, density, diesel fuel, methyl esters, specific gravity.

A large amount of research has been conducted in recent years to investigate alternative fuels for transportation. Renewable biomass resources such as plant seed oils and animal fats could play a role in meeting our society's future energy needs in an environmentally sound way. While the high viscosity of vegetable oils and animal fats tends to cause problems when used directly in diesel engines (1–4), if the oils and fats are transesterified using short-chain alcohols, the resulting monoesters have viscosities that are closer to petroleum-based diesel fuel (5–7). These monoesters have come to be known as biodiesel.

The specific gravity of biodiesel will depend on the fatty acid composition of the mixed esters and their purity. In a similar manner, the specific gravity of petroleum-based diesel fuel varies depending on the refinery feedstock and day-today variability of the blending streams in the diesel fuel boiling range. The specific gravity of diesel fuel is constantly monitored and many performance indicators, such as cetane number and heating value, are correlated against it. However, the specific gravities of hydrocarbons are strongly affected by temperature. Since specific gravity measurements made outside the laboratory are usually at nonstandard temperatures, ASTM standard D 1250 (8) was developed to correct measured specific gravities back to a reference temperature. The standard consists of a series of tables relating specific gravity and temperature.

*To whom correspondence should be addressed at Mechanical Engineering Department, Iowa State University, Ames, IA 50011.
E-mail: jvg@iastate.edu

As biodiesel moves closer to commercialization, a similar procedure for correcting measured specific gravity data will be needed. The specific objective of the research described in this paper was to measure the specific gravity of biodiesel and its blends with diesel fuel as a function of temperature, to compare the temperature-dependent behavior with that predicted by ASTM D 1250, and, if necessary, to develop a new correction table.

Equipment and procedure. In this study, commercially available soybean oil-based biodiesel (NOPEC Corporation, Lakeland, FL) was used and its properties are shown in Table 1. Commercial grades of No. 1 and No. 2 diesel fuel were obtained from local fuel suppliers and their properties are given in Table 2. Blends of 20, 50, and 75% biodiesel with No. 1 and No. 2 diesel fuels were prepared by weight. Owing to the differences in density between the biodiesel and No. 2 diesel fuel, blends prepared by volume would be somewhat different. For example, at 20°C, a 75% biodiesel/25% No. 2 diesel blend prepared by volume would be 75.9%/24.17% by weight.

The hydrometer method described in ASTM D 1298-85 (10) can be used to measure the specific gravity of crude pe-

TABLE 1
Physical and Chemical Properties of the Biodiesel

Properties	Biodiesel
Carbon (%)	76.14
Hydrogen (%)	11.75
Sulfur (%)	<0.005
Heat of combustion (kJ/kg)	37,272
Free glycerin (%)	0.002
Triglycerides (%)	0.140
Diglycerides (%)	0.125
Monoglycerides (%)	0.432
Total glycerin (%)	0.147
Fatty acids (%)[a]	
Palmitic	10.83
Stearic	4.31
Oleic	24.22
Linoleic	54.67
Linolenic	6.78
Acid value	0.53
Peroxide value	50.4
Kinematic viscosity (cSt @ 40°C)	4.48
Vitamin E (IU/kg)	7.3
Cetane number	51.1

[a]Measured as % relative by Woodson-Tenent Laboratories (Des Moines, IA) using AOCS Method Ce 1e-91 (Ref. 9). Glycerides and free glycerin measured by System Lab Services (Kansas City, KS) using gas chromatography.

TABLE 2
Physical and Chemical Properties of the Diesel Fuels Used[a]

Properties	Number 1 diesel	Number 2 diesel
Carbon (%)	86.31	86.23
Hydrogen (%)	13.27	13.14
Sulfur (%)	0.039	0.034
Heat of combustion (kJ/kg)	42,992	42,715
Kinematic viscosity (cSt @ 40°C)	1.89	2.67
Aromatics (%)	27.7	31.0
Paraffin (%)	69.7	64.1
Olefin (%)	2.6	4.9
Distillation (% recovered)	°C	
IBP	165	185
5	187.2	207.2
10	193.8	219.16
20	202.2	231.6
30	211.2	239.4
40	219.4	247.7
50	227.7	255.5
60	236.6	263.8
70	247.7	273.8
80	260	285
90	280	301.6
95	297.7	315

[a]IBP, initial boiling point.

troleum, but the glass hydrometers can only be read to three decimal places. Other, more precise methods are available. A specific gravity balance (Troemner Company, Philadelphia, PA) was available that could be read to four decimal places and was used to measure the specific gravities of the fuels and the blends. To collect temperature-dependent data, a small constant temperature bath was adapted to the balance. A 25-cc graduated cylinder containing the fuel sample was placed in a glass beaker which was fed by a pump which supplied fluid from a constant-temperature bath. The plummet of the balance was placed in the graduated cylinder with the fuel, and the cylinder and beaker were placed into another larger container which collected the fluid overflow and returned it to the constant-temperature bath.

RESULTS

Specific gravity is the ratio of the density of the substance to that of water at 15.6°C. Specific gravity measurements are presented in Figure 1 for the blends with No. 2 diesel fuel and in Figure 2 for the blends with No. 1 diesel fuel. In these figures, the points represent the measured data, and the lines represent straight lines obtained by linear regression using the Excel 97 spreadsheet program.

The form of the regression line used was as follows:

$$SG = a + bt \qquad [1]$$

where SG = specific gravity, t = temperature in °C, and where a and b are given in Table 3 for all the fuels. The straight line correlation fits the data very well, and the lowest R^2 was 0.9989. The mean square deviations of the data from the correlations are also shown in Table 3. The maximal difference between the equations and the measured data was less than 0.22% of the measured values.

The ASTM D 1250 Standard Guide for Petroleum Measurement Tables (8) are used to find the specific gravity, API gravity, and density of crude petroleum and petroleum products at any temperature if that property is available at the reference temperature, which is 15.6°C. More commonly, these tables are used to correct measured specific gravity values at other temperatures back to the standard temperature of 15.6°C and also can be used to compare temperature-dependent behavior of biodiesel and its blends with the behavior of petroleum products.

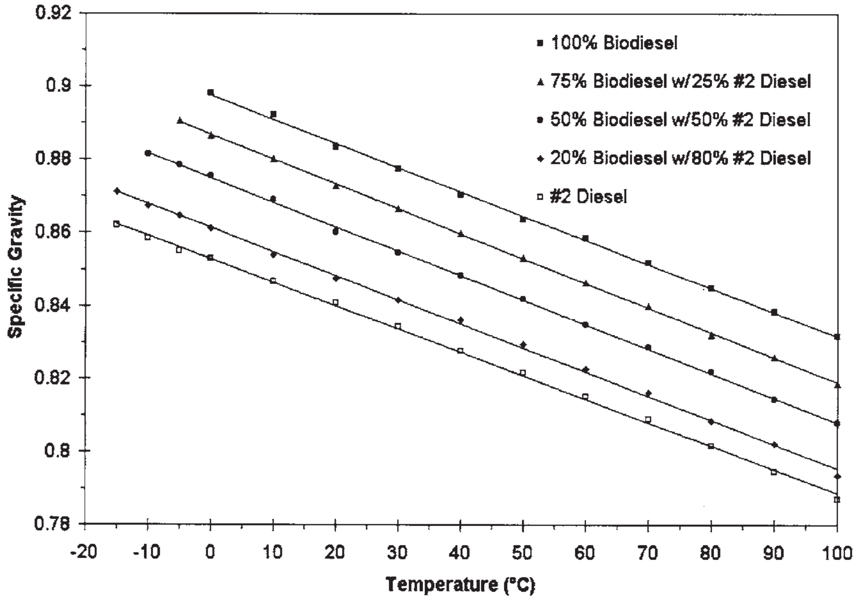

FIG. 1. Specific gravity of biodiesel and its blends with No. 2 diesel fuel.

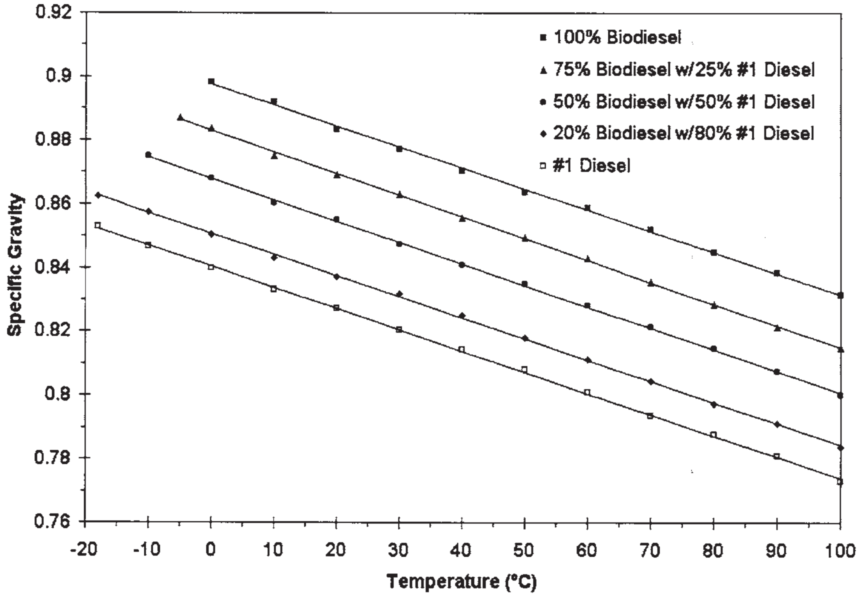

FIG. 2. Specific gravity of biodiesel and its blends with No. 1 diesel fuel.

Since the specific gravity of the fuels was not measured at the precise reference temperature of 15.6°C, the specific gravity values of each of the fuels or blends tested in this study were determined using Equation 1 and the correlation constants given in Table 3. This established a reference specific gravity for the fuels. Then, these reference values were used in the ASTM D 1250 tables (8) to calculate estimated specific gravity values at other temperatures.

The results are presented in Figures 3 and 4 for biodiesel and its blends with No. 2 and No. 1 diesel fuels. In the figures, the points represent the actual measured values of specific gravity. Estimated specific gravities were calculated using the ASTM D 1250 tables (8) at the same temperatures where measured data were available. The lines shown on Figures 3 and 4 consist of straight line segments connecting these estimated specific gravity values. The mean square deviations of the data from the values obtained using ASTM D 1250 (8) are shown in Table 4.

The figures show that, at higher temperatures, particularly over 80°C, the measured values of specific gravity for the samples are somewhat above the lines corresponding to the ASTM table values. However, all samples were close to the table predictions, particularly the 75% blends. The maximal difference was less than 0.28% of the measured value for 100% biodiesel fuel at 100°C. The maximum difference overall was less than 0.52% for No. 2 and No. 1 diesel fuel. The biodiesel and its blends were actually in better agreement with the predictions from the tables than the No. 2 and No. 1 diesel fuels. This indicates that the temperature dependence of the biodiesel's specific gravity is similar to the dependence for No. 1 and No. 2 diesel fuels, and the ASTM D1250 tables (8) can be used for biodiesel and its blends. Although these results are based on tests for soybean oil-based biodiesel, it seems likely that this conclusion will be valid for biodiesel from other feedstocks also.

Since biodiesel is often sold blended with diesel fuel, it would be useful to have a means for predicting the specific gravity of blends when the specific gravities of the con-

TABLE 3
Specific Gravity Correlation Constants for Biodiesel and Blends with No. 2 and No. 1 Diesel Fuel[a]

Fuel type	*a*	*b*	R^2	MSD
100% Biodiesel	0.8976	–6.6200E – 04	0.9989	4.483E – 07
75% Biodiesel w/#2 diesel	0.8869	–6.8021E – 04	0.9997	1.207E – 07
50% Biodiesel w/#2 diesel	0.8750	–6.7089E – 04	0.9994	3.138E – 07
20% Biodiesel w/#2 diesel	0.8613	–6.5982E – 04	0.9989	6.211E – 07
#2 Diesel	0.8527	–6.4097E – 04	0.9989	5.969E – 07
75% Biodiesel w/#1 diesel	0.8831	–6.8204E – 04	0.9995	2.654E – 07
50% Biodiesel w/#1 diesel	0.8678	–6.7010E – 04	0.9995	2.368E – 07
20% Biodiesel w/#1 diesel	0.8506	–6.6130E – 04	0.9995	3.024E – 07
#1 Diesel	0.8403	–6.6331E – 04	0.9994	3.548E – 07

[a]MSD, mean square deviation.

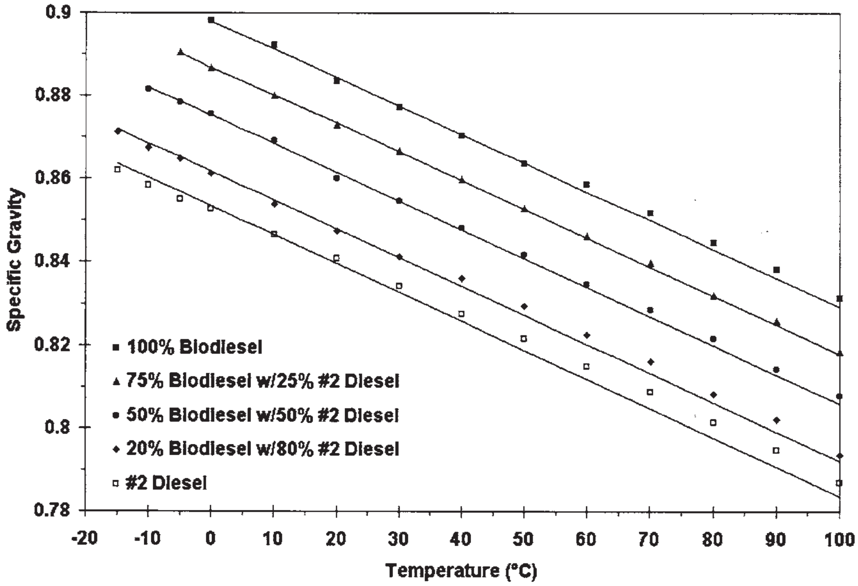

FIG. 3. Comparison between the ASTM D 1250 table (Ref. 8) values (lines) and the measured values (points) for the biodiesel and its blends with No. 2 diesel fuel.

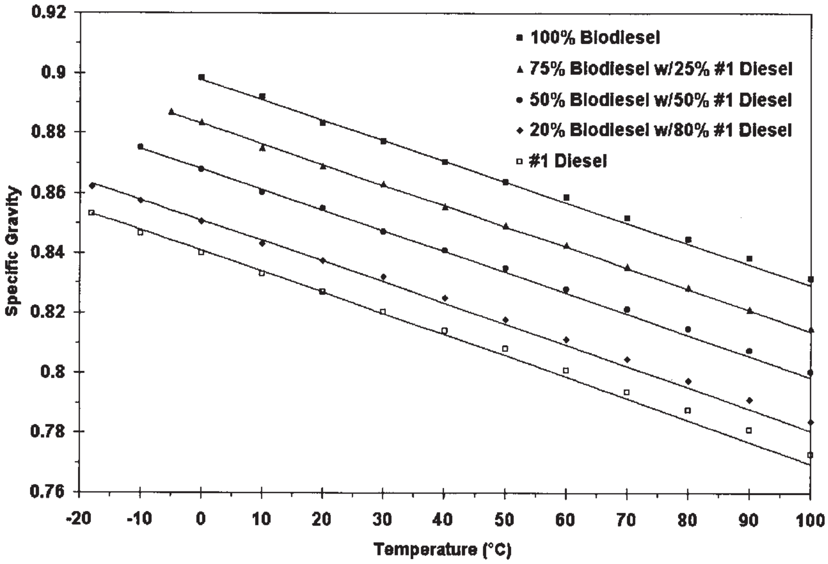

FIG. 4. Comparison between the ASTM D 1250 table (Ref. 8) values (lines) and the measured values (points) for the biodiesel and its blends with No. 1 diesel fuel.

stituents are known. Clements (11) has suggested an equation where the specific gravity is proportional to the mass fraction of the constituents like that given in Equation 2,

$$SG_{Blend} = \sum_i SG_i \times m_i \qquad [2]$$

where SG_{Blend} is the specific gravity of the blend, SG_i is the specific gravity of component i, and m_i is the mass fraction of component i. Predictions made using this equation were compared to the measured blend data, and maximal differences between the equations and the measured data were less than 0.23% for the 75% blend, 0.28% for the 50% blend, and 0.28% for the 20% blend with No. 2 diesel fuel. Equation 2 gave maximal differences of less than 0.31, 0.28, and 0.22% of the measured values for 75, 50, and 20% biodiesel blends with No. 1 diesel fuel, respectively.

TABLE 4
Mean Square Deviations from ASTM D1250 (Ref. 8)[a]

Fuel type	MSD
100% Biodiesel	1.993E–06
75% Biodiesel w/#2 diesel	3.675E–07
50% Biodiesel w/#2 diesel	1.268E–06
20% Biodiesel w/#2 diesel	3.147E–06
#2 Diesel	6.633E–06
75% Biodiesel w/#2 diesel	4.801E–07
50% Biodiesel w/#2 diesel	1.571E–06
50% Biodiesel w/#2 diesel	3.294E–06
#1 Diesel	4.288E–06

[a]See Table 3 for abbreviation.

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