Development of Density Test Kit Prototype for Biodiesel Quality Control

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Abstract

The present prototype of a density test kit was invented to circumvent the challenges of inaccessibility to laboratory-grade equipment for biodiesel quality control. The prototype is economical to manufacture and easy to use, so it is an affordable means for small-scale biodiesel producers to monitor the density of their biodiesel by themselves. The test kit comprises two transparent columns, one for holding water as a reference liquid and the other for biodiesel sample. Both columns are connected to each other via a small air pump. The pressure built up by the air pump results in the difference in height of the two liquids. Based on the hydrostatic pressure principle, the height difference can determine the density of the biodiesel sample, given the density of water as a reference. Calibrated with the ASTM-standard-compliant equipment, the test kit prototype can measure biodiesel density within the range of 0.84-0.92 g/cm^3 with an accuracy of 0.01 g/cm^3, and can operate at room temperature between 15-45 °C.
***Keywords**:* Biodiesel, Density measurement, Test kit.

1. Introduction

Density, defined as the mass of a substance divided by its volume, is one of the most important properties of automotive fuels including biodiesel. Many fuel parameters, such as cetane number and heating value, depends on the density [1]. Density also affects injection behaviors, injection pressure, and fuel spray characteristic, which, in turn, influence the engine performance, combustion and exhaust emissions [2]. Furthermore, the injection systems of diesel engines measure the amount of fuel in terms of volume [3]; consequently, the change in fuel density might give rise to the change of injected fuel mass, resulting in an unexpected power output. Regarding the production aspect, the value of density can be used to indicate the quality of biodiesel production. For instance, biodiesel which has high density indicates that it might contain an excessive amount of contaminates, such as water or glycerol. On the other hand, biodiesel with low density may contain excessive alcohol. For these reasons, density-based quality criteria have been issued for biodiesel as well as other automobile fuels.

In Thailand, by the Department of Energy Business, the density of biodiesel is specified as 860 - 900 kg/m^3 at 15 °C [4].

ASTM Standard D1298 test method [5] is employed to measure the density of biodiesel, as prescribe in the biodiesel quality standard of Thailand. The measurements are carried out by laboratory grade density equipment, such as hydrometer or digital density meter, which has high accuracy and meets the international standard. There are, however, some limitations to this type of measurement. Firstly, the number of laboratories providing this standard measurement is limited, especially in Thailand or other developing countries. Secondly, the locations of these laboratories can be rather far from biodiesel production sites. Last and most importantly, the service charges can be high, resulting in the increase of production cost. These challenges have significant impacts some biodiesel producers, particularly, the small community producers with respect to their production and quality control.

Regarding density measurement, many types of density meters have been invented. Some instruments were developed based on the theory of hydrostatic force and pressure [6-9], in order to measure the density of liquid. These inventions consisted of electrical components and complex signal processors which making them inappropriate for small-scale production, especially in the aspects of cost, operation, and maintenance. In Thailand, a density meter which was specially designed for biodiesel production has recently been reported [10]. This instrument was able to indicate whether the density of biodiesel was within an acceptable range, according to the Thai standard, or not. However, the instrument cannot measure the exact value of biodiesel density. Moreover, the given values were reported at experimental temperature not referring to a temperature of 15°C as mentioned in the biodiesel standard.

In order to overcome the abovementioned challenges faced by the standard density measurement and prior inventions, the objective of this study was to invent a new density test kit that is suitable for small-scale biodiesel production. The details of the test kit, along with test results, are reported in the following sections.

2. Method

2.1 Hydrostatic theory

Hydrostatic pressure is the pressure exerted by a fluid at equilibrium due to the force of gravity. Since many liquids can be considered incompressible, hydrostatic pressure of liquid can be simply calculated according to the following equation:

$$P = \rho g h, \qquad (1)$$

where P, ρ, g, and h represent hydrostatic pressure (Pa), liquid density (kg/m^3), gravitational acceleration (m/s^2), and height of liquid above the reference point (m), respectively [11].

According to the above equation, if the height and density of liquid are known, the pressure can be calculated. This principle was the basis of many pressure measurement devices, such as manometer and barometer. On the other hand, if the pressure and the height of liquid were known, the liquid density could be calculated, leading to the concept of the density test kit prototype developed in this study.

2.2 Development of a density test kit prototype

This test kit, as shown in Fig. 1, comprised two transparent columns, one of which contained reference water and the other contained biodiesel sample. Both columns were connected to each other via a small air pump. The pressure that was built up equally in both columns by the air pump resulted in the changes in heights of water and biodiesel levels. The height difference could indicate the density of the biodiesel sample, based on the following equation:

$$\rho_w h_w = \rho_b h_b , \qquad (2)$$

where ρ_w , h_w , ρ_b , and h_b represent the densities (kg/m^3) of water and biodiesel, and the height (m) of water and biodiesel, respectively.

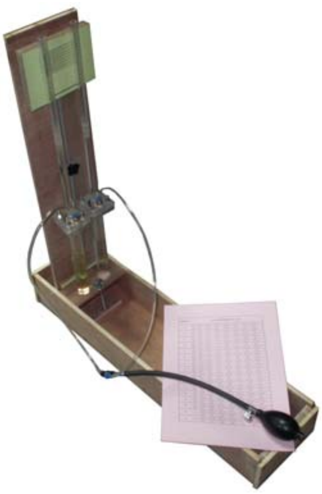

Fig. 1 The density test kit prototype

Nevertheless, according to the biodiesel standard, the density values that could be used to evaluate the quality of biodiesel must be obtained at the temperature of 15°C. Therefore, a density value calculated from Equation (2) must be converted to a corresponding value at 15°C. Thus, the relationship between density of biodiesel and temperature needed to be evaluated, for biodiesel from various feedstock and different manufacturers. Using the digital density meter, densities of various biodiesel at different temperature were measured, as shown in Fig. 2.

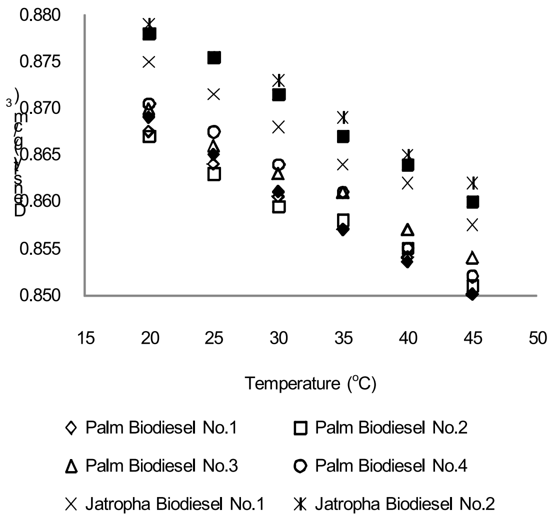

Fig.2 The relationship between biodiesel density and temperature

According to Fig.2, the density of biodiesel decreased linearly with the increase of temperature (R^2>0.99). Moreover, the declining rate of density for all biodiesel samples, derived from palm, canola, and jatropha oil, were almost the same, with an approximated slope of -0.0007. Based on the obtained data, a conversion table was developed. With this table, the users would be able to estimate the biodiesel density at 15°C by simply reading the height of biodiesel, as shown in Fig. 3. Then, the users can determine the density of the biodiesel sample at 15°C by looking up the value that corresponds to the observed height and ambient temperature from the table illustrated in Fig. 4.

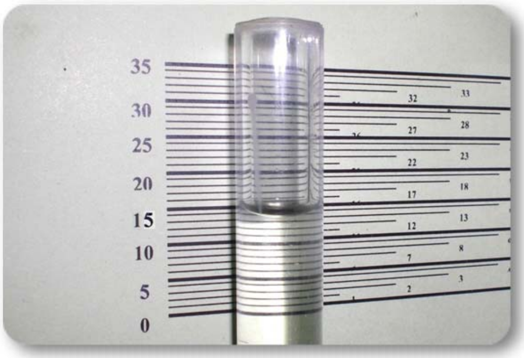

Fig.3 The height of biodiesel level in the transparent column

Fig.4 An example of density-temperature conversion table

3. Results

The present density test kit prototype can measure the density of biodiesel within the range of 0.84-0.92 g/cm3 with an accuracy of 0.01 g/cm3, the ambient temperature range of 15-45 °C. The prototype was used to measure the density of jatropha and palm biodiesel, derived from palm stearin, palm olein, and crude palm oil. The experiments were conducted under two different environmental conditions, 25°C and 30°C, and repeated for three times, in order to verify the performance of the test kit. The results are presented in Table 1. It was illustrated that the density values obtained from the test kit were consistent. Furthermore, with a comparison to the values obtained from a laboratory-grade digital density meter, the difference was very small and insignificant, in the order of less than 0.6 %

Table 1 Density of biodiesel measured by the prototyped density test kit and the digital density analyzer

Types of Biodiesel	Experimental Temperature	Density at 15°C (g/cm^3)					Difference (%)
		Prototyped Density Test Kit				Density Analyzer	
		1	2	3	Average		
Palm Stearin	25	0.87	0.87	0.87	0.87	0.871	-0.11
	30	0.87	0.87	0.87	0.87	0.872	-0.23
Palm Olein	25	0.91	0.91	0.91	0.91	0.913	-0.33
	30	0.91	0.91	0.91	0.91	0.914	-0.44
Crude Palm	25	0.87	0.87	0.87	0.87	0.875	-0.57
	30	0.87	0.87	0.87	0.87	0.875	-0.57
Jatropha	25	0.88	0.88	0.88	0.88	0.883	-0.34
	30	0.88	0.88	0.88	0.88	0.883	-0.34

4. Conclusions

A biodiesel density test kit prototype was developed based on the theory of hydrostatic pressure. It provides accurate and reliable results, compared to those of laboratory-grade equipment. The test kit is also inexpensive to manufacture and easy to use, making it more affordable for small-scale biodiesel producers to monitor the quality of their biodiesel by themselves.

5. References

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