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Ethanol additive addition to gasoline: viscosity investigation using stokes law linear regression

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ABSTRACT

Nowadays, global warming is a tremendous phenomenon in the world. Every country is trying to solve these conditions, including Indonesia, which has a campaign to reduce the emission of CO and HC from vehicles. However, the number of vehicles is increasing every year. Based on that condition, the researchers try to modify the fuel with the additive. This work modified the gasoline with 10% ethanol additive addition, investigated the viscosity properties using Stokes law linear regression method, and compared it to pure gasoline. The viscosity properties are chosen by their effect on the emission of vehicles. The low viscosity of fuel can reduce CO and HC in gas emissions. Then, this work found that the viscosity of gasoline is decreased, but 10% of ethanol does not significantly change the characteristics of gasoline. Even so, linear regression has been successfully used as an analyzed method to determine the viscosity. Then this finding also contributes to the development of fuel in Indonesia to reduce the emission of CO and HC with the modification of gasoline using ethanol in the other concentration.

Keywords: *Ethanol additive, Gasoline, Viscosity, Stokes law linear regression*

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1. INTRODUCTIONS

In 2022, Gunawan et al reported the increasing vehicle number in Indonesia is about 6.13% per year and contributes the largest air pollution, even in the large cities the emission giving more than 50% contribution for the air pollution [1]. Hence, the government of Indonesia has a campaign to control and reduce air pollution, especially the emission that is produced by vehicles which are increasing every year [2]. It is regulated by article 48 of Indonesia law number 22 of 2009 concerning road traffic and transportation, each vehicle that is operating should be fulfill the standard of exhaust emission [3]. Iskandar et al (2019) has given a statement that the emission standard of vehicles is depend on fuel that is used. For gasoline-fueled vehicles, the parameters are seen from the content of carbon monoxide (CO) and hydrocarbon (HC) in the exhaust gas [4]. Referred to Euro-4, the CO standard that is allowed to be contained in the exhaust gas is 0.50 g/km, while HC is about 0.23 g/km [5]. As part of a government campaign regarding exhaust emissions, several researchers are working hard doing research to produce a

fuel that has an exhaust emission according to the standard that is allowed. It can be doing by controlling several of their thermophysical properties, one of them is viscosity [6].

A low viscosity of gasoline can improve an atomization process that results in emission of CO and HC in a low capacity [7,8]. Nowadays, a few investigations have been conducted to produce a low viscosity of fuel by the modification process with addition of additives. Even so, the additive that is added to the fuel must be selected and in accordance with the needs. Several substances that have been used as additives are vegetable oils [9] and ethanol [10]. However, ethanol is more compatible as an additive in gasoline due to their advantages i.e. renewable, the use of ethanol will overcome the global oil crisis in the world [11]. More than that, the mixture of ethanol and gasoline can create a good characteristic of fuel. The ethanol helps the gasoline to reach a complete combustion and reduce exhaust emission in CO and HC [12]. In addition, ethanol has a higher octane number and the mixture of ethanol-gasoline solves the problem for refiners to meet a mixture with increasing the octane number in a low-cost. Also, based on the literature, the best composition of ethanol that added to gasoline is 10% [13]. The addition of ethanol will change some properties of the fuels, for example the viscosity as mentioned previously.

For the investigation of viscosity properties, the falling ball method is reported as one of the best approach due to their accuracy [14]. The falling ball method is conducted with a measurement of the time that takes the ball to travel a certain distance in the fluids [15]. Then, the data that is obtained can be processed using Stokes law linear regression to calculate the viscosity of the fluids. Linear regression on determining the viscosity is giving a benefit, it is easy to fit and easy to interpret [16]. Therefore, this work was investigated the viscosity properties of ethanol-gasoline blends with a ratio 1:9 and compared to the pure gasoline. These viscosity properties were measure with Stokes law linear regression. Then, this work also giving a future perspective through the literature review about the addition of additive to the gasoline.

2. METHODOLOGY

The gasoline with chemical formula in C_8H_{18} and ethanol (C_2H_5OH) were prepared for this simple experimental investigation. This work used several tools that consist of beaker glass, digital scales, a simple set of stokes tube apparatus, stopwatch, and vernier calipers. This experiment was conducted in the laboratory scale. Firstly, the several samples were prepared as shown in Table 1. Then, each sample was tested on density measurement based on equation 1. The measurement was started with weighing the beaker glass until found the weight of it. Then, that process was repeated for the beaker glass that has been filled with the sample. The difference in mass value of both measurements is the mass of samples while the volume of the sample was displayed on the measuring scale of beaker glass.

$$\rho = \frac{m}{V} \tag{1}$$

where ρ, m, and V are respectively the density of samples (kg/m^3), mass of the samples (kg), and volume of the samples (m^3).

Table 1. The samples that prepared in this work

Sample number	Gasoline (%)	Ethanol (%)
1	100	0
2	90	10

Furthermore, the viscosity measurement was conducted using stokes law approach or commonly known as falling ball method and illustrated in Figure 1. This method has been used by several researchers due to their accuracy [17]-[19]. For this step, it started with measuring the volume of the ball that used in this experiment. The volume is calculated using equation 2 [20]. Then, the important variable is the radius of the ball that is obtained from the measurement using vernier calipers.

$$V_{ball} = \frac{4}{3}\pi r^3 \tag{2}$$

where V_{ball} is volume of the ball in m^3. Then, π is the constant value in 22/7 or 3.14, and r is radius of the

ball (m).

Then, the viscosity is measured based on the equation 3 [21]. In this work, the researchers used the Stokes law linear regression for the data analysis of viscosity. Hence, one variable from the equation 3 is varied, it is the distance of the falling ball and marked with the d symbol.

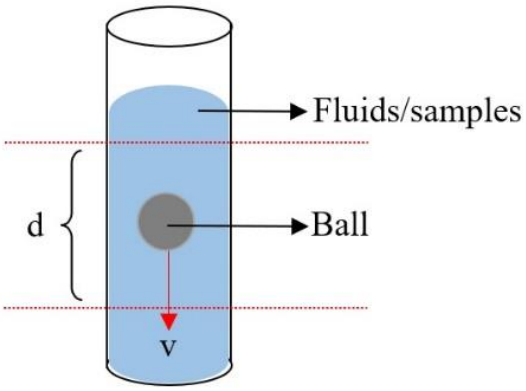

Figure 1. Illustration of the falling ball method.

$$\eta = \frac{2gr^2(\rho_b - \rho_f)}{9v} \tag{3}$$

where g is the acceleration of gravity (9.81 m/s^2), r is the radius of the ball and this is obtained from the previous measurement when calculating the volume of the ball, ρ_b and ρ_f are respectively the density of the ball and samples. The density of the sample has been explained above and the density of the ball is calculated using the same equation (equation 1). The mass of the ball can be directly measured using the digital scale and the volume has been obtained as explained above using equation 2. Then, v is the velocity of the falling ball in the distance that varies. From this measurement, it is obtained the time variable of each distance value. However, in this work the data were processed using the linear regression as illustrated in Figure 2. Based on the explanation, equation 3 can be changed to equation 7. Then, after the viscosity of the sample has been known, this work is processed to the literature review about the performances of each sample when applied as fuel, especially on their future perspective as fuel.

$$v = \frac{2gr^2(\rho_b - \rho_f)}{9\eta} \tag{4}$$

with $v = \frac{d}{t}$

$$\frac{d}{t} = \frac{2gr^2(\rho_b - \rho_f)}{9\eta} \tag{5}$$

$$\frac{1}{t} = \frac{2gr^2(\rho_b - \rho_f)}{9\eta d} \tag{6}$$

$$t = \frac{9\eta d}{2gr^2(\rho_b - \rho_f)} \tag{7}$$

following the linear regression, there is should be $Y = kX$, with k is the slope of the linear graphic [22]. Then, it obtained that k is equal to equation 8 below:

$$k = \frac{9\eta}{2gr^2(\rho_b - \rho_f)} \tag{8}$$

Then, from equation 8, it can be calculated the viscosity of each sample using equation 9.

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$$\eta = \frac{k\,2gr^2(\rho_b - \rho_f)}{9} \quad (9)$$

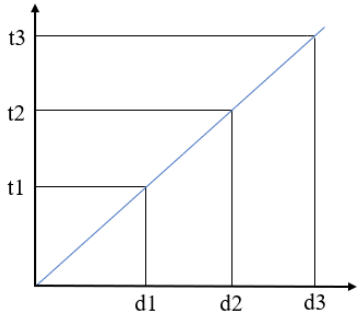

Figure 2. Illustration of linear regression between the distance and time of the falling ball.

3. RESULT AND DISCUSIONS

The investigation started with the density measurement that shown in Table 2. The density was measured using equation 1. The volume of the samples is controlled in 100 ml or equivalent to 10^{-4} m^3. From the calculation, it is known that the density of gasoline increases of about 2.8% when the ethanol is exposed and mixed with it. The increasing of gasoline density is caused by a higher density of pure ethanol [23].

Table 2. The result of density measurement of the samples.

Sample number	m_T (kg)	m_b (kg)	m_s (kg)	ρ (kg/m^3)
1	0.129	0.201	0.072	720
2	0.129	0.202	0.074	740

where m_T is the total mass of beaker glass and sample, m_b is the mass of beaker glass, and m_s is the mass of sample.

Next, the viscosity investigation was conducted by using the linear regression of Stokes law. The first, the volume of the samples has been known from the scale that is displayed in the beaker glass. In this work, it is controlled in 10 ml or equivalent to 10^{-5} m^3. Then, for the preparation of falling ball method, it is to measure the volume of the ball by using the equation 2. The calculation shows that the ball has the volume of about 1.679 x 10^{-5} m^3. The viscosity investigation was conducted with several repetitions experiment in the different distance of the falling ball. From this experiment, it known the time of the falling ball in each distance and can be processed using linear regression. Then, from these data, the linear regression can be analyzed as shown in Figure 3.

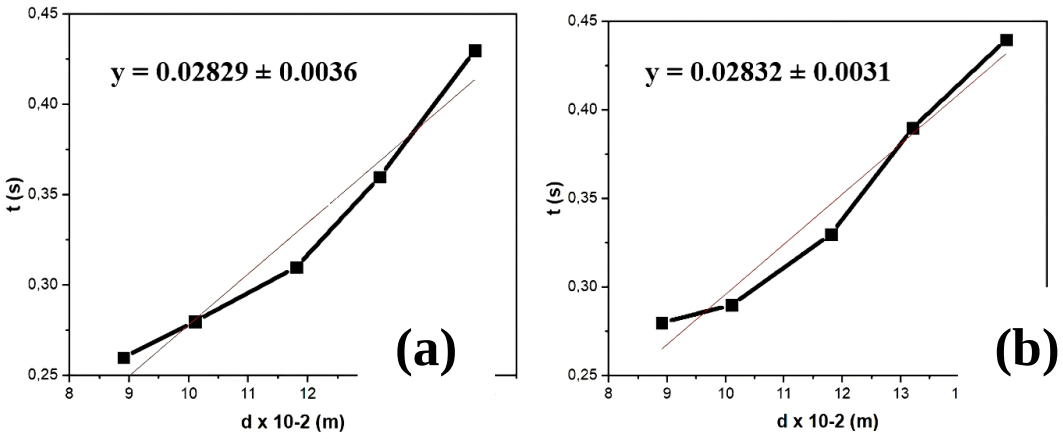

Figure 3. Linear regression of Stokes law in viscosity measurement using falling ball method, for (a) sample 1 and (b) sample 2

The linear regression shows that the slope of graphic is 0.02829 and 0.02832, respectively for sample 1 and sample 2. These results inform that the addition of ethanol additive can decreased the viscosity of gasoline, respectively 0.109 *cP* and 0.106 *cP* for sample 1 and sample 2. These decreasing of viscosity is caused by the thinner boundary between the molecule when the ethanol is exposed [24]. Even so, the decreasing of viscosity is not significant, it means that 10% of ethanol additive that added to the gasoline is not enough to change the characteristics of gasoline. Hence, a low viscosity is a required characteristic for the fuel to have a more environmentally friendly exhaust gas, this condition allows reducing the content of CO and HC in emission gas [25].

4. CONCLUTIONS

In this study, the investigation of the viscosity properties of the ethanol-gasoline blend has been conducted with a linear regression method. This work found that 10% of ethanol has decreased the viscosity of gasoline not significantly. Even so, these findings are informed that ethanol has a characteristic to change gasoline to become a more environmentally fuel with a good emission. The finding contributes to SDG 7: Affordable and clean energy that ensures access to affordable, reliable, sustainable, and modern energy for all.

AUTHOR'S DECLARATION

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

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