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An experimental study to measure the concentration of nanofluids by using refractive index

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Content

Abstract

In a decade, nanofluids are a new kind of fluid that has rapid development and wide application in various fields. Especially, nanofluids as a heat transfer fluids in different industrial instead of the traditional heat transfer fluids such as water, oil, and ethylene glycol…etc. The nanofluids have consisted the nano-size metal or metal oxide particles with base fluids, the nanoparticles have a superior thermo property to enhance the heat transfer performance of based fluids. Concentration is an important factor that can be influenced by most of the thermal properties of nanofluids. In present, the concentration of nanofluids is predetermined, the amount of nanoparticle and the base fluids should be measured before the nanofluids preparation. However, no specific method for the measurement of nanofluids concentration in real-time and by non-contact method until the present. The Refractive index is an important parameter of material. It is also applied in much researches for material analysis such as material concentration analysis. The current study intended to experiment to find out the correlation between the refractive index and concentration of nanofluids for further development of the non-contact method for the measurement of nanofluids. In this study, a total of 10 different concentrations of Titania oxide (TiO_2) nanofluid samples prepared for measurement of refractive index by the minimum deviation method and reference to Jenkin's proposed experiment setting in 1982. The results of this study presented that the refractive index value increased from 1.3411 to 1.3953 by increasing the TiO_2 nanofluid concentration from 0.001% to 0.04%. The results of this works will be very helpful for further development of the method of measurement of the nanofluids concentration.

Keywords: Nanofluids, concentration, refractive index, minimum deviation method

1. Introduction

In two decades, nanofluids rapidly develop and widely application in different fields. However, there is no recognized method to measure the concentration of nanofluid if without any measurement of the quantity of nanoparticle or basic fluid before mixing (Kostic et al., 2006). This matter will hinder nanofluid quality assurance and real-time monitoring of the performance of nanofluids during the operation. Therefore, this experimental study was conducted for the purpose to find out the correlation of refractive index and concentration of nanofluids for the development of the specific non-contact method for the measurement of nanofluids concentration in the future.

2. Literature Review

In 1995, Dr. Choi presented a seminal paper that related nanofluids at the American Society Mechanical Engineers Winter Annual Meeting. He proposed mixing the nanoparticle with the fluids, such as water, oil…etc. as a new kind of heat transfer fluids to improve the heat transfer performance of traditional fluids (Uddin et al., 2016). The particle size which smaller than 100nm is called nanoparticle. Yu et al. (2011) presented that the nanofluids are produced by the "One step method" and "Two steps method" usually. "One step method" is complicated, but that can provide excellent stability of nanofluids and minimized the agglomeration of a nanoparticle. "Two steps method" is a common method for preparing nanofluids and it is attractive to industrial, researchers, and scientists because it is a simple preparation method. However, the nanoparticle is easily agglomeration in the nanofluids which mixing by the "Two steps method".

Nanofluids is an excellent heat transfer fluid due to it have superior thermo properties, such as thermal conductivity, viscosity, and surface tension (Huminic and Huminic, 2012). Besides, it also has unique optical properties like absorption, scattering coefficients, and refractive index…etc. In a decade, many researchers conducted varying studies for analyzing the correlation between the thermo properties and concentration, such as the thermal conductivity ratio of nanofluids approximately linear increased when incrementing in the Zirconia (ZrO_2) or Titania (TiO_2) nanoparticle concentration (Paul et al., 2010). Another experiment reveals that the thermal conductivity increases by 38% when the concentration of Al_2O_3 nanofluids increases from 0 to 20% (Issa, 2016).

In 2016, the experiment measures the viscosity of Fe_3O_4 water magnetic nanofluids by viscometer under the influence of volume fractions of nanoparticles. It is observed that the viscosity of nanofluids increased 1.2% and 14% with increasing of nanoparticle volume fraction of 0.1 and 1%, even the measurement in difference temperature (Malekzadeh et al., 2016).

Many experiments reveal that the surface tension of nanofluids will be changed when nanoparticles were increased. For example, the experiment reported that the nanofluids surface tension increases with increases in the concentration of nanofluids like FeC water nanofluids, the surface tension ration measured increases with the weight concentration of nanoparticle 0.1%, 0.5% and 1.0% (Huminic et al., 2015).

Besides, the change of nanofluids' optical properties is subject to the concentration, such as the refractive index. The Aluminum nanofluids measured the refractive index increase with the mass concentration of nanoparticle and the trend almost linear, at mass concentration 0 to 0.381%, the refractive index increased from 1.427 to 1.697 (Behzad et al., 2016). Based on the above previous studies result, most of the thermophysical properties and optical properties of nanofluids are affected by the concentration coincidentally. That also proved that concentration is a key factor to help us to determine the performance of nanofluids.

Many studies to getting the concentration of nanofluids are based on correlation with the properties of nanofluids. Such as pH level analysis (Konakanchi et al., 2015) and zeta potential analysis (Choudhary et al., 2017)…etc. However, the above methods are not designed for the measurement of nanofluids concentration and lack of agreement to support the feasibility of the method. Some researchers purposed to analyze the concentration of nanofluids by the optical properties, such as the dynamic light scattering method (Vysotskii et al., 2009), ultraviolet-visible spectrophotometer analysis (Mehrali et al., 2014) and refractive index…etc.

Since the year 1982, many researchers carried out the studies to find out the correlation between the refractive index and concentration of liquids, solution, and mixture, because of refractive index is an important optical property of any material. Three different techniques for measurement of refractive index, Interferometric, Total internal reflection, and refractometric. The refractometric techniques are a common use method for the measurement of the refractive index of liquids, gas, and solids. There have two different refractometric methods – the minimum deviation method and pulfrich method. The refractometric technique with minimum deviation method will be detail discusses, due to the current experiment system was installed based on this method.

The refractometric method is commonly used to measure the refractive index of liquids, gas, and solids. When the light passes into the high optically density substances, the light speed will be slow down. In contrast, the light speed will be increase if it passes into less optically density substances. When the light passes through different substances, the light direction also will be changed by changing the speed of light.

$$\frac{Sin\theta_2}{Sin\theta_1} = \frac{V_2}{V_1} = \frac{n_2}{n_1} \tag{1}$$

When θ_1 and θ_2 are the angles of incidence (degree), n_1 and n_2 are the refractive indexes of two different materials and V_1 and V_2 are the velocity of light in the respective medium (m/s). Based on the above equation by Snell's law that is used the relationship between the incident angles and the refraction when the light passes through different media. It is also can calculate the refractive index of different media.

Jenkins (1982) reveals the method to measure the refractive index of water by the minimum deviation method. The refractive index of water in this experiment was calculated 1.3318 at 20°C by the minimum deviation equation. The schematic drawing of the minimum deviation method was shown as follows.

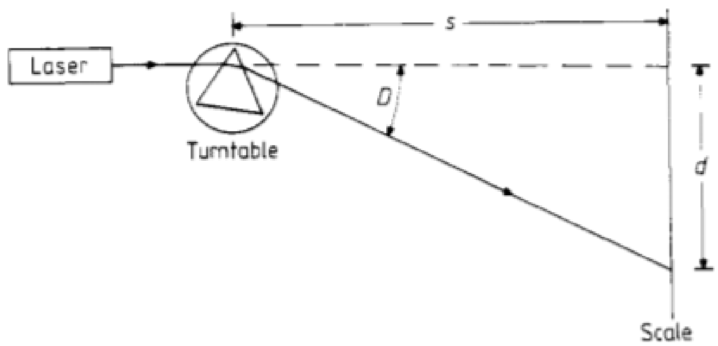

Figure 1. Schematic drawing of the minimum deviation method (Jenkins 1982).

Another experiment also used the minimum deviation method for measurement of refractive index in different solutions with high concentrations, such as sucrose, sodium chloride, glucose, and caster sugar (Mat Yunus and Rahman, 1988). The result of the experiment revealed that the refractive index increased with increased concentration of solutions.

Behzad et al. (2016) experimented to investigate the correlation between the concentration and refractive index of aluminium nanofluids. The result of the experiment, the refractive index of Aluminum nanofluids is rising linearly from 1.427 to 1.697 by increased the concentration from 0 to 0.381%.

3. Experimental Method

3.1 Preparation of nanofluids samples

In this experiment, a total of 10 different concentration TiO_2 nanofluid samples were prepared by the two-step method, the concentration is 0.001% to 0.04%. Before the mixing procedure, the amount of TiO_2 nanopowder and distilled water should be measured to calculate the concentration of nanofluids.

The two steps method can be divided into two parts. The first part is to stir the nanofluids sample by magnetic stirrer in 30 mins with 1600rpm. Afterward, nanofluid samples into an ultrasonic bath for dispersion the nanoparticle in the fluid by the ultrasonic wave in 30mins. This part is very useful for minimalized the agglomeration of nanoparticles.

3.2 Installation and method of experiment

In the current study, the refractive index of various concentrations of TiO_2 nanofluid sample can be getting by minimum deviation methods and the system of the experiment was installed a reference to Jenkin's proposed refractive index measurement method in 1982. The system of the experiment was presented in figure 2.

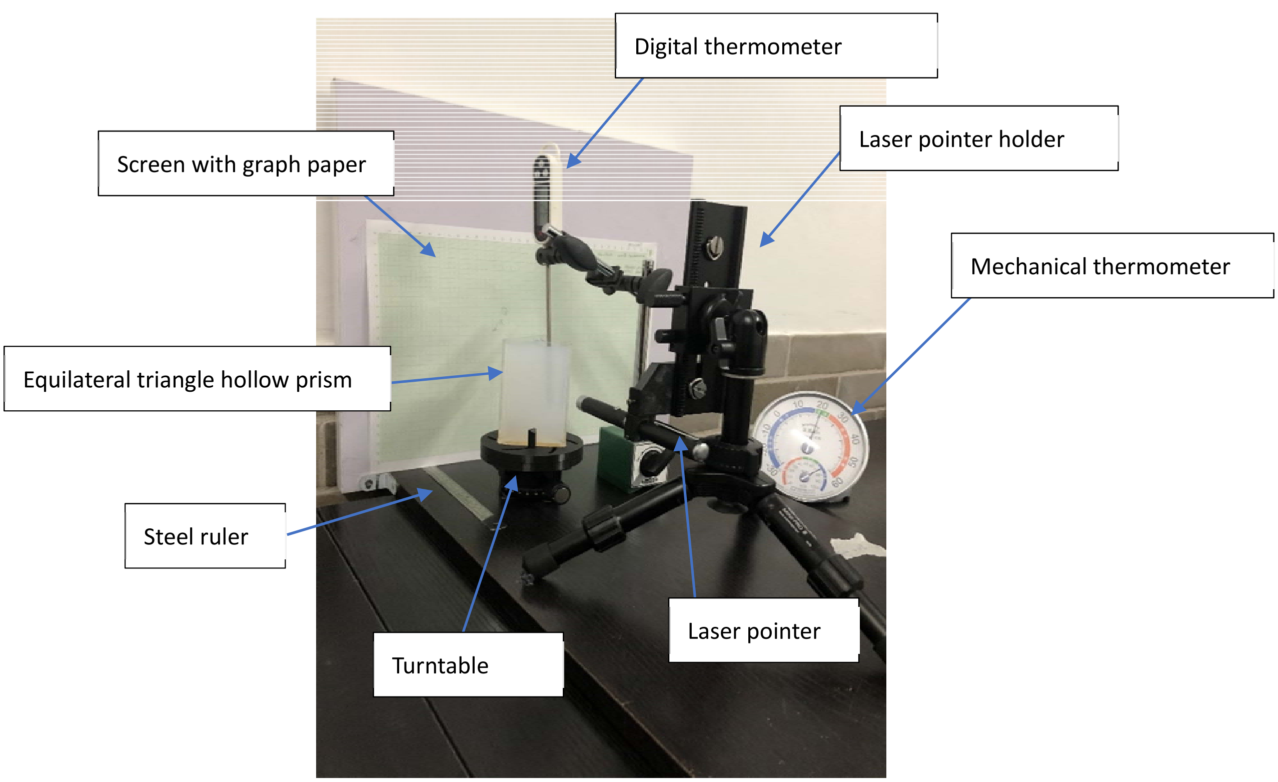

Figure 2. The system of the current experiment

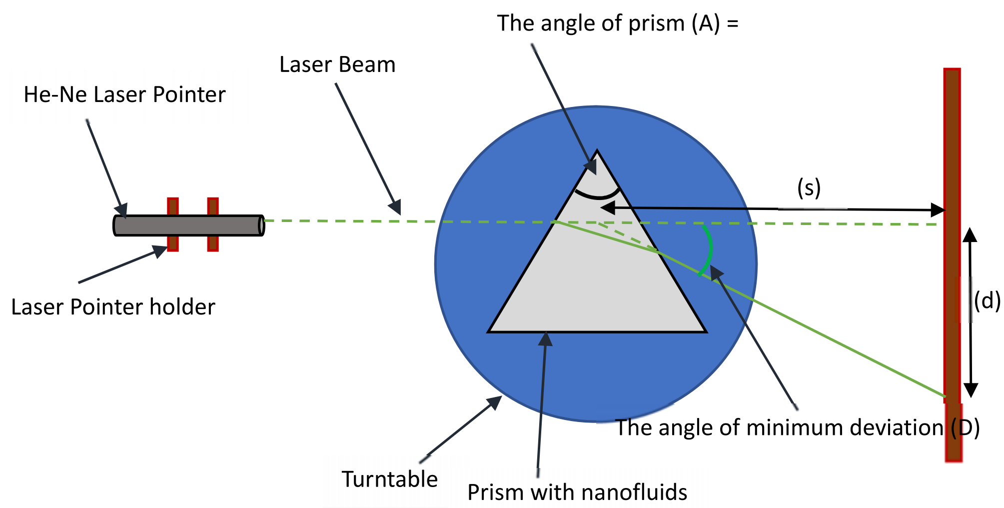

Figure 3. The schematic drawing of the experiment system

The system consisted of the laser pointer, equilateral triangle hollow prism, turntable, screen, and the thermometer. The hollow prism will be fabricated to the equilateral triangle shape and made by Acrylic. The hollow prism contained the nanofluids samples and place them on the turntable. The laser pointer projected the laser beam passes through the prism with samples and spot on the screen accompany refraction. The turntable uses for rotate the hollow prism reach the light defection (d) of a spot on the screen is a minimum and the angle of deviation (D) also minimized. Especially, the laser pointer holder, hollow prism, and the screen should be placed in the fixed distance and remain unchanged. The thermometer with two thermometers installed in the experiment for monitoring the room temperature and nanofluids temperature at 22°C.

According to the minimum deviation equation and Snell's Law, the angle of minimum deviation was calculated by the following equation.

$$D = tan^{-1}(\frac{d}{s}) \quad (2)$$

When d is a distance of light defection (mm) and s is the distance between the intersection point of lights (original & defection) & screen (mm). Distance d required to measured 5 times in 3 different portions in each TiO_2 nanofluid samples and the mean value of collected distance d used to calculate the angle of minimum deviation.

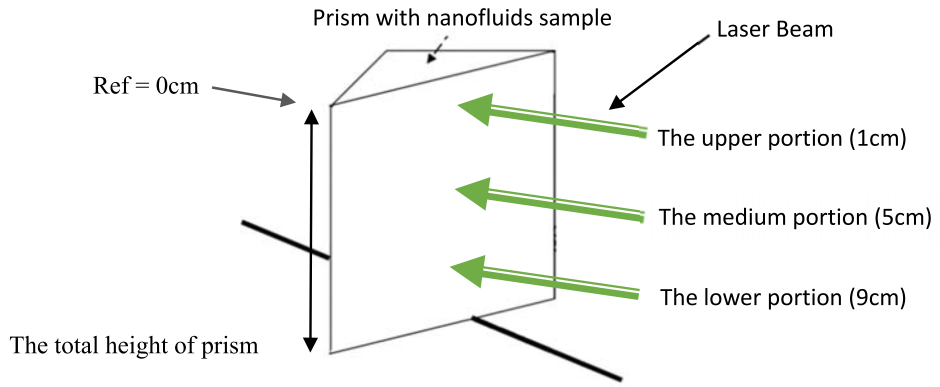

Figure 4. The drawing of 3 different portions of a prism with nanofluids sample

Based on the determined angle of minimum deviation, the refractive index of water was found by the following equation.

$$n = \frac{\sin \frac{1}{2}(A+D)}{\sin \left(\frac{A}{2}\right)} \tag{3}$$

When A is the angle of prism and D is the angle of minimum deviation.

4. Result of the experiment

To ensure the feasibility and reliability of the experiment system, the water, glucose solution, and sodium chloride used as a sample for measure their refractive index by this experiment system, then compare with previous study results. The comparison of the refractive index of water between the current study and previous studies presented in Table 1.

	Refractive index of distilled water	Correction	Percentage of Correction (%)
Current Study	1.3338	---	---
Jenkins (1982)	1.3318	-0.002	- 0.15%
Chandra and Bhaiya (1983)	1.34	+0.0062	+0.46%

Table 1. The calibration results in this experiment by distilled water and compared with Jenkins (1982) and Chandra and Bhaiya (1983) result

Figures 5 and 6 presented the comparison of the refractive index of glucose solution and sodium chloride solution in difference concentration between the current study and the previous study result from Mat Yunns and Rahman in 1988.

The refractive index measured in the current study approximately equal to the previous study when the concentration is below 10% either glucose or solidum chloride solution. Although, the refractive index is 15% concentration of samples found a slightly difference between the current study and the previous study. The max. percentage of correction only 0.25% in Glucose solution and 0.65% in solidum chloride solution. That is a petty small difference. Based on the above result, the experiment system believed reliable.

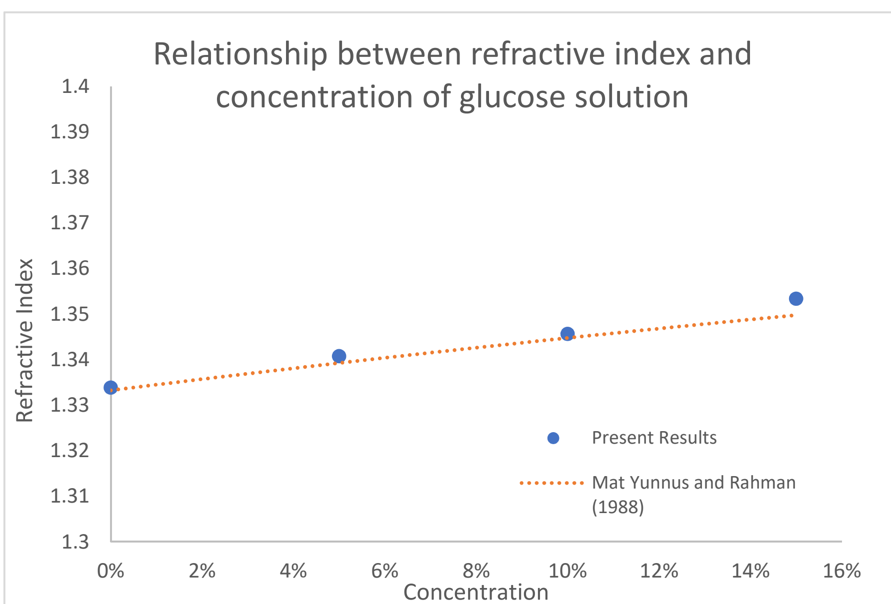

Figure 5. The refractive index variation with concentration for glucose solution

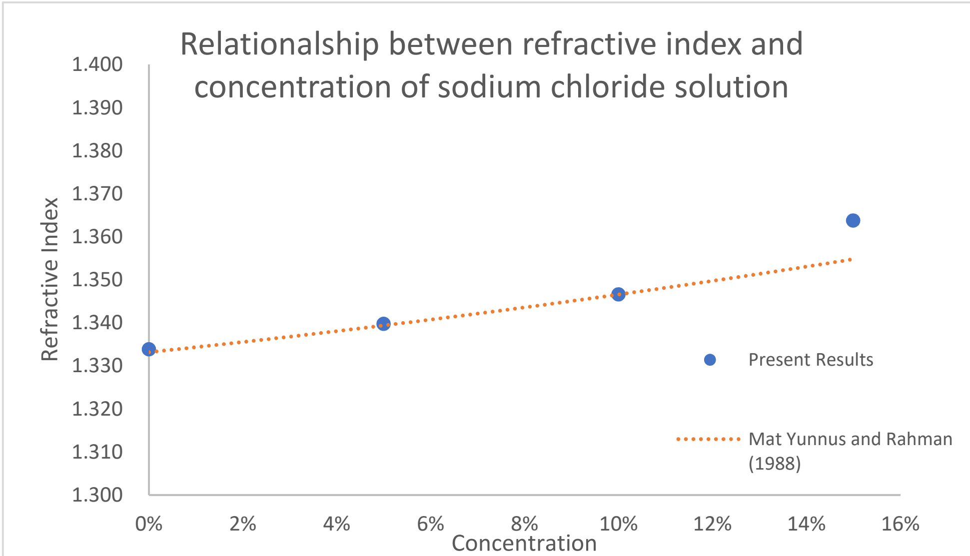

Figure 6. The refractive index variation with concentration for sodium chloride

In figure 7, the angle of the minimum deviation of TiO_2 nanofluid samples was found and reveals. The angle of minimum deviation is increased by 17.6%, from 24.22 degrees to 28.482 degrees, with increased concentration of tio2 nanofluids from 0.001% to 0.04% concentration. The uncertainty of the minimum deviation angle calculated the minimum is 0.357o on 0.001% concentration and the maximum is 0.385o on 0.03% concentration.

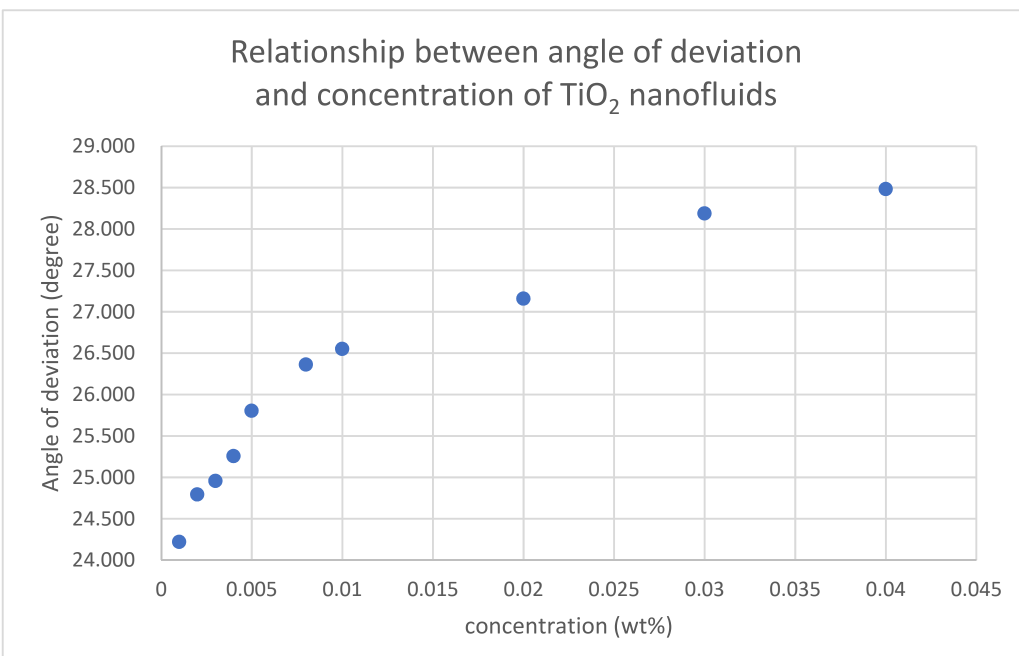

Figure 7. The angle of minimum deviation variation varying mass fraction of TiO_2 nanofluids

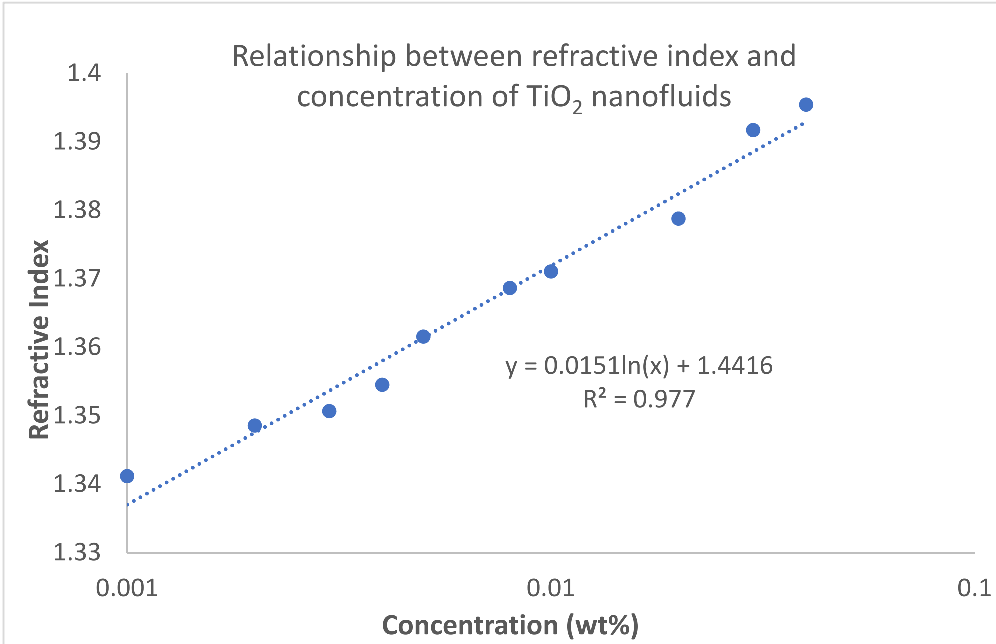

Figure 8. The refractive index variation mass fraction of TiO_2 nanofluids with linear regression

Figure 8 presented the determined refractive index of tio2 nanofluid samples in different concentrations. The refractive index of the TiO2 nanofluid sample found increased from 1.3411 to 1.3953 when it increased the concentration from 0.001% to 0.04%. A new straight line generated from 0.001% to 0.04% concentration after applied logarithmic regression analysis. This is fitted for the equation y = 0.0151ln(x) + 1.4416. The coefficient of determination is 0.977 is approximately equal to 1. That means the modeled value is very closed to the determined refractive index.

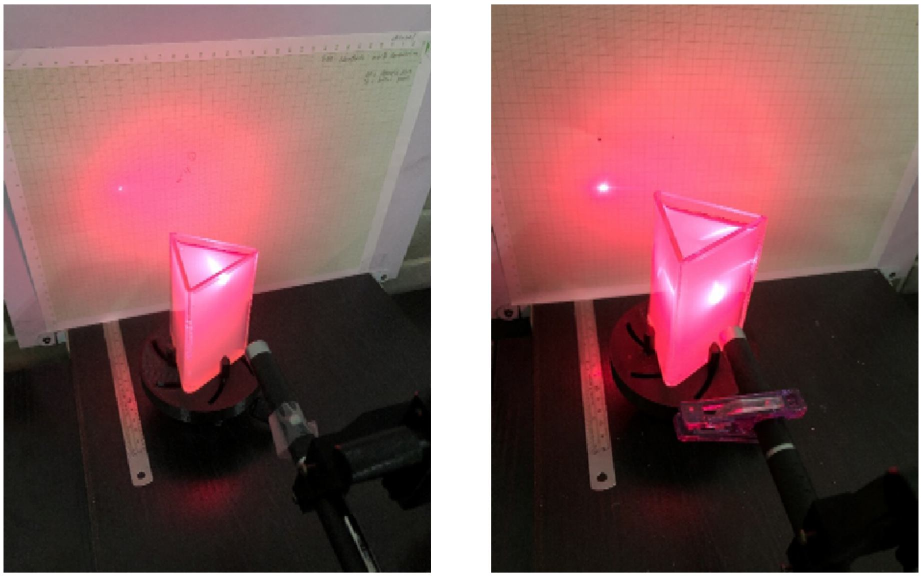

Figure 9. The experiment conducted on the upper and medium portion of prism in the nanofluids sample 0.03 wt%

As a constraint in the existing instrument, this experiment cannot conduct on or above 0.06% concentration of TiO_2 nanofluid sample. Figure 10 was presented the laser beam cannot pass through the 0.06% concentration samples.

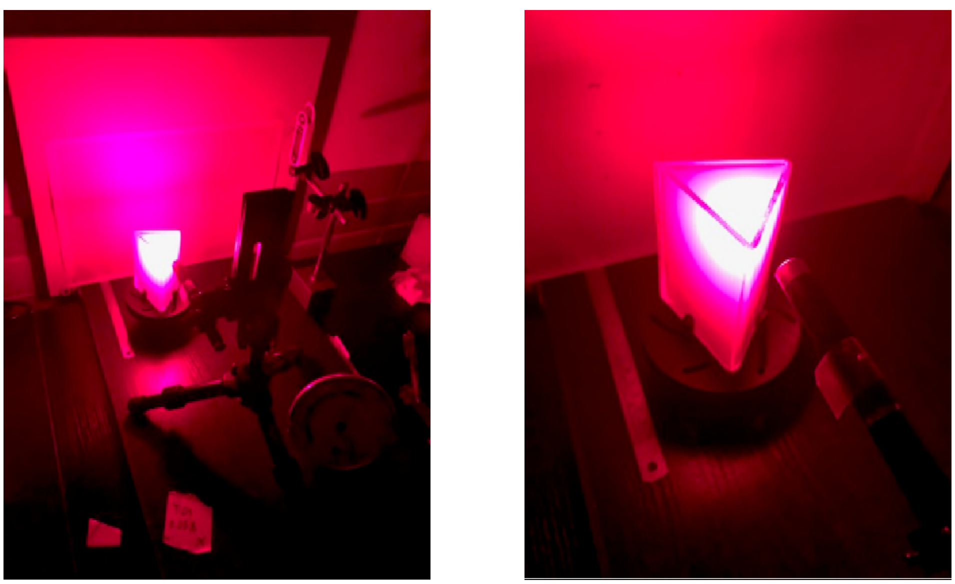

Figure 10. The laser light ray fully scatting by the TiO_2 nanofluids. (0.06 wt%)

5. Conclusion

In the current study, the experiment system was installed for the measurement of the refractive index of TiO_2 nanofluid sample. Based on the result of the experiment to interpret the correlation between refractive index and concentration of TiO_2 nanofluid. The summaries of this study will be shown as follow:-

1. This experiment system is reliable and feasible to measure the refractive index.

2. The angle of minimum deviation and refractive index increased with an increased concentration of nanofluids.

3. The correlation between the refractive index and concentration of TiO2 nanofluid is a trend to linear when fitting to logarithmic regression analysis and the coefficient of determination is very closed to 1.

4. These findings is very useful for further study in another different type of nanofluids and further develop the non-contact method for measurement of nanofluids concentration.

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