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Experimental study of nanoparticles size distribution effect on the Mie scattering intensity

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Abstract

Mie scattering is a phenomenon that happens when an electromagnetic wave (light) is scattered by a particle which has the same size of the particle comparable with the incident light wavelength. This non-destructive scattering technique is recently used in the various study as an alternative for measuring particle size distribution in contrast with other methods which has certain limits (i.e. destructive to the samples). The parameter observed in the Mie scattering experiment is a function of the Mie scattering intensity to the angle. This research aims to analyze the particle distribution effect of the Mie scattering phenomena experimentally via image processing technique as a preliminary study in particle size analyzer development. The nanoparticles samples that have been used to do this research are polystyrene latex with an average size of a particle of 108 nm, and Fumonisin B1 with an average size of a particle of 36.4 nm. The result of the experiment from those two types of samples was the plot of color intensity extracted from the image (photo) at varied scattering angles. The graph of scattering intensity of polystyrene sample with the average size of 108 nm has a peak value higher than sample Fumonisin B1 with an average size of 36.4 nm. Generally, the light has been scattered weaker at Fumonisin B1 samples compared to polystyrene latex nanoparticles samples.

Keywords—Mie scattering, particle size distribution, nanoparticles sample, image processing technique.

Introduction

There are so many material characterization methods that aim to know the size dimensions of particles in the nano order such as Scanning Electron Microscopy (SEM) and Brauer Emmet Teller (BET), but the SEM method could be broke the sample which will measure it. Recently, the measurement of particle sizes focused on the scattering theory by using monochromatic light. The scattering method many times used because of the fastest measurement, might be used for some shapes of the sample, good quality although it continues used and its application is so widely.

The scattering method of light has some techniques that were used to investigate the characteristics of a particle. Especially, in the Dynamics of light scattering based on the Brownian motion of a particle the main objective to investigate is the scattering intensity to the time. In this research, it was used the Mie scattering technique which has the concept to investigate is the scattering intensity to the angle.

The Mie theory was first introduced by Gustav Mie (1868-1957) and Ludvig Lorenz (1829-1891). They introduced a complete mathematical theory for scattering by small particles when the Rayleigh scattering theory had a limitation, namely the ratio of particle size to wavelength is less than one, but Mie's theory has a wider scope [3]. Mie's theory can be used to measure particle sizes in the range of tens of nanometers to thousands of micrometers [2]. In addition to measuring particle size using the Mie theory that its algorithm has a higher accuracy when compared to other algorithms [2]. Using the Mie scattering theory at this time has been widely carried out, especially in terms of modeling which is carried out on single-particle assumptions. Therefore, in this study, the Mie scattering technique experiment will be carried out to determine the effect of the nanoparticles size distribution on the intensity.

Method

Research Object

The object of the research carried out is nano-sized particles, namely: Polystyrene Latex (PSL) and Fumonisin B1. In this study, the data required are the intensity of light scattered by the sample, the angle of scattering, and the wavelength used

Tools and Materials

Hardware

Green laser

Green laser (= 532 nm ±10 nm, max output power < 5 mW, diameter 1.1 mm). The laser used is a green laser with a wavelength of 532 nm, the green laser was chosen because the Mie scattering ratio is the ratio between wavelength and particle size. Green laser coverage for nanoparticles that are small in size is even wider.

a. Polarizer
b. Camera phone
c. Stative
d. Glass Cuvette (Outer dimensions: 12.5x12.5x45 mm, inside dimensions: 10x10x44 mm, refractive index: 1.51).
a. Samples: Polystyrene (mean size 108 nm, refractive index 1.59) and Fumonisin B1 (mean size 36 nm, refractive index 1.66).
b. Diffraction grating (50 lines/mm

Software

a. Matlab
b. Image J

c. Microsoft Excel
d. Gnuplot

Characterization and System Construction
Laser Characterization

The laser wavelength testing used uses the principle of diffraction in a narrow slit.

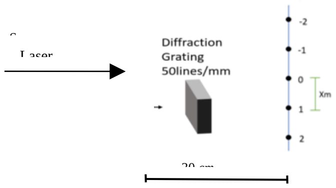


Figure 1.1 *Laser wavelength testing scheme*

The laser will be diffracted into a light and dark pattern, from the measurement of the distance of the pattern center light (in Figure 1 shown point 0) to the first light is biased obtained the value of the wavelength using the equation:

$$X_m = \frac{m\lambda H}{d} \quad (1)$$

X_m=Distance from center 0 to first bright spot (nm)
m = light order: 1, 2, 3,…,m
d = diffraction grating slit width (line/cm)
H = Distance of Diffraction Grating to the screen (cm)

Sample Characterization

Samples of polystyrene latex (PSL) and Fumonisin B1 used then characterized using PSA (Particle Size Analyzer) to determine the size distribution of the sample. A particle size distribution results in both samples is the cause of the value of the intensity of the Mie scattering.

System Construction

The system design to be made can be seen in Figure 1.2. A laser with a wavelength of 532 nm (green) is fired towards the sample, before going to the laser sample will hit the polarizer which serves to rectify electromagnetic waves from the laser as well as to attenuate the laser power so that it is not too strong.

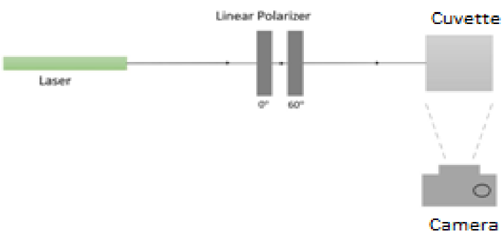


Figure 1.2 *System Scheme*

The nanoparticles sample will scatter the beam laser beam at certain angles which will then be detected by the sensor camera in the form of photos (digital images). The laser, polarizer, and cuvette are placed on one parallel line and the photo was taken from the side of the cuvette [14].

Processing

Image Processing

The stages of Image Processing or image processing are carried out to extract the RGB values on the photos taken during the experiment. The RGB value is used to get the value of color intensity by finding the mean of the three colors.

The software used is MATLAB, with profile tools. The profile is a tool that takes the pixel intensity values along the line or lines created in a grayscale, binary, or RGB Image in the current axis and displays the intensity value plot [11]. Data was obtained from Matlab in the form of intensity values for each color red, green, and blue, and what is used as the intensity value is the average value of the three colors. By drawing a horizontal line from the bottom to the top of the photo, then we get a plot of the intensity value of each pixel.

Scattering Angle measurement

Scattering angle measurement was obtained using the trigonometry formula (see Figure 1.3).

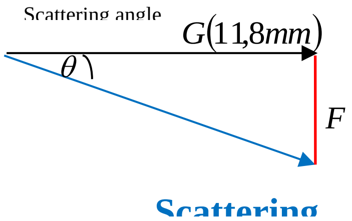


Figure 1.3. *Trigonometry to find the scattering angle*

Scattering angle was found using the following formula:

$$\tan\theta = \frac{F(mm)}{G(mm)} \Rightarrow \theta = \tan^{-1}\left(\frac{F(mm)}{G(mm)}\right) .(2)$$

From equation (2) we need the values of F and G. The value of F is the distance from one point (pixel) to another point (pixel). While the value of G is the distance from the beginning of the scattering, in this event from the beginning of the cuvette to the point F middle. The value of the angle will be obtained in the calculation of equation (2) so that the graph of the experimental results which was originally an intensity graph concerning pixels will be converted into a graph of the intensity concerning the angle.

Validation with the modeling result

Validation with modeling is carried out to equalize the experimental results with the results of modeling done by Felix. In the study conducted by Felix the Mie scattering intensity value $I(\theta)$ is obtained from the calculation of the equation $I(\theta) = \int_{a_{min}}^{a_{max}} K(\theta)f(x)dx$ through modeling using Matlab. In that equation, the value of K is the scattering intensity by a single particle modeled by Felix then get the value of $I(\theta)$ after the value of K is multiplied by f(x) which is a Gaussian distribution.

Result and Discussion

In this section, the results of the research from several methods will be explained as previously described. The results include:

Laser wavelength

The laser is passed to a Diffraction Grating then diffraction will occur and a light-dark pattern is formed which can be seen in figure 3.

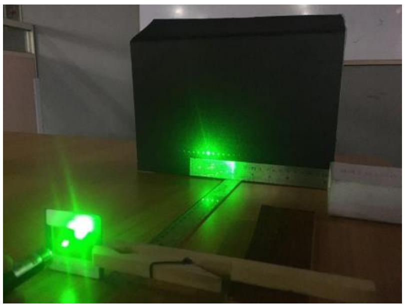


Figure 3. *Laser wavelength testing*

From the test results, the distance from the central bright spot to the bright spot is obtained as 0.8 cm. Through equation (1), we get the wavelength of the laser is 533.3 nm. The value obtained is slightly different from the specifications of the laser, but still within the error range contained in the laser specifications.

Sample Characterization

The results of characterization using PSA (Particle Size Analyzer) are obtained graph of frequency against particle size.

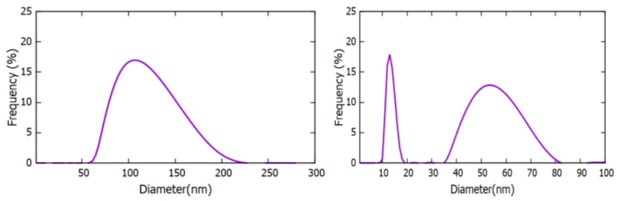


Figure 4. *Results of characterization of Polystyrene samples (left) and Fumonisin B1 (right) by PSA*

Figure 4 shows a graph of the particle size distribution of the Polystyrene sample. The Polystyrene sample (left) has an average particle size of 108 nm. For the sample of Fumonisin B1 (right), there are two peaks. The first peak has an average size of 12.5 nm, the second peak has an average of size 51.0 nm. The average particle size of the whole sample of Fumonisin B1 is 36.4 nm.

Experiment system design

Figure 5 shows the results of the system design that has been made.

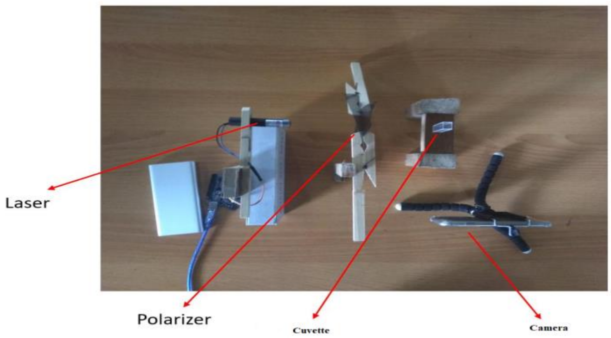


Figure 5. *The results of the experiment system design*

The laser beam is coming from the left of Figure 5 towards the polarizer which is the next step is about the samples in the cuvette. The laser beam will be scattered by the sample in the cuvette, the scattering occurs then captured by the camera from the side of the cuvette.

The left cuvette contains distilled water, right cuvette contains Polystyrene

The first data has been taken of two of these cuvette photos. It was done for the first time to see the comparison of the scattering that will happen at the particle nano and distilled water if it is beamed by a green laser (see figure 6a).

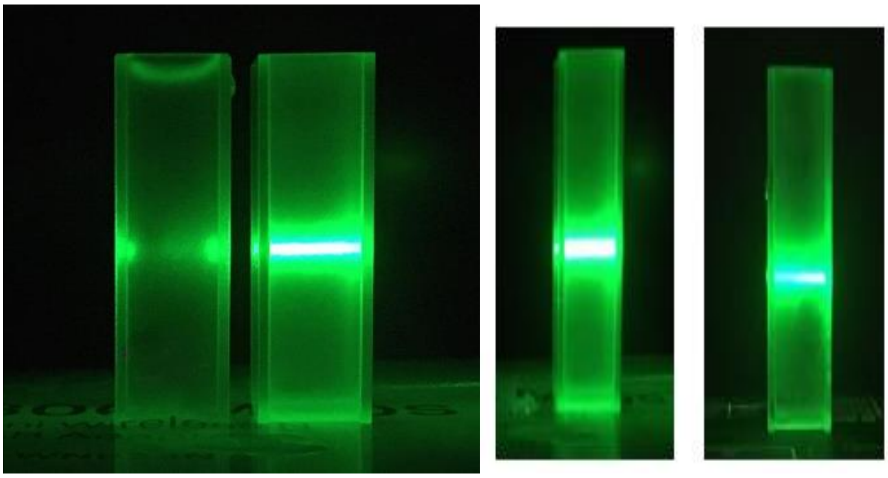


Figure 6. *(a) The left cuvette contains distilled water, the right cuvette contains Polystyrene; (b) The left cuvette contains Polystyrene, the right cuvette contains Fumonisin B1*

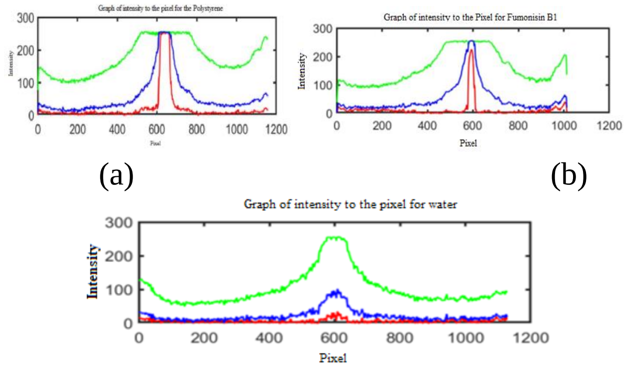
Figure 6b shows the results of taking photos of the two samples used, Polystyrene and Fumonisin B1. In the left cuvette containing Polystyrene, the laser beam looks wider than the right cuvette containing the sample Fumonisin B1. Polystyrene has an average particle size distribution of 108 nm, while the Fumonisin B1 sample has an average particle size distribution of 36.4 nm. Polystyrene samples have an average particle size greater than Fumonisin B1, this makes the laser beam on the photo appear wider than the Fumonisin B1 sample.

The results of image processing obtained data in the form of plots for each color (Red, Green, and Blue) in each sample. For sample Fumonisin B1 the Gaussian shape of the plot of the three colors looks more sloping than the polystyrene sample, while for the cuvette filled with water it appears that there is a slight intensity value affected by water particles and impurities and reflections from the cuvette.

Table 1. *Data sample for color intensity*

Sample polystyrene				Sample Fumonisin B1			
R	**G**	**B**	**Mean RGB**	**R**	**G**	**B**	**Mean RGB**
10	126	25	53.66667	0	39	2	13.66667
10	126	25	53.66667	2	51	6	19.66667
12	128	27	55.66667	7	65	14	28.66667
11	127	26	54.66667	10	78	19	35.66667
9	125	24	52.66667	14	90	25	43
7	122	21	50	20	103	31	51.33333

From the three colors, the average value is then found to be considered the color intensity value [15]. Table 1 shows some of the intensity data colors for sample Polystyrene and Fumonisin B1.



(a) (b)

(c)

Figure 7. *Some of the intensity data colors for the sample: (a) Polystyrene, (b) Fumonisin B1, and (c) water*

Scattering Angle measurement

Scattering angle measurement has been done by using the trigonometry formula (2). The midpoint of the brightness was 0 degrees and then measured to the right and the left every 1 pixel or 0.0446443 mm along the red line drawn. One pixel equal to 0.044643 mm gets by calculating the ratio of the number of pixels on the red line drawn with the actual size. A red line is drawn from the top of the cuvette to the bottom of the cuvette the known height is 45 mm, while the number of pixels is identified by using the ImageJ application. Draw a line along with the line red then select the toolset scale, it will show the number of pixels on the line which is made. In the known distance, replace 45 mm (height of the cuvette), eat below a scale will appear 22,4007 pixels/mm or 0.044643 mm/pixel.

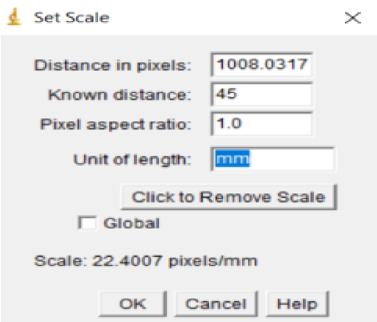
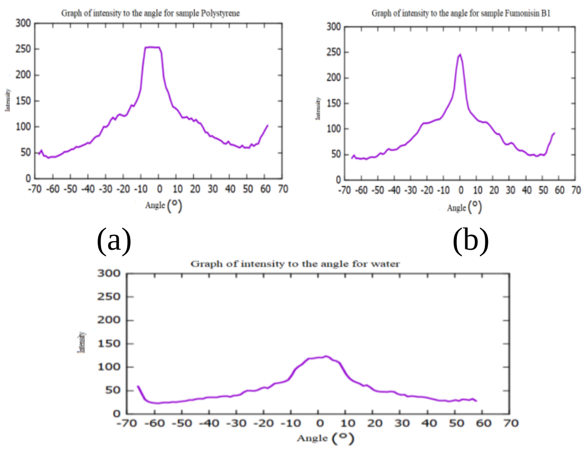


Figure 8. Set scale ImageJ

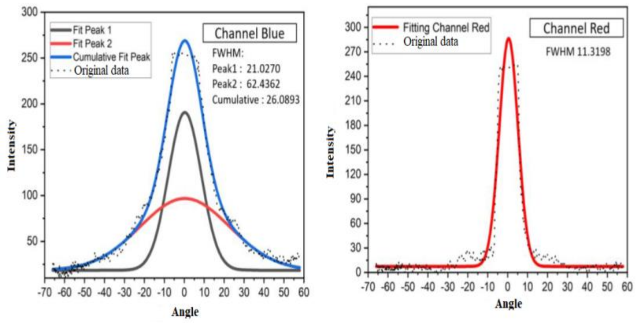


(a) (b)

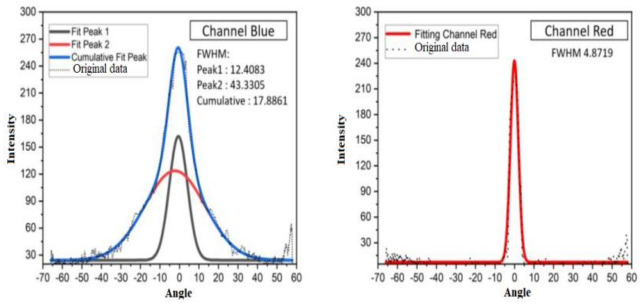
(c)

Figure 9. *Some of the intensity data to the angle for the sample: (a) Polystyrene, (b) Fumonisin B1, and (c) water*

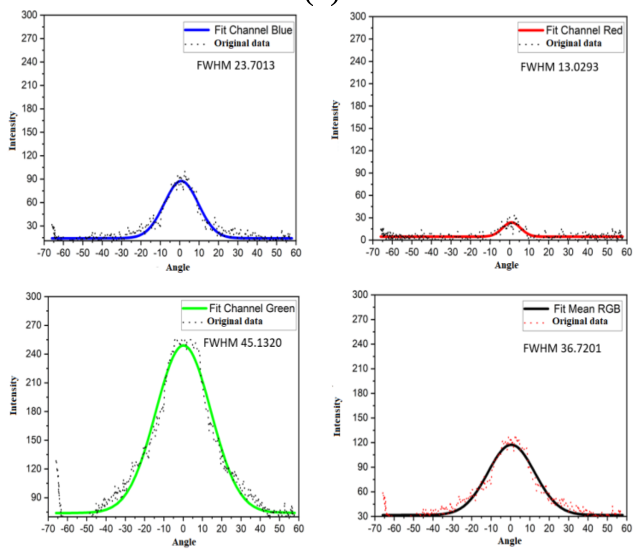
The graph of the intensity concerning the angle in the two samples (Polystyrene and Fumonisin B1) is searched for the FWHM value using the FWHM function in Matlab. The graph of the intensity against the angle of the Polystyrene sample obtained an FWHM value of 28.7543, while for the graph of the intensity against the angle on the Fumonisin sample B1 the FWHM value is 20.6152. Due to the intensity graph data for an angle in the truncated Polystyrene sample, the FWHM value is greater than the Fumonisin B1 sample. This FWHM value represents the distance from half the vertex of the graph. If the data on the Polystyrene sample is not truncated by its FWHM value, then the data will be closer to the FWHM value of the Fumonisin B1 sample.



(a)



(b)



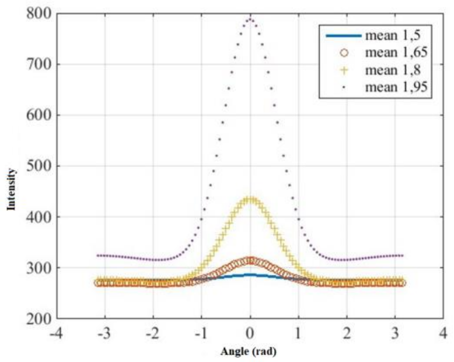
(c)

Figure 10. *Some of the fitting Gaussian for the sample: (a) Polystyrene, (b) Fumonisin B1, and (c) water*

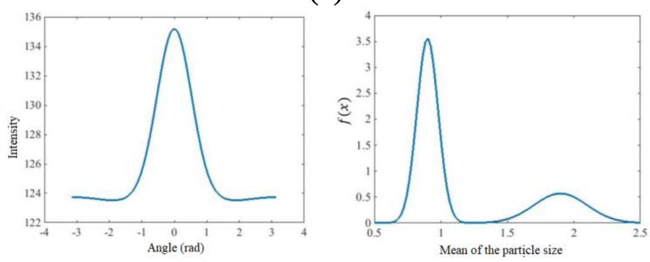
From figures, 9a and 9b fitting are made with nonlinear Gaussian (two Gaussian) to perform a deconvolution to decompose the peaks that are hidden. Two Gaussians are obtained which when accumulated will form a Gaussian one that is similar to the graphical form of the original data. In addition to fitting the mean RGB values of the two samples, used, fitting is also carried out on the red and blue channels (Fig. 7) for Polystyrene and Fumonisin B1 samples, as well as for cuvette that is only filled with water. The red channel is fitted with one Gaussian, while the channel blue is fitted with two Gaussians for both samples because you can see there are two peaks in Figure 7.

Validation with modeling result

The results of the modeling using Matlab carried out by Felix are obtained graph of intensity against angle through equation 1.12. used is a Gaussian distribution by varying the mean represents the average particle size.



(a)



(b)

Figure 11. *(a) Graph of intensity to the angle for modeling result; (b) Modeling result for f(x) two Gaussians*

In Figure 11, it looks more and more like the greater the value of the mean or average particle size, the greater the value of intensity and the peak on the graph looks higher. That the pattern is quite the same in the results of the experiment, where the experiment the more the greater the average value of the size of a particle, the greater the intensity value wasted. After we see the modeling result when f(x) is made in two different distributions the graph of intensity to the angle for those samples, is quite the same as the graph of Lorentz distribution.

Conclusion

Based on the results of the research that has been done, it is obtained conclusion of this research: (1) The design of the Mie scattering experimental system has been successfully designed based on image processing; (2) Different particle size distribution will affect the intensity value scattering where the graph of the relationship between the Mie scattering intensity and the angle will be more sloping if the average particle size distribution the smaller the particle size, the greater the intensity distribution value will also grow.

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