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Determination of Water Viscosity by Tracking The Brownian Motion of a Single Particle using Video Microscopy

Penentuan Kelikatan Air dengan Menjejaki Gerakan Brownian Satu Zarah menggunakan Mikroskopi Video

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Abstract

Micron sized particle exhibits Brownian Motion (BM) in fluidic material. The BM of the particle characterizes the vicinity material due to the existance of thermal force. This paper describes an experiment to determine the water viscosity via BM observation using video microscopy technique. Video microscopy technique using open source Tracker software were employed to track the temporal displacement of the microparticle as a probe. Our viscosity measurement results (906 μPa s at 25.9 °C, 839 μPa s at 26.0 °C and 867 μPa s at 30.1 °C) are within the range resulted by measurement using rheometer. One of the merit of using particle tracking technique is the requirement of only microliter sample.

Keywords Brownian motion (BM), water viscosity, video microscopy technique

Abstrak

Zarah bersaiz mikro mempamerkan Gerakan Brownian (GM) dalam bahan bendalir. GM zarah tersebut mencirikan bahan persekitarannya kesan daripada kewujudan daya terma. Makalah ini menjelaskan uji kaji untuk mendapatkan kelikatan air melalui pencerapan GM menggunakan teknik mikroskopi video. Teknik mikroskopi video dan perisian sumber terbuka Tracker digunakan untuk menjejaki sesaran dalam fungsi masa bagi zarah mikro yang bertindak sebagai prob. Hasil pengukuran kelikatan (906 μPa s pada 25.9 °C, 839 μPa s pada 26.0 °C dan 867 μPa s at 30.1 °C) setanding dengan nilai pengukuran menggunakan rheometer. Salah satu kelebihan menggunakan teknik penjejakan zarah ialah pengukuran hanya memerlukan beberapa mikroliter isipadu sampel.

Kata kunci gerakan Brownian (GM) , kelikatan air, teknik mikroskopi video

INTRODUCTION

The Brownian Motion (BM) is one of the phenomenon describing random motion. Besides, it also provide local rheological characteristics of a fluidic material. The undeterministic pattern follows the Gaussian or Normal statistics (Gillespie, 1996). It means that the system

J. Sci. Math. Lett. UPSI Volume 3 (2015) 1 - 6
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has unique response and free from the external perturbation, such as electric, magnetic or nuclear field. Every parameter inside the system gives same weighting contribution, such as mass distribution, displacement, velocity and acceleration. The local information in the material represents the thermal contribution (Toyabe & Sano, 2008). The exploration of the thermal related factors from the BM give advantages in studies of microrheological properties for fluidic materials (Mason, 2000).

Researchers utilize these benefits to explore and to find pattern of the system and other physical information. The motion of the probe can be explored using the mathematical tools such as analysis and synthesis of algorithms or transformation process. As an example, the previous study of the BM was done to determine viscoelastic moduli of polyethylene oxide solutions (Dasgupta, Tee, Crocker, Frisken, & Weitz, 2002). There are relationships and dependencies between angular frequencies and concentrations of that solutions. These relationships make an impression to the values of viscoelastic moduli. Then, from the viscoelastic moduli, researchers described certain model and energy distribution of the solutions (Popescu, Dogariu, & Rajagopalan, 2002).

There were many ways to study the BM in passive microrheology (Squires & Mason, 2009). One of the study is the application of Generalized Stokes-Einstein Relation (GSER). For the GSER, Mean-Squared Displacements (MSD) can be used directly in order to calculate the Complex Shear Modulus (CSM). The linearity degree of the MSD discriminates between Newtonian or non-Newtonian type of viscoelastic material. The MSD describes the relation between inter-positions and the response toward thermal force using Autocorrelation Function (ACF). The ACF is widely applied in stationary and non-stationary signals (Meirovitch, 2001). The ACF is for the special case, used when the random motion depends on time factor but independent of spatial/space factor.

Although the analysis of BM which lead to the viscosity calculation is widely discussed theoretically, but still rarely proven by experimental work or technique (Grimm, Jeney, & Franosch, 2011; Metzler & Klafter, 2000; Savin & Doyle, 2005). Currently, the viscosity of a fluid is measured by using rheometer which requires several milimeters of sample. However for delicate sample in microliter order, viscosity measurement using rheometer is imposible. Therefore, another techniques such as the one suggested in this study by using a video microscopy is explored.

This paper describes the use of BM to determine the viscosity of water under room temperatures condition. This technique also can be performed to characterize viscoelastic material such as polymer, surfactant solutions and biological materials (Fischer & Berg-Sorensen, 2007; Popescu et al., 2002).

Viscoelastic and Brownion Motion

The motion of a probe in one degree of freedom system is represented by the particle displacement, x, which is subjected to stochastic force, F_s, on the probe due to the thermal fluctuation as described by the following relation:

$$mx + \beta x = F_s(t) \qquad (1)$$

where m is the mass of the probe [kg] and β is the drag coefficient [kg/s].

In time domain, the motion of the microparticle in water is determined according to GSER. GSER is applied in Diffusing-Wave Spectroscopy (DWS) by Mason and Weitz and in microrheology studies by Schnurr and Gittes et al. (Yanagishima, Frenkel, Kotar, & Eiser, 2011). This equation also known as Diffusion Equation which is related to the mean MSD of the probe and the diffusion constant, *D* is given by Equation 2,

$$\left\langle \Delta x^2(\Delta t) \right\rangle = \frac{1}{N-n} \sum_{i=1}^{N-n} (x_{i+n} - x_i)^2 = 2D\Delta t \qquad (2)$$

where i = data position index =1, 2,..., *N*; *N* is the recorded number of frames; n=increment of dt =1, 2,..., *N*-1 and Δt is lag time (Michalet, 2010). It was found that the diffusion constant, *D* depends on the probe geometry, vicinity temperature and viscosity as Equation 3.

$$D = \frac{k_B T}{6\pi\eta R} \qquad (3)$$

where k_B is Boltzmann constant [J/K], η is the viscosity [Pa.s], *R* is radius of probe particle [m] and *T* is the absolute temperature [K] (Jia, Hamilton, Zaman, & Goonewardene, 2007).

By combining Equation 2 and Equation 3, we get the viscosity of the fluid by observing the temporal displacement in one dimension of the probe at known temperature as expressed in Equation 4.

$$\left\langle \Delta x^2(\Delta t) \right\rangle = 2\left(\frac{k_B T}{6\pi\eta R} \right)\Delta t \qquad \text{(1 dimension)} \qquad (4)$$

METHODOLOGY

Samples were prepared using a microparticle as a probe. The microparticle is polybead® polystyrene (2.95±3%) µm. This bead exhibits no chemical reaction with water and available in standard diameter size. The microparticle solution was diluted with deionzed water at the ratio of 1:1,000.

The probe trajectory was observed under Inverted Microscope (Olympus GX51, Oil Immersion, 100×) and the video of probe motion were recorded using digital camera (Motic® Video 3.0 MP). We use Tracker freeware (https://www.cabrillo.edu/~dbrown/tracker/) to get the position of particle probe as function of time by frame rate (fps) which is more than 21 frames/s. We use (Equation 4) to analyze the BM by implementing the equations in algorithms using Matlab® program.

RESULT AND DISCUSSION

The temporal displacement in one dimension of the probe from one of our measurement is shown in Figure 1. The random nature of the motion is clearly visible. Within 15 s, the

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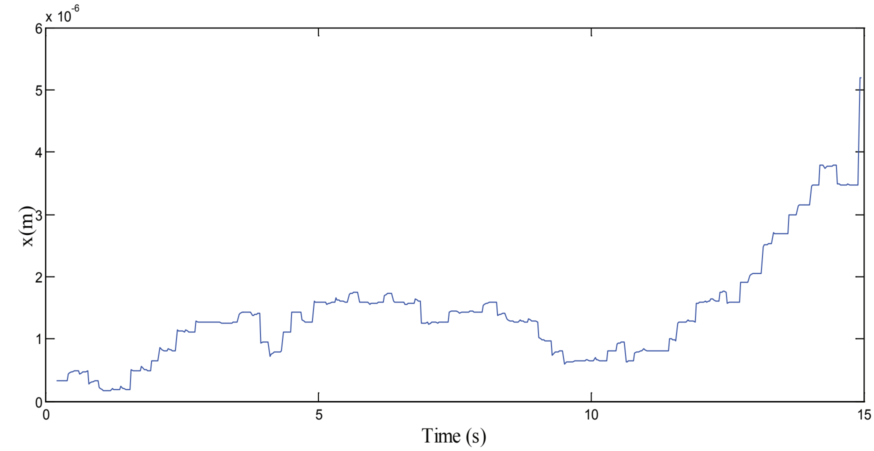

Figure 1 Temporal displacement of a particle shows the Brownian motion

motion range is in the order of several micrometers.

The MSD give information about the amount of thermal energy in order to change the displacements of particle toward the stability condition. Equation 2 is used to convert signal in Figure 1 into mean square displacement as a function of lag time. Figure 2 shows the result after the conversion is performed.

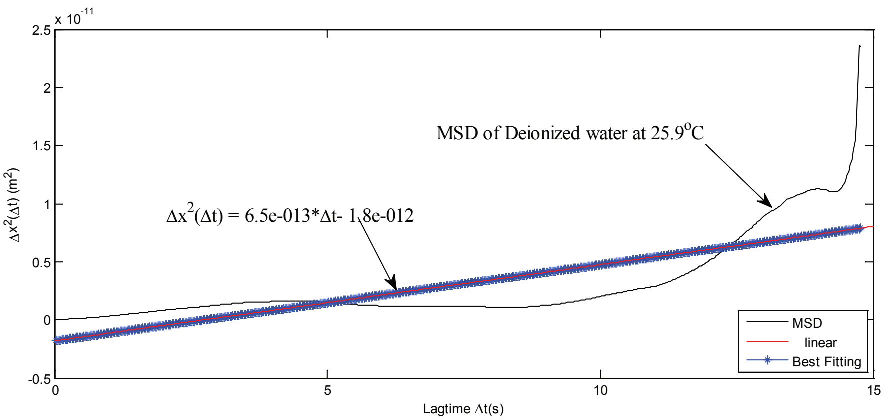

Figure 2 The graph was illustrated shows the MSD and linear fit for data set 24.9°C

The gradient of the graph in Figure 2 includes the diffusion constant, which contains information about the surrounding viscosity. By performing linear fitting, we can determine the value of viscosity of deonized water. The obtained values of viscosity are summarized in Table 1 from 3 set of measurements.

Table 1 Viscosity of deionzed water at different temperatures.

Data set	**Temperature [°C]**	**η experiment** [μPa.s]	**η reference** [μPa.s]	**Discrepancy (%)**
1	30.1	867	800	7.7
2	26.0	839	876	4.4
3	25.9	906	878	3.4

The viscosity values of deionzed water at different temperatures were found to be comparable to the standard values. The measurement is very sensitive to temperature variation at micron scale. Therefore, it is highly advisable to control the environment temperature at constant value during measurement.

CONCLUSION

The viscosity of deonized water was determined by observing the BM of a microparticle using video microscopy with Tracker freeware. The measured viscocity values of deionzed water (906 μPa s at 25.9 °C, 839 μPa s at 26.0 °C and 867 μPa s at 30.1 °C) are found within the range of values using rheometer.

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J. Sci. Math. Lett. UPSI Volume 3 (2015) 1 - 6
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