The determination of fluid viscosity using tracker-assisted falling ball viscosimeter

I Akhlis*, M Syaifurrozaq, Sugiyanto, P Marwoto, RS Iswari
Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia

*Corresponding Author: isa.akhlis@mail.unnes.ac.id

Abstract. This study intends to determine fluid viscosity. The method adopted was the utilization of a tracker-assisted falling ball viscosimeter. The falling ball viscosimeter was employed to get the motion of objects in the fluid, which was then recorded with a video recorder. The motion of objects in the video was analyzed by tracker software to get the terminal speed value of objects in the fluid. The value of fluid viscosity was then calculated using Stokes’ law. The results showed that the liquid viscosity value was 1.298 N.s/m².

1. Introduction
Observation on moving objects is sometimes challenging due to its short duration so that time calculation is somewhat difficult. However, a video recorder could help fix this issue. The recorded moving object can then be analyzed with the help of the computer. In other words, video recording has been proven many times as a reliable technique in explaining motion [1-3].

Tracker software could be another technology to assist in analyzing an object’s motion. The software can perform analysis by identifying the position, speed and acceleration of the object in motion [4,5]. In addition, the software presents data either numerically or graphically [6]. The amount of data analyzed depends on the value of the FPS video recorder.

Several studies employing computer-assisted video analysis have already been carried out. Eadkhong [7] performed an analysis of the rotation of objects with video analysis with great success. Klein [8] used a tablet computer to analyze projectile motion video as an experimental tool. Belloni [9] conducted research on the use of Tracker in astronomy learning. Kinchin [10] and Poonyawatpornkul & Wattanakasiwich [11] used video analysis to discuss harmonic motion. Moreover, Bryan [12] utilized video analysis to investigate the conservation of mechanical energy laws. Furthermore, Wee [3,13] employed video analysis to investigate the motion of projectiles and made use of the same technology to examine falling objects.

The fluid viscosity coefficient expressed by η is defined as a comparison between shear stress and the rate of shear change. At low Reynold numbers, the drag force experienced by objects moving in the fluid is only influenced by the viscous force. If the moving object is spherical with radius r and speed v, then the viscous force is (1).

\[ F = -6\pi\eta rv \] (1)
If a spherical solid has a density $\rho_b$, it is released without initial velocity on the surface of the liquid whose density is $\rho_f$ where $\rho_b > \rho_f$. The ball will accelerate, yet it eventually will achieve maximum or terminal speed $v_T$ due to friction with the fluid and to the fact that the ball moves in a straight line. This situation is obtained when there is a balance between the three forces acting on the ball, namely the weight of the object, the buoyant force, and the viscous force. Hence, when the object reaches the terminal speed, (2) is obtained with $g$ is gravitational acceleration.

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

(2)

This study aims at determining the viscosity value of the liquid using a falling ball viscosimeter with the help of Tracker video analysis software. Tracker was used to obtain terminal speed data.

Determination of terminal speed can also be done by measuring the interval at a certain distance. The time is measured using a stopwatch. However, this is done manually and has the possibility to cause errors.

2. Methods

This study made use of a falling ball viscosimeter. Glycerin, with a 1284 kg/m$^3$ density at 26°C, was the fluid whose viscosity was determined. The fluid was placed in a glass tube, and a marble was dropped in it (Figure 1). There were three marbles, whose mass, radius, and density are recorded in Table 1.

| Marble | Mass (m) (kg) | Radius (r) (m) | Density (kg.m$^{-3}$) |
|--------|--------------|-----------------|----------------------|
| 1      | $1.8 \times 10^{-3}$ | $5.600 \times 10^{-3}$ | 2445.936 |
| 2      | $2.5 \times 10^{-3}$ | $6.175 \times 10^{-3}$ | 2533.762 |
| 3      | $3.3 \times 10^{-3}$ | $6.775 \times 10^{-3}$ | 2532.344 |

Each marble was dropped three times in the fluid, and its motion was recorded using a digital video recorder 25 fps.

![Figure 1. Marble dropped in the fluid](image)

The next step was to analyze the motion video with Tracker software. The analysis strove to obtain terminal velocity data for marbles in fluid motion (Figure 2), and the value of fluid viscosity was calculated using the equation (2).
3. Results and discussion

The overall results of the Tracker analysis and calculation of fluid viscosity are shown in Table 2.

| Marble | \(v_{T1}\) (m.s\(^{-1}\)) | \(v_{T2}\) (m.s\(^{-1}\)) | \(v_{T3}\) (m.s\(^{-1}\)) | \(v_{T}\) (m.s\(^{-1}\)) | \(\eta\) (N.s.m\(^{-2}\)) |
|--------|----------------------------|----------------------------|----------------------------|----------------|----------------|
| 1      | 6.843 \times 10^{-2}      | 6.753 \times 10^{-2}      | 6.656 \times 10^{-2}      | 6.751 \times 10^{-2} | 1.175         |
| 2      | 7.774 \times 10^{-2}      | 7.872 \times 10^{-2}      | 7.895 \times 10^{-2}      | 7.847 \times 10^{-2} | 1.322         |
| 3      | 8.869 \times 10^{-2}      | 8.954 \times 10^{-2}      | 8.982 \times 10^{-2}      | 8.935 \times 10^{-2} | 1.396         |

The average of fluid viscosity was 1.298 N.s/m\(^2\) or smaller than 1.410 N.s/m\(^2\) [14]. The first reason underlying this discrepancy was temperature. Glycerin’s viscosity was measured at 26°C while 1.410 N.s/m\(^2\) is the score of viscosity at 20°C. A second reason for the difference could be the video recorder position over the object, which affects the video analysis results. Third, the contrastive degree could have been a factor [15]. Differences in the method and type of glycerin also affect the difference in results. The object must be in contrast to the background, so that it is easily recognized by Tracker. Table 2 also informs that the marbles’ mass influenced the terminal speed. The higher the mass, the greater increase in the marble terminal speed in the fluid. This fact shows a more significant drag force is needed so that the marble motion is in equilibrium.

4. Conclusion

The use of computer-assisted video analysis is a simple and inexpensive way to analyze the motion of objects. In this study, such a method has been used to determine the viscosity of glycerin. The results showed that the viscosity of glycerin at 26°C was 1.298 N.s/m\(^2\). The thing that needs to be considered in conducting a video-assisted analysis is the position of the video recorder when retrieving data against objects. The object analyzed must also have sufficient contrast to the background so that it can be easily recognized by Tracker.

References

[1] Hu WC, Chen CH, Chen CM and Chen TY 2014 Effective Moving Object Detection from Videos Captured by a Moving Camera. In: Pan JS., Snasel V, Corchado E, Abraham A, Wang SL. (eds)
Intelligent Data analysis and its Applications, Volume I. Advances in Intelligent Systems and Computing, 297. (Springer, Cham)

[2] Vera F, Rivera R and Fuentes R 2013 Brazil: Nuevas Ideas en Informatica Educativa TISE 2013. 121-125

[3] Wee L K, Chew C, Goh GH, Tan S and Lee TL 2012 Phys. Educ. 47(4) 448–455

[4] Ramli H, Chan KT and Fen YW 2016 Solid State Sci. Technol. 24 (2) 297-305

[5] Hockicko P, Krišťák L and Němec M 2014 Eur. J. Eng. Educ. 40(2) 145–166

[6] Rodrigues M and Carvalho PS 2013 Phys. Educ. 48(4) 431–437

[7] Eadkhong T, Rajsadorn R, Jannual P and Danworaphong S 2012 Eur. J. Phys. 33(3) 615–622

[8] Klein P, Gröber S, Kuhn J and Müller A 2013 Phys. Educ. 49(1) 37–40

[9] Belloni M, Christian W and Brown D 2013 Phys. Teach. 51(3) 149–151

[10] Kinchin J 2016 Phys. Educ. 51(5) 053003

[11] Poonyawatpornkul J and Wattanakasiwich P 2013 Phys. Educ. 48(6) 782–789

[12] Bryan JA 2010 Phys. Educ. 45(1) 50–57

[13] Wee LK, Tan KK, Leong TK and Tan C 2015 Phys. Educ. 50(4) 436–442.

[14] Tipler PA and Mosca G 2008 Physics For Scientists and Engineers (sixth) (New York: W. H. Freeman and Company) Pages:446

[15] Sirisatthikul C, Glawtanong P, Eadkong T and Sirisatthikul Y 2013 Rev. Bras. Ensino Fís. 35(1) 1–6.