Density determination of irregular shaped and small glass fragments by Stoke's law: *An alternative technique for the forensic analysis of glass*

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Abstract. Glass fragments are one of evidence that can be found in many crime scenes and used to include or exclude suspects or victims from the criminal event. For many years, a typical method known as sink-float method has been used in many investigation laboratories to prove the correspondence between the questioned glass fragments and the reference ones by matching their density values. However, the major drawback of the method is to use toxic solutions such as Bromoform and Bromobenzene in the investigation process. To overcome such a drawback, a technique based on the Stoke's law is proposed in this study. By using two known properties of fluids in the analysis, size and shape of the questioned glass fragments are unnecessary. Five types of sample glass fragments are examined: laboratory glassware, glass bottles, car glass, architectural glass, and kitchenware glass. To verify the technique, the density values of all glass fragments obtained from the proposed technique are crosschecked against the ones measured by the buoyancy method ASTM Standard test method (C693-93). The results reveal that the density of glass fragments measured from smooth-edged samples were close to the reference values. This preliminary results show that the proposed method in determining the glass density in the forensic analysis is possible but with some limitations.

1. Introduction

Brawls, burglary, and car accidents are samples of crime incidents in which glass fragments may be found among other physical evidence. The glass fragments are considered to be one of valuable forensic evidence that can prove or disprove the involvement of a person who came into the scene and made a contact with the evidence. The verification process of the glass fragments starts from the comparison of the glass fragments collected from the scene to the ones found on the suspected persons' clothes in term of the physical properties like appearances, refractive index, and density. A common method used to determine the values of density in the forensic laboratory is known the sink-float method. In this method, a questioned glass fragment is dropped into a liquid mixture of bromoform and bromobenzene [1]. If the glass density matches the liquid mixture density, the glass fragment neutrally floats in the liquid mixture. However, the use of the liquid mixture has to be very cautious due to their toxicity. So as to avoid such a risk and still be able to be easily performing the density measurement as ever, a technique based on Stoke's law using two non-toxic liquids with known density and viscosity is proposed. This technique is widely used to determine the particle density of small biological aerosols such as pollens. The information obtained can be used to predict the dispersion thorough the air of the particles over a large area [2]. The proposed technique involves the measurement of the terminal velocities of the particle separately dropped into two liquids and subsequently the measured values and used to work out its density size and shape is unnecessary.

Therefore, the aim of this research is to propose an alternative method for density determination based on Stoke's law. The sample required for this method is just small glass fragments with an irregular shape. In addition, the density determination by the buoyancy method that the ASTM standard test method (C693-93) is used to crosscheck the density values obtained from the proposed method [3].

2. Principle of measurement

Stoke's law can be utilized for determining the density of a spherical shaped particle by measuring the terminal velocity (U_S) in a liquid.

$$U_S = \frac{V_P}{CL} \times \frac{(\rho_P - \rho_f)g}{\mu_f} \quad (1)$$

where V_P is the volume of a particle, C is a constant affects by the shape of the particle, L is a typical length of the particle, ρ_P and ρ_f are densities of the particle and the liquid, respectively, μ_f is the liquid viscosity, and g is the gravitational acceleration.

The terminal velocity can be described as in equation (1) [2]. The volume geometry (V_P /CL) is included the expression to allow the extension of the Stoke's law for the non-spherical object analysis. The factor depends on the size and shape of the particle under investigation. In fact, the equation can be used to determine the particle density without assumption on its liquids with different properties. The ratio of the particle terminal velocity in two liquids 1 (U_{S1}) and liquid 2 (U_{S2}) with different properties can be written as:

$$\frac{U_{S1}}{U_{S2}} = \frac{(\rho_P - \rho_{f1})/\mu_1}{(\rho_P - \rho_{f2})/\mu_2} \quad (2)$$

where ρ_{f1} and ρ_{f2} represent the density of the first and the second liquids, respectively, and μ_1 and μ_2 are the values of liquid viscosity of the first and the second liquids.

Clearly, the geometry factor can be eliminated and the particle density (ρ_P) without concerning the size and shape of the particle can be rewritten as [2]:

$$\rho_P = \left(\frac{B}{B-1} \times \rho_{f2}\right) - \left(\frac{1}{1-B} \times \rho_{f1}\right) \quad (3)$$

where $B = \frac{(U_{S1} \times \mu_1)}{(U_{S2} \times \mu_2)}$.

Therefore, this is the key equation in this research for determining the density of the glass fragments without any prior knowledge on the particle size and shape.

3. Methodology

3.1. Preparation of samples

Five types; i.e. laboratory glassware, glass bottles, car glass, architectural glass, and kitchenware glass, of the glass samples were smashed into small fragments for examination. Their average sizes were 1×2 cm. The standard cleaning procedure was done before the glass fragment density determination started. The cleaning process consists of sonicating the glass samples in 5% of nitric acid (HNO_3) for 15 min, rinse them with distilled water for 3 times, repeatedly rinse them with ethanol (C_2H_5OH), and dry them at the room temperature. Eventually, the clean glass fragments were to keep in a suitable package such as the plastic box.

3.2. Experimental setup

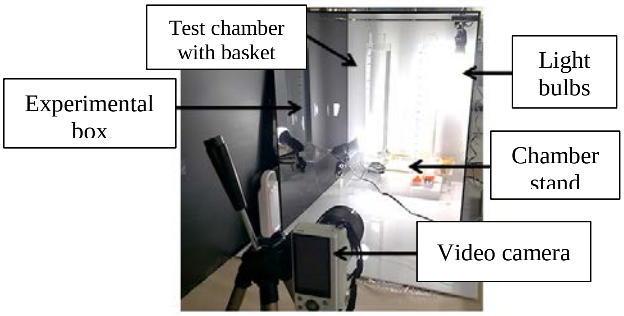

Figure 1. Experimental setup is composed a test chamber with basket in the experimental box and the video camera. Light bulbs for enhancing the field of view.

The acrylic chambers with basket were constructed for containing two liquids (glycerol: 99.5% AR Grade, and natural cane syrup) separately and placed them on the chamber stand in the experimental box. The video camera (Sony Alpha a5100) was set on the position that could cover all fluids of view for recording the particle movement in each liquid. In addition, the light bulbs were installed under two test chambers, and behind the camera for enhancing the field of view.

3.3. Experimental procedure

The clean glass fragments were carefully handled with a forceps. They are dropped into each liquid from the liquid surface and their movement was recorded by the video camera. The basket was used to recover fragments from the bottom of the chamber. The terminal velocity (cm/s) can be determined the ratio of fixed distance (cm) on the scale of test chamber to the steady time (s) over the distance by using the Tracker program. It is one of variables used to calculate the glass density (ρ_P) as seen in equation (3). In addition, the density and viscosity of liquids required for the density calculation are shown in table 1.

Table 1. The density and viscosity of two liquids (glycerol and cane syrup).

Liquid	Density [a] (kg•m^{-3}) at 25.5ºC	Viscosity [b] (kg•m^{-1}s^{-1}) at 24ºC
1. 99.5% Glycerol, AR Grade	1281.7380	1.927
2. Natural cane syrup	1418.4913	3.468

[a] Liquid density was determined by using Pycnometer.
[b] Liquid viscosity was determined by using the method based on Stoke's law.

Moreover, the buoyancy method based on the ASTM Standard test method (C693-93) is used to determine the glass density for crosschecking the measured results by using the density determination kit.

4. Results and discussions

4.1. Density determination method based on buoyancy method

Density values of fifteen samples of five-glass types were determined by using the density determination kit based on the buoyancy method complied with the ASTM Standard test method. The results were presented in figures 2 and 3. The measured values are in close proximity to the reference (vertical solid lines) and the density values of individual glass types were clearly separated. However, some density values from different types of glass samples still overlap. This could be from some common elements in the glass samples. To be able to completely separate the glass sample, this would suggest the use of other techniques with higher precision such as refractometer to determine the refractive index.

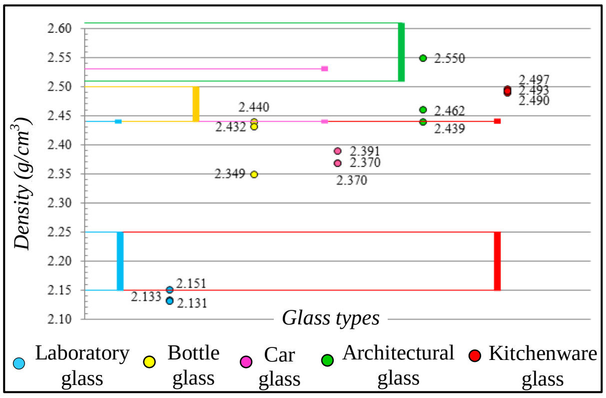

Figure 2. The comparison of the glass density and the reference values (vertical solid lines).

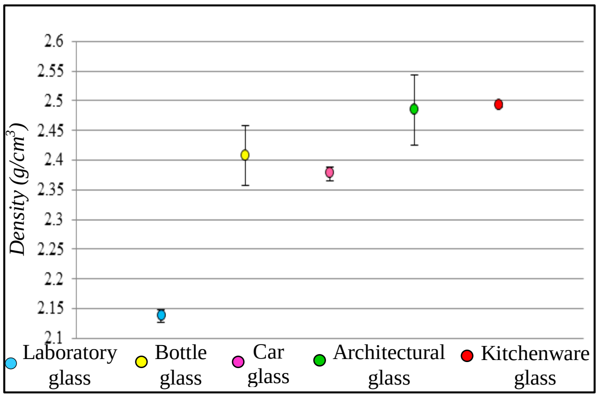

Figure 3. The average values of glass density of each glass type and their variation.

4.2. Density determination method based on Stoke's law

The values of glass density of each glass type were determined by this proposed method and compared with measured values obtained from the buoyancy method. The inconsistent results were found from determining the glass fragments with indented edges. The error was thought to be directly from an inaccurate measurement of the travelling time leading to an inaccurate terminal velocity and finally incorrect densities. The unsmooth edges can induce unbalance forces causing the sample motion to deviate from the direct vertical direction and possibly lengthen the travelling time of the sample. To check the assumption, the PYREX glass fragments with smooth edges were used in this part to avoid an error from the indented edges. The results clearly indicate that this proposed method for determining reliable glass fragment density requires a sample with irregular shape and smooth edges. The results are shown in table 2.

Table 2. The comparison of the glass density.

Glass samples	Density (g/cm^3): *(ρ_P-bar)*		
	Buoyancy method (ASTM)	Method based on Stoke's law	
		Indented edges	*Smooth edges*
Laboratory glassware	2.138 ± 0.011	1.128 ± 0.008	2.013 ± 0.077
Glass bottles	2.405 ± 0.037	1.128 ± 0.025	
Car glass	2.382 ± 0.014	1.128 ± 0.006	
Architectural glass	2.484 ± 0.059	1.128 ± 0.038	
Kitchenware glass	2.493 ± 0.003	1.128 ± 0.017	

5. Conclusion

The method based on Stoke's law proposed in this work has a possibility to be used to determine the density of the glass fragments, but its limitation is that the glass fragments have to be smooth enough such that their movements are vertical in the test chamber.

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References

[1] Saferstein R 2002 *Forecsic Science Handbook* vol 1 (United States of America: Prentice Hall Publishing) pp 161-213

[2] Rene V Hout and Katz J 2004 A method for measuring the density of irregularly shaped biological aerosols such as pollen *J. Aer. Sci.* **35** 1369-84

[3] International ASTM 2003 *ASTM C693-93(2003): Standard Test Method for Density of Glass by Buoyancy* (United state: PA- West Conshohocken) pp 1-3