Single Droplet Size and Volume Measurement – Comparison Between Experiment and Theory

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ABSTRACT

The main objective of this paper is to conduct a manual drop test experiment to investigate the actual size and volume of a single droplet. Both experimental result and theoretical value were calculated for comparison. In this study methanol was chosen as the test liquid. The drop test was repeated numerous times with the droplet size measurement being calculated for every 50, 100 and 150 drops. A digital weight measurement was used to precisely measure the droplet weight in the drop test. Meanwhile for theoretical calculation, measurement was made based on chemical properties of the liquid itself. Based on the comparison, it was found that the experimental measurement of droplet size and volume is comparable with the theoretical calculation.

Keywords: *Single Droplet; Size; Volume; Methanol Liquid*

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Introduction

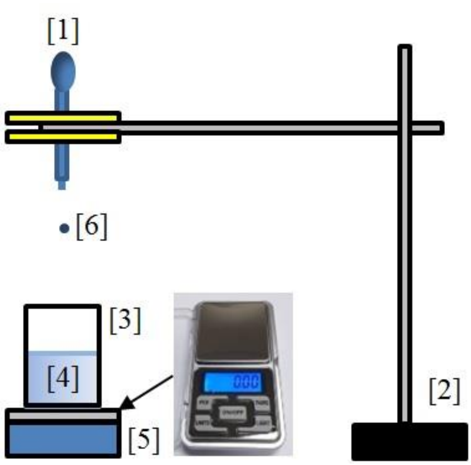
Drop test experiment is very important in heat and mass transfer study. For decades, it has been used to enhance the understanding regarding the nucleate boiling [1]-[2], transition boiling [3]-[5] and film boiling [6]-[8] process. This technique was used to study the boiling process and evaporation characteristic of droplet during impact on solid surfaces whether when being heated or in room temperature. This basic experimental work normally is equipped and supported with the usage of high-speed camera. The high-speed video camera is used to analyze the sequential images of every drop during the impact process. The drop test experiment and its results is important in thermal engineering application such as power plant [9]-[10], material manufacturing process [11], thermal energy and cooling studies [12]-[14], quenching and spray cooling studies [15]-[17] and many others. Drop impact researcher such as Moita and Moreira [18], Illias et al. [19]-[26], Mitsutake et al. [27]-[28], Inada et al. [29]-[30] and many other uses a single drop test in their experimental work. Drop test experiment can be used to study the behavior of impacting droplets, evaporation characteristic, vapor film generation, heat flux analysis and many others. Therefore, a precise droplet size and volume is needed to ensure the accuracy of the result.

Moita and Moreira [18] conducted an experimental work to study the deformation of spherical liquid droplets impacting onto flat and dry surfaces using a charged-coupled device (CCD) camera. During the experiments, each measurement was systematically repeated five times to confirm the reproducibility of the phenomena and to obtain the average values. The results show that an accurate characterization of the physical processes occurring during deformation and splash must take into account the forces involved (surface tension, shear forces and inertial), as well as the liquid properties and the nature of the impact surface. Illias et al. [19] conducted an experimental work to study the transient transition boiling phenomena that occur when a single ethanol droplet comes in contact with a hot surface (nickel). An extremely fast response chromel-nickel thermocouple was fixed at approximately 3 μm beneath the surface. This sensor has a very short response time of 80 μs. Therefore, it is capable enough to measure the transient boiling heat transfer. The outcomes of the studies confirm that droplet impact velocity, degrees of liquid subcooling, and the initial temperature of the solid may give an effect on the generation time of stable vapor film.

In this experimental work, the size and volume of single droplet were measured using scientific measurement and theoretical calculation. Methanol which has a low boiling point of 64.7 °C was chosen as a test liquid. A digital weight measurement was used in the experimental work to measure the liquid weight. A manual droplet dispenser which has a nozzle size of approximately 3.0 mm diameter was used in the drop test. Based on the findings, it was found that the experimental measurement of droplet size and volume is comparable with the theoretical calculation. Therefore, it can be concluded that the technique outline in this paper may be used to maintain constant droplet size for other droplet studies which would increase the credibility of the findings of the studies.

Experimental Set-Up

This study primarily consists of drop test with schematic diagram of the experimental setup shown in Figure 1. The experimental apparatus consists of a droplet dispenser, retort stand, beaker and digital weight measurement. Methanol liquid was used in the experimental work. The drop test was performed for every 50, 100 and 150 times in order to measure the average of the single droplet weight. A digital weight measurement (MH-100 pocket scale) has been used to precisely measure the single droplet weight. As shown in Figure 2a, this digital weight measurement can give reading up to two digits (0.00 g). Therefore, it can produce an accurate and consistent reading. A manual droplet dispenser was used to release the droplet. The inner nozzle of manual droplet dispenser is 3.0 mm in diameter. Image of the manual droplet dispenser and its nozzle are shown in Figure 2b and 2c for easy reference. Meanwhile, Equations (1) and (2) [22] are used experimentally and theoretically to predict the radius and diameter of the falling droplet. In Equation (2), σ, g and ρ_{liq} represents the surface tension, gravity and density of the methanol liquid. The experimental conditions are tabulated in Table 1 for easy references and understanding.



[1] Manual droplet dispenser
[2] Retort stand
[3] Beaker
[4] Methanol liquid
[5] Digital weight measurement
[6] Methanol droplet

Test 1: 50 drops
Test 2: 100 drops
Test 3: 150 drops

Figure 1: Schematic diagram of experimental apparatus

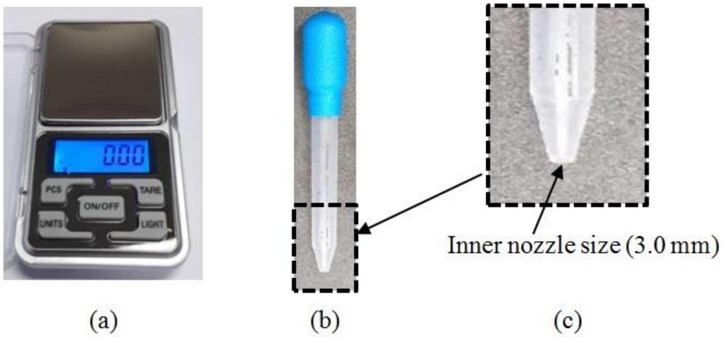


Figure 2: (a) Digital weight measurement, (b) manual droplet dispenser, and (c) inner nozzle size (3.0 mm)

$$V = (4/3)\pi r^3 \quad (1)$$

$$d = (6\sigma d_{needle}/\rho_{liq} g)^{1/3} \quad (2)$$

$$Percentage\ error\ (\%) = |\ (E_d - T_d) / (T_d)\ |\ x\ 100\% \quad (3)$$

Table 1: Experimental conditions and related information

Density of methanol ρ_{liq} (kg/m^3)	792
Surface tension of methanol, σ (N/m)	0.0219
Gravity, g (m/s^2)	9.81
Boiling point of methanol (°C)	64.7
Inner nozzle size diameter (mm)	3.0

Results and Discussion

The overall results from the methanol drop test measurement are shown in Table 2. A total number of 450 drops has been conducted during the experimental work. In Table 2, number of drops, mass of drops in gram, average mass per drop and estimation diameter of droplet has been listed systematically for easy understanding. From the overall results, it was observed that the average data for 50, 100 and 150 drops were approximately 1.083 g, 2.286 g and 3.260 g, respectively. Meanwhile, the average mass per drop for 50, 100 and 150 drops were 0.02166 g, 0.02286 g and 0.02173 g, respectively. Therefore, the cumulative average for single droplet was 0.022083 g. By using Equation (1), the estimation diameter of droplet measured is 3.4804 mm in cumulative average. The results from these two different equations are shown in Table 3 for comparison. As evident in Table 3, the estimated diameter of methanol droplet calculated from the Equation (1) gives 3.4804 mm and Equation (2), 3.702 mm for experimental and theoretical value, respectively. In Table 3, we also provide a percentage differences between experimental data and theoretical calculation for references. The percentage of differences is based on Equation (3). The experimental and theoretical values were represented by E_d and T_d, respectively. Figure 3 shows an experimental result for three different number of drop test conducted. Each test numbered by 1, 2 and 3 were represented by the black, red and blue square dots, respectively in the plots. It was observed in Figure 3a that the average mass for 50 drops is 1.083 g as shown by the green dashed line. On top of that, average mass for 100 and 150 drops are 2.286 g and 3.260 g, respectively. From Figure 3, it can be concluded that the overall result is good agreement among each other. Figure 4 shows the experimental result of droplet diameter that was calculated based on Equation (1). The calculated diameter for single droplet based on the equation is 3.4580 mm for 50 drops, 3.5211 mm (100 drops) and 3.4621 mm (150 drops). Therefore, the average droplet diameter from the overall experimental work is 3.4804 mm. From Figure 4, the average result was represented by orange dashed line for easy understanding.

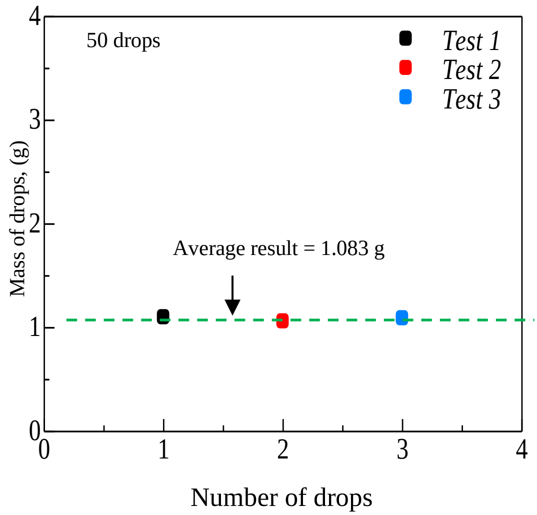
Based on the theoretical calculation, the estimated diameter of single methanol droplet is 3.702 mm. The calculation was based on the Equation (2) which uses methanol properties such as density and surface tension in the calculation. From Table 2 and Table 3, it can be concluded that the experimental result agrees closely with the theoretical calculation. The obtained results are similar to that already reported in our previous paper [22] which also employed the same technique of measurement.

Table 2: Overall result from drop test

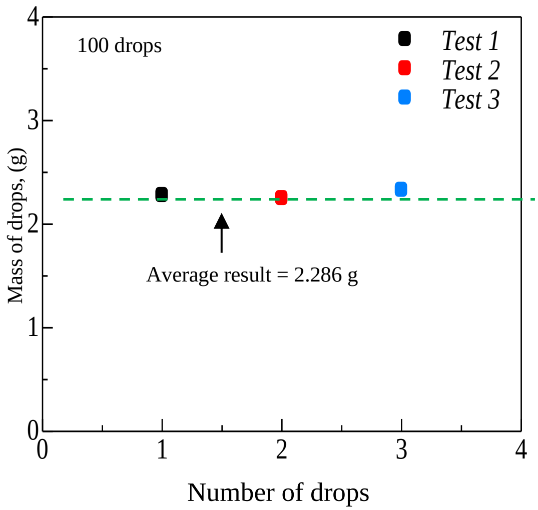
No. of drops	Mass of drops (g)			Average mass (g)	Average mass per drop (g)	Estimation diameter of droplet from Equation (1) (mm)
	Test 1	Test 2	Test 3			
50	1.10	1.06	1.09	1.083	0.02166	3.4580
100	2.28	2.25	2.33	2.286	0.02286	3.5211
150	3.21	3.25	3.34	3.260	0.02173	3.4621
Cumulative average					**0.022083**	**3.4804**

Table 3: Comparison result between Equation (1) and Equation (2)

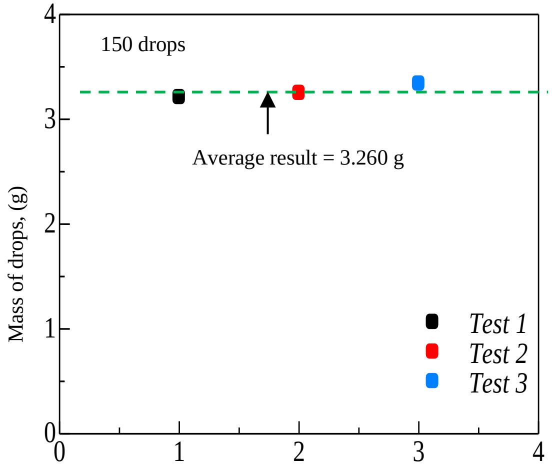
Formula	Equation (1) (mm)	Equation (2) (mm)	Percentage error based on Equation (3) (%)
Estimated diameter of methanol droplet	3.4804	3.702	6%



(a)



(b)



(c)

Figure 3: Experimental result for; (a) 50 drops, (b) 100 drops, and (c) 150 drops

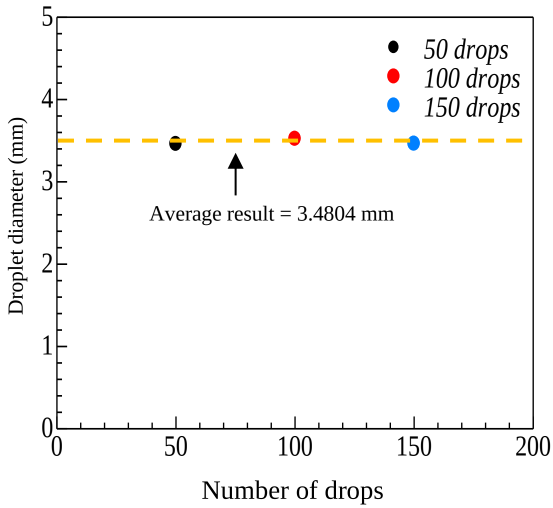


Figure 4: Relationship between number of drops and droplet diameter from Equation (1)

Conclusion

The experimental work has been conducted to investigate the size and volume of single droplet using simple drop test. A digital weight measurement was used to precisely measure the droplet weight in the drop test. For theoretical calculation, measurement was made based on chemical properties of the liquid itself. Based on the comparison, it can be concluded that the experimental measurement of droplet size and volume is comparable with the theoretical calculation. Therefore, it can be concluded that the technique outline in this paper may be used to maintain constant droplet size for other droplet studies which would increase the credibility of the findings of the studies.

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Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interest

The authors declare that they have no competing interests.

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