1.0 | INTRODUCTION

My mother decided to spring clean the whole house which includes the kitchen. She put the dishwashing liquid outside as well, under a very hot environment. I observed that the dishwashing liquid has lost its ‘thickness’ when it becomes hotter than the usual temperature. From that moment, it has since fascinated me about the physical concepts behind the unique phenomenon. When I browsed on the Internet to research more, I found out that the thickness that occurs in liquid or Newtonian liquid has been abided by the physical concept of viscosity. At the moment, I realised that many investigations that has been undergone by previous researchers only decides to conduct the viscosity research on Newtonian liquids that are food based such as juices and food oils. In my opinion, the extent that dishwashing liquids has to be considered in this topic as well because it is also considered as a Newtonian liquid, which is defined as a liquid that obey the Viscosity Law by Newton.[1]

Subsequently, I became very interested to find out the relationship between the temperature of dishwashing liquid and its effect on its kinematic viscosity. The concept of thermal physics is truly common amongst college Physics students. However, the influence of it towards the viscosity of liquids, especially Newtonian liquid has made me to investigate further on the research question and to run a very comprehensive research on the aforementioned topic. In this case it has created a significant lead for me to pursue my research question which is “How does the temperature of dishwashing liquid affect its kinematic viscosity by measuring the flow velocity of a steel ball when it is immersed in the liquid?”. My hypothesis for this question is that when the temperature of dishwashing liquid increases, its kinematic viscosity will increase as well.

The internal resistance of a liquid to flow or shear is determined by viscosity, which would be a physical definition.[2] Absolute or dynamic viscosity and kinematic viscosity are the two forms of viscosity that exist.[3] The tangential force needed to transfer one horizontal plane per unit area is known as absolute viscosity.[4] The ratio of absolute viscosity, η, to liquid density, ρ, is known as kinematic viscosity.[5] The mathematical formula for kinematic viscosity, v, is as follow[6],

$$v = \frac{\eta}{\rho} \tag{1}$$

The kinematic viscosity of a Newtonian fluid is affected by the temperature of the fluid. This is because the frequency of intermolecular collisions in a Newtonian fluid increases when its temperature increases. The cohesive forces between the molecules of the fluid are reduced, which increases the rate of the molecular

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[1] Wayne L Elban, “Viscosity of Household Fluids” (Baltimore, Maryland, 2014), www.materialseducation.org.
[2] Masahiro Fujita, Indradeep Ghosh, and Mukul Prasad, “Introduction to Viscosity,” *Verification Techniques for System-Level Design*, 2008, 1–4, https://doi.org/10.1016/b978-012370616-4.50002-1.
[3] Ibid.
[4] “Absolute, Dynamic and Kinematic Viscosity,” accessed May 18, 2020, https://www.engineeringtoolbox.com/dynamic-absolute-kinematic-viscosity-d_412.html.
[5] Ibid.
[6] Ibid.

interchange. It will cause a decrease in shear stress which indicates that the viscosity of the liquid decreases with increasing temperature, therefore, the drag force will also decrease.[7]

2.0 | METHODOLOGY

2.1 | VARIABLES

The independent variable for this experiment is the temperature of dishwashing liquid, T in which the unit for T is $°C$. The variable is conducted in twelve different temperatures with intervals of 25.0 °C, 30.0 °C, 35.0 °C, 40.0 °C, 45.0 °C, 50.0 °C, 55.0 °C, 60.0 °C, 65.0 °C, 70.0 °C, 75.0 °C, 80.0 °C. The dependent variable is the time taken for the steel ball to travel from reference point A to reference point B. kinematic viscosity of dishwashing liquid, t_{AB} with the unit of second, s. The aforementioned variable is done by calculating the kinematic viscosity by using equation (1). The controlled variables for this experiment are as follow,

- The first one is the volume of dishwashing liquid which is maintained at 100 cm^3 and it is constantly measured by using a 100 cm^3 measuring cylinder.
- The atmospheric pressure is remained constant. Atmospheric pressure is fixed because it takes into account of the surroundings of the conducted experiment. However, it needs to be measured by using a mercury barometer. The pressure measured is 760 mmHg.
- Steel balls that were used for this experiment has the same sizes. Therefore, a few variables are considered to be constant which are the following variables,
    - The diameter of the steel ball, d_{SB}, in which the ball is prepared by the physics laboratory is measured by using a Vernier calliper. The unit for the variable is in mm.
    - The radius of the steel ball, r_{SB}, is also fixed and it is measured by using the formula $r_{SB} = \frac{d}{2}$. The unit for the variable is also in mm.
    - The volume of the steel ball, V_{SB}, is also remained constant in which it is measured by using the formula $V_{SB} = \frac{4}{3}\pi r^3$. The volume is in m^3 unit.
    - The mass of steel ball, m_{SB}, is kept by using an electronic balance and it is measured in unit kg.
    - The density of the steel ball, ρ_{SB}, is retained in unit kgm^{-3} by applying the formula $\rho_{DWV} = \frac{Average\ m_{DL}}{V_{DL}}$, with $Average\ m_{DL}$ defined as the average mass of dishwashing liquid, and V_{DL} as the volume of dishwashing liquid.
- The distance between reference point A and reference point B, d_{AB}, is preserved at 70.0 cm and it is measured by using a metre rule (refer to figure 1).

[7] "How Does Temperature Change Viscosity in Liquids and Gases?," accessed May 18, 2020, https://www.azom.com/article.aspx?ArticleID=10036.

2.2 | EXPERIMENTAL PROCEDURE

It is decided that an experiment will be conducted to perform the purpose of the research. In this experiment, I firstly prepare the liquid that will be used for the experiment according to the temperature. The first set of data that is used in this experiment is with dishwashing liquid that is in room temperature. The room temperature of the physics laboratory, which is the place where my experiment has been conducted.

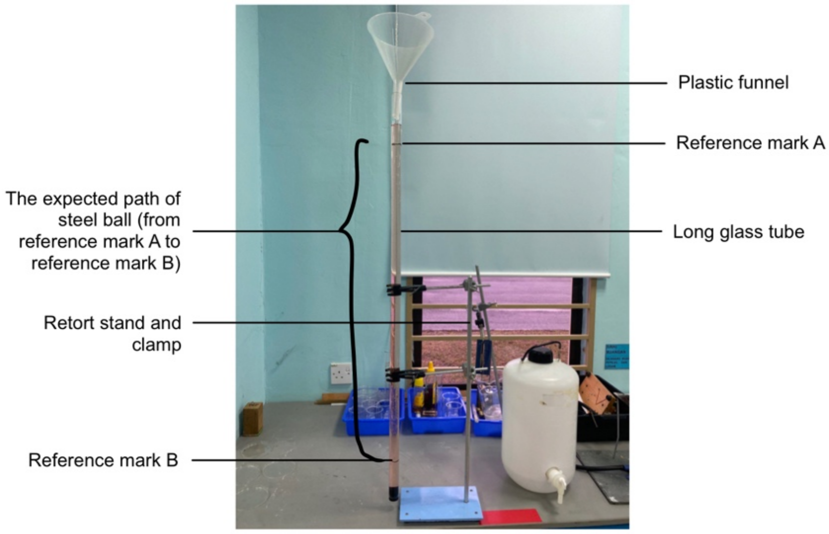

Figure 1: The experiment setup

After that, I marked reference mark A on an empty long glass tube as shown in Figure 1. I then measured the length between reference point A and reference point B at 70 cm by using a metre rule. The marks are done by using a black permanent marker. Then, I filled the marked long glass tube with the same dishwashing liquid until it reaches to reference point A. After that, I proceeded with dropping a steel ball into the liquid. The steel ball will fall in the liquid and it will be accelerated for some time until it travels with a uniform flow velocity. I dropped the steel ball into the long glass tube containing the dishwashing liquid carefully and the stopwatch is started when the ball reaches reference point A. When the ball passes through reference point B, the stopwatch is stopped and I recorded the time taken for the steel ball to pass through from reference point A to reference point B, t_{AB}. These steps are repeated three times to ensure an average measurement can be produced. All steps are repeated by varying the temperature of dishwashing liquid at 30.0 °C, 35.0 °C, 40.0 °C, 45.0 °C, 50.0 °C, 55.0 °C, 60.0 °C, 65.0 °C, 70.0 °C, 75.0 °C, and 80.0 °C.

For the aforementioned temperatures, I decided to heat the dishwashing liquid in a water bath. I poured a very generous amount of dishwashing liquid into a large beaker. I put the beaker in a water bath with the constant temperature that I have set onto the water bath. From here, I then repeat all the steps, which is from the dropping of the steel ball into the long glass tube containing the dishwashing liquid until the measurement takings of the time taken for the steel ball to pass through from reference point A to reference point B.

Figure 2: Preparation of dishwashing liquid in water bath

The average mass of the dishwashing liquid, m_{DL} and the average time taken for the steel ball to pass through reference point A and reference point B, t_{AB} is calculated. Then, the density of dishwashing liquid, ρ_{DL}, is calculated using the following formula.

$$\rho_{DL} = \frac{m_{DL}}{V_{DL}} \tag{3}$$

$Average\ m_{DL}$ is defined as the average mass of dishwashing liquid, and V_{DL} is defined as the volume of dishwashing liquid. Then, the flow velocity of the steel ball, v_f, is calculated using the following formula,

$$v_f = \frac{d_{AB}}{Average\ t} \tag{4}$$

The absolute viscosity of dishwashing liquid, η_{DL}, is calculated by using the following formula[8],

$$\eta_{DL} = \frac{2(\Delta\rho)gr^2}{9v_f} \tag{5}$$

From the formula above, $\Delta\rho$ is defined as the density difference of the dishwashing liquid and the steel ball. r is defined as the radius of steel ball used in this experiment. In the formula above, g is the constant of the acceleration of free fall for the Earth's surface of 9.81 ms^{-2}. Lastly, the variable v_f is defined as the flow velocity of the steel ball when it passes through from reference point A to reference point B in the long glass tube. Finally, the kinematic viscosity of dishwashing liquid, v, can be calculated. A graph of the temperature of dishwashing liquid, T_{DL}, vs. its kinematic viscosity, v, is displayed for analysation.

2.3 | WEAKNESSES AND MODIFICATIONS MADE ON METHODOLOGY

From my methodology, there were many obstacles that I have faced when undergoing this experiment. At the beginning, the experiment that I wanted to do was involving the use of distilled white vinegar. However, when I used the material for this methodology, it was observed that the material was unfitted to be used in

[8] "Activity: Viscosity," accessed May 18, 2020, http://www.spacegrant.hawaii.edu/class_acts/Viscosity.html.

this methodology. This is because the material was too runny for the experiment. When using this material, the steel ball that is used for the experiment was too fast when it passed through from reference point A to reference point B. This has created a problem for me to record the time taken for the steel ball to travel from reference point A to reference point B. Therefore, I made modifications on my experimental procedure in which I have changed my material from distilled white vinegar to dishwashing liquid. The reason I chose dishwashing liquid is because the liquid is viscous enough for my methodology to work. From here, I can imply that my methodology can only work on very viscous liquids only. The weakness of my experimental procedures is that only viscous liquids are fit to be used because less viscous liquid will be difficult for the time taken for the steel ball to pass through from reference point A to reference point B to be recorded for analysation. However, the procedure should work if one uses a very long vertical transparent tube for less viscous liquids.

Next, I initially used a 100 cm^3 measuring cylinder as the medium for the steel ball to travel from reference point A to reference point B. In this case, I have made the length between reference point A and reference point B as 20 cm. However, even if my material used was dishwashing liquid, I observed that when the temperature increases, the thickness of the liquid decreases as well. Even at 40 ℃, the steel ball travelled from reference point A to reference point B was very fast, which becomes harder for me to precisely record the time taken for the steel ball to travel from reference point A to reference point B. From here, I decided to modify my experimental procedures by changing the apparatus for the medium of the dishwashing liquid from 100 cm^3 measuring cylinder to a long glass tube that has already available in the laboratory at my educational institution.

2.4 | SAFETY, ETHICAL, ENVIRONMENTAL CONSIDERATIONS ON METHODOLOGY

My experiment involves the variation of temperature and its dependency towards the kinematic viscosity for dishwashing liquid. Therefore, surely the aforementioned variation relies on the use of heat for the experiment. When I conducted the experiment, I made sure that I use an insulator such as a cloth to wrap the heated beaker from the water bath. Without the said cloth, my hands would be very hot, and it would be difficult for me to handle such a hot apparatus. Other than that, the material that I use is dishwashing liquid which is very slippery to handle. Therefore, I made sure that all apparatus is washed before reusing them. This is to ensure that the apparatus will not slip from my hands. I would also use a basin under the experimental arrangements to prevent any spillage of dishwashing liquid on the floor. There are insignificant ethical and environmental considerations on the methodology.

3.0 | DATA COLLECTION AND ANALYSIS

3.1 | RAW QUANTITATIVE DATA

From Table 1 below, the measurements will be used to determine the density of dishwashing liquid which will be used to eventually determine the density of dishwashing liquid, ρ_{DL}. This table also will be used to determine the density of steel ball, ρ_{SB} which will finally determine the density difference of the steel ball and the dishwashing liquid, which is defined as $\Delta\rho$.

Table 1: Trial readings of 100 cm³ measuring cylinder, m_{MC}, the mass of 100 cm³ measuring cylinder with dishwashing liquid, m_{MCDL}, the diameter of steel ball, d_{SB}, and the mass of steel ball, m_{SB}.

Trial	**1**	**2**	**3**
Mass of 100cm3 measuring cylinder, m_{MC} ($\pm$0.001 g)	125.794	125.792	125.776
Mass of 100 cm3 measuring cylinder with dishwashing liquid, m_{MCDL} ($\pm$0.001 g)	229.242	229.242	229.239
Diameter of steel ball, d_{SB} ($\pm$ 0.02 cm)	1.50	1.48	1.52
Mass of steel ball, m_{SB} ($\pm$ 0.001 g)	14.035	14.033	14.032

Readings from Table 1 will be used to find the flow velocity of the steel ball in the dishwashing liquid.

Table 2: Trial readings of the time taken for the steel ball to pass from reference point A to reference point B, t_{AB} with temperature of dishwashing liquid

Temperature of dishwashing liquid, T_{DL} ($\pm$ 0.25 ℃)	**Time taken for the steel ball to pass from reference point A to reference point B, t_{AB} ($\pm$ 0.01 s)**		
	Reading 1	Reading 2	Reading 3
25.00	16.13	15.71	15.31
30.00	6.94	6.96	7.08
35.00	4.15	5.04	5.23
40.00	3.45	3.74	3.62
45.00	2.81	3.13	3.06
50.00	2.28	2.48	2.40
55.00	1.54	2.13	2.68
60.00	1.44	1.38	1.39
65.00	1.31	1.31	1.44
70.00	1.19	1.34	1.21
75.00	1.17	1.28	1.08
80.00	1.11	1.10	1.11

3.2 | QUALITATIVE DATA

The qualitative data that has been obtained from the experiment are the following,

- When dishwashing liquid is poured into the long glass tube, there is a presence of bubbles in the liquid. The bubbles in the liquid take a very long time to disappear.
- The texture of dishwashing liquid also becomes runnier when its temperature increases.
- At the beginning, the movement of steel ball is observed fast. However, the travel is seen to be at a constant flow when a longer time is taken to observe the traffic of the steel ball in the long glass tube.
- When the temperature is achieved at 50.0 $°C$, the dishwashing liquid began to evaporate, indicating that the point of evaporation of the dishwashing liquid has been exceeded.
- When the temperature is achieved at 85.0 $°C$, the dishwashing liquid began to evaporate vigorously. It can be observed by the presence of the large amount of liquid vapour produced during the heating process of the liquid in the water bath.

3.3 | PROCESSED DATA AND ANALYSIS

Volume of dishwashing liquid, $V_{DL} = (100 \times 10^{-6} \pm 1 \times 10^{-6})\ m^3$

Average mass of measuring cylinder, $\text{Average } m_{MC} = \frac{\text{Sum of } m_{MC} \text{ trials}}{3}$, $\text{Sum of } m_{MC} \text{ trials}$ is the sum of the mass of measuring cylinder for all three trials.

$$\text{Average } m_{MC} = \frac{125.794 + 125.792 + 125.776}{3}$$
$$= 125.787\ g = 125.787 \times 10^{-3}\ kg$$

Uncertainty for Average m_{mc},

$$\Delta \text{ Average } m_{mc} = \frac{0.001 + 0.001 + 0.001}{3}$$
$$\Delta \text{ Average } m_{mc} = 0.001\ g = 0.001 \times 10^{-3}\ kg$$

Therefore, the average mass of 100 cm^3 measuring cylinder, m_{mc} is $(125.787 \times 10^{-3} \pm 0.001 \times 10^{-3})\ kg$. Next, the average mass of 100 cm^3 measuring cylinder with dishwashing liquid, $Average\ m_{MCDL}$ is also calculated. The uncertainty for the average mass of measuring cylinder with dishwashing liquid, $\Delta \text{ Average } m_{MCDL}$, will be similar to the average masses of measuring cylinder, $\Delta \text{ Average } m_{MC}$ since the weighing instrument used is the same.

$$\text{Average } m_{MCDL} = \frac{229.242 + 229.242 + 229.239}{3}$$
$$= 229.241\ g$$
$$= 229.241 \times 10^{-3}\ kg$$

The average mass of 100 cm^3 measuring cylinder with dishwashing liquid, $Average\ m_{MCDL}$ is $(229.241 \times 10^{-3} \pm 0.001 \times 10^{-3})\ kg$. I can now calculate the mass of dishwashing liquid, m_{DL} and its uncertainty, Δm_{DL}.

$$m_{DL} = Average\ m_{MCDL} - Average\ m_{MC}$$
$$= 229.241 \times 10^{-3} - 125.787 \times 10^{-3}$$
$$= 103.454 \times 10^{-3}\ kg$$
$$\Delta m_{DL} = \Delta\ Average\ m_{MCDL} + \Delta\ Average\ m_{MC}$$
$$= 0.001 \times 10^{-3} + 0.001 \times 10^{-3}$$
$$= 0.002 \times 10^{-3}\ kg$$

Hence, the mass of dishwashing liquid, m_{DL} is $(103.454 \times 10^{-3} \pm 0.002 \times 10^{-3})\ kg$. Now, I can calculate the density of dishwashing liquid, ρ_{DL}, and its uncertainty, $\Delta\rho_{DL}$. ρ_{DL} is calculated by using equation (3).

$$\rho_{DL} = \frac{103.454 \times 10^{-3}}{1.0 \times 10^{-4}} \approx 1034.54\ kgm^{-3} = 1.0 \times 10^3\ kgm^{-3}$$

$$\frac{\Delta\rho_{DL}}{\rho_{DL}} = \frac{\Delta m_{DL}}{m_{DL}} + \frac{\Delta V_{DL}}{V_{DL}}$$

$$\Delta\rho_{DL} = \left(\frac{0.002 \times 10^{-3}}{103.454 \times 10^{-3}} + \frac{1 \times 10^{-6}}{100 \times 10^{-6}}\right)(1034.54) = 10.37 \approx 10\ kgm^{-3}$$

Hence, the density of dishwashing liquid, ρ_{DL} is $(1 \times 10^3 \pm 10)\ kgm^{-3}$. The average diameter of steel ball, $Average\ d_{SB}$ and its uncertainty, $\Delta\ Average\ d_{SB}$ is calculated.

$$Average\ d_{SB} = \frac{1.50 + 1.48 + 1.52}{3} = 1.50\ cm$$
$$= 1.50 \times 10^{-2}\ m$$

$$\Delta\ Average\ d_{SB} = \frac{0.02 + 0.02 + 0.02}{3} = 0.02\ cm$$
$$= 0.02 \times 10^{-2}\ m$$

The average diameter of steel ball used for the experiment, $Average\ d_{SB}$ is $(1.50 \times 10^{-2} \pm 0.02 \times 10^{-2})\ kg$. From the average diameter, we can also calculate the radius of steel ball, r_{SB}. Its uncertainty, Δr_{SB} is also calculated.

$$r_{SB} = \frac{Average\ d_{SB}}{2} = \frac{1.50 \times 10^{-2}}{2}$$
$$= 0.75 \times 10^{-2}\ m$$
$$\frac{\Delta r_{SB}}{r_{SB}} = \frac{\Delta d_{SB}}{d_{SB}}$$
$$\Delta r_{SB} = \left(\frac{0.02 \times 10^{-2}}{1.50 \times 10^{-2}}\right)(0.75 \times 10^{-2})]$$
$$= 0.01 \times 10^{-2}\ m$$

The uncertainty for the radius of steel ball, Δr_{SB} is remained the same as to the uncertainty of the diameter of steel ball, Δd_{SB}, which is $0.02 \times 10^{-3}\ m$. Hence, the radius of steel ball, r_{SB} is $(0.75 \times 10^{-2} \pm 0.02 \times 10^{-2})\ m$. Now, I can calculate the volume of steel ball, V_{SB}. The uncertainty of the volume of steel ball, ΔV_{SB}, can also be calculated.

$$V_{SB} = \frac{4}{3}\pi(r_{SB})^3 = \frac{4}{3}\pi(0.75 \times 10^{-2})^3$$
$$= 1.76714587 \times 10^{-6}$$
$$\approx 1.77 \times 10^{-6}\ m^3$$
$$\frac{\Delta V_{SB}}{V_{SB}} = 3\left(\frac{\Delta r_{SB}}{r_{SB}}\right)$$
$$\Delta V_{SB} = 3\left(\frac{0.02 \times 10^{-2}}{0.75 \times 10^{-2}}\right)(1.77 \times 10^{-6})$$
$$= 1.416 \times 10^{-7}\ m^3 \approx 0.10 \times 10^{-6}\ m^3$$

Therefore, the volume of steel ball, V_{SB} is $(1.77 \times 10^{-6} \pm 0.14 \times 10^{-6})\ m^3$. The average mass of steel ball, $Average\ m_{SB}$, is calculated based on the information that I have obtained from Table 2. Its uncertainty, $\Delta\ Average\ m_{SB}$ is equal to the uncertainty of the average mass of measuring cylinder since I used the same weighing equipment.

$$Average\ m_{SB}$$
$$= \frac{14.035 + 14.033 + 14.032}{3}$$
$$= 14.033\ g = 14.033 \times 10^{-3}\ kg$$

Therefore, the average mass of steel ball, $Average\ m_{SB}$, is $(14.033 \times 10^{-3} \pm 0.001 \times 10^{-3})\ kg$. From here, I can calculate the density of steel ball, ρ_{SB} and its uncertainty, $\Delta\rho_{SB}$.

$$\rho_{SB} = \frac{Average\ m_{SB}}{V_{SB}} = \frac{14.033 \times 10^{-3}}{1.77 \times 10^{-6}} = 7928.2 \approx 7.93 \times 10^3\ kgm^{-3}$$
$$\frac{\Delta\rho_{SB}}{\rho_{SB}} = \frac{\Delta\ Average\ m_{SB}}{Average\ m_{SB}} + \frac{\Delta V_{SB}}{V_{SB}}$$
$$\Delta\rho_{SB} = \left(\frac{0.001 \times 10^{-3}}{14.033 \times 10^{-3}} + \frac{0.10 \times 10^{-6}}{1.77 \times 10^{-6}}\right)(7930) \approx 448.59\ kgm^{-3} = 0.4 \times 10^3\ kgm^{-3}$$

Now, the density of steel ball, ρ_{SB}, is $(7.9 \times 10^3 \pm 0.4 \times 10^3)\ kgm^{-3}$. The difference of density between the dishwashing liquids and the steel ball, $\Delta\rho$, and its uncertainty, $\Delta\Delta\rho$ is calculated.

$$\Delta\rho = |\rho_{DL} - \rho_{SB}| = |1 \times 10^3 - 7.9 \times 10^3|$$
$$= 6.9 \times 10^3\ kgm^{-3}$$
$$\approx 7.0 \times 10^3\ kgm^{-3}$$

$$\Delta\Delta\rho = \Delta\rho_{DL} + \Delta\rho_{SB} = 10 + 0.4 \times 10^3$$
$$= 0.4 \times 10^3\ kgm^{-3}$$

When the temperature of dishwashing liquid, T_{DL}, is at (25.00 ± 0.25)℃, the average time taken for the steel ball to pass through from reference point A to reference point B, $Average\ t_{AB}$, and its uncertainty, $\Delta\ Average\ t_{AB}$,is calculated.

$$\text{Average } t_{AB} = \frac{16.13 + 15.71 + 15.31}{3} = 15.72\ s$$

$$\Delta\ Average\ t_{AB} = \frac{0.01 + 0.01 + 0.01}{3} = 0.01\ s$$

Therefore, the average time taken for the steel ball to pass through from reference point A to reference point B, t_{AB}, is $(15.72 \pm 0.01)\ s$ when the temperature of dishwashing liquid, T_{DL}, is at (25.00 ± 0.25)℃.

Table 3: Average Time taken for the steel ball to pass from reference point A to reference point B, $Average\ t_{AB}$ against the temperature of dishwashing liquid, T_{DL}

T_{DL} ($\pm$ 0.25 ℃)	$Average\ t_{AB}$ ($\pm$ 0.01 s)
25.00	15.72
30.00	6.99
35.00	4.81
40.00	3.60
45.00	3.00
50.00	2.39
55.00	2.12
60.00	1.40
65.00	1.35
70.00	1.25
75.00	1.18
80.00	1.11

The distance between reference point A and reference B, d_{AB}, is $(70.0 \pm 0.1)\ cm$ or $(70.0 \times 10^{-2} \pm 0.1 \times 10^{-2})\ m$. Now, the flow velocity for each temperature of dishwashing, T_{DL} is calculated. When the temperature of dishwashing liquid, T_{DL}, is at (25.00 ± 0.25)℃, the flow velocity, v_f and its uncertainty, Δv_f, is calculated. v_f is calculated by using equation (4).

$$v_f = \frac{70.0 \times 10^{-2}}{15.72} = 0.044538706 \approx 0.0445\ ms^{-1}$$

$$\frac{\Delta v_f}{v_f} = \frac{\Delta d_{AB}}{d_{AB}} + \frac{\Delta\ Average\ t_{AB}}{Average\ t_{AB}}$$

$$\Delta v_f = \left(\frac{0.1 \times 10^{-2}}{70.0 \times 10^{-2}} + \frac{0.01}{15.72}\right)(0.0445) = 0.00009\ ms^{-1} = 0.009 \times 10^{-2}\ ms^{-1}$$
$$= 0.00009\ ms^{-1} = 0.009 \times 10^{-2}\ ms^{-1}$$

Then, the flow velocity of the steel ball, v_f, together with its uncertainties, Δv_f according to the variation of the temperature of dishwashing liquid is tabulated.

Table 4: The flow velocity of steel ball through dishwashing liquid, v_f, against the temperature of dishwashing liquid, T_{DL}, with its uncertainties

T_{DL} ($\pm$ **0.25** ℃)	v_f ($\times 10^{-2}\ ms^{-1}$)	Δv_f ($\times 10^{-2}\ ms^{-1}$)
25.00	4.450	± 0.009
30.00	10.000	± 0.030
35.00	14.600	± 0.050
40.00	19.400	± 0.080
45.00	23.300	± 0.100
50.00	29.300	± 0.200
55.00	33.100	± 0.200
60.00	49.900	± 0.400
65.00	51.700	± 0.500
70.00	56.100	± 0.500
75.00	59.500	± 0.600
80.00	63.300	± 0.700

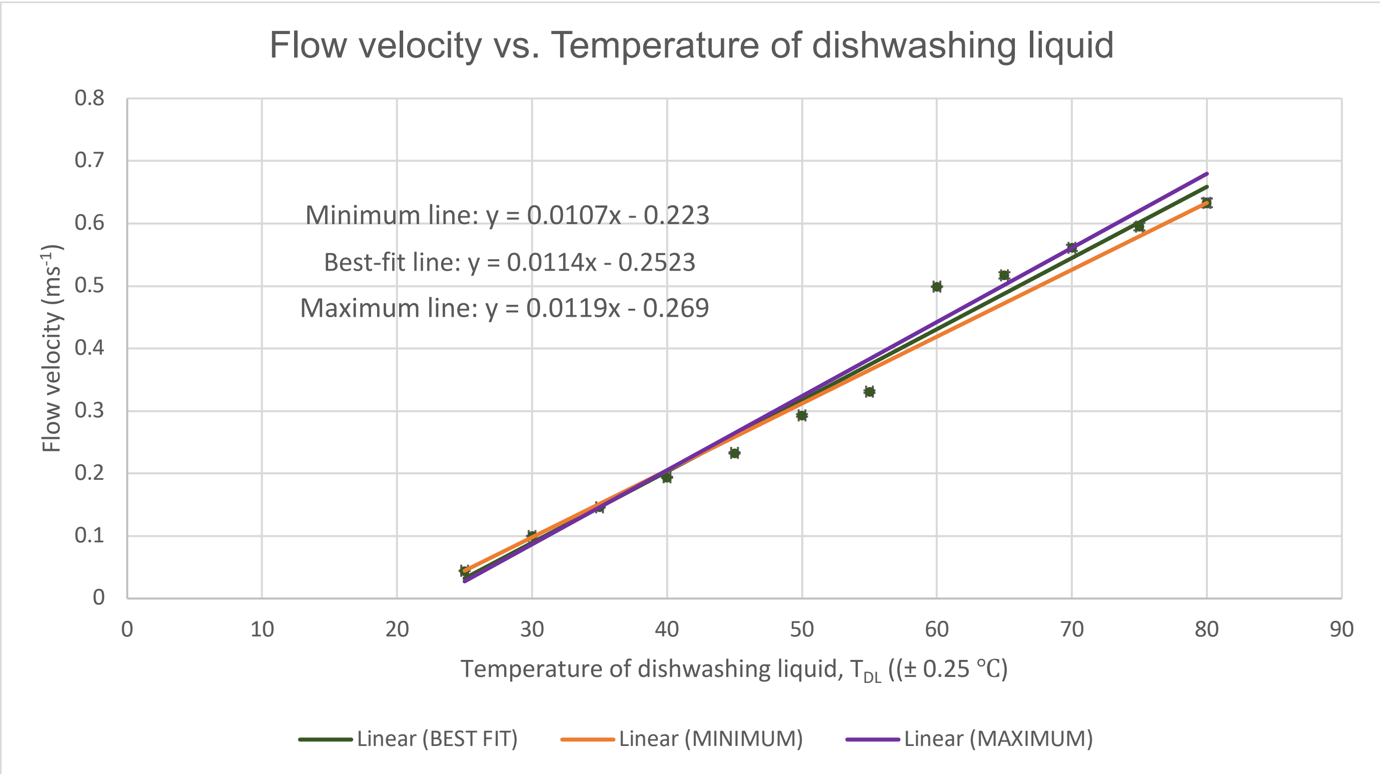

Figure 3: The graph of flow velocity, v_f, against the temperature of dishwashing liquid, T_{DL}

It is shown that the when the temperature of dishwashing liquid, T_{DL}, increases, the flow velocity, v_f, also increases.

Table 5: Explanation for data anomalies ignored for maximum line and minimum line as shown in Figure 3

Line	Data anomalies ignored	Explanation
Maximum	(55.00 ± 0.25)℃ (60.00 ± 0.25)℃ (80.00 ± 0.25)℃	The fluid flow velocity of the dishwashing liquid increases substantially until it reaches between the data of (55.00 ± 0.25)℃ and (60.00 ± 0.25)℃ when there is a jump of flow velocity. At this stage, the heat received by the fluid is increased. This increases

		the flow turbulence of the fluid which increases the frictional force between the fluid and the glass surface of the tube.[9] For the data of (80.00 ± 0.25)℃, the dishwashing liquid involved was experiencing high amount of heat received. Therefore, when the steel ball was inserted into the fluid in the glass tube, the steel ball was moving very fast. In this case, I may have experienced random error as I have taken the wrong time taken for the steel ball to travel from reference mark A to reference mark B.
Minimum	(55.00 ± 0.25)℃ (60.00 ± 0.25)℃ (65.00 ± 0.25)℃ (70.00 ± 0.25)℃	The explanation for data of (55.00 ± 0.25)℃ and (60.00 ± 0.25)℃ is similar as above. For the data of (65.00 ± 0.25)℃ and (70.00 ± 0.25)℃, the fluid received high amount of heat which leads to high rates of evaporation. This stage of evaporation may have led to significant loss of heat to the surroundings which made the data unreliable.

In this graph, it also shows that there are five outliers from the best fit line. As shown in this graph also, the error bars are too small to be shown. By using slope uncertainty formula[10], I can now find the gradient uncertainty for the graph as shown in Figure 3.

$$\Delta \text{ gradient} = \frac{\text{maximum gradient} - \text{minimum gradient}}{2} \tag{6}$$

$$\Delta \text{ gradient of graph in Figure 3} = \frac{0.0119 - 0.0107}{2} = 0.0012$$

The gradient of the best fit line graph of flow velocity against the temperature of dishwashing liquid is $(0.0114 \pm 0.0012)\ ms^{-1}\ ℃^{-1}$. Since I do not have a theoretical value of the gradient that I can compare with, I can find the percentage uncertainty of the gradient.

$$\text{Percentage uncertainty} = \frac{0.0012}{0.0114} \times 100\% = 10.52631579\% \approx 10.53\%$$

The percentage uncertainty for the gradient of the graph in Figure 3 is approximately 10.53%. Now, the absolute viscosity of dishwashing liquid, η_{DL}, is calculated when the temperature of dishwashing liquid, T_{DL}, is at 25.00℃. and its uncertainty, $\Delta\eta_{DL}$. T_{DL} is calculated by using equation (5).

$$\eta_{DL} = \frac{2(\Delta\rho)gr^2}{9v_f} = \frac{2(7.0 \times 10^3)(9.81)(0.75 \times 10^{-2})^2}{9(4.450 \times 10^{-2})} = 19.29 \approx 19\ kgm^{-1}s^{-1}$$

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[9] Mike Bonner, "Heat Exchanger Fluid Velocity – Why Should I Care?," 2017, https://blog.viscosity.com/blog/bid/372966/heat-exchanger-velocity-why-should-i-care.
[10] "Slope Uncertainty," accessed March 30, 2021, https://www2.southeastern.edu/Academics/Faculty/rallain/plab193/page1/page35/page36/page36.html.

$$\frac{\Delta\eta_{DL}}{\eta_{DL}} = \frac{\Delta\Delta\rho}{\Delta\rho} + 2\left(\frac{\Delta r_{SB}}{r_{SB}}\right) + \frac{\Delta v_f}{v_f}$$

$$\Delta\eta_{DL} = \left(\frac{0.4 \times 10^3}{7.0 \times 10^3} + 2\left(\frac{0.01 \times 10^{-2}}{0.75 \times 10^{-2}}\right) + \frac{0.009 \times 10^{-2}}{4.450 \times 10^{-2}}\right)(19) = 1.63081 \approx 2\ kgm^{-1}s^{-1}$$

Hence, the absolute viscosity of dishwashing liquid when its temperature is (25.00 ± 0.25)℃ is $(19 \pm 2)\ kgm^{-1}s^{-1}$.

Table 6: The absolute viscosity of dishwashing liquid, η_{DL}, with its uncertainties against the temperature of dishwashing liquid, T_{DL}

T_{DL} ($\pm$0.25 ℃)	η_{DL} ($kgm^{-1}s^{-1}$)	$\Delta\eta_{DL}$ ($kgm^{-1}s^{-1}$)
25.00	19.0	$\pm$ 2.0
30.00	8.6	$\pm$ 0.7
35.00	5.9	$\pm$ 0.5
40.00	4.4	$\pm$ 0.4
45.00	3.7	$\pm$ 0.3
50.00	2.9	$\pm$ 0.3
55.00	2.6	$\pm$ 0.2
60.00	1.7	$\pm$ 0.1
65.00	1.7	$\pm$ 0.1
70.00	1.5	$\pm$ 0.1
75.00	1.4	$\pm$ 0.1
80.00	1.4	$\pm$ 0.1

From Figure 4, there is an anomalistic data which is the first data of (25.00 ± 0.25)℃. This is because the experiment is conducted in an air-conditioned laboratory. In this case, the laboratory during the time of the experiment may not be accurately measured at 25℃ - the temperature might have been less at 25℃. This is one of the random errors that have occurred in this experiment. However, this anomaly is still important in the graphical analysis to show the high viscosity of the dishwashing liquid. Neglecting the outlier may result in high errors in finding the relationship between the temperature of dishwashing liquid, T_{DL} and its absolute and kinematic viscosity.

It is shown by the curve fit that does not consider the data with its error bars shown. Now, I find the percentage error of my experimental results from the literature value. The literature value of the absolute viscosity of detergents is 1470 centipoise or 1.47 kgm^{-1}s^{-1} at 70℃.[11] The literature value of detergents is taken since the active ingredients of the dishwashing liquid I used is quite similar[12] when compared to the active ingredients contained in general detergents.[13] The experimental value of the absolute viscosity of dishwashing liquid is 1.5 kgm^{-1}s^{-1} at 70℃, as calculated in Table 6.

$$\text{Percentage error} = \left|\frac{\text{Literature value } - \text{ Experimental value}}{\text{Literature value}}\right| \times 100\% = \left|\frac{1.47 - 1.5}{1.47}\right| \times 100\%$$
$$= 2.040816327\% = 2.0\%$$

[11] "Viscosities of Common Liquids by Type of Liquid," accessed March 30, 2021, https://www.michael-smith-engineers.co.uk/resources/useful-info/approximate-viscosities-of-common-liquids-by-type.
[12] "SAFETY DATA SHEETS: Sunlight Dishwashing Liquid Lemon" (Shepparton, 2018).
[13] "Curiosities: What's the Difference between Dishwasher Detergent, Laundry Detergent and Dish Soap? | Local News | Madison.Com," accessed March 30, 2021, https://madison.com/wsj/news/local/curiosities-whats-the-difference-between-dishwasher-detergent-laundry-detergent-and-dish-soap/article_6b343d66-9663-11df-bef2-001cc4c002e0.html.

Thus, the percentage error for my experimental results is 2.0% compared to the actual literature value.

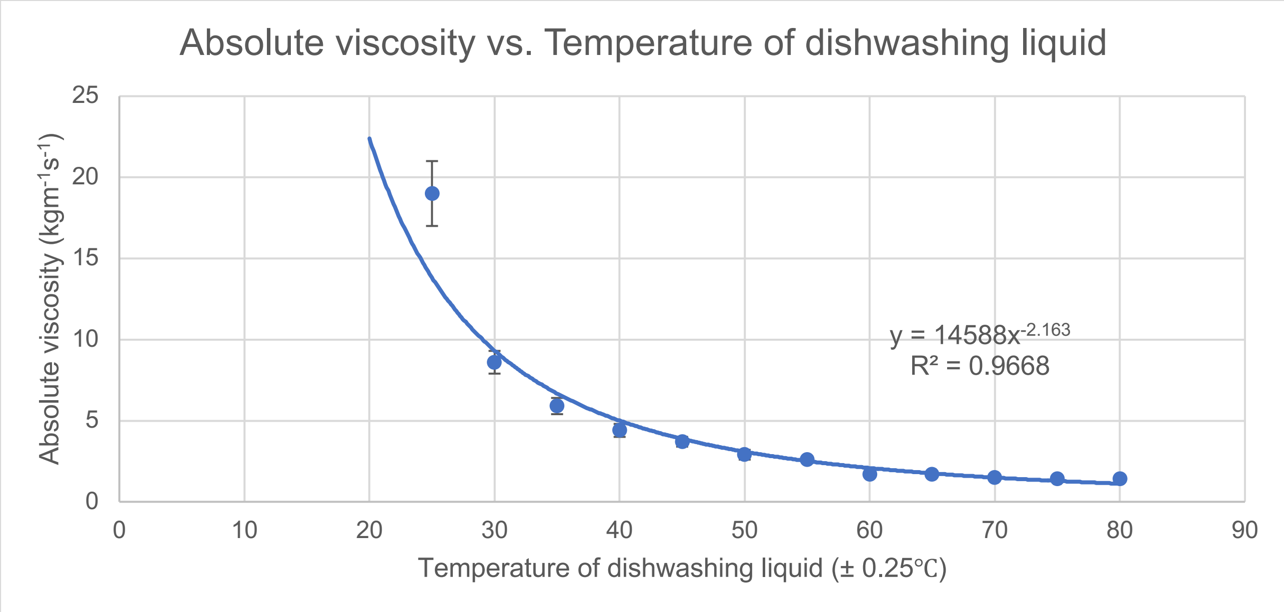

Figure 4: The graph of absolute viscosity against the temperature of dishwashing liquid

Now, the kinematic viscosity is determined by using equation (1). The following calculations are the kinematic viscosity of dishwashing liquid, v_{DL} and its uncertainty when its temperature is at (25.00 ± 0.25)℃.

$$v_{DL} = \frac{\eta_{DL}}{\rho_{DL}} = \frac{19.0}{1 \times 10^3} = 19.0 \times 10^{-3} \approx 20 \times 10^{-3}\ m^2 s^{-1}$$

$$\frac{\Delta v_{DL}}{v_{DL}} = \frac{\Delta \eta_{DL}}{\eta_{DL}} + \frac{\Delta \rho_{DL}}{\rho_{DL}}$$

$$\Delta v_{DL} = \left(\frac{2.0}{19.0} + \frac{10}{1 \times 10^3}\right)(2 \times 10^{-3}) = 0.00231 \approx 2.0 \times 10^{-3}\ m^2 s^{-1}$$

So, the kinematic viscosity of dishwashing liquid, v_{DL} and its uncertainty when its temperature is at (25.00 ± 0.25)℃ is $(2.0 \times 10^{-3} \pm 0.2 \times 10^{-3})\ m^2 s^{-1}$. The kinematic viscosity of dishwashing liquid, v_{DL}, with its uncertainty, Δv_{DL}, against the variation of its temperature, T_{DL} is tabulated.

Table 7: The kinematic viscosity of dishwashing liquid, v_{DL}, with its uncertainty, Δv_{DL}, against the variation of its temperature, T_{DL}

T_{DL} (± 0.25 ℃)	v_{DL} ($\times 10^{-3}\ m^2 s^{-1}$)	Δv_{DL} ($\times 10^{-3}\ m^2 s^{-1}$)
25.00	20.0	± 2.0
30.00	9.0	± 1.0
35.00	6.0	± 0.7
40.00	4.0	± 0.5
45.00	4.0	± 0.5
50.00	3.0	± 0.3
55.00	3.0	± 0.3
60.00	2.0	± 0.2
65.00	2.0	± 0.2
70.00	2.0	± 0.2
75.00	1.0	± 0.1
80.00	1.0	± 0.1

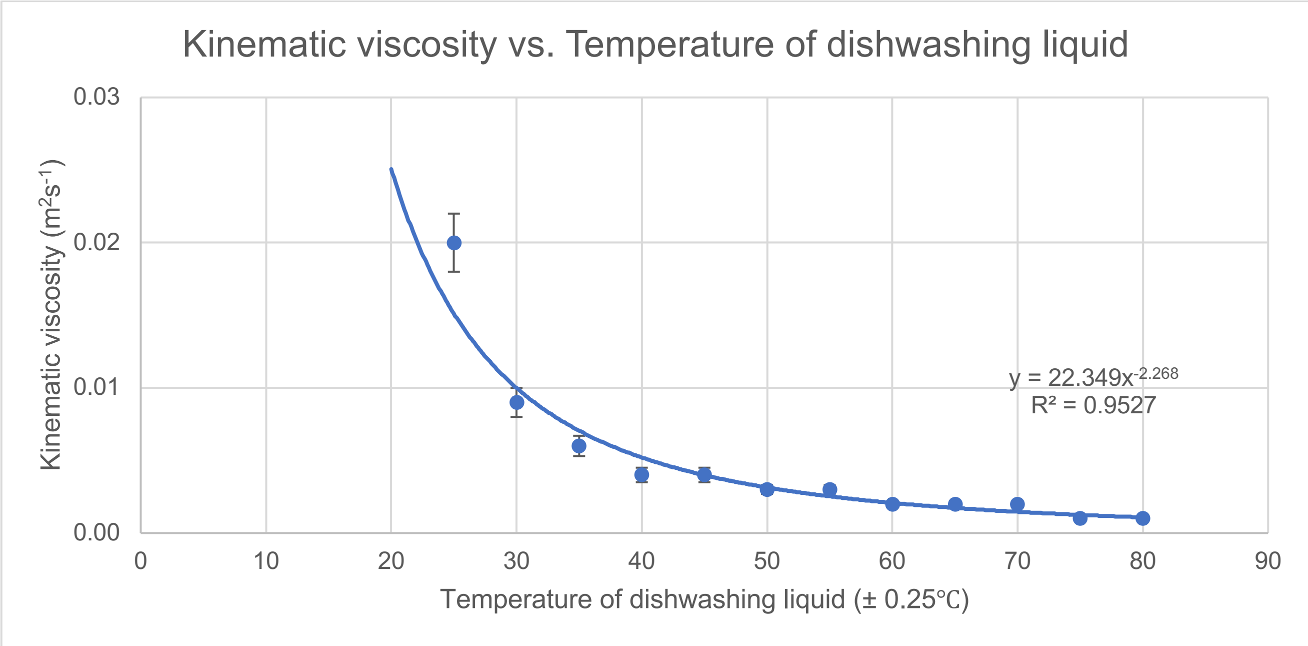

Figure 5: Graph of kinematic viscosity of dishwashing liquid against its temperature.

From Figure 5, there is one data of anomaly which is indicated at the $T_{DL} = (25.00 \pm 0.25)$℃. Some of the data have no error bars because it is too small to be shown in the graph. Figure 6 shows that the approximate inverse square root of the kinematic viscosity of dishwashing liquid, $\frac{1}{\sqrt[2.183]{v_{DL}}}$, against the temperature of dishwashing liquid, T_{DL}.

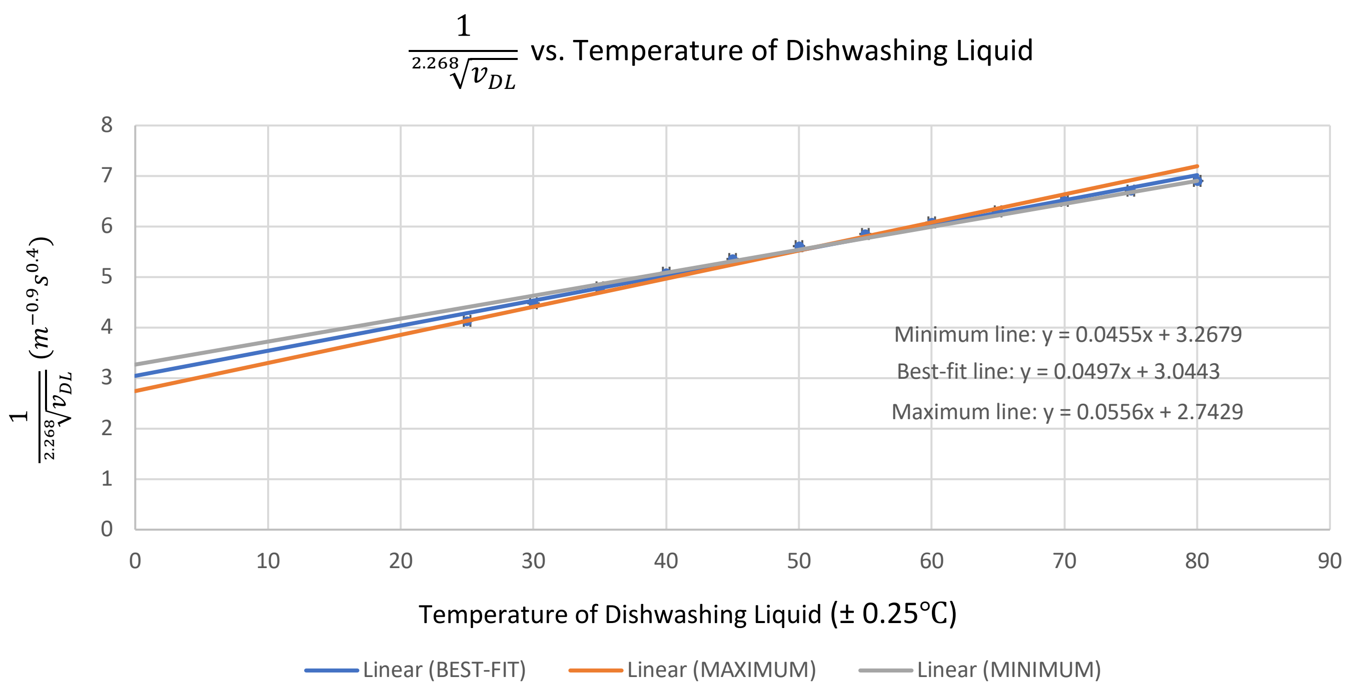

Figure 6: The graph of approximate inverse square root of the kinematic viscosity of dishwashing liquid against temperature of dishwashing liquid

Figure 6 shows that $\frac{1}{2.168\sqrt{v_{DL}}}$ increases linearly with T_{DL}. As shown in figure above, there are no outliers in the data. Since I do not have a theoretical value of the gradient that I can compare with, I find the percentage uncertainty of the gradient by using equation (6).

$$\Delta \text{ gradient of graph in Figure 6} = \frac{0.0556 - 0.0455}{2} = 0.0101$$

The gradient of the graph of flow velocity against the temperature of dishwashing liquid is $(0.0497 \pm 0.0101)\ m^{-0.9}s^{0.5}{}^{\circ}\mathrm{C}^{-1}$. Since I do not have a theoretical value of the gradient that I can compare with, I find the percentage uncertainty of the gradient.

$$\text{Percentage uncertainty} = \frac{0.0101}{0.0497} \times 100\% = 20.32193159\% \approx 20.32\%$$

The percentage uncertainty for the gradient of the graph in Figure 3 is 20.32%.

4.0 | CONCLUSION, EVALUATION AND EXTENSIONS

This investigation is conducted to answer the research question of "How does the temperature of dishwashing liquid affect its kinematic viscosity by measuring the flow velocity of a steel ball when immersed in the liquid?". The hypothesis that I have given was that when the temperature of dishwashing liquid increases, the kinematic viscosity of the liquid increases. After conducting the experiment and analysed the results, I have concluded that the proposed hypothesis is accepted. The relationship between the two variables can be represented with the equation of $y = 0.0497x + 7.8031$, with x represent the temperature of dishwashing liquid and y represents the approximate square root of the kinematic viscosity of the dishwashing liquid. It is shown that the gradient of the equation is $(0.0497 \pm 0.0101)\ m^{-0.9}s^{0.4}$. The gradient does not give meaning to the outcome of the result, either experimentally or theoretically. The percentage error between my experimental results and the literature value for the absolute viscosity is very low which is at 2.0%, which indicate high accuracy of results of the experiment. Additionally, the percentage difference of the gradient is 20.32%. This means that there are more random errors compared to the systematic errors for my system of experiment. However, systematic errors still exist that happened throughout the experiment. There were many problems throughout the proceedings of this experiment, however I managed to overcome all the problems by making explicit modifications to ensure that my system of experiment and be accurately determine the kinematic viscosity of dishwashing liquid as I have explained in Chapter 3.3. I have also elaborated on my decisions on the safety, ethical and environmental considerations of my methodology as mentioned in Chapter 3.4.

Overall, this experiment is seen to have obtained satisfied results. However, this experiment has some random and systematic errors which has altered the precision and accuracy of the outcome of this investigation. There were random errors throughout this experiment, such as the inaccuracies of measuring the volume of dishwashing liquid due to the parallax error caused by human error. Therefore, I must reduce the error by making sure that my eyes are at the same level with the meniscus of the measurements. such as the measuring cylinder, that I have used during the experiment and this has hindered the accuracy of the result of the experiment as well. The most major flaw from my experiment is that the dishwashing liquid was not properly set at a constant temperature. My experimental design does not consider the continuous constant of temperature for the experiment. This is because the temperature of the surroundings is far less than the system of the experiment since I was conducting the experiment inside an air-conditioned laboratory. The heat that has been absorbed by the molecules of the dishwashing liquid may lost to the surroundings, thus reducing the accuracy of experimental outcome relative to the experimented temperatures. In my experimental design, the experimental setup has no particular apparatus or materials to act as a fully functional insulator. It should prevent heat from getting lost to the surrounding. This has majorly contributed to the systematic error of the experiment, even when the percentage uncertainty is small.

As an extension to my methodology, it can be experimented how temperature of other household liquids can affect its kinematic viscosity. For example, detergents are also Newtonian liquid that are very viscous. A comparative study between normal detergents and concentrated detergents can be done and their kinematic viscosities can be compared. Next, the angle of inclination can also change the viscosity of fluid.[14] Example of research question could be, "How does different angles of inclination can affect the kinematic viscosity of dishwashing liquid at 30º, 35º, 40º, 45º, 50º and 55º?"

[14] A. A. Keller, V. Broje, and K. Setty, "Effect of Advancing Velocity and Fluid Viscosity on the Dynamic Contact Angle of Petroleum Hydrocarbons," *Journal of Petroleum Science and Engineering* 58, no. 1–2 (2007): 201–6, https://doi.org/10.1016/j.petrol.2006.12.002.

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