# Measurement of the dynamic viscosity of Canola Oil using a ball drop

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The viscosity of a particular fluid is an interesting parameter that plays an important role in fluid dynamics of that fluid. We chose the common household cooking item canola oil. Using a ball drop, we set out to measure viscosity at various temperatures and create a model for $\eta(T)$ between 0°C and 100°C, as well as an accurate measurement for viscosity at room temperature, $\eta(T = 20°C)$. It was found that the viscosity between 0°C and 40°C can be approximated using the function $\eta(T) = \alpha e^{-\beta T}$, where $\alpha = 440.65 \pm 30.40\ mPa \cdot s$ and $\beta = 0.03761\ \frac{1}{°C}$ and that an estimation for viscosity at room temperature is equivalent to $207.6901 \pm 14.3306\ mPa \cdot s$. The precision of this measurement was limited by uncertainty in lab equipment used to measure various quantities as well as the image analysis software we used and the limited frame-rate of our camera.

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## I. INTRODUCTION

Viscosity is one of the most important parameters to describe a fluid and is, in a sense, how 'thick' the fluid is and is a measurement of how much resistance is encountered when trying to move an object through that fluid. Viscosity is an important parameter in fluid dynamics and consequently in many engineering applications, such as hydraulic systems and hydrodynamic lubrication of engines[1].

We chose to measure the viscosity of canola oil as a function of temperature for a few reasons. For one thing, it was a convenient household item, and so we had easy access to large quantities of it. We wanted to develop it as a function of temperature because temperature varies significantly on a day to day basis, and so this is a commonly fluctuating variable that could change the properties of oil on a daily basis. We wanted to measure viscosity as a function of temperature between 0°C and 100°C as to have a more complete picture of the change in viscosity over temperature, but our data taken in the lab room was unusable as the camera we used was too low resolution and the frame-rate was too low.

Here I (we) report a simple approach to measuring the dynamic viscosity of canola oil as a function of temperature using a simple ball drop experiment. This approach yielded a function of $\eta(T)$, and an estimate at room temperature for the viscosity of canola oil. The precision of this measurement was limited by uncertainty in lab equipment used to measure various quantities, as well as the image analysis software we used and the limited frame-rate of our camera.

## II. THEORY

Our calculation for viscosity will use the forces acting on a ball during a "ball drop" experiment, where a ball is dropped and the time taken to fall is measured. Viscosity is involved in one of the forces(Stokes' Drag)[2] and so we can solve the corresponding equations for Viscosity.

We start out with an expression stating the various forces involved.

$$F_{total} = \sum_{i=1} F_i = F_{gravity} - F_{buoyant} - F_{stokes'drag} \quad (1)$$

Now, making the substitutions[3] that $F_{total} = ma$, $F_{gravity} = mg$, $F_{buoyant} = m_{disp}g$[4], and $F_{stokesdrag} = 6\pi\eta Rv$, we can create the equation:

$$ma = mg - m_{disp}g - 6\pi\eta Rv \quad (2)$$

Next we make the substitutions that $\Delta x = \frac{1}{2}at^2$ (and thus $a = \frac{2\Delta x}{t^2}$) and $v = \frac{\Delta x}{t}$.

$$m\frac{2\Delta x}{t^2} = mg - m_{disp} - 6\pi\eta R\frac{\Delta x}{t} \quad (3)$$

Now, we do some simple algebra to solve for $\eta$, as a function of our parameters $\Delta x$, $t$, $R$, $m$, and $m_{disp}$.

$$\eta = \frac{mgt}{6\pi R\Delta x} - \frac{m_{disp}gt}{6\pi R\Delta x} - \frac{m}{3\pi Rt} \quad (4)$$

## III. APPROACH

Our approach was to place the canola oil into a standard household drinking glass, and to drop the ball from

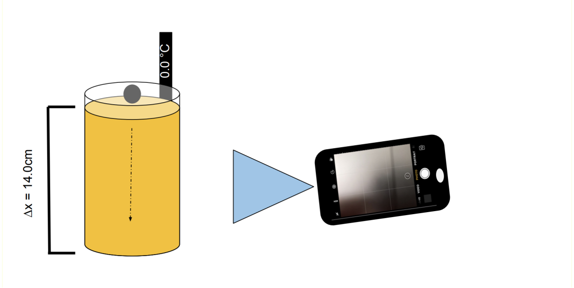

FIG. 1: Schematic of the ball drop and the measurement. The canola oil is placed in a 14.0 $cm$ tall cylindrical drinking glass. The marble is held above the canola oil, ready to drop. A thermometer is placed in the drinking glass. A smartphone is placed adjacent to the glass, recording video.

the top of the glass, and to measure the time taken for the ball to fall to the bottom. We varied the temperature of the oil by placing the drinking glass in a hot water bath, aswell as initially putting it in a freezer overnight. We would additionally measure the height of the glass($\Delta x$), the radius of the ball ($R$), and the mass of the ball($m$) at the beginning, and keep these factors constant.

The canola oil was placed in a cylindrical drinking glass, of a height slightly more than 14 $cm$. Temperature was measured using a digital meat thermometer, of precision to 0.1°C.

We took data by recording a video of the ball drop on a smartphone, recorded at 30 frames per second and 60 frames per second (we switched recording options for a higher framerate). Videos were analyzed using a slow motion video editor, Movavi Video Editor 5, to see when the ball began to fall, and when it reached the bottom. For each temperature, we performed three trials, and we took the average of these three trials for our value aswell as the standard deviation for our uncertainty. If the uncertainty obtained from the standard deviation was less than the digital uncertainty based on the framerate, however, we used the digital uncertainty instead.

Measurements were made for the other variables in the equation for dynamic viscosity, $\Delta x$, $R$, and $m$. $m_{disp}$ was calculated using the formula $\rho_{oil} V_{sphere} = \rho_{oil} \frac{4}{3}\pi R^3$. We took the value of the density of oil to be 920 $kg/m^3$[5]. $m$ was measured using a scale, of precision to 1 $g$. $\Delta x$ and $R$ were measured using a ruler, $R$ being obtained by measuring the diameter of the object and dividing by two. $\Delta x$ was measured by merely measuring the distance from bottom of the glass to the top of the oil. Precision for these measurements was to 1 $mm$.

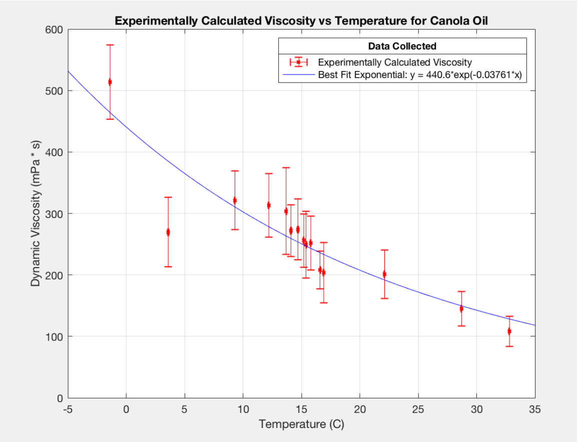

FIG. 2: Graph of experimentally calculated data points for viscosity as a function of temperature, overlayed with the best fit exponential function. Error bars represent a 68% confidence interval.

## IV. REVIEW

Data was processed using the programming language and development environment MATLAB[6], provided by licensing from the University of California, Santa Barbara. Graphs were also generated using MATLAB. Viscosity was calculated using Equation (4), with our inputs being $m_{disp}$, $m$, $t$, $R$, and $\Delta x$, aswell as using the numerical constants $\pi$ and taking the accepted value of gravitational acceleration to be $g = 9.80655 m/s^2$[7].

Viscosity was calculated for each individual temperature, and an exponential fit was applied to the data set. Uncertainty in viscosity was derived from the uncertainty in the 5 measured quantities, and was propagated through using standard error propagation techniques involving adding in quadrature and partial differentiation[8]. Uncertainty in the exponential fit was obtained from the curve-fitting software in MATLAB.

Our measurements for time, viscosity, and their associated uncertainties can be viewed in Figure 4. Our raw data for viscosity as a function of temperature aswell as our exponential fit can be viewed graphically in Figure 2.

Our exponential fit function for $\eta(T)$ is $\eta(T) = \alpha e^{-\beta T}$, where $\alpha = 440.65 \pm 30.40\ mPa \cdot s$ and $\beta = 0.03761\ \frac{1}{°C}$. This fit resulted in an R-Square value of 0.8193 and an adjusted R-Square value of 0.8054.

It was difficult to find consistent results for the viscosity of canola oil, it is not the most common of experiments. One group of experimentalists, Diamante and Lan[9], obtained a value of $46.2 mPa \cdot s \pm 0.5 mPa \cdot s$ at $30°C$. This result is markedly lower than our result of $142.6 \pm 9.8$, and so I believe there may have been a sys-

| Temperature(°C) | Viscosity(mPa·s) |
|---|---|
| 0 | 440.6482 ± 30.4047 |
| 5 | 365.1094 ± 25.1925 |
| 10 | 302.5199 ± 20.8739 |
| 15 | 250.6599 ± 17.2955 |
| 20 | 207.6901 ± 14.3306 |
| 25 | 172.0864 ± 11.8740 |
| 30 | 142.5862 ± 09.8384 |

FIG. 3: Viscosity values generated via the Exponential Fit

tematic uncertainty in our measurement, perhaps due to constraints of the experiment, perhaps due to the constraints of the image analysis software. Additionally, the existence of a few outliers in our data, possibly due to the image analysis software, may have altered our result.

Suggestions for a better experiment would include more resources. A taller container for the ball drop would be useful, so there is a lower relative uncertainty in the time data. A more precise scale to measure mass and more fine calipers to measure distance would also help diminish uncertainty. The most important part to improve on would be the video analysis portion of the experiment. A larger container would allow for a longer video, which would be helpful for analysis. More sophisticated video analysis software would allow us to obtain a more precise measurement for position as a function of time, which would allow us to have more precise definitions for $v$ and $a$. We would be able to use $\frac{\partial^2 x}{\partial t^2}$ and $\frac{\partial x}{\partial t}$, as opposed to $< a >$ and $< v >$. This in particular might allow for diminished systematic error.

In summary, we have measured the dynamic viscosity of canola oil as a function of temperature to be $\eta(T) = \alpha e^{-\beta T}$, where $\alpha = 440.65 \pm 30.40\ mPa \cdot s$ and $\beta = 0.03761\ \frac{1}{^\circ C}$. Our measurement suffered errors due to the large uncertainty of some of the measurements, such as that of radius and mass. Our measurement also suffered from a lack of number of data points, I believe more trials on a larger range of temperatures could paint a clearer picture of how $\eta$ changes with temperature. The most marked improvements to this approach would come from a larger set of data, more accurate measuring tools, and more sophisticated video analysis software.

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| Temperature(°C) | Time(s) | Viscosity(mPa·s) |
|---|---|---|
| -1.4 | 0.3685 ± 0.0144 | 513.92 ± 60.56 |
| 3.6 | 0.2778 ± 0.0164 | 269.65 ± 56.69 |
| 9.3 | 0.2957 ± 0.0120 | 321.12 ± 47.82 |
| 12.2 | 0.2929 ± 0.0140 | 313.20 ± 51.75 |
| 13.7 | 0.2895 ± 0.0219 | 303.54 ± 70.49 |
| 14.1 | 0.2786 ± 0.0102 | 272.00 ± 42.43 |
| 14.7 | 0.2793 ± 0.0134 | 274.05 ± 49.52 |
| 15.2 | 0.2731 ± 0.0109 | 255.78 ± 43.41 |
| 15.4 | 0.2709 ± 0.0156 | 249.23 ± 54.57 |
| 15.8 | 0.2718 ± 0.0110 | 251.91 ± 43.52 |
| 16.6 | 0.2573 ± 0.0054 | 207.89 ± 30.45 |
| 16.9 | 0.2560 ± 0.0136 | 203.85 ± 49.20 |
| 22.1 | 0.2550 ± 0.0098 | 200.74 ± 39.44 |
| 28.7 | 0.2376 ± 0.0056 | 145.00 ± 27.94 |
| 32.8 | 0.2267 ± 0.0048 | 108.37 ± 24.76 |

FIG. 4: List of measured times at each temperature, and calculated viscosity at each temperature. Other variables: $\Delta x = 14.0cm \pm 0.0288cm$, $R = 0.7mm \pm 0.144mm$, $m = 5g \pm 0.288g$, $m_{disp} = 1.3g \pm 0.086g$.