PHYSICS EXTENDED ESSAY

Viscosity and its relation to Temperature

What is the effect of Temperature on the Viscosity of a fluid and objects moving within the fluid?

Word Count:3739

Exam Session: May 2017

Abstract

This essay studies the motion of a projectile in different mediums in a bid to answer the question "What is the effect of temperature on the viscosity of a fluid?". This investigation will involve two sets of experiments, first conducting experiments with various sizes of projectiles for the selected mediums and accurately recording the relevant data that is required and then conducting the experiments at various other temperatures to work out viscosity-temperature curve for each medium. In the experiments to be conducted, a transparent measuring cylinder was filled with the selected liquid mediums. Numerous projectiles, in this case different sizes of ball bearings, were dropped from the surface of the medium to measure the velocity it travelled with inside the mediums. This experiment was conducted with each of the mediums and re-conducted at the various temperatures selected. Due to the lack of availability of sufficient amounts of all the selected mediums, the experiments were conducted with liquid columns of a considerable height, rather the values were extrapolated for larger distances from these experiments. The liquid mediums were not heated and were instead cooled to conduct the experiment at different temperatures so as to avoid volatility issues and to ensure the experiment was conducted safely. The investigation showed evidence that the less the viscosity, the higher the velocity of a moving particle within it. Additionally the increase in temperature causes a decrease in viscosity, thus causing an increase in the velocity. Further study of this topic can help in the enhanced understanding of movement of bodies at great oceanic depths with temperatures much colder than at the surface.

(Word Count: 267)

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Reasons for choosing this topic

While taking a course on scuba diving and deep sea diving, I began to wonder about how the water at deeper levels in the sea is much colder than at the top, and the fact that it gets more difficult to manoeuvre the lower you go. This train of thought eventually led me to wonder about the effect that the density of a medium might have on objects moving within it, and also how temperature may affect this change, provided the force acting on the body is identical and remains constant, keeping the concept of buoyancy in mind.

This led me to conduct numerous experiments in mediums of different densities however the results were irregular and vastly inconclusive. It seemed as if the density had no real effect on the velocity of a moving body within it. After careful examination of the evidence I collected from my experiments, I came to the conclusion that it is Viscosity that matters in the velocity of objects. The densities of two mediums could be exactly the same, but as long as the viscosity differs, the velocity of objects within it will differ, provided they are under the same physical conditions. Viscosity, in the simplest terms is the layman concept of thickness in liquids. It can also be described as the quantity used to measure a liquids resistance to flow. I readjusted my thinking to deal with Viscosity and the effect of varying temperatures on it. Thus with this newfound knowledge of the concepts I was testing, I began conducting my experiments at the different physical conditions that would be required to investigate the effect of change in temperature of a fluid on the velocity of a body moving through that medium and on its viscosity.

Introduction

Quite simply, viscosity in liquids is dependent upon the space between the molecules of the liquid. These particles of the liquid are the cause for the resistance faced by the projectile in the experiment that is conducted. Upon cooling, the particles within the liquid lose their energy and the space between them decreases, thus increasing the viscosity of the liquid. Whereas upon heating, the particles of the liquid medium gain energy and thus start moving about, in turn reducing the molecular attraction between the particles, essentially decreasing the viscosity of the medium. The effect on viscosity by heating liquids can be observed in day to day activities as well, such as how while cooking with oil, it seems to be more fluid than before. However these are only passive observations, and I hoped to conduct sufficient experiments in order to obtain a Viscosity-Temperature curve to find their relation in some common fluids we use.

However in order to attempt to find the Viscosity of a fluid, we needed to find the velocity of objects travelling within it, to use in the equation V = $^{2}/_{9}\,^{(\rho_p - \rho_f)}/_{\mu} \times g \times R^2$.Additionally the data inferred at the end of the investigation would be accurate only towards bodies moving vertically downwards in the medium and not to bodies moving horizontally as the physical forces acting upon the bodies in those two cases differ vastly, however since we are simply attempting to find a relation between Temperature and Viscosity, this can be overlooked, as this relation should not change, regardless of what type of motion the projectile undergoes while submerged in the fluid.

"Stokes' Law" will be used to compare the experimental data and the theoretical data of each experiment and at different temperatures. The dynamic velocity in the formula will be calculated for the different temperatures and used within the formula. The velocity used will be the velocity that the projectile reaches halfway through the column of fluid, so as to allow the projectile to reach a velocity close to its terminal velocity.

Designing the Experiment:

For this experiment, a vessel in which the projectile would be clearly visible was to be used, and transparent/semi-transparent liquid mediums needed to be used.

First I considered horizontal motion for the projectiles travelling in the mediums, since I initially assumed there would be no change in velocity and the motion was in a single plane, but since there is resistance provided by the liquid medium and also downward motion due to gravity, the formula for projectile motion in a horizontally projected body would have to be used and with the buoyant force acting upon the ball as well, there would have been too many factors to consider and would have overcomplicated the experiment with no gain in the conclusion and understanding of the problem since one would have to consider both horizontal and vertical motion along with the acceleration due to gravity and the resistance provided by the liquid medium. Additionally, projecting the objects horizontally each time with the same amount of force would have posed an obstacle

However vertical projection of the body proves fruitful as one need only consider the motion of the object in one plane, and the acceleration due to gravity and the deceleration due to viscosity and buoyant force is easy enough to factor into that problem.

Sample experiments were conducted in measuring cylinders of capacity of 100 millilitres, however certain problems were encountered in that as well.

Firstly, the measuring cylinder of 100 millilitres proved to be too narrow to provide unimpeded descent within the liquid mediums. The collision of the ball bearings against the walls of the measuring cylinder would add to the error calculations of the experiment.

Secondly, the measuring cylinder of 100 millilitres was too short to get a value even remotely close to that of the terminal velocity of a projectile in water, thus I decided to utilise a measuring cylinder of 500 millilitres, which provided us with ample height, and a large enough diameter for the liquid column.

The experiments were conducted against a white background, to ensure that the projectile is clearly visible in the recordings for precision purposes.

The distance marked from 350 millilitres to 50 millilitres on the measuring cylinder was used in order to allow the projectile to reach terminal velocity, and provide concordant results. For each liquid medium, 4 sizes of ball bearings were used, and at 3 different temperatures, in order to provide a more accurate sample set of readings. The same temperatures could not be used for each liquid medium as cooling times differed. Instead, temperatures that were at least 2.5°C apart were used so as to observe a significant change in the viscosity of the fluid.

A Stainless Steel Temperature Probe from Vernier Software & Technology© was used to collect the temperature readings rather than a conventional thermometer to minimise uncertainty in the temperature listings.

The samples were recorded by a camera capable of recording at a frame rate of 60 frames per second to get accurate velocities for the projectiles in the liquid mediums. The recordings were viewed frame by frame from the point the projectile passes the initial point of measurement, until it has traversed a vertical distance of 0.15 metres. The two frames are considered, and the time is taken as the number of frames divided by 60 and is in seconds. The camera used was a Canon VIXIA HF R400, and the videos were recorded at dimensions of 1920 by 1080 pixels at a frame rate of 60 frames per second. (Specifications shown during conduction of experiment)

Img 1: The Camera used for the experiment (Canon VIXIA HF R400) [Source: https://shop.usa.canon.com/wcsstore/ExtendedSitesCatalogAssetStore/26700_1_l.jpg]

The various mediums were chosen to provide a broad spectrum of viscosities. Water was chosen as the default, as it is the most commonly used liquid and I was of the opinion that it would set an appropriate baseline for the experiment.

Prior to finalising the list of mediums to be used, Sunflower Oil was used to conduct some samples, but the results were too close to the viscosity of water, and thus it was decided not to use it.

Glycerol proved to be an appropriate medium to use due to its transparency, and the difference in its viscosity in comparison to that of water. It's easy availability in the lab cemented the decision to use this fluid.

Castor Oil was another suitable candidate for this experiment, and despite the difficulties faced in the cleaning of apparatus after the experiments were conducted in this medium, it was still utilised.

Lastly, Honey was chosen as the final medium, due to its high viscosity, which would ensure that we did indeed use mediums of varying viscosities.

For these reason, a measuring cylinder of the capacity 500 millilitres was used while conducting the experiments and ball bearings of four different sizes was dropped in at three different temperatures per liquid medium in order to calculate the dynamic viscosity of the liquid mediums and its variation with changes in the temperature. The four liquid mediums to be used were finalised to be Water, Honey, Castor Oil, and Glycerol, due to the comprehensive coverage they offer in the field of viscosity.

Experiment:

Aim:

To measure the time taken by the projectile (marble) to move through the selected medium vertically and hence calculate the velocity of the moving projectile within it, in order to obtain the relation between viscosity and temperature.

Hypothesis:

With decrease in temperature, dynamic viscosity should increase, and velocity of particles should decrease.

Variables (Table 1)

Independent Variable	Controlled Variable	Dependent Variable
Temperature of the Fluid	Density of the Projectile	Viscosity of the Fluid
	Distance travelled by the Projectile	Velocity of the Projectile

Independent Variable:

The temperature of the fluids is varied by cooling the fluids in the refrigerator, and allowing them to reach room temperature whilst conducting the experiments. This is repeated for different fluids. The fluids used are Water, Glycerol, Castor Oil, and Honey

Dependent Variable:

1. The viscosity of the fluid: Dependent on the temperature of the fluid.
2. The velocity of the projectile: Dependent on the viscosity of the liquid medium.

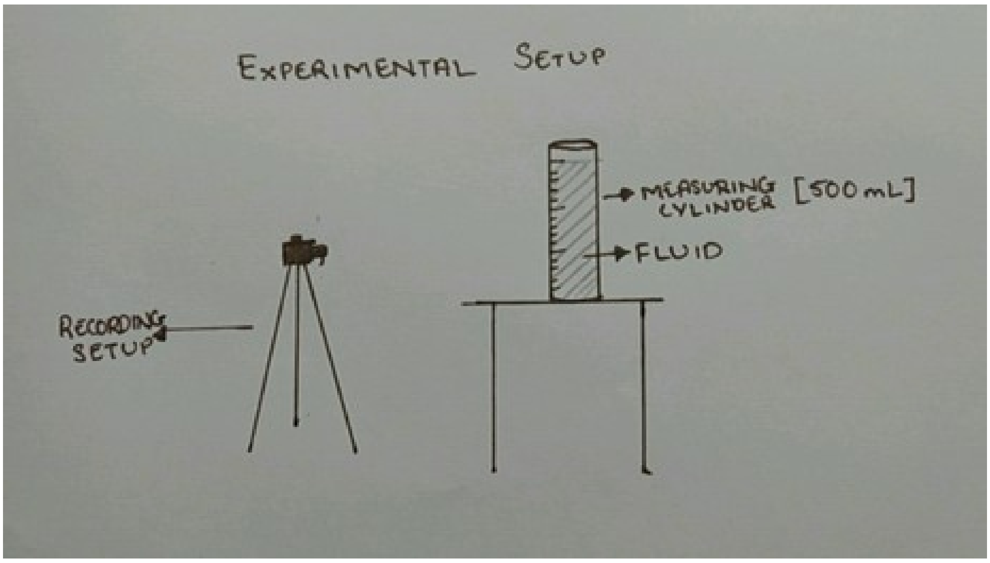
Controlled Variable:

1. Density of the projectile: Unchanged throughout the experiment. Experimentally found to be 8646.7 $kg \cdot m^{-3}$.
2. Distance travelled by projectile is fixed and unchanged throughout the experiment.

Apparatus:

1. Measuring Cylinder, 500 ml.

2. Ball bearings of diameter 3.9688 cm, 5.5562 cm, 7.1438 cm and9.5250 cm respectively.
3. Recording setup to record data.
    a. Camera capable of recording at 60 fps.
4. A Stainless Steel Temperature Probe to measure the temperature.
5. 500 ml of Liquid Mediums to be tested:
    a. Water
    b. Glycerol
    c. Honey
    d. Castor Oil



Img2: Experiment model used (See **Appendix** for images of experimental setup)

Procedure:

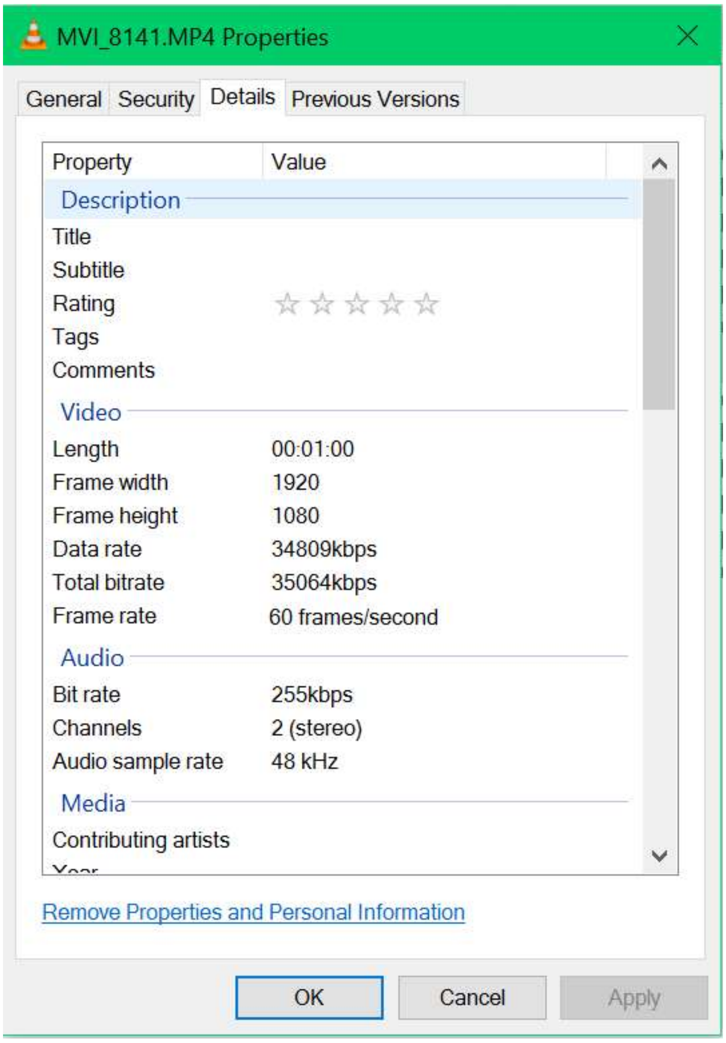
1. Cool the liquid samples within the refrigerator
2. Fill the measuring cylinder with the liquid medium to be used.

3. Drop the projectiles into the liquid mediums and record the path they follow along a vertical distance of 15 cm. (Velocity will be extrapolated from this for larger distances)
4. Calculate the amount of time taken by the projectiles to traverse the vertical distance with the help of the recording equipment used and thus using the formula velocity=distance/time, calculate the velocity in the different mediums. Initial differences to the velocity of the projectiles in the different mediums is noted and values are recorded to be used in Stokes' Law [Through Stokes' Law we can find that μ= ${}^{2}/{}_{9}\,{}^{(\rho_p - \rho_f)}/{}_{v} \times g \times R^2$].
5. The experiment is repeated at the different temperatures while the fluid reaches room temperature after being cooled. The temperature of the fluid is carefully observed with the Temperature Probe and the experiment is conducted at the temperatures required to calculate the velocity of the projectile at different temperatures to be used in the formula in order to see the variation of the viscosity of the liquid with temperature.

Calculation of Data

Img 3: Time at initial frame, when the projectile is at the initial position. (Glycerol at 27.6°C with a projectile of radius 0.3479 cm)

Img 4: Time at final frame, when the projectile is at the final position. (Glycerol at 27.6°C with a projectile of radius 0.3479 cm)



Img 5: The specifications used for the recordings (Viewed in Windows Explorer)

1. The Recordings of the experiments conducted are analyzed frame by frame in order to get the time taken for the projectile to travel the predetermined distance marked on the measuring cylinder.

   Example [Projectile of radius 0.3479 cm in Glycerol at 27.6°C]:

   Distance = 0.15 m

   Time = 55/60 s

   = 0.9167 s

2. From the distance and the time taken, the velocity of the projectile is calculated by the formula $Velocity = \frac{Distancetravelledbytheprojectile}{Timetakentotravelthatdistan}$.

   Example [Projectile of radius 0.3479 cm in Glycerol at 27.6°C]:

   Velocity = 0.15/(55/60)

   $= 0.164\ m \cdot s^{-1}$

3. Next we find the density of the particles (ball bearings) with the help of an electronic weighing scale and a micrometer screw gauge. Experimentally, this is found to be $8646.7\ kg \cdot m^{-3}$.

4. The density of the liquid mediums is calculated by finding their masses and measuring their respective volumes, by the formula $Density = \frac{Mass}{Volume}$

   Example [Projectile of radius 0.3479 cm in Glycerol at 27.6°C]:

   Mass = 629.45 gm

   Volume = 500 cm^3

   Density = $1.2589\ g \cdot cm^{-3}$

   Density = $1258.9\ kg \cdot m^{-3}$

5. The radius of the projectiles is calculated while finding the density of the projectiles. These radii are 0.4204 cm, 0.3479 cm, 0.2661 cm, 0.2170 cm.

6. Gravitational acceleration is assumed to be $9.81\ m \cdot s^{-2}$.

7. From the above values, the dynamic viscosity of the liquid mediums is calculated by the formula μ = ${}^{2}\!/_{9}\ {}^{(\rho_p - \rho_f)}\!/_{v} \times g \times R^2$, where:

   a. v = Velocity

   b. ρ_p = Density of particles [Ball Bearings]

   c. ρ_f= Density of the liquid mediums

   d. μ = Dynamic viscosity of the liquid mediums

e. g = gravitational acceleration

f. R = Radius of the projectile

Example [Projectile of radius 0.3479 cm in Glycerol at 27.6°C]:

Velocity = 0.164 $m \cdot s^{-1}$

ρ_p = 8646.7 $kg \cdot m^{-3}$

ρ_f=1258.9 $kg \cdot m^{-3}$

g = 9.81 $m \cdot s^{-2}$

R = 0.003479 m

Therefore $\mu = [(2/9) \times (8646.7 - 1258.9)/0.164] \times 9.81 \times (0.003479)^2]$

μ = 1.18698 $kg \cdot m^{-1} \cdot s^{-1}$

Data collected for ball bearing of radius 0.4204 cm (Table 2)

Liquid Medium	**Temperature (°C)**	**Time taken: (s)**	**Velocity ($m \cdot s^{-1}$)**	**Density ($kg \cdot m^{-3}$)**	**Dynamic Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**
Water	16	8/60	1.125	999	0.261922
Water	20.3	8/60	1.125	997.9	0.261953
Water	23.1	8/60	1.125	997.3	0.261973
Glycerol	12.1	99/60	0.09091	1269	3.1267
Glycerol	16.5	65/60	0.13846	1266.2	2.05376
Glycerol	27.6	39/60	0.23077	1258.9	1.22334
Castor Oil	15.7	69/60	0.1304	974	2.267
Castor Oil	19.7	49/60	0.1837	961	1.612

Castor Oil	22.6	34/60	0.2647	950	1.1203
Honey	16.6	582/60	0.01546	1421.4	18.0065
Honey	19.3	518/60	0.01738	1419.8	16.0208
Honey	26.5	325/60	0.0277	1416	10.0573

Data collected for ball bearing of radius 0.3479 cm (Table 3)

Liquid Medium	**Temperature (°C)**	**Time taken: (s)**	**Velocity ($m \cdot s^{-1}$)**	**Density ($kg \cdot m^{-3}$)**	**Dynamic Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**
Water	16	9/60	1	999	0.201794
Water	20.3	9/60	1	997.9	0.201817
Water	23.1	9/60	1	997.3	0.201833
Glycerol	12.1	145/60	0.06207	1269	3.1362
Glycerol	16.5	92/60	0.0978	1266.2	1.9912
Glycerol	27.6	55/60	0.164	1258.9	1.1886
Castor Oil	15.7	102/60	0.0882	974	2.2953
Castor Oil	19.7	71/60	0.1267	961	1.6006
Castor Oil	22.6	49/60	0.1837	950	1.1055
Honey	16.6	850/60	0.01059	1421.4	18.0022
Honey	19.3	759/60	0.01186	1419.8	16.078
Honey	26.5	470/60	0.01915	1416	9.9627

Data collected for ball bearing of radius 0.2661 cm (Table 4)

Liquid	**Temperature**	**Time**	**Velocity**	**Density**	**Dynamic**

Medium	(°C)	taken: (s)	($m \cdot s^{-1}$)	($kg \cdot m^{-3}$)	Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)
Water	16	10/60	0.9	999	0.131173
Water	20.3	10/60	0.9	997.9	0.131189
Water	23.1	10/60	0.9	997.3	0.131199
Glycerol	12.1	245/60	0.03673	1269	3.1006
Glycerol	16.5	158/60	0.05696	1266.2	2.00017
Glycerol	27.6	96/60	0.09375	1258.9	1.21644
Castor Oil	15.7	175/60	0.05143	974	2.3029
Castor Oil	19.7	120/60	0.075	961	1.581861
Castor Oil	22.6	70/60	0.1286	950	0.923868
Honey	16.6	1466/60	0.00614	1421.4	18.1649
Honey	19.3	1270/60	0.007087	1419.8	15.7411
Honey	26.5	820/60	0.01098	1416	10.1654

Data collected for ball bearing of radius 0.2170 cm (Table 5)

Liquid Medium	Temperature (°C)	Time taken: (s)	Velocity ($m \cdot s^{-1}$)	Density ($kg \cdot m^{-3}$)	Dynamic Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)
Water	16	11/60	0.82	999	0.095742
Water	20.3	11/60	0.82	997.9	0.095754
Water	23.1	11/60	0.82	997.3	0.095761
Glycerol	12.1	365/60	0.02466	1269	3.0712
Glycerol	16.5	234/60	0.03856	1266.2	1.96486
Glycerol	27.6	141/60	0.06383	1258.9	1.18814

Castor Oil	15.7	252/60	0.0357	974	2.20626
Castor Oil	19.7	181/60	0.0497	961	1.58186
Castor Oil	22.6	129/60	0.06977	950	1.13243
Honey	16.6	2145/60	0.004196	1421.4	17.6765
Honey	19.3	1921/60	0.004685	1419.8	15.835
Honey	26.5	1202/60	0.007488	1416	9.91267

1. It is observed that the mediums such as water that have a lower viscosity have the projectile moving through it at a higher velocity and this velocity steadily decreases as we move from one liquid medium to another, showing the effect that the viscosity has on the projectile. The velocity in glycerol is slower than that in water, the velocity of the projectile is slower in Castor Oil than it is in Glycerol, and finally, the velocity of the projectile in honey is the slowest of all, with the projectile moving almost agonizingly slow through this medium.
2. The decreasing velocity with the decrease in temperature shows the relation between velocity and the temperature of the fluid, with the velocity of a projectile being proportional to the temperature of the fluid (the projectile travels through the liquid medium faster when the temperature is higher, and slower when the temperature is lower), therefore Velocity ∝ Temperature.
3. Thus since we know that the velocity of the projectile depends on the viscosity, as the projectile moves slower in the more viscous fluids, and we have observed that the projectile moves faster when the temperatures of the fluids increase, we can state that Viscosity of the Fluid is inversely proportional to the Temperature of the Fluid, however, since we obtain a

curve for line of best fit rather than a straight line, we can say that Viscosity is inversely proportional to an exponential value of temperature that is Viscosity $\propto$ 1/Temperature^n.

4. The velocity of the projectile increases with overall increase in the radius and the mass (size) of the projectiles.
5. From the experiments conducted, we can obtain the average viscosities for each liquid at the different temperature, and thus obtain the line of best fit.
6. The reasons for the irregularity and non- conformity with the values of water in comparison to the trends followed by the values of water will be explored in detail in the evaluation.

Table 6 (Viscosities for Glycerol):

Instance	Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)
Projectile of Radius 0.4204 cm at 12.1°C	3.1267
Projectile of Radius 0.4204 cm at 16.5°C	2.05376
Projectile of Radius 0.4204 cm at 27.6°C	1.22334
Projectile of Radius 0.3479 cm at 12.1°C	3.1362
Projectile of Radius 0.3479 cm at 16.5°C	1.9912
Projectile of Radius 0.3479 cm at 27.6°C	1.1886
Projectile of Radius 0.2661 cm at 12.1°C	3.1006
Projectile of Radius 0.2661 cm at 16.5°C	2.00017
Projectile of Radius 0.2661 cm at 27.6°C	1.21644
Projectile of Radius 0.2170 cm at 12.1°C	3.0712
Projectile of Radius 0.2170 cm at 16.5°C	1.96486
Projectile of Radius 0.2170 cm at 27.6°C	1.18814

Table 7 (Viscosities for Castor Oil):

Instance	Viscosity (kg·m^{-1}·s^{-1})
Projectile of Radius 0.4204 cm at 15.7°C	2.267
Projectile of Radius 0.4204 cm at 19.7°C	1.612
Projectile of Radius 0.4204 cm at 22.6°C	1.1203
Projectile of Radius 0.3479 cm at 15.7°C	2.2953
Projectile of Radius 0.3479 cm at 19.7°C	1.6006
Projectile of Radius 0.3479 cm at 22.6°C	1.1055
Projectile of Radius 0.2661 cm at 15.7°C	2.3029
Projectile of Radius 0.2661 cm at 19.7°C	1.581861
Projectile of Radius 0.2661 cm at 22.6°C	0.923868
Projectile of Radius 0.2170 cm at 15.7°C	2.20626
Projectile of Radius 0.2170 cm at 19.7°C	1.58186
Projectile of Radius 0.2170 cm at 22.6°C	1.13243

Table 8 (Viscosities for Honey):

Instance	Viscosity (kg·m^{-1}·s^{-1})
Projectile of Radius 0.4204 cm at 16.6°C	18.0065
Projectile of Radius 0.4204 cm at 19.3°C	16.0208
Projectile of Radius 0.4204 cm at 26.5°C	10.0573
Projectile of Radius 0.3479 cm at 16.6°C	18.0022
Projectile of Radius 0.3479 cm at 19.3°C	16.078
Projectile of Radius 0.3479 cm at 26.5°C	9.9627
Projectile of Radius 0.2661 cm at 16.6°C	18.1649

Projectile of Radius 0.2661 cm at 19.3°C	15.7411
Projectile of Radius 0.2661 cm at 26.5°C	10.1654
Projectile of Radius 0.2170 cm at 16.6°C	17.6765
Projectile of Radius 0.2170 cm at 19.3°C	15.835
Projectile of Radius 0.2170 cm at 26.5°C	9.91267

Uncertainty Calculation

All the apparatus used in this experiment has a certain amount of uncertainty that goes with its measurements, thus to calculate the end total uncertainty, the uncertainty of all the values in the formula μ = ${}^{2}/_{9}\ {}^{(\rho_p - \rho_f)}/_{\mathrm{V}} \times g \times R^2$ will need to be calculated.

1. Uncertainty in the velocity of the projectile:

   = $\pm(\frac{0.0005}{0.15} + \frac{0.01}{TimetakenbyProjectile}) \times Velocity$

   Example: Uncertainty in Velocity of Glycerol for Projectile of radius 0.4204 cm at 12.1°C:

   = $\pm(\frac{0.000}{0.15} + \frac{0.01}{99/60}) \times 0.09091$

   = ±0.000854 m·s^{-1}

2. Uncertainty in the density of the projectile:

   = $\pm(\frac{0.1}{\text{Mass of Projectile}} + \left(3 \cdot \frac{0.0005}{\text{Radius of Projectile}}\right)) \times \text{Density of Projectile}$

   Example: Uncertainty in the density of Projectile of radius 0.4204 cm:

   = $\pm(\frac{0.1}{2.7} + \left(3 \cdot \frac{0.0005}{0.4204}\right)) \times 8.6467$ g·cm^{-3}

   = ±0.3511 g·cm^{-3}

   = ±351.1 kg·m^{-3}

3. Uncertainty in the density of the liquid mediums:

$= \pm \left(\frac{0.1}{\text{Mass of Fluid}} + \frac{0.5}{500}\right) \times \text{Density of fluid}$

Example: Uncertainty in the density of Glycerol at 12.1°C

$= \pm \left(\frac{0.1}{634.5} + \frac{0.5}{500}\right) \times 1269$

=±1.469 $g \cdot cm^{-3}$

= ±1469 $kg \cdot m^{-3}$

4. Therefore, Uncertainty inμ = $2/_9 \, {(\rho_p - \rho_f)}/_{\mathrm{V}} \times g \times R^2$

$= \pm[\frac{Uncertainty of \quad _p - \rho_f}{\rho_p - \rho_f} + \frac{Uncertainty of V}{V} + 2 \times \frac{Uncertainty of Radius}{Radius}] \times Viscosity$

Example: Uncertainty in Viscosity of Glycerol at 12.1°C for projectile of radius 0.004204 m:

= [((351.1+1469)/(8646.7-1269))+(0.0008/0.0909)+(2×(0.000005/0.004204))] ×3.1267

= ±0.8082

Therefore Uncertainties for the viscosities are:

Viscosity and Uncertainty for Glycerol (Table 9):

Instance	Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)	Uncertainty ($kg \cdot m^{-1} \cdot s^{-1}$)
Projectile of Radius 0.4204 cm at 12.1°C	3.1267	±0.8082
Projectile of Radius 0.4204 cm at 16.5°C	2.0538	±0.5364
Projectile of Radius 0.4204 cm at 27.6°C	1.2233	±0.3255
Projectile of Radius	3.1362	±0.9178

0.3479 cm at 12.1°C		
Projectile of Radius 0.3479 cm at 16.5°C	1.9912	±0.5865
Projectile of Radius 0.3479 cm at 27.6°C	1.1886	±0.3538
Projectile of Radius 0.2661 cm at 12.1°C	3.1006	±1.1866
Projectile of Radius 0.2661 cm at 16.5°C	2.0002	±0.7671
Projectile of Radius 0.2661 cm at 27.6°C	1.2164	±0.4678
Projectile of Radius 0.2170 cm at 12.1°C	3.0712	±1.6387
Projectile of Radius 0.2170 cm at 16.5°C	1.9649	±1.0490
Projectile of Radius 0.2170 cm at 27.6°C	1.1881	±0.6346

Viscosity and Uncertainty for Castor Oil (Table 10):

Instance	**Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**Uncertainty ($kg \cdot m^{-1} \cdot s^{-1}$)**
Projectile of Radius 0.4204 cm at 15.7°C	2.2667	±0.4833
Projectile of Radius 0.4204 cm at 19.7°C	1.6120	±0.3461

Projectile of Radius 0.4204 cm at 22.6°C	1.1203	±0.2446
Projectile of Radius 0.3479 cm at 15.7°C	2.2953	±0.5625
Projectile of Radius 0.3479 cm at 19.7°C	1.6006	±0.3930
Projectile of Radius 0.3479 cm at 22.6°C	1.1055	±0.2737
Projectile of Radius 0.2661 cm at 15.7°C	2.3029	±0.7619
Projectile of Radius 0.2661 cm at 19.7°C	1.5819	±0.5223
Projectile of Radius 0.2661 cm at 22.6°C	0.9239	±0.3066
Projectile of Radius 0.2170 cm at 15.7°C	2.2063	±1.0495
Projectile of Radius 0.2170 cm at 19.7°C	1.5819	±0.7500
Projectile of Radius 0.2170 cm at 22.6°C	1.1324	±0.5361

Viscosity and Uncertainty for Honey (Table 11):

Instance	**Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**Uncertainty ($kg \cdot m^{-1} \cdot s^{-1}$)**
Projectile of Radius	18.0065	±5.0372

0.4204 cm at 16.6°C		
Projectile of Radius 0.4204 cm at 19.3°C	16.0208	±4.4792
Projectile of Radius 0.4204 cm at 26.5°C	10.0573	±2.8121
Projectile of Radius 0.3479 cm at 16.6°C	18.0022	±5.6934
Projectile of Radius 0.3479 cm at 19.3°C	16.0780	±5.0815
Projectile of Radius 0.3479 cm at 26.5°C	9.9627	±3.1467
Projectile of Radius 0.2661 cm at 16.6°C	18.1649	±7.4406
Projectile of Radius 0.2661 cm at 19.3°C	15.7411	±6.4439
Projectile of Radius 0.2661 cm at 26.5°C	10.1654	±4.1565
Projectile of Radius 0.2170 cm at 16.6°C	17.6765	±9.9755
Projectile of Radius 0.2170 cm at 19.3°C	18.0065	±8.9313
Projectile of Radius 0.2170 cm at 26.5°C	9.9127	±5.5847

Observation:

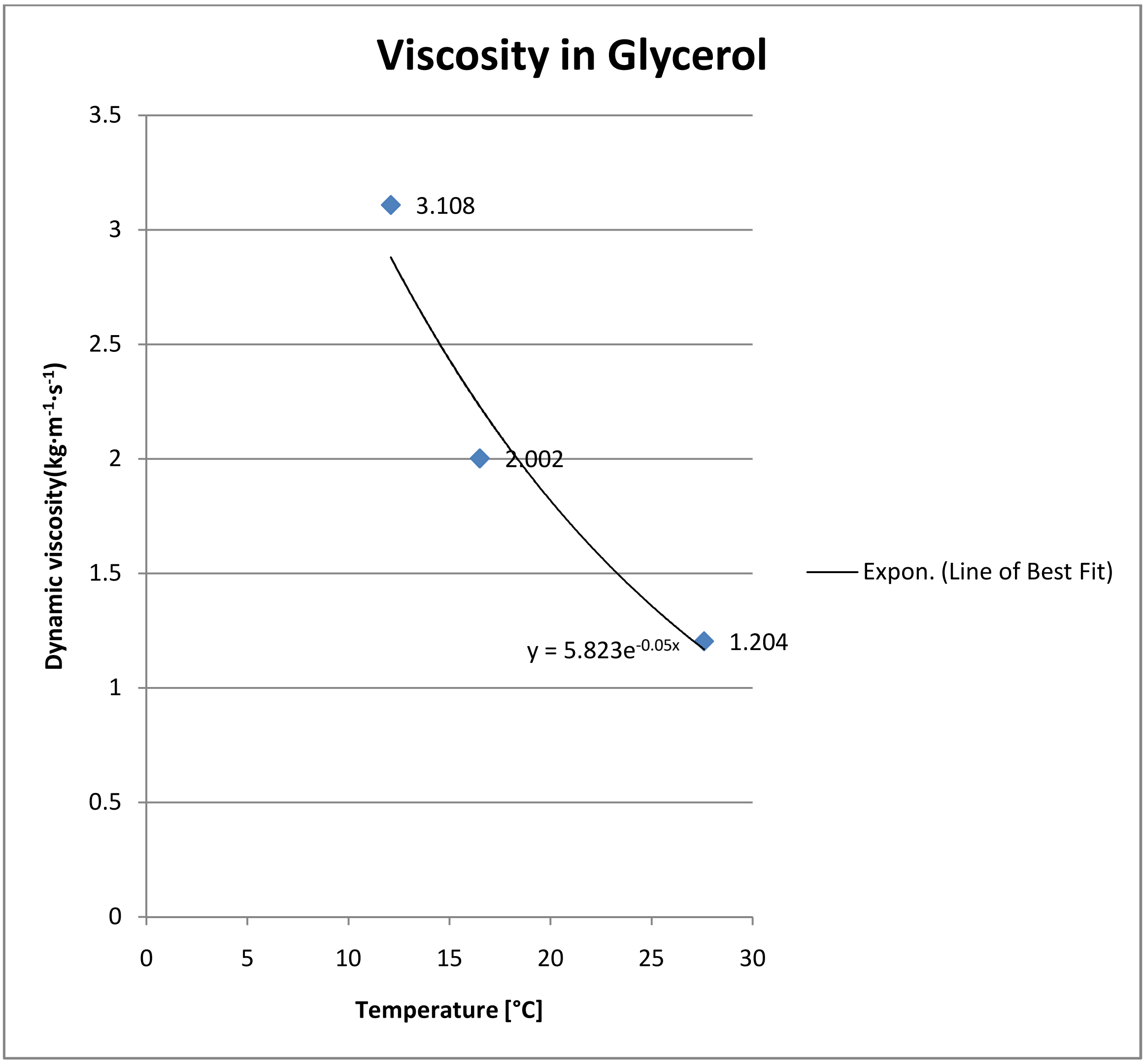
A graph of average viscosity verses temperature for each liquid.

Glycerol(Table 12)

Temperature °C	**Viscosity ($kg·m^{-1}·s^{-1}$)**	**Absolute error in Viscosity ($kg·m^{-1}·s^{-1}$)**	**%error in Viscosity**
12.1	3.108	±1.138	36.6
16.5	2.002	±0.735	36.7
27.6	1.204	±0.445	37.0

Average percentage error = 36.7%

Graph 1

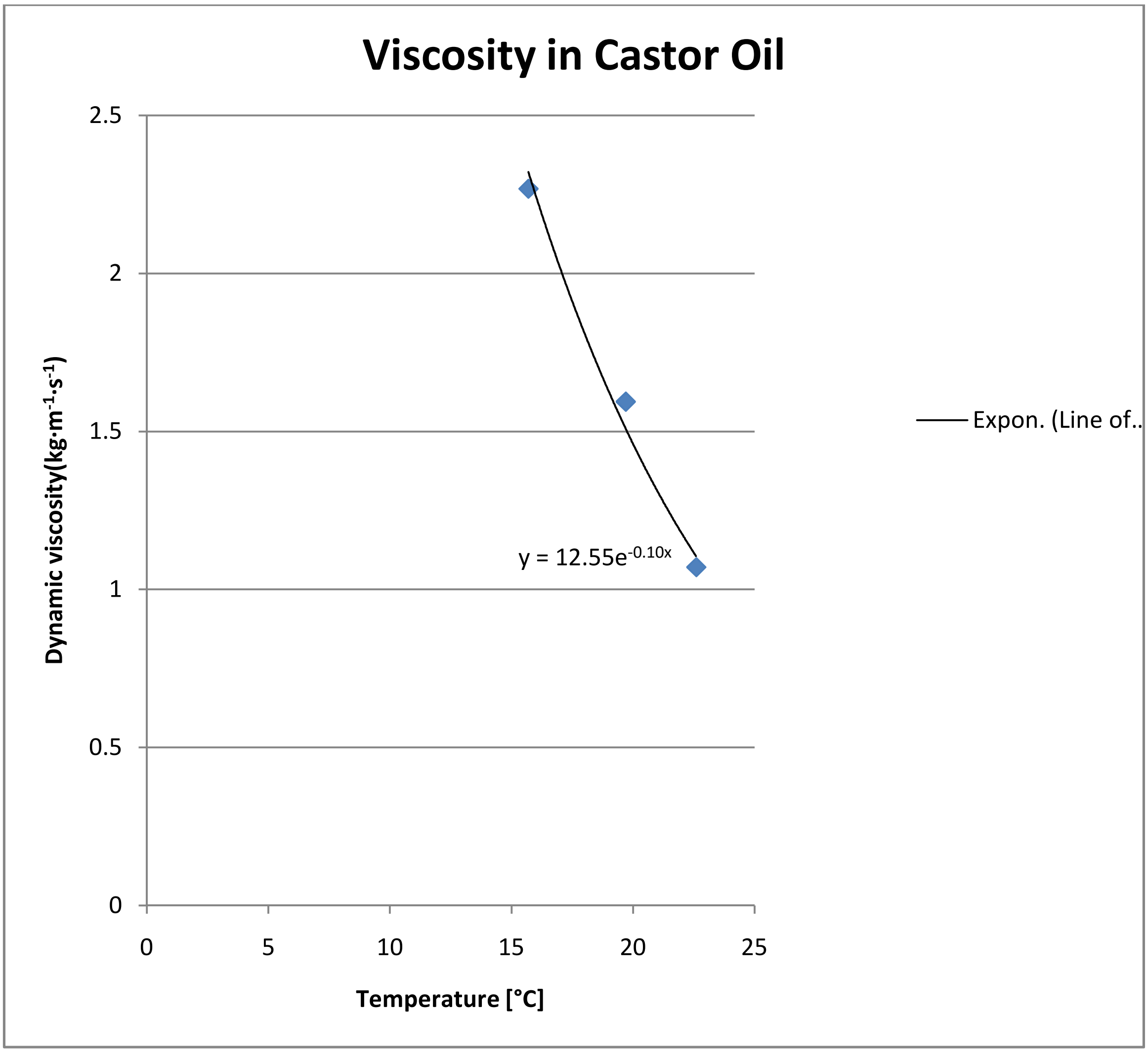


Castor Oil (Table 13)

Temperature °C	**Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**Absolute error in Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**%error in Viscosity**
15.7	2.2678	±0.714	31.5
19.7	1.598	±0.503	31.5
22.6	1.0705	±0.340	31.8

Average percentage error = 31.6%

Graph 2

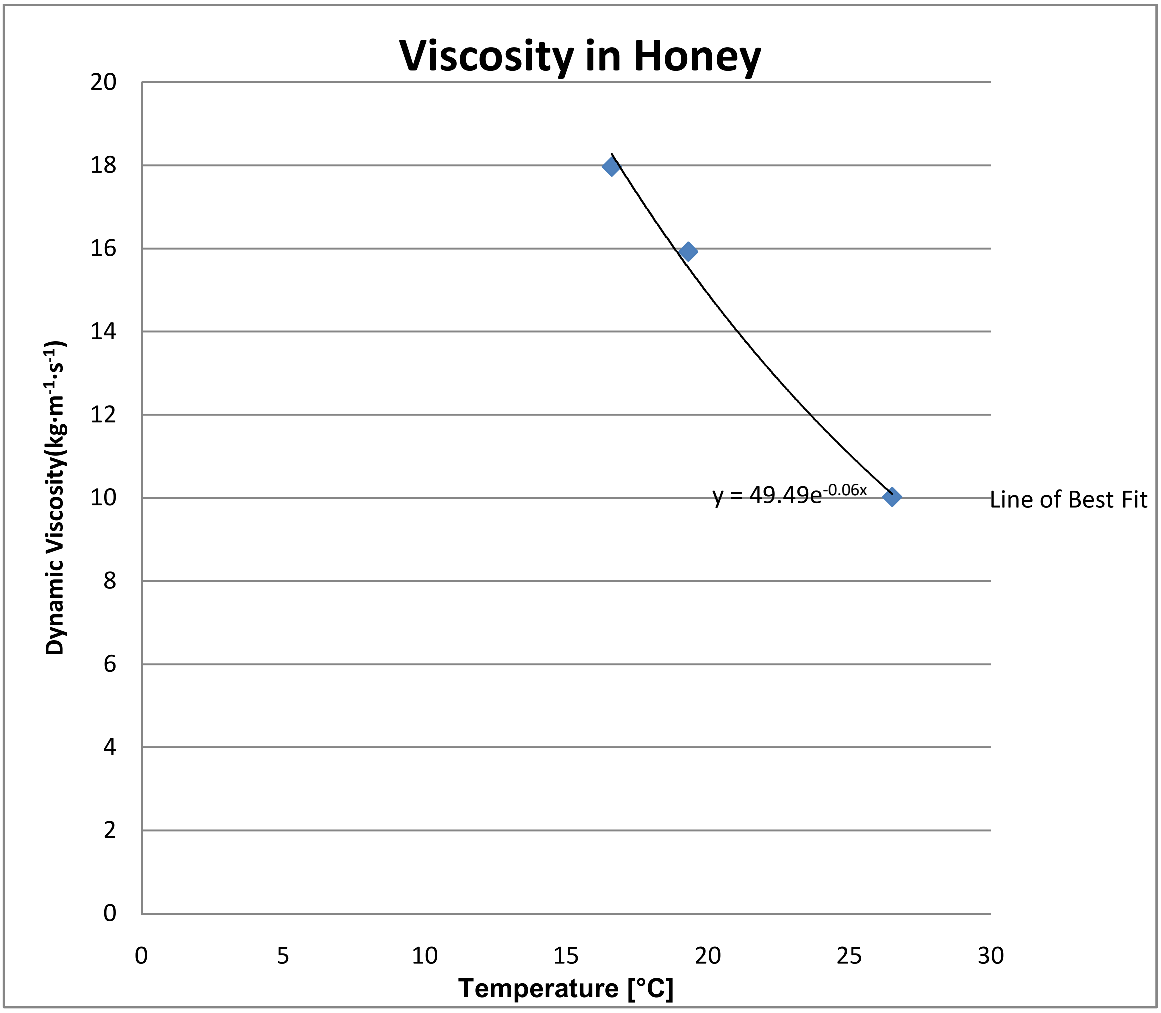


Honey (Table 14)

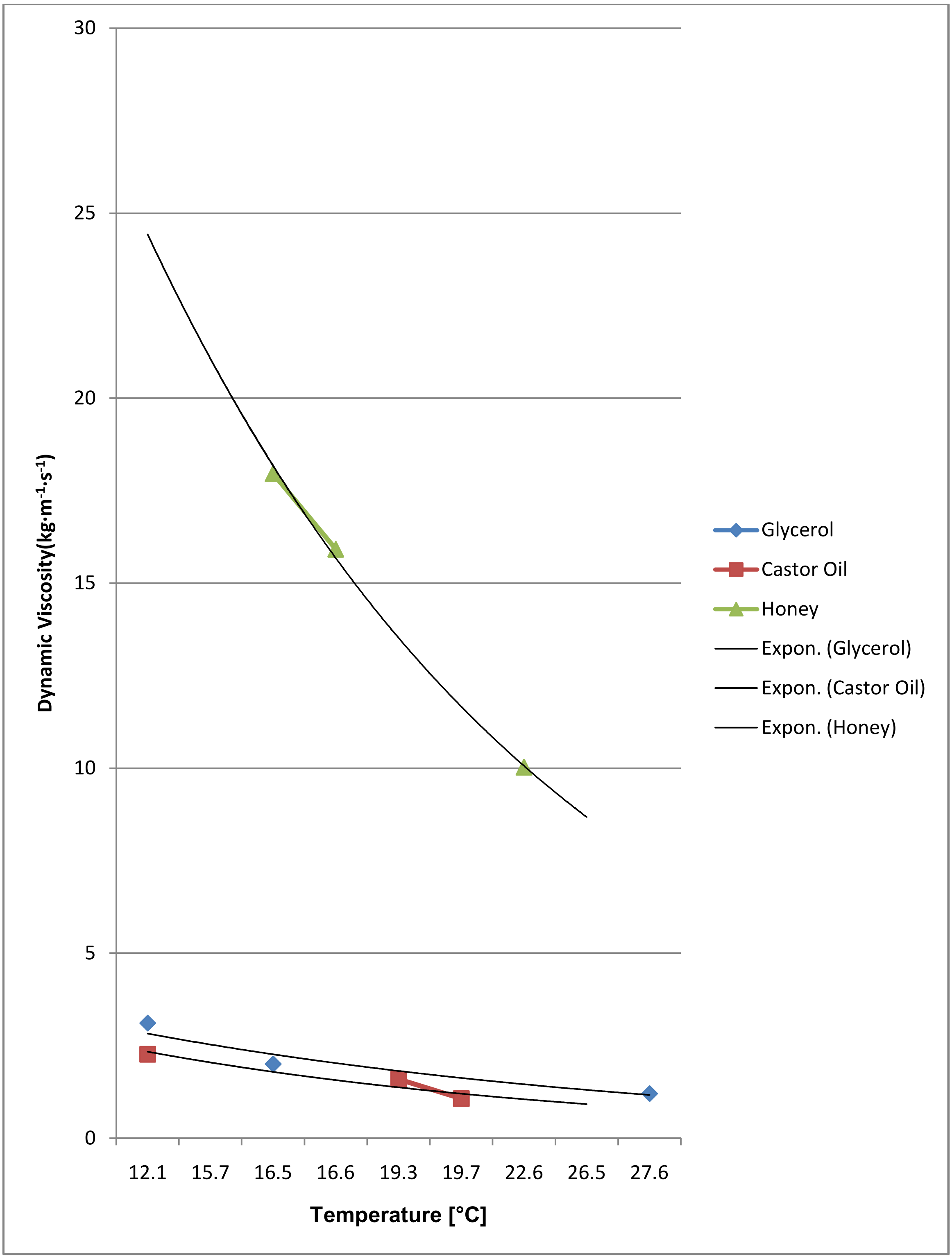
Temperature °C	**Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**Absolute error in Viscosity ($kg \cdot m^{-1} \cdot s^{-1}$)**	**%error in Viscosity**
16.6	17.962	7.037	39.2
19.3	15.918	6.234	39.2
26.5	10.024	4.175	41.7

Average percentage error = 40.0%

Graph 3


Viscosity in Honey
Dynamic Viscosity(kg·m-1·s-1)
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
Temperature [°C]
y = 49.49e-0.06x
Line of Best Fit

Graph 4 Combination Graph



Conclusion

From the experiments conducted and the data obtained, I am able to verify that the viscosity does indeed change with change in temperature, with the viscosity increasing with a decrease in temperature. This trend follows almost an inverse proportionality in the case of Glycerol but an exponential curve for Castrol and Honey.

I am also able to obtain the relationship between the viscosity of a liquid and the velocity of a projectile travelling through it, and the relation between the temperature of a liquid and the velocity of a projectile travelling through it.

The equation obtained from Stokes Law is verified as we obtain concordant results, and this could only be possible if the equation itself was correct and applicable to this situation.

Evaluation

Problems arise while trying to determine the viscosity of water using the velocity of the projectile in water. Lack of sufficient vertical distance for the water to reach its terminal velocity is a major problem. In addition to that certain limitations of Stokes Law come into play when considering the viscosity of water and the velocity of objects travelling through it. Stokes Law applies when the projectile moving through a liquid medium does so in a smooth and gradual manner. This does not apply to a projectile freely falling in water, because in this case, the motion of the ball bearings is rapid and since the water flow around the ball is not laminar, but turbulent. Therefore rather than Stokes Law being used to calculate the velocity here, Newton's Resistance Law would be applicable. Newton's law does not deal with the viscosity of the liquid mediums, rather, it considers the drag force within the fluid. For these reasons, the results obtained from the experiments conducted in water, are vastly inconclusive and non- concordant with the rest of the values obtained from this experiment.

Applications

This experiment can be used when conducting experiments or working with fluids in different parts of the world as temperature conditions differ around the world, such as at the equator and north of the arctic circle. It can be used to find the deviations of viscosity of fluids from their S.T.P. values in order to make up for any inaccuracies in experiments. Additionally, by comparing the calculated viscosity of a fluid and the temperature, we can find the estimated purity of substances.

Calculation of Percentage Uncertainty

The theoretical values for the viscosities of the liquid mediums utilised differ slightly from the values that we have obtained experimentally. The errors obtained for each liquid medium's viscosity, with the average percentage error taken across each temperature, are (using the formula Percentage Uncertainty= $\frac{Uncertainty}{Experimental\,Value} \times 100$):

Table 12, 13 and 14 prior to the viscosity verses temperature graphs clearly show the uncertainty in viscosity of fluids considered. For example in the case of glycerol the uncertainty is calculated as

Glycerol(Table 12)

Temperature °C	**Viscosity ($kg\cdot m^{-1}\cdot s^{-1}$)**	**Absolute error in Viscosity ($kg\cdot m^{-1}\cdot s^{-1}$)**	**%error in Viscosity**
12.1	3.108	±1.138	36.6
16.5	2.002	±0.735	36.7
27.6	1.204	±0.445	37.0

There could be many reasons for this uncertainty. These could include:

1. A trend can be observed in the uncertainties, such that the uncertainties increase the smaller the projectile is. Thus to obtain definite results, a projectile of radius greater than 0.3 cm should be used.

   Table 15:

Glycerol	**Experimental Value of Viscosity ($kg\cdot m^{-1}\cdot s^{-1}$)**	**Uncertainty ($kg\cdot m^{-1}\cdot s^{-1}$)**	**Percentage Uncertainty**
Projectile of Radius 0.4204 cm at 12.1°C	3.1267	±0.8082	25.85%
Projectile of Radius 0.4204 cm at 16.5°C	2.0538	±0.5364	26.12%
Projectile of Radius 0.4204 cm at 27.6°C	1.2233	±0.3255	26.61%

Projectile of Radius 0.3479 cm at 12.1°C	3.1362	±0.9178	29.26%
Projectile of Radius 0.3479 cm at 16.5°C	1.9912	±0.5865	29.45%
Projectile of Radius 0.3479 cm at 27.6°C	1.1886	±0.3538	29.77%
Projectile of Radius 0.2661 cm at 12.1°C	3.1006	±1.1866	36.08%
Projectile of Radius 0.2661 cm at 16.5°C	2.0002	±0.7671	38.35%
Projectile of Radius 0.2661 cm at 27.6°C	1.2164	±0.4678	38.46%
Projectile of Radius 0.2170 cm at 12.1°C	3.0712	±1.6387	54.82%
Projectile of Radius 0.2170 cm at 16.5°C	1.9649	±1.0490	53.38%
Projectile of Radius 0.2170 cm at 27.6°C	1.1881	±0.6346	53.41%

2. A change in the actual temperature of the liquid medium between the time of measuring the temperature and the time of conducting the experiment can bring about a change in the viscosity from the time of measurement and the time of conducting the experiment, and thus cause the theoretical value to differ from the experimentally obtained value.

3. The theoretical values assume that the experiment is conducted at standard pressure conditions (Since temperature is varying, standard temperature conditions are not considered), and the experiment is not actually conducted at the exact required conditions.
4. Misinterpretation of apparatus readings and random human error can also cause a slight error in the values obtained from the experiment that are used in the calculations.
5. Limitations in the camera's frame rate (only being able to record at 60 frames per second), could provide slight inaccuracy in the time taken by the projectile and thus lead to inaccuracy in the calculated velocity of the projectile.
6. The inability of a projectile to reach its terminal velocity in a water medium in a measuring cylinder of this size can be a cause of further inaccuracy when considering the experiment conducted in a water medium.

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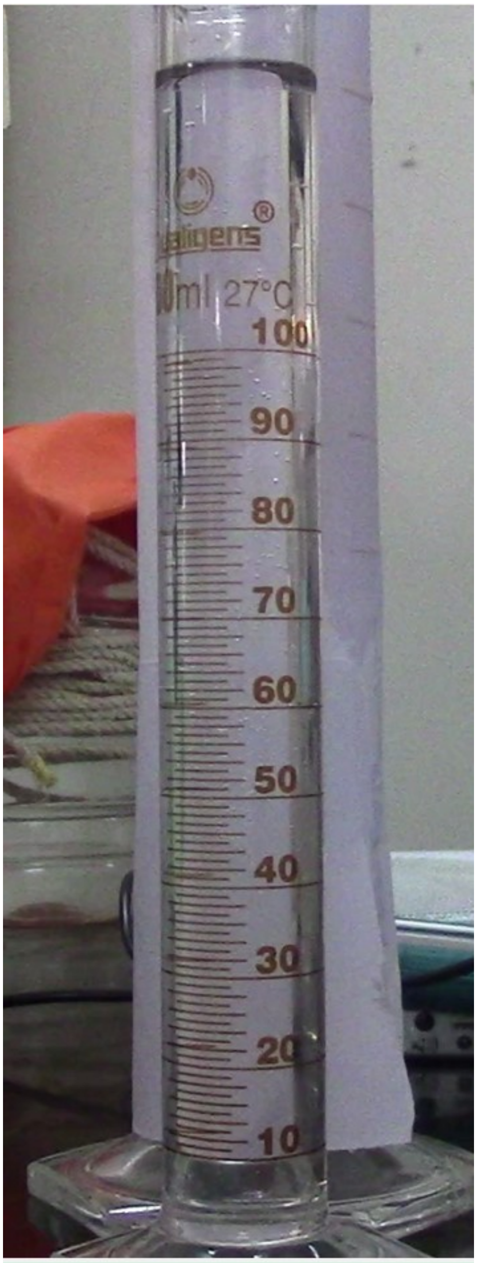
Appendix



Img6: Initial setup of the experiment.

Img7: Final revised setup of the experiment. (Image of Experiment for Glycerol)

Img8: Image of Experiment for Honey

Img 9: Image of Experiment for Castor Oil

Img 10: Image of Experiment for water