# Viscosity Measurements

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## Abstract

Experimentation determined viscosities of two unknown liquids within viscometers by measuring the timed the descent of an object within the fluids. A full uncertainty analysis was done to determine systematic strengths and weaknesses within the experiment, and find the accuracy of the experimental results. Twenty repeated observations averaged the time each object fell a set distance within each fluid. Fluids B and C showed fairly similar drop times of respectively 32.76 and 35.21 seconds. Even so, because of the different weights of the objects dropped in each fluid, the viscosity calculated for each was $34.45 \pm 0.41cP$ and $137.11 \pm 1.39cP$ for fluids B and C. Uncertainty in the viscosity formulation of fluid B and C is respectively 1.18% 1.01%, confirming the precision of the experiment and matching the viscometer's documentation on estimated uncertainty for a given experiment.

(138 words)

## Introduction

The purpose of these experiments is to determine the viscosity of two unknown fluids. The uncertainty of the measured viscosities are reasonable if they are between $\pm 0.2 to \pm 1.0\%$ according to documentation on the Gilmont falling ball viscometer [1]. Viewed in Figure 1, the Gilmont Falling Ball viscometer contains a viscous oil and a sphere that moves within it.

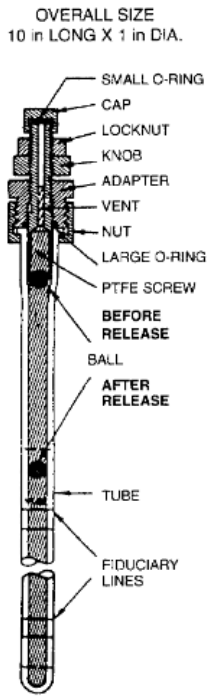


Figure 1: Gilmont Falling Ball Viscometer Design [1]

Viscosity is an intensive fluid property, independent of the system's mass. A fluid is a liquid or gas that deforms continuously under shear stress. As a force is applied on a fluid element it approaches a constant rate of shear strain, unlike solids that stop deforming at a fixed angular displacement. The viscosity of the fluid is its internal resistance to the applied force. Therefore, the viscosity of a fluid quantifies the relationship between its shear stress and the rate of deformation. Viscosity can be proportionally linear as seen in Newtonian fluids, non-linear in Pseudoplastics and Dilatant fluids, or develop a linear proportionality after the yield stress is overcome, like Bingham plastics. This type of viscosity is known as Dynamic Viscosity. The Kinematic Viscosity quantifies the relationship between dynamic viscosity and the density of the fluid. The dynamic viscosity measures the fluid resistance to flow when a force is applied, while kinematic viscosity measures

the resistance of its own flow, due to its weight. Because of the external weight of an object was applied to each fluid, this test the measured dynamic viscosity of each fluid. This is confirmed by use of the unit Poise, exclusively measuring dynamic viscosity.

Prudence when measuring with the given instrumentation ensures accuracy to a certain confidence interval. Uncertainty analysis quantifies the confidence interval by accounting for errors added by measured variables within the viscosity calculation. This technique uses partial derivatives to quantify the uncertainty produced by each individual variable.

The subsequent section is an experimental set-up explaining the techniques and steps taken to perform the experiment. Next, the resulting data is explained and interpreted, including calculation of experimental uncertainty. A discussion of these results will analyze and explain agreement to expected results, as well as interpreting trends and inspecting sources of experimental error. To conclude this study, its importance is evaluated and improvements are suggested.

## Experimental Set-up

Two viscometers (as shown in Figure 1) were selected at random. Each viscometer was labeled with a letter and each was full of a different oil. The letters on the two that were chosen, B and C respectively, corresponded with graduated cylinders of the same two respective oils. The density of each oil was determined by finding the mass of the oil alone and dividing by the volume.

Viscometer B was in a pitcher full of water at $20.1^oC$ and viscometer C was in a pitcher full of water at $20.6^oC$. This was to keep the oils at a constant and measurable temperature because viscosity is affected by temperature. The ball in viscometer B was made of stainless steel, while the ball in viscometer C was made of glass. The viscometers were inverted to let the ball sink to the top. The viscometers were then placed upright in the water. The descent of each ball was timed. The stopwatch was started when the ball was halfway between the two marks (fiduciary lines) near the top, and then stopped when the ball fell halfway between the bottom fiduciary lines on the viscometer. There was space between the top of the viscometer and the upper fiduciary lines to ensure that the ball had accelerated to near terminal velocity before timing began. Each ball was timed 20 times to reduce the effect of random error.

## Results

Measuring the mass of the empty and full beakers and reading the volume of the liquid in each produced the values in Table 1. This preceded determining the densities of fluid B and C to be 0.845 g/mL and 0.853 g/mL, respectively. Fluid densities ($\rho_{fluid}$) were used along with the densities of the glass balls ($\rho_{ball}$), the average time the ball traveled between the fiduciary lines (t, from Table 1), and a viscometer constant (K), in the equation below to discern the viscosity ($\mu$) of each oil.

$$\mu = Kt(\rho_{ball} - \rho_{fluid})$$

The oils had similar densities, as seen in Table 1, and the balls each fell the same distance in a similar amount of time. The stainless steel ball in fluid B was more dense than the glass ball, and so even though they fell at similar rates, oil B was evaluated to have a viscosity of 34.45 ± 0.41 cP while fluid C's viscosity was 137.11 ± 1.39 cP. Each property recorded after one produced an uncertainty based on the precision of the tool used to measure it. In the case of the time variable containing 20 measurements, either the uncertainty given by the precision of the watch, or the uncertainty given in the noise of the twenty experiments can be used. The uncertainty in each variable compounded, so what alone would have been ±0.001% eventually affected the total outcome slightly more. Using the precision of each variable, uncertainties compounded to 1.01% for fluid C and 1.18% for fluid B. Instead using the noise within the twenty time measurements along with the rest of the precision uncertainties produced a total uncertainty of 1.08% and 1.54% for C and B, respectively. In both cases, the uncertainty value for C varied by less, so was more accurate.

| **Fluid** | **Empty Beaker** (g) | **Mass full** (g) | **Mass Oil** (m) | **Volume** ($cm^2$) | **Density** at $20^oC(g/mL)$ | **Temperature** |
|---|---|---|---|---|---|---|
| B | 108.3 | 131.2 | 22.9 | 27.1 | 0.8450 | $20.1^oC$ |
| C | 104.4 | 142.2 | 37.8 | 44.3 | 0.8532 | $69.0^oF$ |

Table 1: Measurements for calculating fluid densities before testing

See Appendix A: Raw Data

## Discussion

It was assumed that the velocity of the balls falling in fluid remained near constant throughout each trial, so the time of descent would also. Assuming fluid temperature was not changing and

the viscometer was not altered during the ball's descent, there should not be physical property changes of the fluid between the twenty trials. Also because of the large differences in ball density even though the times of descent were very similar, the densities were expected to be relatively far apart. Ultimately, the fluid surrounding the glass ball was expected to be less viscous than the fluid surrounding the stainless steel ball. This is because in order to reach a constant speed similar to that of the denser stainless steel ball, the less massive glass ball needs less viscous drag resisting its mass accelerating downwards. There would have to be less resistance to deformation caused by the fluid on the surface of the sphere, and so the fluid would have to be less viscous.

The results confirm that the fluid the glass ball descended in was less viscous than the fluid the stainless steel ball descended in. The densities of the fluids were very similar, as were the descent times. Any discrepancies in the descent times for a fluid were then mainly caused by reaction time of the tester. Overall precisional uncertainty in measuring each other variable compounded upon this. The uncertainty in the time variable using the noise within the timed trials rather than the precision of the stopwatch yielded slightly larger uncertainties for the fluid's viscosities. This made sense, as the stopwatches timed to the hundredth of a second equating to an uncertainty of $\pm 0.005s$, compared to the uncertainty in reaction time varying up to $\pm 0.5s$. In this case the larger uncertainty should be used because it comprises the main source of error introduced to the experiment.

This lab was designed to find the viscosity of two fluids by comparing traits with Gilmont Falling Ball Viscometers. The results yielded viscosities for each that varied in magnitude relative one another as expected, C's viscosity larger than B's. The low error, just over 1% for each, is very close to the range of error the documentation of these particular viscometers predicted, from $\pm$ 0.2 *to* 1%. These results fulfill each objective of the study.

The only data collected by hand was the density of the fluid and the time it takes for the balls to fall a certain distance. Because some variable values were provided and sources for experimental error were scarce, the error in calculation was very low. Other factors built into this experiment that reduced errors were keeping the tubes in water so that the fluid temperature would not vary significantly at room temperature, or providing space in the tubes for the balls to fully accelerate before their descent was timed. Increasing temperature would affect viscosity, and the space allowing the ball to fully accelerate ensures constant velocity for reliable testing. Otherwise a calibration curve would be needed to adjust for the time spent accelerating, or else the relationship between the ball's time of descent and the dynamic viscosity would not be constant. The documentation

of the viscometer only supports fluids within a range of viscosities, possibly for this reason. These factors made the assumptions listed earlier very accurate.

A limitation of this experimental design is that the viscometer constant is given without the testing providing data needing to prove it, mainly the actual fluid viscosities were not supplied for comparison after calculation. In the viscosity equation, having no viscosity value to compare to and no understanding of where the constant comes from is similar to one equation with two unknowns. Overall, there were not significant difficulties in the testing of this experiment because it was well designed and many sources of error were mitigated.

## Conclusion

Similar experimentation could be used to determine viscosities while fabricating lubricants to optimize performance. With the innumerable uses for friction reducing solvents like oils, that must be a very large industrial application for like experiments. The calculated viscosities are supported directly by the data and contained low uncertainty, so these results are highly likely to be precise. In a similar future experiment, more information and understanding would be gained from instead having one fluid with a documented viscosity but missing a viscometer constant, and one fluid without a viscometer constant or a viscosity. This would both compare viscosities like this experiment was meant to do, and prove the viscometer constant through application.

## References

[1] Gilmont, R., 1963, "A Falling-Ball Viscometer," https://pim-resources.coleparmer.com/instruction-manual/08702-10.pdf

## Appendix A:

| Trial | Viscometer B (s) | Viscometer C (s) |
|---|---|---|
| 1 | 32.76 | 35.70 |
| 2 | 33.22 | 35.34 |
| 3 | 32.96 | 35.25 |
| 4 | 33.51 | 35.32 |
| 5 | 33.15 | 35.15 |
| 6 | 32.78 | 35.27 |
| 7 | 32.95 | 35.18 |
| 8 | 32.45 | 35.03 |
| 9 | 32.84 | 35.46 |
| 10 | 32.82 | 35.20 |
| 11 | 33.02 | 35.21 |
| 12 | 32.45 | 35.10 |
| 13 | 32.44 | 35.28 |
| 14 | 32.77 | 35.01 |
| 15 | 32.57 | 35.08 |
| 16 | 32.78 | 34.88 |
| 17 | 32.87 | 35.10 |
| 18 | 32.59 | 35.26 |
| 19 | 33.00 | 35.21 |
| 20 | 32.22 | 35.15 |

Table 2: Timed Descent of dense balls in each fluid

## Re-submission Reflection

The week of submission, my team met and appointed sections we could individually do, then planned to meet up again and edit before submission. Although everything was written, because of time constraints and planning issues, editing and revision were not completed even on a basic level. I knew we could have look over each other's work more closely, though I expected a B. We received a C+ not because I expected easier grading, but because I did not realize the extent of simple mistakes, oversight, and confusion caused by our lack of editing. Our strengths included finding interesting tangents, and willingness to write in bulk. That is not often the case in a group. These strengths were weaknesses in the context of a formal lab, however. In the sections we completed last, instead of revisions the sections were made longer in the mentality of 'We'll include this, just in case'. This was a poor use of time, and instead allocating item to revision would have greatly increased the quality. Specifically, some sections needed more concise, less narration style language. The most painful mistakes were due to forgetting to fix something, or focusing on something that makes no sense in the context of a formal report.

I am not the strongest writer in the group, though many of the mistakes only required revision. Errors were addressed by rewording a nebulous phrase, cutting large chunks of unneeded text, and reorganizing. The most extreme cases involved rewriting large portions of text, with the hope that being more careful will increase clarity and answer the questions asked. I re-wrote the entire abstract, cut entire paragraphs from the introduction and discussion, reworded here and there, and added to the discussion more carefully. In all, with busy schedules and one of us being out of the state for a day or two before the deadline, I estimate the group worked 15-20 hours on this report. A good report can be written in this time, but with better use of it.