**Coursework Title**

### **Report 2: Viscous Fluids**

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| **Name (s)**  **Mingdong He**  **Yu’ang Li**  **Tianyu Sun** | **ID Number (s)**  **20126521**  **20126362**  **20126367** | **Date Handed In**  **2018/12/4** |
| **Module Title:** Foundation Science A | | **Module Convenor**  Neil Arnold |
| **Coursework Title:** Viscous Fluids | | **Module Code**  CELEN039 |

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### **SUMMARY:**

The diameter and the time of a ball- bearing falling from a certain distant were measured to investigated that whether the laws of fluid dynamics can model the motion of a ball-bearing travelling through glycerol and correctly predict its terminal velocity. The diameter of a ball-bearing and the length between the mark of 600 ml and 300 ml were measured by a caliper and a ruler respectively. The ball was dropped into the oil closed to the surface, and the time of travelling the distant between the mark of 600ml and 300 ml, was measured by using a stopwatch. The procedure was repeated with different diameter of the ball. But only one of the results agrees with the predicted value, when reasonable uncertainties from measurement and modelling assumptions were considered. Therefore, these experimental results could not be used to support the hypothesis.

### **OBJECTIVES:**

The aim of this experiment is to investigate the law of fluid dynamics, which states that;

*The terminal velocity is equal to the product of the quantity of the gravitation and the quantity of the difference between the ball’s density and the fluid’s density and the quantity of the diameter squared divided by the 18 times the viscosity.*

Eqn.1

Where the units of g, D, , are , m, , Pas respectively.

### **INTRODUCTION:**

In 1851, Stokes proposed the Stokes’ law. The laws of fluid dynamics were found to give a description of the motion of objects travelling through fluid. In this experiment, we investigated whether the laws of fluid dynamics can model the motion of a ball-bearing travelling through glycerol and correctly predict its terminal velocity



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**Figure 1*.*** Free-body diagram showing the force acting on the metal ball-bearing.

The ball-bearing was released at zero velocity. The initial drag force was zero due to the initial velocity. At the beginning, the weight was greater than the buoyancy so the velocity of the ball started to increase. As the ball-bearing moved, the drag force increased so the acceleration decreased. Consequently, the ball-bearing moved at a terminal velocity constantly and it was subjected to 3 forces as the Figure 1. shows: the weight of the ball , the buoyancy of the ball , due to it being submerged; and an instantaneous drag force , due to the viscosity of the fluid according to Stokes law. And the net force of the ball-bearing was zero. Assuming that the Reynolds’ number of the largest ball-bearing was less than 1, so we can use the Stokes’ law. The temperature of oil and the gravitation were assumed to be constant, with g=9.81ms-2 respectively.

According to the formula of Reynolds’ number:

Eqn.2

Then we calculate this value for the largest ball-bearing. For measurement 6.

Then we calculate the measurement 5.

Therefore, for the measurement 1.2.3.4.5, the assumption was valid.

As Figure 1. shows the force acting on the metal ball-bearing

Eqn.3

According to Archimedes principle, the buoyancy of the ball is given by

Eqn.4

Eqn.5

By using Stokes law, the drag force of the ball is given by

Eqn.6

The weight is given by

Eqn.7

By plugging the expressions of these forces into the Eqn.

Therefore

Eqn.8

By simplifying the equation,

Therefore

Eqn.1

### **APPARATUS**

* Stopwatch.
* Thermometer
* Electronic scales
* 6 metal ball bearings
* Graduated cylinder
* Ruler
* Calipers
* Sample of oil

### **PROCEDURE**

The apparatus was assembled and the diameter and the mass of the ball-bearing were measured. The length between the mark of 600ml and 300 ml was measured. A ball was dropped into the oil closed to the surface, and the time of travelling the distant between the mark of 600ml and 300 ml, was measured by using a stopwatch. The step was repeated for each of the ball-bearing. The measured terminal velocity for each measurement could be calculated and by using the laws of fluid dynamics, the predicted terminal velocity could be calculated and these values were recorded in Table 1.

**RESULTS:**

As an example, the volume of the ball was calculated by using the following equation when the diameter of the ball was 0.00099 m

Eqn.9

So the density of the ball- bearing was calculated to be

Eqn.10

The measured velocity and the predicted velocity were calculated by using the following equations, and these are recorded in the seven and eight column of Table 1.

Eqn.11

Eqn.1

**Table 1.** Measured and predicted values for each ball bearing.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Measurement no.** | **Diameter** | **Volume** | **Mass** | **Density** | **Time** | **Terminal Velocity** | |
| **(m)** | **(** | **(kg)** |  | **(s)** | **(m/s)** | **(m/s)** |
| 1 |  |  |  |  | 30.6 |  |  |
| 2 |  |  |  |  | 13.9 |  |  |
| 3 |  |  |  |  | 7.74 |  |  |
| 4 |  |  |  |  | 5.09 |  |  |
| 5 |  |  |  |  | 4.00 |  |  |
| 6 |  |  |  |  | 2.00 |  |  |

**Table 2.** Additional measurements

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measurement** | **Length**  **(m)** | **Average density** | **Density of the fluid** | **Viscosity** |
| **Value** | 0.0895 | 7018.2 | 1262.6 | 1.1786 |

Figure 2.

**UNCERTAINTY ANALYSIS:**

The length was measured by a ruler with a precision of uncertainty of 1 mm. This leads to uncertainty

Eqn.12

m

All diameters were measured by a calipers with a precision of uncertainty of 0.001 mm. This leads to uncertainty in each diameter

Eqn.13

The uncertainty associated with the measured mass, 𝑀, can be calculated using the following equation

Eqn.14

The uncertainty associated with the measured time, 𝑡, can be calculated using the following equation

Eqn.15

s

The uncertainty associated with the volume of the ball-bearing, 𝛿𝑉, can be calculated using the following equation

Eqn.16

The uncertainty associated with the density of the ball, 𝛿𝜌𝑏, can be calculated using the following equation

Eqn.17

The uncertainty associated with the average density of the ball,,can be calculated using the following equation;

Eqn.18

The uncertainty associated with the measured terminal velocity 𝛿𝑉∞,𝑚 , can be calculated using the following equation;

Eqn.19

The uncertainty associated with the predicted terminal velocity, 𝛿𝑉∞,p , can be calculated using the following equation;

Eqn.20

The standard uncertainty was calculated to be +/-, and is shown in the first row of column 8 of Table 3. All figures in Table 3 are given to two decimal places.

**Table 3.** Uncertainties associated with measured and predicted values for each ball bearing.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Measurement no.** | **Diameter** | **Volume** | **Mass** | **Density** | **Time** | **Terminal Velocity** | |
| **(m)** | **(** | **(kg)** |  | **(s)** | **(m/s)** | **(m/s)** |
| 1 |  |  |  | 570 | 0.105 |  |  |
| 2 |  |  |  | 170 | 0.101 |  |  |
| 3 |  |  |  | 77.0 | 0.100 |  |  |
| 4 |  |  |  | 45.0 | 0.100 |  |  |
| 5 |  |  |  | 35.9 | 0.100 |  |  |
| 6 |  |  |  | 29.1 | 0.100 |  |  |

**Table 4.** Uncertainties associated with additional measurements

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Measurement** | **Length**  **(m)** | **Average density** | **Density of the fluid** | **Viscosity** |
| **Uncertainty** | 0.00091782 | 114.5 | 0.3 | 0.0012 |

**DISCUSSION:**

It is clear from examining Tables 1&3 only one of the measured period values comes within the corresponding terminal velocity value range. Figure 2 shows a graphical definitive trend that as the value of diameter squared increases the measured terminal velocity become great and all the measured terminal velocity are greater than the predicted values. This demonstrates there is an issue with either the mathematical model used for this experiment or an error in the experimental technique, regardless these results do not support the initial hypothesis. These results which do not agree with predicted values are all larger than expected, therefore the most likely causes of this discrepancy are:

* the motion of the ball-bearing was not completely at a constant velocity and it still had acceleration, which made the measured terminal velocity greater.
* There was bubble when the ball was dropped into the oil, which made the volume of the ball increase so the viscosity became bigger. According to the equation (1), the denominator increased so that the predicted velocity was less than the measured velocity.

For Figure 2. we can obtain the equation which can best depict the measured values

y = 2656.3x - 0.0005 Eqn.21

Compare this to equation(1)

Eqn.1

As y= and x=D2 has been plotted the theoretical straight line equation is

Eqn.22

Comparing these values

**Table 5.** Measured and predicted values for the trendline coefficients.

|  |  |  |
| --- | --- | --- |
|  | **Predicted Value** | **Measured Value** |
| **Gradient ()** |  | 2656.3 |
| **Intercept ()** | 0 0.00017 | -0.0005 0.00008 |

Obviously, the predicted measured values do not correspond one another so this experiment cannot be used to support out initial hypothesis. However, the value of the coefficient of determination, R2 is 0.9674 and the product moment correlation coefficient, r, is 0.9835, which implies that there is a very strong relationship between the x and y values. Although the equation which modelled for this relationship is not what was expected, there is a clear relationship between terminal velocity and the diameter squared.

**CONCLUSION:**

To conclude, in this experiment, the law of fluid dynamics was investigated. Only one of the results obtained was found to be within the corresponding predicted velocity. Although the value of R2 exactly suggest a strong relationship between the variables drawn in Figure 2, this cannot provide solid evidence to support our initial hypothesis. The key factor which affected the results is mostly likely to be the motion of the ball-bearing was not completely at a constant velocity, which could have caused a big discrepancy when calculating the velocity. This experiment could be further improved by;

* ensuring the ball-bearing have a enough distance to travel so that the terminal velocity could be more accurate
* ensuring that there is no bubble when drop the ball-bearing.
* ensuring that the operator’s sight line is tangent to the mark of the cylinder to reduce the error of measuring the time.