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EXPERIMENTAL ANALYSIS OF UPWARD MOTION OF OBJECT INSIDE LIQUID

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INTRODUCTION

Density of a substance is defined as the amount of mass contained per unit volume. And the force which opposes the motion object inside liquid is termed as Drag force. It is given by the expression

$F_{drag} = -\frac{1}{2}\rho_l C_D h'^2 A$

Where,

F_{drag} = Drag force

ρ_l = Density of liquid

C_D = Coffeicient of Drag

h' = Velocity

A = Cross section Area of the object

From the expression we can see drag force is proportional to the square of velocity of the object.[6]

When an object attains terminal velocity the drag force is equal and opposite to constant external force, so the velocity is constant,

We can explain this observation by taking microscopic model for viscosity. As the object is pulled through the fluid by a constant force, the object is also subjected to huge no. of microscopic collisions with fluid molecules. If we assume these collisions are periodic, there is one collision per time Δt. let's also assume that as a result of each collision, our object's velocity is "reset" to same random value v_o. Then before the next collision, the object moves freely, influenced only by the constant external force. The constant force produces a constant acceleration a= F_{ext}/m, so the object's velocity is given by the usual kinematic equation for constant acceleration.

$$v = v_o + \left(\frac{F_{ext}}{m}\right)\Delta t$$

We can imagine an object in motion in a viscous medium as experiencing "interrupted acceleration". The object accelerates for a short time Δt then it undergoes a collision, and its velocity is "reset" to some random value. Then it accelerates again for a short time and its acceleration is interrupted again. The overall result of interrupted acceleration is motion at a constant velocity[1].

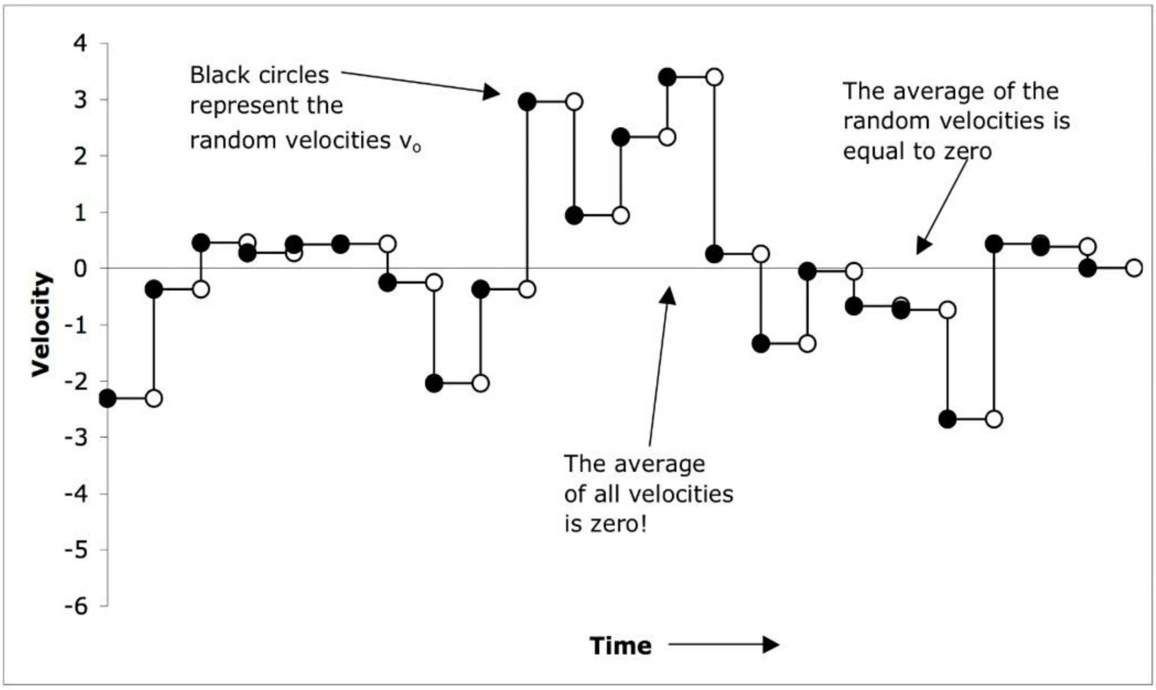

Figure 1.1 The object moves at a constant random velocity over each time interval as shown in graph.

According to Stoke ,if a sphere of radius 'r' moves through a liquid or fluid of coefficient of viscosity 'ŋ' with a constant velocity called terminal velocity 'v_t' then the viscous force on the sphere is given by F=6πŋrv_t[2]. This is known as Stoke's formula for viscous force. In other words, when viscous force acting on the body due to fluid plus the upthrust experienced by it is balanced by the weight of the object, the object starts to fall with constant velocity known as terminal velocity [2]. The velocity is attained due to effect of gravity. Similarly, Archimedes' Principle states that when a body is partially or completely immersed in a liquid (or a fluid), it experiences an upthrust which is equal to the weight of the displaced liquid (or fluid) [3]. When a body is partially or wholly immersed in a liquid, the liquid exerts an upward force on it and that upward force on the body is called upthrust [3]. The property of the fluid which opposes the relative motion between the two surfaces of the fluid is called viscosity [6] and when a layer of a fluid tends to move over another layer there acts a tangential force between the two layers of the fluid in a direction opposite to the flow of fluid and that tangential force is known as viscous force [7]. The two principles explain the properties of liquid and its effect on motion of immersed object on the following ways:

a. An object falls inside the liquid with constant velocity due to the balance between weight of the object and viscous force plus upthrust due to liquid[2].
b. When object is less dense than the liquid the object is pushed upward and when object is more dense then the liquid the object falls downward[2].
c. The weight of the object is equal to the upthrust it experiences due to liquid [3].

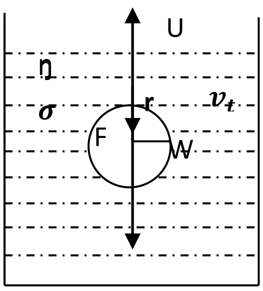

Figure 1.2 Figure showing forces acting on moving object inside liquid

In the figure,

U=Upthrust due to liquid

F=Viscous Force

W=weight of the object

Case I:($\boldsymbol{\sigma}$<$\boldsymbol{\rho}$)

From Stoke's law, W=F+U and the object falls with the constant velocity 'v_t'(terminal velocity).

Case II: ($\boldsymbol{\sigma}$>$\boldsymbol{\rho}$)

The object still moves up with constant velocity 'u' when allowed to move from bottom experiencing some force.

In case I, although the net force on object is zero, it falls down with constant velocity (terminal velocity) due to effect of gravity. But in cases II, it should not be misconceptized that the object moving up experiences the same magnitude of force as the force due to effect of gravity. In case it happens,

Resultant upward force = force due to effect of gravity

Then, there will be no any force for the motion of object. As a result, object should be in stationary position which doesn't happen in actual. Therefore the net force acting upward overcomes the force due to effect of gravity.

REVIEW

A pragmatic knowledge of fluid flow was exhibited by ancient civilization, such as in the design of arrows, spears, boats and particularly hydraulic engineering projects for flood protection, irrigation, drainage and water supply [4]. And the study of fluid dynamics goes back to at least the days of ancient Greece, when Archimedes investigated fluid statics and buoyancy. He formulated his famous law on the basis of these properties which is famously known Archimedes' principle. This law was published in his work 'On Floating Bodies' and is considered to be the first work on fluid dynamics. After him, Leonardo Da Vinci's observations and experiments, invention of barometer by Evangelista Torriceli, Isaac Newton's investigation of viscosity, research in hydrostatics and formulation of Pascal's law by Blaise Pascal gave a rapid advancement to fluid dynamics. Similarly, in 1738, Daniel Bernoulli introduced the mathematical fluid dynamics in his book named *Hydrodynamica*.

Mathematicians like Leonard Euler, Jean le Rond d'alembert, Joseph Louis Lagrange, Pierre-Simon Laplace, Simeon Denis Poisson further explored the inviscid flow and viscous flow was analyzed by Jean Leonard Marie Poiseuille and Gotthilf Hagen. Similarly the scientists like Claude-Louis Navier and George Gabriel stokes gave mathematical justification in Navier-Stokes equation.Also,Ludwig Prandtl and Theodore von Karman investigated the boundary layers of fluid. Further advanced understanding of fluid viscosity and turbulence was given by scientists such as Obsorne Reynolds, Andrey Kolmogorov and Geoffrey Ingram Taylor[5].

In 1904, a German engineer, Ludwig Prandtl (1875-1953), published perhaps the most important paper ever written on fluid mechanics. Prandtl pointed out that fluid flows with small viscosity (water and air flows) can be divided into a thin viscous layer, or boundary layer, near solid surfaces and interfaces, patched onto a nearly inviscid outer layer, where the Euler and Bernoulli equation apply. Boundary-layer theory has proven to be the single most important tool in modern flow analysis. The twetentieth-century foundations for the present state of the art in fluid mechanics were laid in a series of broad-based experiments by Prandtl and his two chief friendly competitors, Theodore von Karman (1881-1963) and sir Geoffrey I. Taylor (1886-1975)[12].

In 1851,George Gabriel Stokes derived an expression, now known as Stoke's law for the frictional force also called drag force exerted on spherical objects with very small Reynolds numbers(i.e. very small particle) in a viscous fluid[6]. During his experiment he found out that the ball's velocity go on

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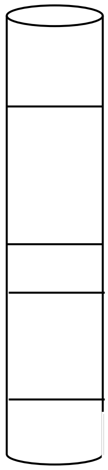
increasing initially and with the increase in velocity viscous force also increases. In this way, the velocity of sphere increases until the weight of the sphere is completely balanced by the viscous force and the force of upthrust. At this stage ball continues to move with constant velocity known as terminal velocity. And the expression for viscous force from his law is given by F=6πηrv_t, where symbols have their usual meanings [2].

METHODOLOGY



Experimental method is used to find out the velocity of object moving upward from the bottom inside liquid and to observe the motion of object. For this, domestically available liquid is used that is soyabean oil as experimental liquid. Similarly as experimental object different shapes of wax are used. For performing these experiments, experimental liquid is taken in a tube which is made from cylindrical tube of tubelight with suitable opening and suitable depth. For conducting experiment object is inserted to the bottom of tube using some heavy metal and a thin string, then is released and time will be noted. The experiment is repeated several times with different shapes of wax and data are collected as correct as possible. From the collected data velocity is calculated along with drag force.
The graph is plotted between velocity and drag force and the conclusions are drawn from the nature of curve so obtained. Also observing the velocity we concluded whether the velocity is constant or not.
The experiment will be carried out in the following way
Different sections of the tube will be considered as shown in figure. Oil will be filled inside tube above point D and stop watch will be initiated when the object (wax) reaches to point A starting from bottom. Time will be recorded at point C, B and D. To calculate the velocity, four different sections will be taken in account and those are AB, CD, CB and AD. Time taken in those different sections will be found out by simple algebra and hence velocity, average time, average height and average velocity are calculated from all the sections. No. of experiments will be repeated taking different shapes of object (wax) and velocities will be found out experimentally and hence drag force theoretically.

EXPERIMENTAL RESULT

Experiment 1
(Cylindrical wax)

Height of Tube(in cm) AD	Time(in second)	Velocity(cm/s)
70	240.930	0.291
70	237.944	0.292
70	241.060	0.290
70	243.732	0.287
70	240.929	0.291

Observation table 2.1

Height of Tube(in cm)AB	Time(in second)	Velocity(cm/s)
50	170.903	0.293
50	167.586	0.298
50	172.319	0.290
50	175.696	0.285
50	169.612	0.294
Height of Tube(in cm)CD	Time(in second)	Velocity(cm/s)
50	173.502	0.288

50	169.502	0.294
50	170.259	0.294
50	173.557	0.288
50	172.036	0.290
Height of Tube(in cm)CB	Time(in second)	Velocity(cm/s)
30	103.475	0.290
30	99.442	0.301
30	101.518	0.295
30	105.521	0.284
30	103.719	0.289

Observation table 2.2

Experiment 2
(Cylindrical Wax)

Height of Tube(in cm)AB	Time(in second)	Velocity(cm/s)
70	332.703	0.210
70	322.839	0.216
70	328.479	0.213
70	335.079	0.208
70	332.998	0.210

Observation table 3.1

Height of Tube(in cm)AB	Time(in second)	Velocity(cm/s)
50	240.428	0.208
50	227.038	0.220
50	240.113	0.208
50	241.208	0.207
50	244.02	0.205
Height of Tube(in cm)CD	Time(in second)	Velocity(cm/s)
50	234.886	0.213
50	221.385	0.225
50	229.568	0.217
50	234.66	0.213
50	235.803	0.212
Height of Tube(in cm)CB	Time(in second)	Velocity(cm/s)
30	130.611	0.229
30	125.584	0.238
30	141.202	0.212
30	140.789	0.213
30	146.825	0.204

Observation table 3.2

Experiment 3
(Cylindrical Wax)

Height of Tube(in cm)AB	Time(in second)	Velocity(cm/s)
70	270.339	0.259
70	266.032	0.263
70	272.058	0.257
70	278.7	0.251
70	268.592	0.260

Observation table 4.1

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Height of Tube(in cm)AB	Time(in second)	Velocity(cm/s)
50	194.644	0.257
50	195.166	0.256
50	197.291	0.253
50	201.657	0.248
50	201.818	0.248
Height of Tube(in cm)CD	Time(in second)	Velocity(cm/s)
50	192.15	0.260
50	188.184	0.265
50	195.694	0.256
50	201.812	0.248
50	190.599	0.262
Height of Tube(in cm)CB	Time(in second)	Velocity(cm/s)
30	126.455	0.237
30	117.318	0.255
30	120.927	0.248
30	124.769	0.240
30	123.825	0.242

Observation table 4.2

Height and Velocity

Height(in cm)	Average Velocity(cm/s)
Experiment 1	
30	0.292
50	0.291
70	0.290
Experiment 2	
30	0.219
50	0.213
70	0.211
Experiment 3	
30	0.244
50	0.255
70	0.258

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Table for plotting graph 5.1

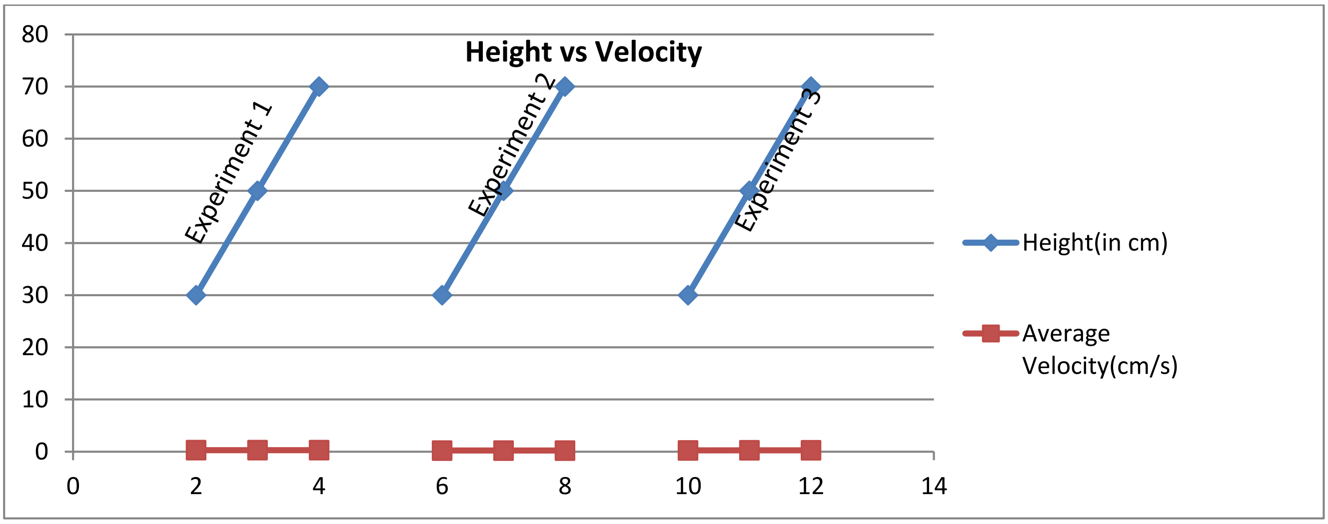

Figure 1.4 Plot between drag Height and Average velocity

CONCLUSION

Three different heights were taken for plotting graph and their average velocities were calculated for three different experiments. From the experiment and graph we found the velocity of object moving upward inside viscous liquid is constant. If we observe graph (Figure 1.4) then we can see at different height the object has nearly same velocity. The above inclined line represents the increasing height whereas the horizontal line below represents the average velocity. This proves that the object moving up inside liquid attains constant velocity throughout the travel. Some errors were seen during the recording of time due to the friction between object and wall of tube and due to the complicacies in making perfect shape of object as required but errors were minimized by performing the experiment several times and considering different sections of height of tube.

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