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Development of Local Apparatus for Investigation of Laminar and Turbulent Flow in Pipelines

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ABSTRACT: Fluid flows play an important role in a great number of natural phenomena and manmade systems. Fluid flow in pipes is commonly encountered in practice. A prototypeOsborne Reynolds apparatus was design and fabricated according to laid down engineering and industrial design procedure ethics. Standard design calculations were used to develop the drawing and specifications. The design drawings were then used in the fabrication of the apparatus, the functional component of the apparatus was either fabricated or purchased locally. The apparatus designed and fabricated was used to test for laminar and turbulent flowusing water and dye. The following flow rate was calculated (from the volume and time of flow discovered); 0.0000172, 0.0000179, 0.0000323, 0.0000345, 0.0000588 and 0.0000714 and their Reynolds number were 1249.73, 1294.67, 2341.43, 2499.66, 4264.12 and 5177.86 respectively.It was discovered that as the flow rate increased, the flow became more turbulent. From the above result it can be concluded that the Osborne Reynolds apparatus designed and fabricated can be used in the determination of laminar, transitional and turbulent flows.

KEYWORDS: Reynolds number, Laminar, Turbulent, Transitional, Osborne Reynolds Apparatus.

I. INTRODUCTION

Fluid flows play an important role in a great number of natural phenomena and manmade systems. Fluid flow in pipes is commonly encountered in practice. Water distribution in cities are done using extensive piping networks. Oil and natural gas are also transported over a long distance by large pipelines. Blood flows throughout our bodies via arteries and veins. The cooling water in an engine is circulated through hoses to the pipes in the radiator where it is cooled as it flows. Thermal energy in a hydronic space heating system is transferred to the circulating water in the boiler, and then it is transported to the desired locations through pipes [1].

Flows completely confined by solid surfaces are called **internal flows** which include flows through pipes (Round cross section), ducts (Not Round cross section), nozzles, valves, sudden contractions and expansions, diffusers and fittings. Small pipes are called tube in fluid mechanics. Flow line is the path of an individual particle in a fluid undergoing motion [8]. Thebasic properties of any fluid tend to affect it flow behaviour in a pipe. The flow regime (laminar or turbulent) of internal flows is primarily a function of the Reynolds number [1].Fluid flow in pipeline is classified into two major types which are:

- Laminar flow
- Turbulent flow

Laminar flows are flow where the fluid layers are not mixing together. The fluid flow smoothly causing very little friction between the layers. Laminar flow is characterized by smooth streamlines and highly ordered motion [8]. Turbulent flow can therefore be referred to as flow in which the layers of the fluid are moving in a disordered pattern that creates eddies and swirls.

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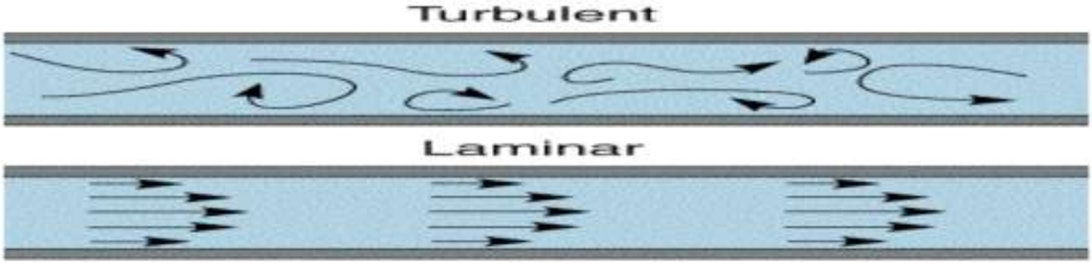
Turbulent flow is characterized by velocity fluctuations and highly disordered motion [1]. The changes from laminar to turbulent flow does not occur suddenly; but rather gradually, it occurs over some region in which the flow fluctuates between laminar and turbulent flows before it becomes fully turbulent. Most flows encountered in practice are turbulent. Laminar flow is encountered when highly viscous fluids such as oil flow in small pipes or narrow passages [1].

Fig1: Turbulent and laminar flows in pipeline



In this work, a Reynolds apparatus for investigation of laminar and turbulent flow in pipelines will be developed using locally available materials. To develop this apparatus an understanding of what Reynolds number is critical.

Reynolds Number

The transition from laminar flow to turbulent flow depends on the geometry,flow velocity, surface temperature, surface roughness, and type of fluid, among other things. After exhaustive experiments in the 1880s, Osborne Reynolds discovered that the flow regime depends mainly on the ratio of inertial forces to viscous forces in the fluid. This ratio is called the Reynolds number and is expressed for internal flow in a circular pipe [1].

$$Re = \frac{\text{Inertial Forces}}{\text{Viscous Forces}} = \frac{V_{avg}\, D}{v} = \frac{\rho V_{avg}\, D}{\mu}$$

Where $V_{avg}$is the average flow velocity (m/s), D is the characteristic length of the geometry (diameter in this case, in m), and $v = \frac{\mu}{\rho}$ is the kinematic viscosity of the fluid (m^2/s). Note that the Reynolds number is a dimensionless quantity. At large Reynolds numbers, the ratio of the inertial forces to the viscous forces is large, and thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid. However, at small or moderate Reynolds numbers, the viscous forces are large enough to suppress these fluctuations and to keep the fluid “in line” thus, the flow is turbulent in the first case and laminar in the second case. The Reynolds number at which the flow changes from laminar to turbulent is called the critical Reynolds number, Re_{cr}. The value of the critical Reynolds number is different for different geometries and flow conditions. For internal flow in a circular pipe, the generally accepted value of the critical Reynolds number is $Re_{cr} = 2300$ [1].

It is certainly desirable to have precise values of Reynolds numbers for laminar, transitional, and turbulent flows, but this is not the case in practice. It turns out that the transition of flow from laminar to turbulent is also dependent on the degree of disturbance of the flow bypipe vibrations, surface roughnessand fluctuations in the flow. Under most practical conditions, the flow in a circular pipe is laminar for Re $\leq$2300, turbulent for Re $\geq$ 4000 and transitional when in between [1].

In this work, a Reynolds apparatus for investigation of laminar and turbulent flow in pipelines was developed while establishing standard experimental template and analysis using the developed apparatus, and while determining the Reynolds number for the different flow regimes.

II. LITERATURE REVIEW

It will be very difficult to talk about laminar and turbulent flows in pipelines without making reference to the works of Hagen(1839) and Poiseuille (1840) as well as other scientists that contributed in one way or the other inorder to find a way to distinguish between laminar, transitional and turbulent flow. Before and after the works of Reynolds, several scientists carried out research in order to find a way to distinguish between the different flows regimes.

The majority of the subsequent experimental investigations of this problem have concentrated on the effects of disturbances created at the inlet, as reviewed by Mullin [10]. On the other hand, the majority of the theoretical investigations of pipe flow transition have been concerned with fully developed Hagen-Poiseuille flow [2].

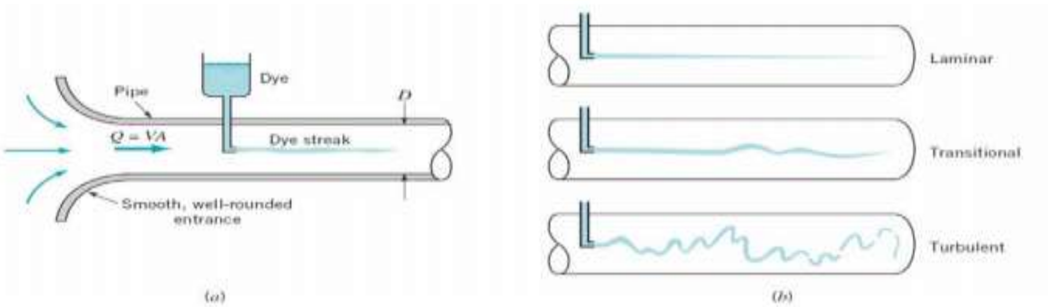


Fig2: Osborne Reynolds experiment
(Jyh-Cherngshieh, 2007. Fundamentals of Fluid Mechanics)

Turbulent flow, however, has a very erratic motion of fluid particles, with a violent transverse interchange of momentum [1]. It can also be defined as a flow field that is not streamlined in its nature. It is for this reason that turbulent flows are treated statistically rather than deterministically. In turbulent flow, the inertia stresses are larger than the viscous stresses, leading to small-scale chaotic behaviour in the fluid motion.
For high Reynolds numbers, the momentum of the fluid determines its behaviour more than theviscosity and the flow is unsteady, churning, roiling, or turbulent. For intermediate Reynolds numbers, the flow is transitional – partly laminar and partly turbulent[3].

Flow Visualization Technique

Flow visualisation in fluid mechanics is the study method to display flow patterns or dynamic behaviours in liquids and gases. The field of flow visualisation dates back to the mid-1400 when Leonardo Da Vinci a renowned artist and engineer sketched images of fine particles of sand and wood shavings that had been dropped into flowing liquids. Since then, laboratory flow visualization has become increasingly more exact, with careful control of the particulate size and distribution. Innovations in photography and particle imaging have also helped extend our understanding of how fluids flow under various circumstances and conditions.

More recently, scientists make use of computational fluid dynamics to study flow by creating simulations of dynamic behaviour of fluids under a wide range of conditions [13]. As time progresses, researchers dealing with flows began to use experimental setups to grasp an impression of the properties and structures, to further improve related works and to evaluate existing models. The three basic types of experimental techniques used by researchersare as explained below [9].

- **Addition of a foreign material**

In order to visualize flow dynamics, foreign materials such as liquid dye or ink is injected into the flowing liquid. Meanwhile, in gaseous flows, oil droplets or smoke may be introduced into the flow medium. A problem may be encountered during the process of injecting the foreign material and this may influence the flow. Using electrolytic technique for generating hydrogen bubbles within the flow decreases these problems to a certain extent. Also, petrochemical method can be used, for instance, generating dye within the flow using laser beam. Applying tufts to the wall of flow simulation, or coating certain boarder surfaces of interest with some viscous material like oil, visualizes flow behavior near object within the flow, for example, flow close to aircraft wings in a wing tunnel. [9]

- **Addition of heat/energy**

Addition of heat to flows can artificially increase the density variation after which optical techniques are then used for visualization. Shooting electrons into the flow volume makes the gas molecules to become excited. After being excited the molecules emit their extra energy as light particles, which visualize flow patterns [9]

- **Optical techniques**

Optical methods are a practical means to reduce flow disturbances. Optical properties of fluids like light refraction change at places within the flow where there are big local differences in flow density. Another visual property that changes in regions of high-density gradients is the phase of light rays. Interferometry is an example of a technique that exploits such phase shifts [9].

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III. MATERIALSAND DESIGN PROCEDURE

Design Concept and Description

The Osborne Reynolds' Apparatus is floor mounted and was designed to allow for vertical flow of a liquid through a precision bore glass pipe. The apparatus is mounted vertically to allow for the vertical direction of flow in order to compensate for the effect of any small deviations in the density of dye relative to that of the working fluid. The operating fluid was supplied from a small-bore supply point by means of a pipe. Fluid enters a cuboidal water tank through a PVC pipe coming from the cubical overhead tank and then through a stilling bedto eliminate any gross variations of fluid velocity in the head tank. This water tank therefore provides uniform, low-velocity head conditions upstream of the entry to the vertically mounted pipe test section. Fluid enters this section through a profiled bell mouth funnel, designed to uniformly accelerate the fluid without any spurious inertial effects.

The cylindrical pipe test section is mounted inside a fabricated stand that provides an uninterrupted background for observations of the dye trace behavior. Dye solution is admitted to the test section through a cuboidal dye storage tank and the rate of flow of dye is controlled by a stop cock (valve) on the outlet of the dye reservoir. The gate valve regulates the flow rate of the working fluid through the test section. The rate of flow is measured volumetrically and the apparatus alters the kinetic viscosity of the fluid, by using different fluids.

Parts List

- Wooden base
- Water reservoir
- Overhead water reservoir tank
- Bell mouth funnel
- Dye storage tank
- Dye injector (dye tank valve)
- Dye injection tip
- Flow control valve
- Test pipe section
- Overflow valve
- Drain valve
- Overhead tank valve
- Elbows and unions of different sizes
- Hoses
- PVC pipe of different sizes ($\frac{1}{2}, \frac{3}{4}$ *and* 1 inch) for inflow and overflow
- Bolts and nuts

Material Selection

Before any machine, apparatus or system is designed and constructed, it must be ensured that the most economical and best materials are selected for it. Factors considered for the selection of materials are classified into three and they include:

1. Physical properties.
2. Mechanical properties
3. The economic and environmental factorsthe material will be subjected to

Physical Properties: It comprises the density, coefficient of thermal expansion, electrical conductivity, fusibility, reluctance, corrosion resistance and thermal conductivity [11].

Mechanical Properties: It comprises of tensile strength, shear strength, hardness, malleability, ductility, toughness, brittleness, plasticity, elasticity, yield strength, fatigue and creep resistance [11].

Economic Factors: They include; cost constraint, durability of material, availability of material, ease of manufacture (which include machinability, ease of joining by welding, forging, forming and casting) [11].

Based on the above factors the following materials were selected as shown in Table 1.

Table 1:Parts and the material selection for the apparatus

S/N	PART LIST	MATERIAL RECOMMENDED	REASONS
1	Stand	Mild steel pipe	Ease of fabrication Easily machined
2	Wooden base	Ply wood	Cheap Ease of joining, cutting and shaping
3	Water reservoir	PVC transparent	Cheap Rigid Easily workable
4	Overhead water reservoir tank	PVC transparent	Cheap Rigid

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			Easily workable
5	Bell mouth funnel	Plastic	Cheap Corrosion resistance
6	Dye storage tank	PVC transparent	Cheap Rigid Easily workable
7	Dye injector (dye tank valve)	Stop cock (steel valve)	Ease of regulation
8	Dye injection tip	Stainless steel tip	Corrosion resistance
9	Flow control valve	Gate valve (steel)	Good regulation of flow i.e good accuracy
10	Test pipe section	Flint glass pipe	Good optical quality
11	Over flow valve	Ball valve (plastic)	Cheap Corrosion resistance
12	Connection forwater supply	Rubber hose	Good elasticity and it is easily bent
13	Drain valve	Ball valve (plastic)	Cheap Corrosion resistance
14	PVC pipe of different sizes	PVC plastic	Corrosion resistance Readily available
15	Elbows and unions of different sizes	PVC plastic	Readily available Corrosion resistance
16	Bolts and nuts	Mild steel	Suitable for fast and easy assembling and disassembling

Design Calculations

- **Volume of Water Reservoir**

Volume of water reservoir $V_{w,}$= length × breadth × height

V_w= 0.3×0.3×0.25 = 0.0225m^3 = 22.5dm^3 = 22.5L

- **Volume of Base Tank**

Volume of water reservoir V_b= length × breadth × height

V_b= 0.26×0.25×0.26 = 0.0169m^3 = 16.9dm^3 = 16.9L

- **Volume of Overhead Water Reservoir Tank**

Volume of water reservoir V_o= $(\text{length})^3$

V_o= 0.3^3= 0.027m^3 = 27dm^3 = 27L

- **Volume of Dye Storage Tank**

Volume of dye storage tank V_d= l^3

V_d= 0.105^3= 0.001157625m^3 = 1.158dm^3 = 1.158l

- **Volume of Flow Visualization Pipe**

Volume of flow visualization pipe $V_p= \pi {r_p}^2 h_p$

Where r_p = r = internal radius of visualization pipe = 0.01m

h_p = height of die storage tank = 0.6m

Therefore $V_p= \frac{22}{7} \times 0.01^2 \times 0.6$

V_p = 0.0001885m^3 =0.1885dm^3 = 0.1885l

- **Cross Sectional Area of Flow Visualization Pipe**

Cross sectional area of flow visualization pipe $A_p= \pi {r_p}^2 = \frac{22}{7} \times 0.01^2 = 0.00031m^2$

- **Volume of the Whole Apparatus**

Volume of the whole apparatus = length × width × height = 0.36 × 0.36 × 2.08= 0.27m^3

- **Velocity of Flow**

$v = \frac{vol}{A_p \times \Delta t}$

Where: v = Velocity of flow

vol = Volume of water collected

A_p = Cross sectional area of flow visualization pipe

Δt = Time required to collect it

- **Volume Flow Rate of Water**

Q = A_p×v

Where: Q = Volume flow rate of water

- **Mass Flow Rate of Water**

$\dot{m} = \rho_{water} \times Q$

Where: $\dot{m}$ = Mass flow rate of water

ρ_{water} = density of water

- **Mass of Water**

$m = \rho_{water} \times V_w$

Where: m = Mass of water

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V_w= Volume of water

- **Weight Flow Rate of Water**

$\dot{w}$ = Q × γ

Where: $\dot{w}$ = Weight flow rate of water
Q = Volume flow rate of water
γ = specific gravity
Where: $\gamma = \rho \times$ g and g = acceleration due to gravity

Reynolds Number

$$Re = \frac{Inertial\ \ Forces}{Viscous\ \ Forces} = \frac{VD}{v} = \frac{\rho VD}{\mu}$$

WhereVis the average flow velocity (m/s)
D_p = D is the diameter of flow visualization pipe (m)

v = $\frac{\mu}{\rho}$ is the kinematic viscosity of the fluid (m^2/s).
μ = absolute viscousity

Friction Factor

For laminar flow, friction factor f = $\frac{64}{Re} \geq \frac{64}{2300} \geq$ 0.027826 as the value of Re decreases
For turbulent flow, friction factor is expressed using Colebrook equation

$$\frac{1}{\sqrt{f}} = -2.0\ log\ (\frac{\varepsilon/_D}{3.7} + \frac{2.51}{Re\sqrt{f}})$$

Colebrook equation is implicit in f, and thus the determination of the friction factor requires iteration. An approximately explicit relation for f was given by S. E. Haaland in 1983 as

$$\frac{1}{\sqrt{f}} \cong -1.8\ log\ [\frac{69}{Re} + \left(\frac{\varepsilon/_D}{3.7}\right)^{1.11}]$$

Entry Length

For laminar flow

$$\frac{L_{h,laminar}}{D} \cong 0.05Re$$

Where D_h is the hydraulic diameter for circular pipe
'D' was gotten from the equation of hydraulic diameter given as;

$$D_h = \frac{4A_c}{p} = \frac{4(\frac{D^2}{4})}{\pi D} = D$$

Where: A_c is the cross-sectional area of the pipe
p = wetted parameter
In the limiting laminar case of Re = 2300, the hydrodynamic entry length is 115D

For turbulent flow

Entry length, $\frac{L_{h,turbulent}}{D} = 1.359\ Re^{1/4}$ For Re $\leq 10^6$

The entry length is much shorter in turbulent flow, as expected, and its dependence on the Reynolds number is weaker. In many pipe flows of practical engineering interest, the entrance effects become insignificant beyond a pipe length of 10 diameters, and the hydrodynamic entry length is approximated asEntry length, $\frac{L_{h,turbulent}}{D} \approx 10$

Pipe Roughness

The friction factor in fully developed turbulent pipe flow is dependent on the Reynolds number and the relative roughness. Pipe roughness can be classified into absolute roughness and relative roughness (which is the ratio of the mean height of roughness of the pipe to the pipe diameter). Every engineering material has its own absolute roughness [1]. Table 2 shows the absolute roughness of the different pipe surfaces, hence glass was selected for the flow visualization pipe because of its lower pipe roughness as compared to others.

Table 2: Absolute roughness for different pipe surface

S/N	SURFACE	ABSOLUTE ROUGHNESS (ε)	
		mm (m × 10^{-3})	Feet
1	Glass, copper, lead, aluminum and brass	0.0001 – 0.002	(0.333 – 6.7) × 10^{-6}
2	PVC and plastic pipes	0.0015 – 0.007	(0.5 – 2.33) × 10^{-5}
3	Stainless steel	0.015	5 × 10^{-5}
4	Steel commercial pipe	0.045 – 0.09	(1.5 – 3) × 10^{-4}
5	Stretched steel	0.015	5 × 10^{-5}
6	Weld steel	0.045	1.5 × 10^{-4}
7	Galvanized steel	0.15	5 × 10^{-4}
8	Rusted steel (corrosion)	0.15 – 4	(5 – 133) × 10^{-4}
9	New cast iron	0.25 – 0.8	(8 - 27) × 10^{-4}
10	Worn cast iron	0.8 – 1.5	(2.7 – 5) × 10^{-3}
11	Rusty cast iron	1.5 – 2.5	(5 – 8.3) × 10^{-3}

12	Sheet or asphalted cast iron	0.01 – 0.015	$(3.33 – 5) \times 10^{-5}$
13	Smoothed cement	0.3	1×10^{-3}
14	Ordinary concrete	0.3 – 1	$(1 – 3.33) \times 10^{-3}$
15	Coarse concrete	0.3 – 5	$(1 – 16.7) \times 10^{-3}$
16	Well planned wood	0.18 – 0.9	$(6 – 30) \times 10^{-3}$
17	Ordinary wood	5	16.7×10^{-3}

Source: Cengelet al. 2012 Fundamentals of thermo-fluid science

Relative Roughness = $\frac{Absolute\ \ roug\ hness}{Hydraulic\ \ Diameter} = \frac{\varepsilon}{D_h}$

Since we are using glass pipe with 22mm diameter, the relative roughness will be $\frac{(0.0001-0.002)mm}{20mm}$ = $(0.5– 1.0)\times 10^{-5}$.

The friction factor for a glass pipe is zero because of the negligible relative pipe roughness[1].

Pressure Loss

In practice, it is found convenient to express the pressure loss for all types of fully developed internal flows (laminar or turbulent flows, circular or noncircular pipes, smooth or rough surfaces, horizontal or inclined pipes) as

Pressure loss = $\Delta P_L = f\frac{L}{D}\frac{\rho V^2}{2}$

Where; L is the pipe length
D is the pipe diameter
V is fluid velocity
f is friction factor

Head Loss

In the analysis of piping systems, pressure losses are commonly expressed in terms of the equivalent fluid column height, called the head lossh_L. The head loss $h_L$represents the additional height that the fluid needs to be raised by a pump in order to overcome the frictional losses in the pipe. Thehead loss is caused by viscosity, and it is directly related to the wall shear stress [1]

Head loss = $H_L = \frac{\Delta P_L}{\rho g} = f\frac{L}{D}\frac{V^2}{2g}$

Minor Local Loss

Minor losses are terms used to describe losses that occur in fittings, expansions, contractions and of course, valves used to control flow. Fittings commonly used in the industry include bends, tees, elbows and unions [4].

$h_m = K_L\frac{V^2}{2g}$ Where K_L is called the loss coefficient

From the above equation, gate valve, ball valves and stop cock were selected based on their relative openness and losses[4].

Power

The power required to overcome friction is given as;

$Power = \Delta PQ = \gamma H_L Q$

Viscosity

Viscosity is the resistance of fluid to shear stress
Absolute or dynamic viscosity

$\mu = \frac{shear\ stress\ in\ fluid}{slope\ \ of\ velocity\ \ profile} = \frac{\tau}{^v/_y} = \frac{^F/_A}{^v/_y}$

Where: F is the force acting on the fluid
A is the area of the pipe in which the fluid is flowing

Kinematic viscosity $\nu = \frac{absolute\ \ viscosity}{density} = \frac{\mu}{\rho}$

Where ρ is the density.
Fluidity is referred to as the inverse of absolute viscosity [4]. The viscosity of water, dye and ink in relation to their different temperature are shown in Table 3.

Table 3: Viscosity of water, dye and ink at different temperature

MATERIALS		TEMPERATURE(°C)						
		20	25	30	35	40	45	50
Water	Dynamic viscosity [mPa.s]	1.0016	0.89	0.7972	0.7191	0.6527	0.5958	0.5465
	Kinematic	1.0034	0.8926	0.8007	0.7234	0.6579	0.6017	0.5531

	viscosity [mm^2/s]							
Dye	Dynamic viscosity [mPa.s]	1.123	0.997	0.893	0.806	0.733	0.671	0.619
	Kinematic viscosity [mm^2/s]	1.11	0.99	0.89	0.80	0.73	0.67	0.621
Ink(blue)	Dynamic viscosity [mPa.s]	1.123	0.997	0.893	0.806	0.733	0.671	0.619
	Kinematic viscosity [mm^2/s]	1.11	0.99	0.89	0.80	0.73	0.67	0.621
Ink(red)	Dynamic viscosity [mPa.s]	1.114	0.989	0.885	0.800	0.726	0.665	0.613
	Kinematic viscosity [mm^2/s]	1.10	0.98	0.88	0.79	0.72	0.66	0.612
Ink(black)	Dynamic viscosity [mPa.s]	5.751	4.875	4.177	3.615	3.156	2.776	2.260
	Kinematic viscosity [mm^2/s]	5.35	4.55	3.91	3.39	2.97	2.62	2.324

Source: http://www.viscopedia.com/viscosity-table/substance/.html

Design Drawing of the Apparatus

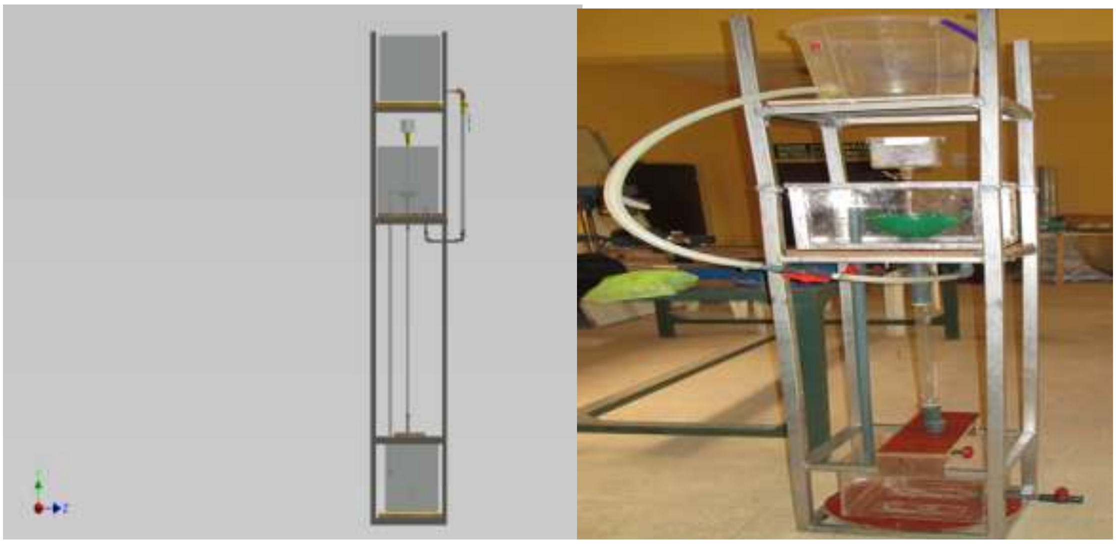

Fig3: Assembly drawing/Setup of the apparatus

IV. CARRYING OUT EXPERIMENTS USING THE LOCALLY DEVELOPED OSBORNE REYNOLD'S DEMONSTRATION APPARATUS

Title of Experiment:
Investigation of laminar and turbulent flows in pipelines.

Apparatus:

- Osborne Reynolds Demonstration Apparatus (The inside diameter of test pipe section, $d_p = d = 20$ mm)
- Stop watch
- Dye
- Measuring cylinder

Experimental Procedures:

1. The apparatus was set up, and then the diameter of the pipe and also the room temperature were taken. The dye storage tank was filled with dye. It should be noted that the metering tap (dye flow valve) and flow control valve must be closed.
2. The tap of the overhead water tank was switched on and adjusted in other to produce a constant water level in the water reservoir. After a time, the test pipe section was completely filled.
3. The flow control valve was opened slightly to produce a low rate of flow into the test pipe section.
4. The metering tap (dye flow valve) was opened and the dye was allowed to flow from the nozzle at the entrance of the channel until a coloured stream was visible along the test pipe section. The velocity of water flow would be increased if the dye accumulates around the nozzle.
5. The water flow was adjusted until a laminar flow pattern which is a straight thin line or streamline of dye wasseen along the whole test pipe (flow visualization) section.
6. The time in seconds was collected for the volume of coloured wastewater that flows down at the outlet pipe. The volumetric flow rate was calculated from the volume and a known time.
7. Steps 5-6 were repeated with an increasing rate of flow by opening the flow control valve and the flow pattern of the fluid was observed as the flow changes from laminar to transition and turbulent.

Five to six readings were taken until the dye stream in the test pipe section break up and got diffused in water.

8. All the apparatus was cleaned after the experiment was done.

Performance Evaluation

The performance evaluation was a three-step process and they include;

1. Test for the repeatability which was determined by the experimental flow rate determination: The flow rate is determined by varying the gate valve in other to either increase or decrease the flow. Below is a diagram showing the graduation ofagatevalve.

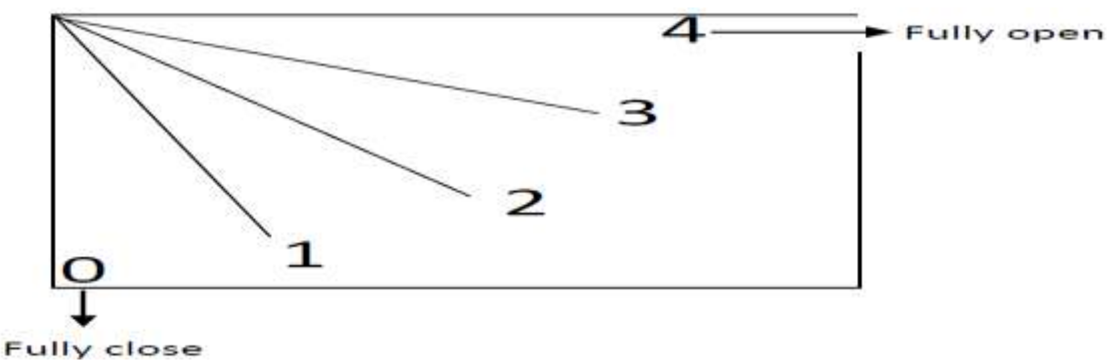

Fig4: Graduation placed at the gate valve to ensure repeatability of flow data

2. **Testing:** Operation of the apparatus and carrying out experiment with the apparatus.
3. **Post-testing/ Maintenance and Safety precaution**

The maintenance procedures are listed below;

- The remaining water in the first reservoir was drained.
- Excess water in the work area was swept out of the working area in the laboratory.
- The test pipe was cleaned by running water through it.

- The base tank was cleaned by running water through it and by opening the drain valve.

The safety precautions are also listed below;

- The test pipe section should be handled with care in other to prevent it from breaking.
- The experiment should be carried out in a well-illuminated environment inother to allow for proper visualization of the type of flow.
- Check whether the water in the tube flows in the correct way and we should also make sure that the flow is stable before measuring the flow rate by monitoring the time taken for collecting an amount of water in the volumetric measuring tank.
- Before injecting the dye into the fluid, we should make sure the dye is not too much and not too insufficient else it will be hard to stable the fluid to get a laminar flow.

V. EXPERIMENTAL RESULT

Inside diameter of the pipe section,d = 0.020 m
Cross-sectional area of the pipe, A = 0.00031m^2
Density of water, ρ = 1000 kg/m3
Dynamic viscosity of water at room temperature = 0.89 mPa.s
Average room temperature = 25ºC

Formula:

$$A = \frac{\pi d^2}{4}$$

$$Q = \frac{V}{t}$$

$$V = \frac{Q}{A}$$

$$Re = \frac{\rho V d}{\mu} = \frac{Vd}{v}$$

Table4: Experimental Result

Run No.	Volume,V (m^3)	Time,t (s)	Flow rate,Q (m^3/s)	Velocity, v (m/s)	Reynolds Number(Re)	Type of Flow
1	0.001	58	0.0000172	0.05561	1249.73	Laminar
2	0.001	56	0.0000179	0.05761	1294.67	Laminar
3	0.001	31	0.0000323	0.1042	2341.43	Transitional
4	0.001	29	0.0000345	0.1112	2499.66	Transitional
5	0.001	17	0.0000588	0.1898	4264.12	Turbulent
6	0.001	14	0.0000714	0.2304	5177.86	Turbulent

VI. ANALYSIS

The analysis was done by plotting the graph of Reynolds number against the flow rate and also, by plotting the graph of Reynolds number against the velocity. The datawas analysed using Microsoft Excel (2010) program.

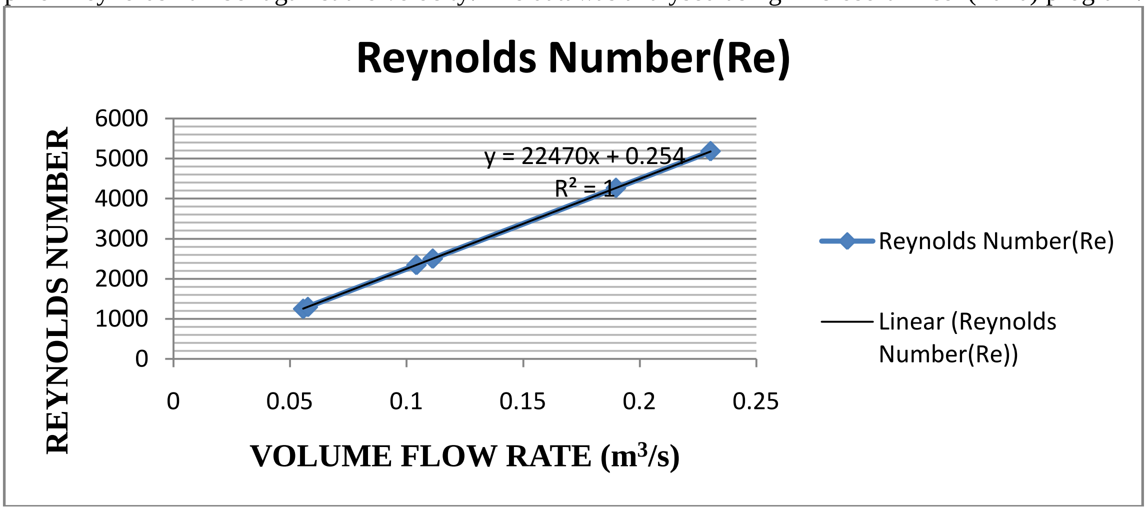

Fig 5:Graph of Reynolds number against the Volume flow rate showing the equation of the line

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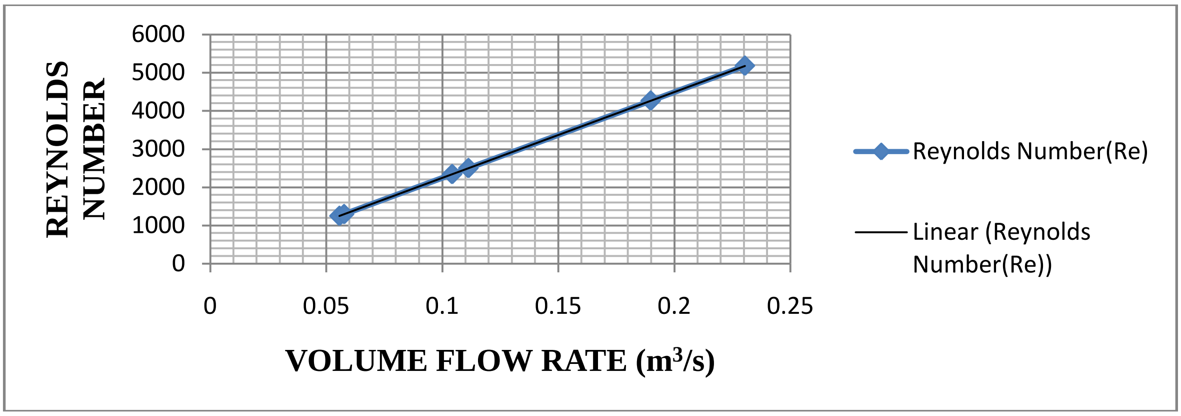

Fig6:Graph of Reynolds number against the Volume flow rate

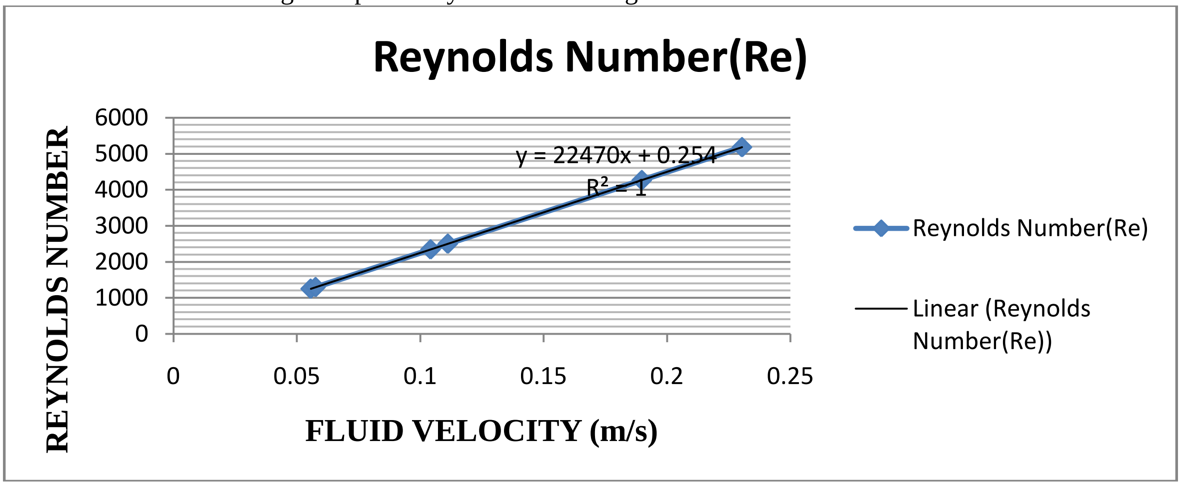

Fig7:Graph of Reynolds number against the Fluid velocity showing the equation of the line

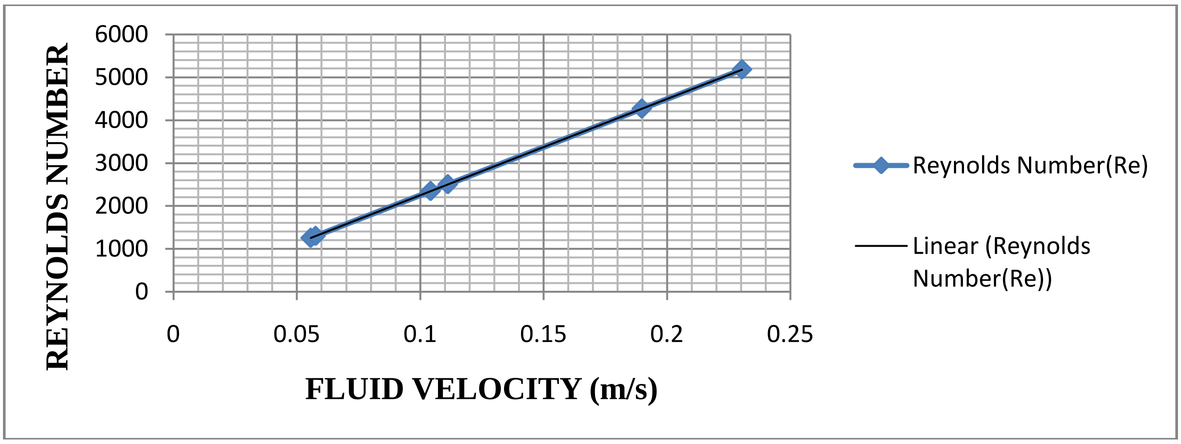

Fig 8:Graph of Reynolds number against the Fluid velocity

VII. CONCLUSION

In conclusion, as the water flow rate increases, the Reynolds number will automatically increase aswell, and the blue dye line changes from a straight line to swirling streamlines. Laminar flow is obtained if the Reynolds number is less than 2300; meanwhile, the Reynolds number for turbulent flow is more than 4000. The Reynolds number for transition flow is between 2300 and 4000.

Limitations
Below are the lists of limitations to this experiment;

- The quantity of water required for the experiment is more compared to the size of the overhead tank provided.
- The test pipe section is not graduated and at the same time, it is fragile.
- Fluid collection might not begin immediately when the person monitoring the stopwatch started ticking on it, and might also not stop collecting it exactly after the stopwatch is stopped. Therefore, the values calculated in the results section might not be exactly 100% correct.

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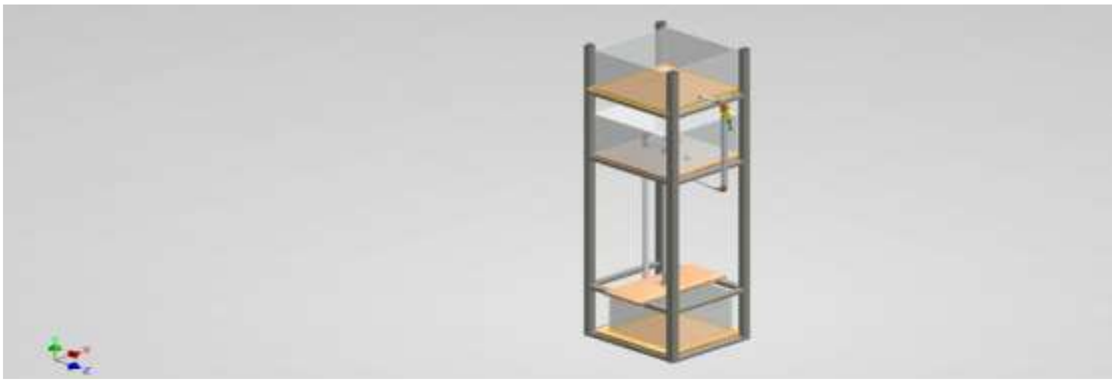
APPENDICES
APPENDIX A
3D Drawing of The Apparatus Showing the XYZ Plane



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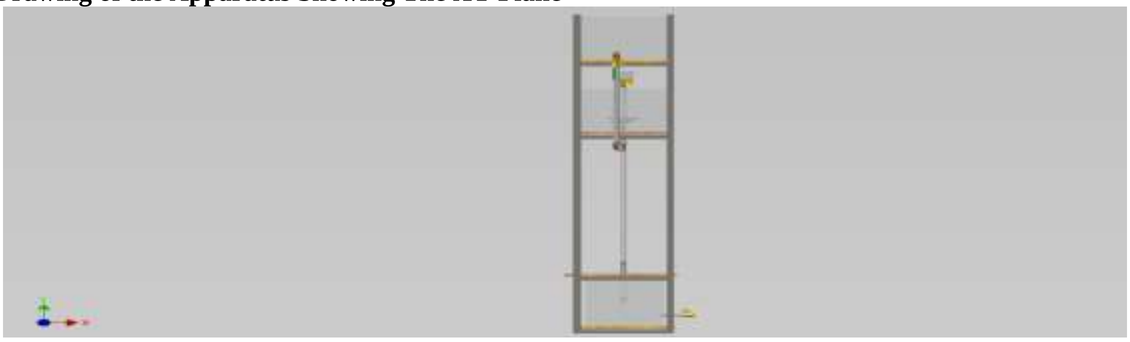
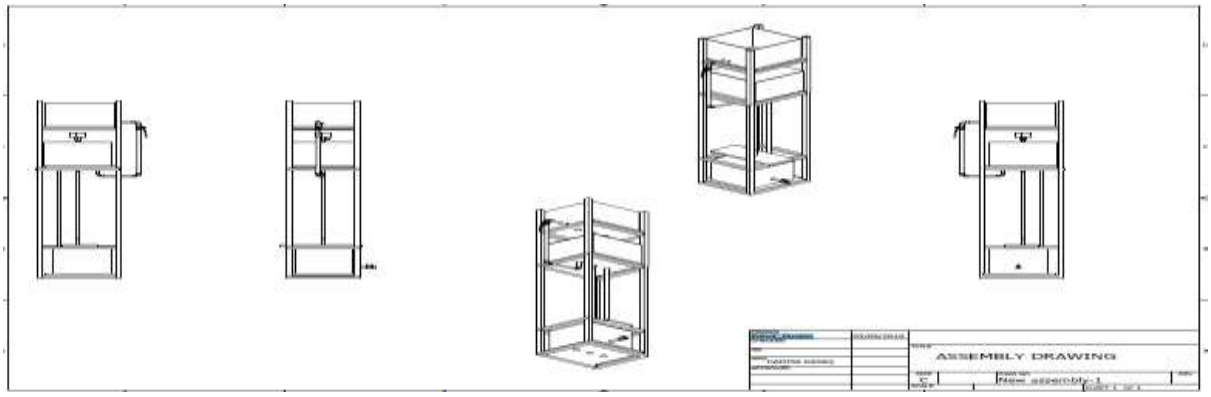
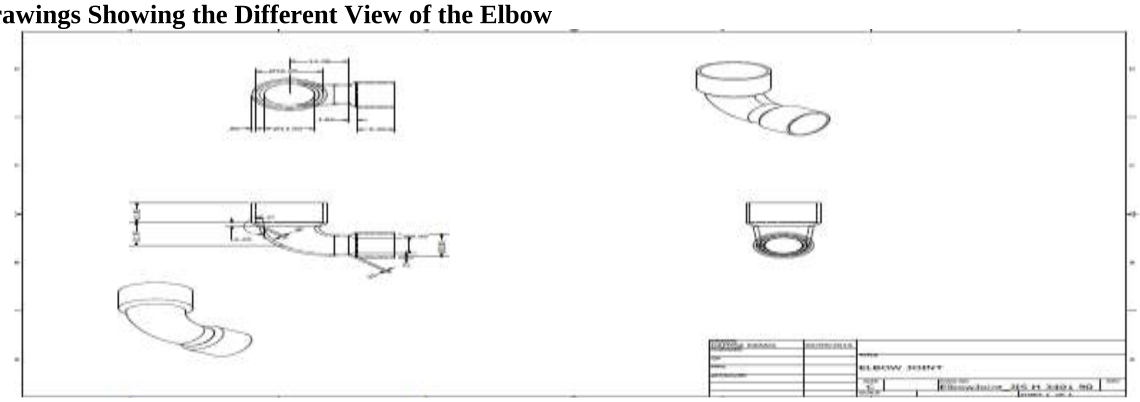
APPENDIX B
3d Drawing of the Apparatus Showing The XY Plane



APPENDIX C
Drawings of the Apparatus Showing the Different Views



APPENDIX D
Drawings Showing the Different View of the Elbow



APPENDIX E
Bill of Material and Quantity

S/N.	PART	DESCRIPTION/ SPECIFICATION	QUANTITY	UNIT COST	TOTAL COST	MATERIAL USED	PROCESS EMPLOYED
1.	Stand	210cm × 30.6 × 30.6	1	**₦15000**	**₦15000**	Mild steel	Cutting, welding and grinding

2.	Base	• 36 cm × 36cm(for water reservoir) • 36 cm diameter(for the base tank) • 36 cm × 30cm(for overhead tank)	1 1 1	**₦7000**	**₦7000**	Ply wood (MDF)	Cutting and drilling
3.	Water reservoir	30cm × 30cm × 25cm	6 pieces of 30.5cm transparent PVC plate	**₦2500**	**₦15000**	Transparent PVC plastic plate	Cutting and adhesive joining
4	Aluminum angle	18ft (549cm)	Full length	**₦5500**	**₦5500**	Aluminum	Cutting and drilling
5.	Plastic bucket		1	**₦1200**	**₦1200**	Plastic	Bought out
6.	Dye tank	10.5cm × 10.5cm × 10.5cm	1 piece of 30.5cm transparent PVC plate	**₦1250**	**₦1250**	Transparent PVC plastic plate	Cutting and adhesive joining
7.	Base tank	25 × 26 × 26	5 pieces of 30.5cm transparent PVC plate	**₦1000**	**₦5000**	Transparent PVC plastic plate	Cutting and adhesive joining
8.	Test pipe	650mm length and 20mm inner diameter	1	**₦10000**	**₦10000**	Flint glass pipe	Bought out
9.	PVC pipes	• 20 mm diameter • 23 mm diameter • 35 mm diameter	1 1 1	**₦600** **₦700** **₦1300**	**₦2600**	PVC pipe	Bought out
10.	Hose		2	**₦550**	**₦1100**	Rubber	Bought out
11.	Stop cock	½ inch diameter	1	**₦750**	**₦750**	Metal	Bought out

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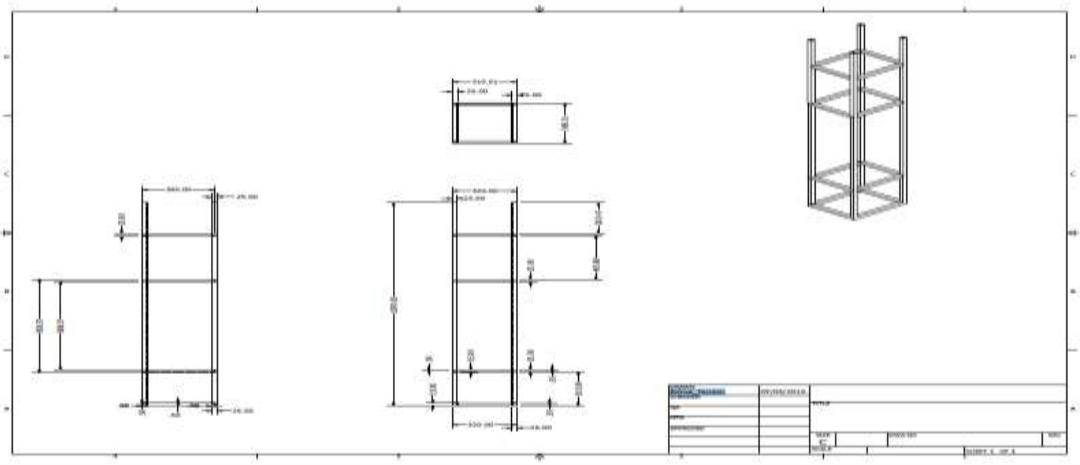
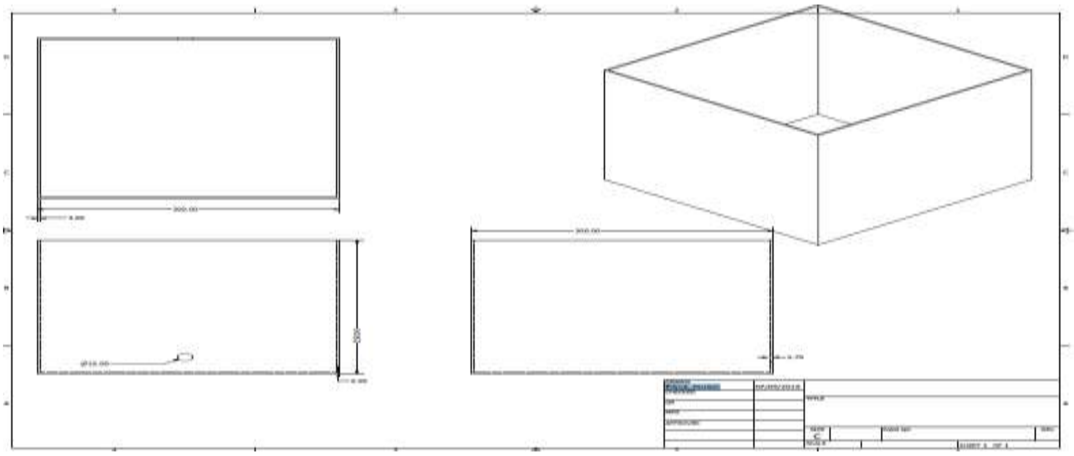
		(metal)					
12.	Ball valve	½ inch diameter (plastic)	3	**₦400**	**₦1200**	PVC plastic	Bought out
13.	Gate valve	½ inch diameter (metal)	1	**₦800**	**₦800**	Metal	Bought out
14.	Silicone sealant		1	**₦3500**	**₦3500**		Bought out
15.	Adhesive glue		5	**₦500**	**₦2500**		Bought out
16.	Union	½ inch diameter ¾ inch diameter	1 1	**₦100** **₦200**	**₦300**	PVC plastic	Bought out
17.	Elbow	½ inch diameter	1	**₦100**	**₦100**	PVC plastic	Bought out
18.	Adapter	½ inch diameter	2	**₦100**	**₦200**	PVC plastic	Bought out
19.	Socket	¾ by 1 inch diameter	1	**₦920**	**₦920**	PVC plastic	Bought out
20.	Nut and bolt	Mild steel	7	**₦50**	**₦350**	Stainless steel	Bought out
21	Enamel paint	Silver colour	1	**₦1500**	**₦1500**		Bought out
22.	Funnel	Plastic	1	**₦500**	**₦500**	Plastic	Bought out
				TOTAL	**₦74,320**		

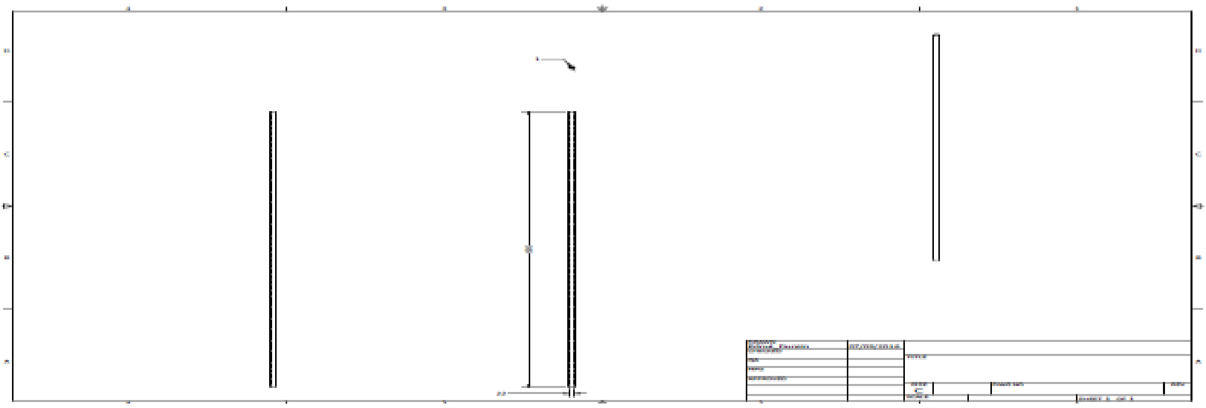
APPENDIX F
Drawings of the Stand Showing the Dimensions



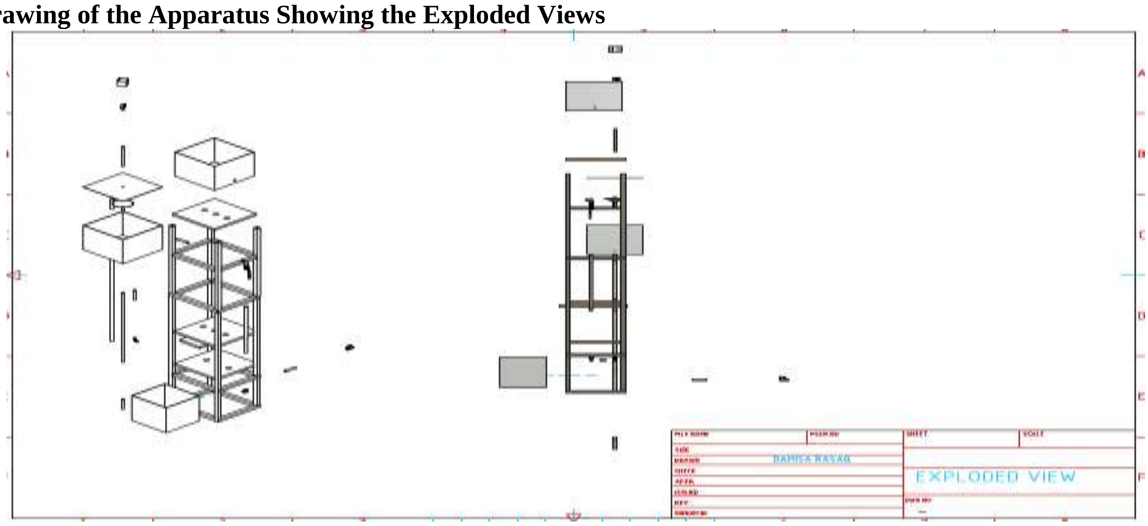
APPENDIX G
Drawings of the Water Storage Tank Showing the Dimensions



APPENDIX H
Drawings of the Glass Visualization Pipe Showing the Dimensions



APPENDIX I
Drawing of the Apparatus Showing the Exploded Views



APPENDIX J
EQUIPMENT USED

- **Hack saw:** For cutting the mild steel pipe and also for cutting the PVC pipe

- **Jig saw:** For cutting the transparent PVC plate and the ply wood
- **Rip saw:** Also used for cutting some part of the wood
- **Hand drill:** Used for drilling hole through the wood and the metal stand so that it can be screwed together
- **Grinder:** Used to grind off excessive weld
- **Welding machine:** Used to join the metal stand together using electrode.