DEVELOPMENT OF LOCAL APPARATUS FOR INVESTIGATION OF LAMINAR AND TURBULENT FLOW IN PIPELINES

BY

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DECLARATION

I DAMISA RASAQ OLUWASEGUN with matriculation number MEE/11/0405 hereby declare that this research project titled "DEVELOPMENT OF LOCAL APPARATUS FOR INVESTIGATION LAMINAR AND TURBULENT FLOW IN PIPELINES" is a product of my research and is original. Other authors whose work is used in the project have been duly acknowledged

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CERTIFICATION

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DEDICATION

This project work is dedicated to the glory of the Almighty God and to all the student of Mechanical Engineering of Federal University of Oye-Ekiti, Ekiti State, Nigeria.

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My gratitude goes to my Incomparable Omniscience, ever loving, caring and invisible father - The Almighty God who kept me through it all.

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I express my profound gratitude to my caring parent, Mr. and Mrs. Damisa for their unending support and love shown toward me. May you live long to reap the fruit of your labour.I am indeed grateful to all the past and present lecturers aswell as the technologists of the Department of Mechanical Engineering in Federal University Oye-Ekiti Ekiti State Nigeria for the various roles they played in my life particularly towards my Engineering career so far.

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ABSTRACT

Fluid flows play a crucial role in a vast variety of natural phenomena and manmade systems. Fluid flow in circular and noncircular pipes is commonly encountered in practice. A prototype Osborne 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 were either fabricated or purchased locally. The apparatus designed and fabricated was used to test for laminar and turbulent flow using 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 the higher the flow rate the more turbulent the flow. 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.

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND OF THE STUDY

Fluid flows play a crucial role in a vast variety of natural phenomena and manmade systems. Fluid flow in circular and noncircular pipes is commonly encountered in practice. Water in a city is distributed by extensive piping networks. Oil and natural gas are transported hundreds of miles by large pipelines. Blood is carried throughout our bodies by arteries and veins. The cooling water in an engine is transported by 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 (Cengel, *et al.* 2012).

Flows completely bounded by solid surfaces are called ***internal flows*** which include flows through pipes (Round cross section), ducts (Not Round cross section), nozzles, diffusers, sudden contractions and expansions, valves, and fittings. Small pipes are called tube in fluid mechanics. Flow line is the path of an individual particle in a fluid undergoing motion (Kaminsk, *et al.* 2011). The basic principles involved are independent of the cross-sectional shape. although the details of the flow may be dependent on it. The flow regime (laminar or turbulent) of internal flows is primarily a function of the Reynolds number (Cengel, *et al.* 2012).

Fluid flow in pipeline is classified into two major types which are:

- Laminar flow
- Turbulent flow

Transitional flow which is the third type of fluid flow is not really recognised as the other two (Cengel, *et al.* 2012). Now what then is laminar 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 (Kaminsk, *et al.* 2011). 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. Turbulent flow is characterized by velocity fluctuations and highly disordered motion (Cengel, *et al.* 2012). The transition from laminar to turbulent flow does not occur suddenly; rather, 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 oils flow in small pipes or narrow passages (Cengel *et al.* 2012).

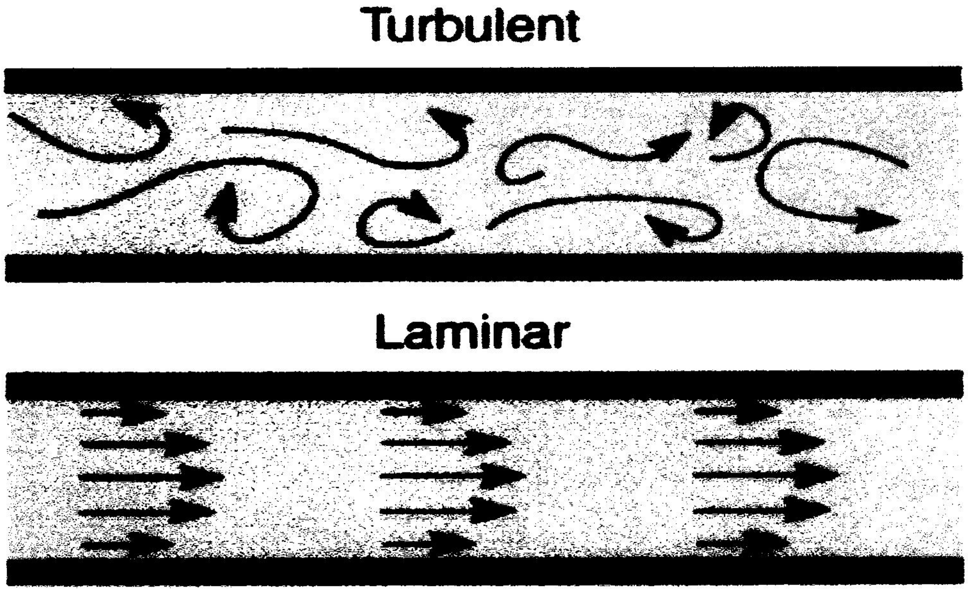

Fig1.1: Turbulent and laminar flows in pipeline

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 to turbulent flow depends on the geometry, surface roughness, flow velocity, surface temperature, 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 (Cengel, *et al.* 2012).

$$Re = \frac{Inertial\ Forces}{Viscous\ Forces} = \frac{V_{avg}D}{v} = \frac{\rho V_{avg}D}{\mu} \qquad (1.1)$$

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. Also, kinematic viscosity has the unit m^2/s, and can be viewed as viscous diffusivity or diffusivity for momentum (Cengel, *et al.* 2012). At large Reynolds numbers, the inertial forces, are large relative to the viscous forces, and thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid. At small or moderate Reynolds numbers, however, 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. The Reynolds number at which the flow becomes 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 $Re_{cr} = 2300$ (Cengel, *et al.* 2012).

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 from laminar to turbulent flow also depends on the degree of disturbance of the flow by surface roughness, pipe vibrations and fluctuations in the flow. Under most practical conditions, the flow in a circular pipe is laminar for Re ≤ 2300, turbulent for Re ≥ 4000 and transitional when in between (Cengel *et al.* 2012). Maxwell (1860) as cited by Cacao-Pasia (2009) derived Newton's Law for Momentum Transport stating that the stress applied to a part of the fluid is directly proportional to the strain or the time rate of change of velocity or the absolute viscosity.

The acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object (Young *et al.*, 2004). In relation, the microscopic or molecular transfer of momentum results to the forces acting on a fluid, such as pressure and shear stress (Cacao-Pasia, 2009). At low flow, the dye pattern was regular and formed a single line of color. At high flow rates, on the other hand, the dye became dispersed throughout the pipe cross-section because of very irregular fluid motion.

1.1 AIMS AND OBJECTIVES OF THE STUDY

The aim of the study is to:

- develop an apparatus that can be of use in FUOYE fluid mechanics laboratory for investigation of laminar and turbulent flow in a pipeline.

The objectives of the study are to:

- establish standard experimental template and analysis using the developed apparatus.
- determine the Reynolds number for the different flow regime

1.2 JUSTIFICATION OF THE STUDY

Having found out that the fluid mechanics laboratory of most tertiary institution is lacking in apparatus to carry out experiment on fluid flow in pipeline, and that apparatus use for this experiment in some Nigerian universities and polytechnics are usually being imported, there is therefore a need to come up with an apparatus which can be developed using locally available materials. This will help to tackle the need for the apparatus and with this the students can carry out their experiment in the field of fluid flow.

1.3 SCOPE OF STUDY

1. To carry out a literature review on fluid flow in pipelines with respect to the types of flow, their Reynolds number and how to distinguish between the various type of flow.
2. To obtain some data or information that will be required and will be suitable for the design and fabrication of the apparatus.
3. To select suitable materials based on the result of the analysis for the fabrication of the apparatus.
4. To prepare a neat and detailed working drawing of the apparatus showing the 3D and the 2D with different views.
5. To discuss the result of the performance test.

6. To present the necessary information on the importance and limitations of the apparatus.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

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 researches in order to find a way to distinguish between the different flows regime. The stability of Hagen–Poiseuille flow (Hagen, 1839; Poiseuille, 1840) in a long circular pipe has intrigued scientists ever since Reynolds' (1883) original experiments. Reynolds showed that the single control parameter for the flow is what is now called the Reynolds number (Cengel, *et al.* 2012). His research was mainly focused on transition initiated at the entrance to the pipe, and an important aspect of his work was in showing the importance of controlling entry conditions. 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 (in preparation) (Mullin *et al.* 2006). On the other hand, the majority of the theoretical investigations of pipe flow transition have been concerned with fully developed Hagen-Poiseuille flow (Eckhardt, *et al.* 2007).

The central issue is that Hagen-Poiseuille flow is widely accepted to be stable to infinitesimal perturbations and yet, in practice, most pipe flows are turbulent. The process whereby turbulence arises is still not understood even in outline and given its history and practical importance, this problem has become the outstanding challenge of hydrodynamic stability theory. The engineering implications of understanding transition in pipe flows are widely spread, most notably in determining how large a pipe and how great a pressure gradient are needed to achieve a specified flow rate (Wills, *et al.* 2008). There is need to review some widely accepted facts about the stability of Hagen-Poiseuille flow before discussing advances made this century on the topic. Hagen-Poiseuille flow takes approximately Re/30 diameters (Fargie *et al.*, 1971) to develop from a uniform inlet flow into a pipe, and the stability characteristics of this spatially evolving flow have attracted fewer investigations (as reviewed by Duck 2005) than the fully developed case. In carefully controlled experiments, developed Hagen-Poiseuille flow can be maintained up to Re~100000 (Pfenniger, 1961). Hence, if it were possible to carry out a noise-free experiment in a perfectly circular, very long pipe, all evidence suggests that the flow would be laminar. A natural consequence of this is that, being dependent on both amplitude and form of the initial disturbance, there is no well-defined critical value of Re for transition to turbulence. At low or transitional Re, a more meaningful question is to ask whether a critical value Re exists, below which turbulence cannot be maintained, i.e. indicating the transition from turbulence of a disturbance to the laminar state. The only theoretical energy stability result is 81.49 below which all disturbances are guaranteed to decay monotonically. This strict lower bound is, however, very conservative given experimental evidence places $Re_{low} = 2300$ (Joseph, *et al.* 1969)

Transition from laminar flow is a result of finite amplitude disturbances either intentionally introduced or naturally present in the experiment, and thus explains the wide range of values of Re quoted in the literature (Mullin in preparation). This sensitivity naturally poses a series of questions, such as which disturbance is the most dangerous? (i.e. triggers turbulence with the minimal energy or amplitude) and how does this threshold amplitude or energy scale with increasing Re? The linear mechanism of transient growth is an important ingredient in the answers to these questions and was the focus of several studies at the end of the last century (Trefethen *et al.* (1993) and Schmid *et al.* (1994) and the review by Grossman (2000)). When transition occurs, it is generally abrupt and the character of the state achieved is Re dependent. For 1760 ≤Re≥ 2300 localized 'puffs' appears (Wygnanski et al. 1973). This metastability of puffs has undoubtedly contributed to the uncertainty surrounding the minimal Re for sustained turbulence. Several other experiments carried out by Wygnanski et al. (1975) shows that transition takes place in the Re range approximately 2300-2700. The findings have been confirmed for disturbances created in fully developed flow under constant mass flux conditions by Darbyshire *et al.* (1995).

As early as 1883, Reynolds realized that a finite amplitude disturbance is required to trigger transition and that the laminar flow becomes more and more sensitive to background disturbances as Re increases (Reynold, 1883). In order to establish whether the threshold for transition depends systematically on Re, control of the disturbance needs to be established. The exact positioning of the disturbance is also important as a distinction needs to be drawn between disturbances added to the inlet and those introduced into developed flow. Adding disturbances to developing flow is important for practical applications but making contact with theory is difficult since there is complex interaction between the developing base flow and any added disturbance. Binnie & Fowler (1947) showed that these interactions could produce surprisingly long transient effects. Osborne Reynolds (23 August 1832 - 21 February 1912), a British scientist and mathematician, was the first to distinguish the difference between laminar and turbulent flow by using a simple apparatus called Osborne Reynold's demonstration apparatus. The visualization of flow streams began with the work of Reynolds. He began the experiments in 1880 and published the results in 1883.

The original apparatus as identified by Osborne Reynolds consists of water resource for the system supply, fix-head water input to big and small transparent pipes, dye input by injection unit, and water output unit to determine water flow rate. The laminar, transition and turbulent flows can be obtained by varying the water flow rate using the water outlet control valve. Water flow rate and hence the flow velocity is measured by the volumetric measuring tank. The supply tank consists of glass beads to reduce flow disturbances. Flow patterns are visualized using dye injection through a needle valve. The dye injection rate can be controlled and adjusted to improve the quality of flow patterns.

The results of the experiment are given below:

- Laminar when Re < 2300
- Transition when 2300 < Re < 4000
- Turbulent when Re > 4000

Reynolds number is the criterion of dynamic similarity. The derivation of this dimensionless quantity is absolutely general for all systems which involve relative motion between fluids and solids except in the presence of appreciable gravitational or elastic effects. Considered as a criterion, the Reynolds number is found to be of great utility in all types of fluid flow problems and is significant when applied to geometrically similar systems (McCabe *et al.*, 1993). Osborne Reynolds never fully realized the implications of the dimensionless number he was able to develop, the Reynolds number. Reynolds merely considered the ratio as a criterion for the critical velocity in pipe flow. It was Lord Rayleigh who has shown that it is a non-dimensional factor governing all problems on fluid flow frictional resistance, and that similar non-dimensional constants exist for many other natural phenomena (Anderson, 2005).

It is a practice in engineering design that when a large object such as a ship, airplane, or building is to be made, a scale model is constructed and tested so that the performance of the large object can be calculated from the test results of the scale model. Lord Rayleigh showed that the scale model tests gave comparable results only when the non-dimensional factor of the model is equal to that of the large object when working under its design conditions (Anderson, 2005). By equating the non-dimensional factor of the large object to that of the model, the test speed of the model is obtained. This is known as the corresponding speed and the comparison of the two conditions between the large object and the test results of a scale model at its corresponding speed is known as the principle of dynamic similarity (Anderson, 2005).

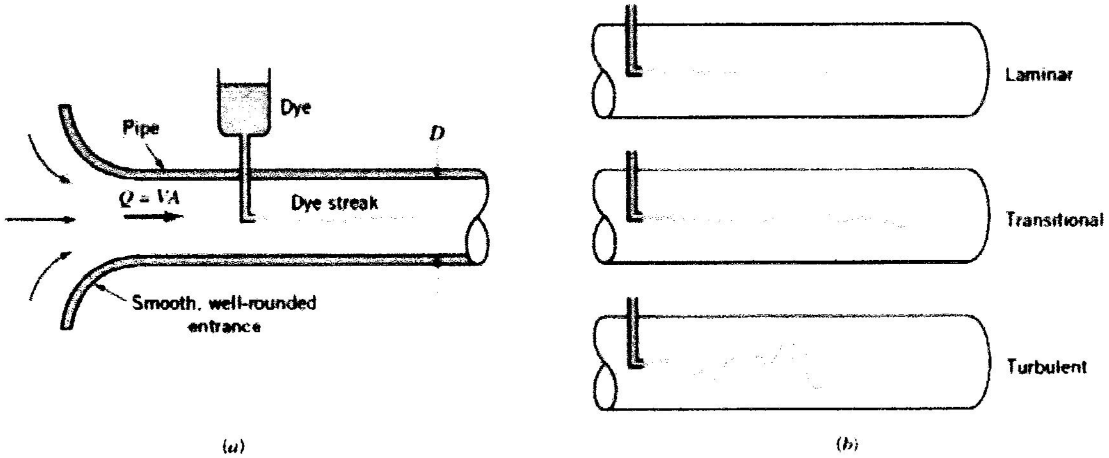

Fig2.1: Osborne Reynolds experiment

(Jyh-Cherngshieh, 2007. Fundamentals of Fluid Mechanics)

Eventually, Osborne Reynolds was able to predict flow regimes (majorly laminar flow and turbulent flow) based on one dimensionless group – now known in science and engineering as the Reynolds number.

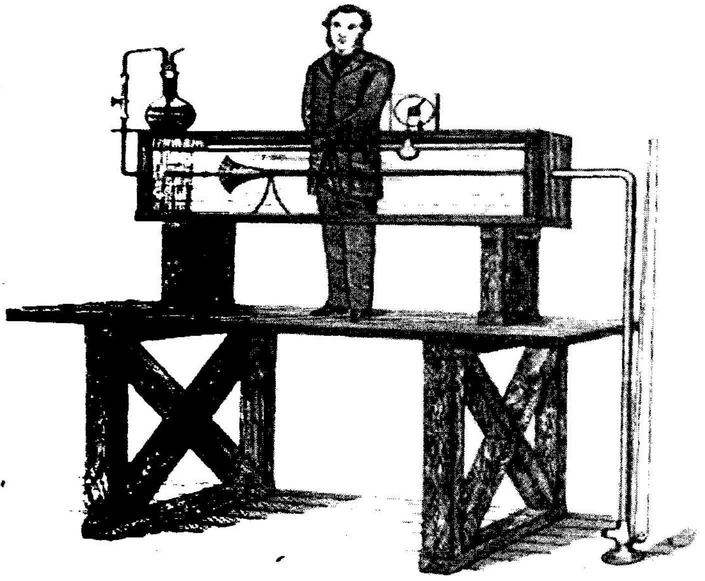

Fig2.2: Drawing of one of Reynolds' original apparatus

("American Society for Engineering Education", 2003)

2.1 FLOW REGIME

Laminar flow is defined as flow in which the fluid moves in layers, or *laminas*, one layer gliding smoothly over an adjacent layer with only a molecular interchange of momentum. Any tendencies toward instability and turbulence are damped out by viscous shear forces that resist relative motion of adjacent fluid layers. It is also defined as an organized flow field that can be described with streamlines. In order for laminar flow to be permissible, the viscous stresses must dominate over the fluid inertia stresses. Turbulent flow, however, has very erratic motion of fluid particles, with a violent transverse interchange of momentum (Cengel, *et al.* 2012). It can also be defined as a flow field that cannot be described with streamlines in the absolute sense. However, time-averaged streamlines can be defined to describe the average behavior of the flow. In turbulent flow, the inertia stresses dominate over the viscous stresses, leading to small-scale chaotic behavior in the fluid motion. Reynolds found out in his experiment that, at low rates of flow, a colored jet of water flowed intact along with the mainstream and no cross mixing occurred. In laminar flow, the behavior of the color band showed clearly that the water was flowing in parallel straight lines. As the flow rate was increased and upon reaching the critical velocity, the thread of color became wavy which gradually disappeared, as the dye was spread uniformly throughout the entire cross section of the stream of water (McCabe *et al.*, 1993).

On the other hand, McCabe *et al.* (1993) indicated that as the rate of flow is increased; the eddy becomes larger and more complex, which results into a rather more turbulent flow. Flow lines around a small particle are more likely to be characterized as laminar. Meanwhile, if the particle is large, the liquid flow is likely to be turbulent accompanied by the formation of eddies and vortices in the fluid behind the particle in motion. Likewise, fluid viscosity is an important determinant and factor in calculating for the resistance and in the classification of the flow. For low Reynolds numbers the behavior of a fluid depends mostly on its viscosity and the flow is steady, smooth, viscous, or laminar. For high Reynolds numbers the momentum of the fluid determines its behavior more than the viscosity and the flow is unsteady, churning, roiling, or turbulent. For intermediate Reynolds numbers the flow is transitional – partly laminar and partly turbulent (Elert, 2008).

2.2 BOUNDARY LAYER FORMATION

Young *et al.* (2004) pointed out that a viscous fluid consistently tends to cling to a solid surface in which it has a contact with. There always is a thin boundary layer of fluid near the surface in which the fluid is nearly at rest with respect to the surface. McCabe *et al.* (1993) defines a boundary layer as a part of a moving fluid in which the fluid motion is influenced by the presence of a solid boundary. Considering a straight thin-walled tube with fluid entering at a uniform velocity, a boundary layer begins to form at the entrance to the tube. As the fluid moves through the first part of the channel, the layer builds up and thickens. On the other hand, a fully developed turbulence results at a point where the boundary layer occupies the entire cross section of the stream flowing in the tube. In such a case, a fluid has already progressed through a duct far enough in such a way that no further change takes place in the velocity pattern through the duct or pipe (McCabe *et al.*, 1993).

Ludwig Prandtl first theorized in his paper "*Über Flussigkeitsbewegung bei sehr kleiner Reigbung*" (*"On the Motion of Fluid with Very Little Friction")*, as cited by Anderson (2005), that an effect of friction was to cause the fluid immediately adjacent to the surface stick to the surface. In other words, Prandtl assumed that there exist a no-slip condition at the surface and the frictional effects are experienced only in the boundary layer. He furthered that outside the boundary layer, flow is inviscid. If the viscosity was very small and the fluid path along the wall is not too long, the fluid velocity ought to resume its normal value at a very short distance from the wall. However, in the very thin transition layer, the sharp changes in velocity, even with a small coefficient of friction, produce marked results.

2.3 FLOW VISUALIZATION TECHNIQUE

Flow visualization is the study of methods to display dynamic behavior in liquids and gases. The field dates back at least to the mid-1400, where Leonardo Da Vinci sketched images of fine particles of sand and wood shavings which had been dropped into flowing liquids. Since then, laboratory flow visualization has become more and more exact, with careful control of the particulate size and distribution. Advances in photography have also helped extend our understanding of how fluids flow under various circumstances. More recently, computational fluid dynamics has extended the abilities of scientists to study flow by creating simulations of dynamic behavior of fluids under a wide range of conditions (Ward, 1994). 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. Three basic types of experimental techniques can be distinguished (Loffelmann, 1998).

2.3.1 Addition of a foreign material

In order to visualize flow dynamics, dye is injected into the flowing liquid. Meanwhile, in gaseous flows, smoke or oil droplets may be introduced. 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 behaviour near object within the flow, for example, flow close to aircraft wings in a wing tunnel. (Loffelmann, 1998).

2.3.2 Adding heat/energy

Heat can be applied to flows to artificially increase the density variation – 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 (Loffelmann, 1998).

2.3.3 Optical techniques

Optical methods are a practical means to minimize flow disturbances. Optical properties like light refraction change at places within the flow where there are big local differences in flow density. Working with a light beam, images are generated with shadows and caustics. Another visual property which changes in regions of high density gradients is the phase of light rays. Interferometry is an example of a technique which exploits such phase shifts (Loffelmann, 1998).

2.4 PRESENT DESIGN

The apparatus is a vertical Osborne Reynolds' Apparatus using a flow visualization technique known as addition of foreign materials. The foreign material is dye while the home material is water, for this reason, it has four tanks; the smaller one is for the dye while the larger ones are for the water. It has a flow visualization section which is made of glass pipe. This section is also referred to as the test pipe section. It contains several length of pipe as well as three ball valves, a gate valve and a stop cock.

CHAPTER THREE

MATERIALS, METHODS AND DESIGN PROCEDURE

3.0 DESIGN CONCEPT AND DESCRIPTION

The Osborne Reynolds' Apparatus is floor mounted and is designed for the vertical flow of a liquid through a precision bore glass pipe. The use of a vertical direction for the flow compensates for the effect of any small deviations of the density of dye relative to that of the working fluid. The operating fluid may be supplied from any 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 bed (which is not necessary) to 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, 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 behaviour. 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 flow rate of the working fluid through the test section is regulated by a gate valve. The rate of flow is measured volumetrically and the apparatus alters the kinetic viscosity of the fluid, by using different fluids.

3.1 PARTS LIST

1. Wooden base
2. Water reservoir
3. Overhead water reservoir tank
4. Bell mouth funnel
5. Dye storage tank
6. Dye injector (dye tank valve)
7. Dye injection tip
8. Flow control valve
9. Test pipe section
10. Overflow valve
11. Drain valve
12. Overhead tank valve
13. Elbows and unions of different sizes
14. Hoses
15. PVC pipe of different sizes ($\frac{1}{2}, \frac{3}{4}$ *and* 1 inch) for inflow and overflow
16. Bolts and nuts

3.2 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 factors and the environmental condition in which the material will operate.

PHYSICAL PROPERTIES: It comprises the density, coefficient of thermal expansion, electrical conductivity, fusibility, reluctance, corrosion resistance and thermal conductivity (Shaymaa, 2014).

MECHANICAL PROPERTIES: It comprises of tensile strength, shear strength, hardness, malleability, ductility, toughness, brittleness, plasticity, elasticity, yield strength, fatigue and creep resistance (Shaymaa, 2014).

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) (Shaymaa, 2014).

Based on the above factors the following materials were selected as shown in Table 3.1

Table 3.1 showing the 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 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 for water 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

3.3 DESIGN CALCULATION

3.3.1 VOLUME OF WATER RESERVOIR

Volume of water reservoir V_w = length × breadth × height (3.1)

$V_w = 0.3\times0.3\times0.25 = 0.0225m^3 = 22.5dm^3 = 22.5l$

3.3.2 VOLUME OF BASE TANK

Volume of water reservoir V_b = length × breadth × height (3.2)

$V_b = 0.26\times0.25\times0.26 = 0.0169m^3 = 16.9dm^3 = 16.9l$

3.3.3 VOLUME OF OVERHEAD WATER RESERVOIR TANK

Volume of water reservoir $V_o = l^3$ (3.3)

$V_o = 0.3^3 = 0.027m^3 = 27dm^3 = 27l$

3.3.4 VOLUME OF DYE STORAGE TANK

Volume of dye storage tank $V_d = l^3$ (3.4)

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

3.3.5 VOLUME OF FLOW VISUALISATION PIPE

Volume of flow visualization pipe $V_p = \pi r_p^2 h_p$ (3.5)

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

$h_p =$ height of die storage tank = 0.6m

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

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

3.3.6 CROSS SECTIONAL AREA OF FLOW VISUALISATION PIPE

Cross sectional area of flow visualisation pipe $A_p = \pi r_p^2$ (3.6)

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

$$= 0.00031m^2$$

3.3.7 VOLUME OF THE WHOLE APPARATUS

Volume of the whole apparatus = length × width × height (3.7)

$$= 0.36 \times 0.36 \times 2.08$$

$$= 0.27m^3$$

3.3.8 VELOCITY OF FLOW

$$v = \frac{vol}{A_p \times \Delta t} \quad (3.8)$$

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

3.3.9 VOLUME FLOW RATE OF WATER

$$Q = A_p \times v \tag{3.9}$$

Where: Q = Volume flow rate of water

3.3.10 MASS FLOW RATE OF WATER

$$\dot{m} = \rho_{water} \times Q \tag{3.10}$$

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

ρ_{water} = density of water

3.3.11 MASS OF WATER

$$m = \rho_{water} \times V_w \tag{3.11}$$

Where: m = Mass of water

V_w = Volume of water

3.3.12 WEIGHT FLOW RATE OF WATER

$$\dot{w} = Q \times \gamma \tag{3.12}$$

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 (3.13)

3.3.13 REYNOLDS NUMBER

$$Re = \frac{Inertial\ Forces}{Viscous\ Forces} = \frac{VD}{v} = \frac{\rho VD}{\mu} \quad (3.14)$$

Where, V is 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

3.3.14 FRICTION FACTOR

For laminar flow, friction factor f = $\frac{64}{Re} \geq \frac{64}{2300} \geq 0.027826$ as the value of Re decreases (3.15)

For turbulent flow, friction factor is expressed using Colebrook equation

$$\frac{1}{\sqrt{f}} = -2.0\ log\ (\frac{\varepsilon/_D}{3.7} + \frac{2.51}{Re\sqrt{f}}) \quad (3.16)$$

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

$$\frac{1}{\sqrt{f}} \cong -1.8\ log\ [\frac{69}{Re} + \left(\frac{\varepsilon/_D}{3.7}\right)^{1.11}] \quad (3.17)$$

3.3.15 ENTRY LENGTH

For laminar flow

$$\frac{L_{h,laminar}}{D} \cong 0.05\text{Re} \tag{3.18}$$

Where D_h is the hydraulic diameter for circular pipe

'D' was gotten from the equation of hydraulic diameter given as;

$$D_h = \frac{4A_c}{p} = \frac{4(\frac{D^2}{4})}{\pi D} = D \tag{3.19}$$

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, $\frac{L_{h,turbulent}}{D} = 1.359Re^{1/4}$ For Re $\leq 10^6$ (3.20)

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 as

Entry length, $\frac{L_{h,turbulent}}{D} \approx 10$

3.3.16 PIPE ROUGHNESS

The friction factor in fully developed turbulent pipe flow depends 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 (Cengel *et al.* 2012). Table 3.2 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 3.2: Absolute roughness for different pipe surfaces

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

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: Cengel *et al.* 2012 Fundamentals of thermo-fluid science

$$\text{Relative Roughness} = \frac{Absolute\ roughness}{Hydraulic\ Diameter} = \frac{\varepsilon}{D_h} \qquad (3.21)$$

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 (Cengel, *et al.* 2012).

3.3.17 PRESSSURE 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**

$$\text{Pressure loss} = \Delta P_L = f\frac{L}{D}\frac{\rho V^2}{2} \qquad (3.22)$$

Where; L is the pipe length

D is the pipe diameter

V is fluid velocity

f is friction factor

3.3.18 HEAD LOSS

In the analysis of piping systems, pressure losses are commonly expressed in terms of the equivalent fluid column height, called the head loss h_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. The head loss is caused by viscosity, and it is directly related to the wall shear stress (Cengel *et al.* 2012)

$$\text{Head loss} = H_L = \frac{\Delta P_L}{\rho g} = f\frac{L}{D}\frac{V^2}{2g} \tag{3.23}$$

3.3.19 MINOR OR 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 (Esposito, A., 2009).

$h_m = K_L\frac{V^2}{2g}$ Where K_L is called the loss coefficient (3.24)

From the above equation, gate valve, ball valves and stop cock were selected based on their relative openness and losses (Esposito, A., 2009).

3.3.20 POWER

The power required to overcome friction is given as;

$$Power = \Delta PQ = \gamma H_L Q \tag{3.25}$$