# Equipment and Experimental Design for Reynolds Number Analysis

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**Abstract. Fluid flow properties is an important parameter in many industries, especially when designing an equipment. Fluid have three types of flow directions namely laminar, transitional or transient, and turbulent. Dimensionless number of Reynolds is the way to differentiate types of fluid flow based on a specific range of numbers. In this experiment, a simple yet effective equipment was design and built to produce laminar and turbulent flow. Moreover, the fluid flow also proven by the calculation of Reynolds number using known quantities from the experiment. Water at 25°C was chosen as the material for this experiment, but the other material can also be used in this equipment as long as it have low viscosity. The experiment was conducted five times and laminar flow produced from the equipment have Reynolds number of 1480, while turbulent flow showed much higher Reynolds number of 12760.**

Keywords: Fluid flow, Reynolds number, Laminar, Turbulent

## 1. INTRODUCTION

Fluid flow inside of a pipe can be distinguished into two types of flow characteristics: laminar and turbulent flow depending on the velocity of the fluid. Reynolds number is used to differentiate fluid flow using a dimensionless number (McCabe, et al., 2005)

This study proposes an economical and straightforward approach to assess the Reynolds number of water at room temperature (25° C) passing through a cylindrical opening and using pressure different to change from laminar to turbulent flow. Instead of expensive commercial tools, this design advocate for using basic laboratory instruments like stopwatches, measuring cylinders, and plastic bottles. By measuring average flow rates and computing average fluid velocity, Reynolds number (Re) then can be calculated.

Understanding fluid mechanics holds significant importance across various physics and engineering, especially in chemical engineering, where concepts such as laminar and turbulent flow, viscosity, and Reynolds number are pivotal. Reynolds number (Re) serves as a dimensionless parameter to outline fluid flow stability by comparing inertial and frictional forces within the fluid.

By measuring the time taken to accumulate a set volume of water under laminar and turbulent flow conditions, it can be used to compute mean flow rates and bulk velocity of the fluid. These values, combined with relevant parameters such as fluid density, viscosity, and characteristic length, facilitate the determination of Reynolds numbers.

## 2. LITERATURE REVIEW

### 2.1 Reynold's Number

The Reynold's number is a dimensionless parameter utilized for classifying fluid systems where viscosity plays a significant role in regulating fluid velocities or flow patterns. Fluid in motions that can be expressed using Reynolds number not only restricted to fluid but also gas, hence Reynolds number used in many areas such as car or airplane design.

Reynold's number (Re) is defined as the ratio of the inertial forces to viscous forces within a fluid flow system (Kolmogonov, 1991). It is expressed as:

$$Re = \frac{\rho v D p}{\eta} \qquad \text{Eq. 1}$$

P = density of the fluid (kg/m$^3$)
v = average velocity (m/s)
Dp = diameter of the pipe (m)
M = viscosity of the fluid (Pa.s)

There are several equations to calculate Reynolds number based on the known quantities, the most common one is to used average velocity of the fluid flow inside of a pipe. Average velocity is used due to different velocity experienced by the fluid as the effect of friction force of pipe surface. This friction forced also differ based on the material of pipes used, hence selecting the correct pipe material will be crucial when designing an equipment.

Reynolds number is a dimensionless number and critical when determining fluid's behavior (Adrian and Marusic, 2012). If Reynolds number is lower than 2000 then it is considered as laminar flow, if Re number is between 2000 to 4000 it called as transient or transitional flow and lastly if Re number is above 4000 it can be concluded as turbulent flow (Guo and Ghalambar, 2012).

## 2.2 Fluid Flow Characteristics

### 2.2.1 Laminar flow

Laminar flow refers to the smooth flow of fluid in layers with minimal mixing, and usually happen in low Reynolds number. White (2016) research has highlighted its prevalence when the Reynold's number is below approximately 2000, showing predictable flow patterns often seen in viscous fluids moving through narrow passages. Laminar flow also called as one directional flow due to its nature that only have one direction flow, differ with transitional and turbulent flow that have unidirectional flow.

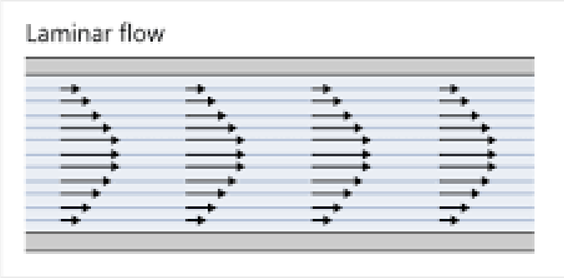

Figure 1. Laminar Flow
Source: Altair Engineering, 2023

### 2.2.2 Turbulent flow

Conversely, turbulent flow arises at higher Reynold's numbers, where inertial forces dominate, leading to chaotic fluid motion. Studies by Pope (2000) and Lumley & Falkovich (2007) illustrate turbulent flow through the presence of eddies, vortices, and fluctuations. This type of flow is commonly observed in industrial processes, atmospheric phenomena, and natural water systems. As can be seen from figure 2 below, turbulent flow is more chaotic and have more than 1 direction or called as unidirectional flow. This type of fluid flow usually more preferred in the industrial process, in comparison to laminar flow.

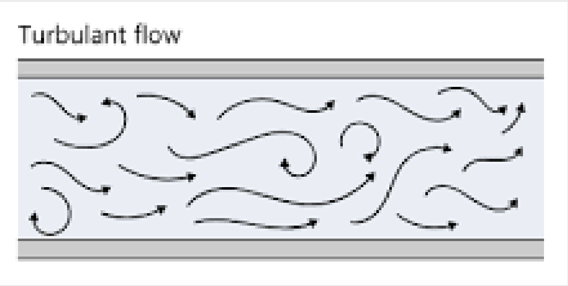

Figure 2. Turbulent Flow
Source: Altair Engineering, 2023

### 2.3 Utilization of Reynolds Number

As mention previously that Reynolds number can be used to determine fluid flow not only flor liquid but also gas and the principles of Reynold's number can happen in everyday life in numerous situations, such as:

Driving, in which Reynold's number affects the airflow around the car while driving. It influences factors like drag, which impacts fuel efficiency and stability. Engineers use Reynolds number calculations when designing cars to optimize aerodynamics.

Showering, which is when the flow of water from the showerhead can transition from laminar to turbulent depending on factors like water pressure and nozzle design. Understanding Reynold's number helps manufacturers design showerheads for a pleasant and efficient water flow.

Reynolds number also used when constructing miniature models of large machinery. For example, when building a new airplane, Reynolds number was used to understand about the wind tunnel (Dauxois, et al., 2000). Scale model of the airplane need to be identical to the reality to ensure the reliability of any test result used during the design (Daviaud, et al., 1992)

## 3. METHODOLOGY

### 3.1 Equipment

- 1 liter water bottle
- Measuring cylinder (500 ml)
- Basin
- Stopwatch
- Drilling machine

### 3.2 Material

To conduct the experiment using built equipment, water at 25ºC was chosen as the main material. Physical and chemical properties of the material used in this experiment can be seen in table 1.

Table 1. Properties of Water at 25 ºC

| Property | Value | Unit |
|---|---|---|
| Kinematic Viscosity | $0.8927 \times 10^{-6}$ | $m^2/s$ |
| Density | 997 | $kg/m^3$ |
| Viscosity | $8.9 \times 10^{-4}$ | Pa.s |

Source: researchgate.net

### 3.3 Equipment

This simple equipment was designed to determine Reynolds number by using the help of gravitational force. Hole at the bottom of the water bottle served as the outlet to produce laminar and turbulent flow as can be seen in figure 2 below.

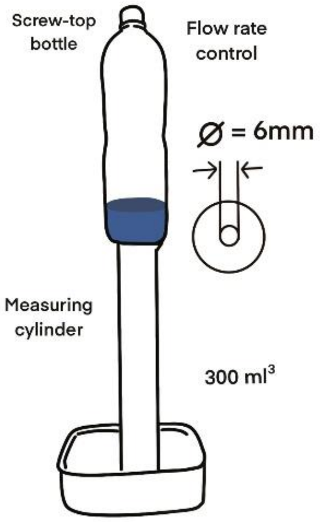

Figure 2. Design of Reynolds Number Measuring Equipment

From figure 3, clearly can be seen that built equipment was exactly as the design with outlet hole at exact 6 mm. Basin at the bottom was used to capture any spillage from the bottle or from the measuring cylinder. 1 liter bottle is chosen to ensure there are enough pressure inside the bottle to produce turbulent flow.

Figure 3. Equipment Built to Measure Reynolds Number

### 3.4 Procedure

A 6 mm hole was drilled using drilling machine at the bottom of a 1-liter water bottle as the outlet. Then the water bottle was filled with water whilst using a finger to prevent spilling. Once finger was removed from the hole, water was collected using measuring cylinder and stopwatch was used to determine the time needed to get 300 ml.

The main point of this experiment is the use of bottle water cap to change from laminar flow to turbulent flow. Opening the bottle cap will allow the water to undergo laminar flow and as the bottle cap is loosened, the water flow will turn to turbulent. Therefore, the bottle cap serves as the flow rate control. When the bottle cap is tightened, the flow would come to a halt since the pressure at the surface of the water which is caused the expansion of the available volume for the air to occupy due to the loss of fluid.

Measurements are then conducted. Once the flow is established and seems steady, the bottle is positioned above a 500 $ml^3$ measuring cylinder, triggering the start of a stopwatch. When 300 $ml^3$ of water has been gathered, the stopwatch is stopped. The bottle can then be replenished, and the measuring cylinder emptied to repeat the experiment. The experiment was repeated 5 times for each laminar and turbulent flow.

## 4. RESULT

By the help of different pressure inside the water bottle controlled by the bottle cap, both types of fluid flow can be achieved by using this equipment. Laminar flow which is more steady is the one on the left from Figure 4 and can be seen as one straight line. On the other hand, turbulent flow produced by the equipment as can be seen on the right picture in Figure 4, is more crooked and not as straight line as laminar flow due to it have multiple directions.

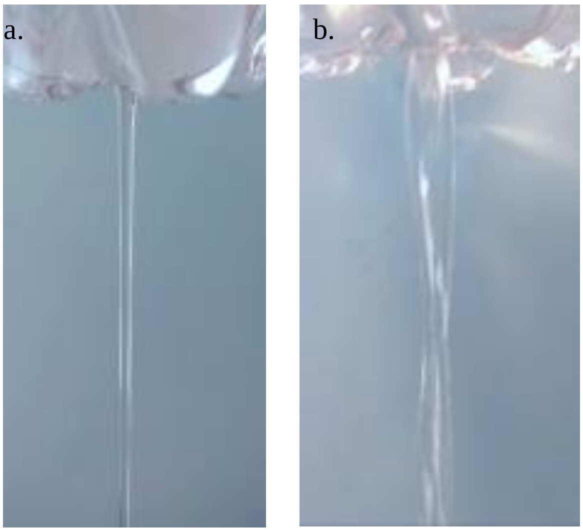

Figure 4. a). Laminar flow b.) Turbulent Flow

After following the procedure, the time taken for 300 ml$^3$ to be collected with laminar and turbulent flow is measured. The experiment is repeated 5 times and to also estimate uncertainty as can be seen in table 2.

Table 2. Time needed to reach 300 ml

| **Time (s)** | | | | | | |
|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **Mean time** |
| **Laminar** | 47 | 48.4 | 49 | 47.7 | 48.2 | 48 |
| **Turbulent** | 7.7 | 7.92 | 7.85 | 8.01 | 7.88 | 7.9 |

Volumetric flowrate (Q) of the experiment then calculated using equation 2 below:

$$Q = \frac{V}{t} \qquad \text{Eq. 2}$$

For this equipment volume of water has been pre determined which is 300 ml and time used to calculate volumetric flowrate using mean time from table 2. It was calculated that volumetric flowrate for laminar flow was 6.25 ± 1.30 x $10^{-3}$ m$^3$/s and for turbulent flow 37.97 ± 4.33 $\times 10^{-3}$m$^3$/s.

$$v = \frac{Q}{A} \qquad \text{Eq. 3}$$

To calculate Reynolds number using equation 1, average fluid velocity need to be known. Since different layers of fluid have different velocity, then average velocity was calculated using equation 3 above. And since the outlet hole is circular, the equation of cross sectional area of a circle is used to calculate A ($\pi r^2$) with r is equal to 6 mm.

Table 3. Calculation Result

| | **Laminar** | **Turbulent** | **Units** |
|---|---|---|---|
| **t** | 48 | 7.9 | s |
| **Q** | 6.25 x $10^{-3}$ | $37.97 \times 10^{-3}$ | m$^3$/s |
| **A** | 1.13 x $10^{-4}$ | 1.13 x $10^{-4}$ | m$^2$ |
| **v** | 0.221 | 1.344 | m/s |
| **Re** | 1480 | 12760 | - |

Table 3 above shown that fluid flow produced by this equipment following the rule of Reynolds number. The calculated values are within the range of 2000 < Re < 4000 as the laminar flow is 1480 ± 310 which is <2000 and for turbulent flow, 12760 ± 1440 which is >4000.

The alignment observed between the computed Reynolds numbers and theoretical projections confirms the precision and dependability of the experimental method. The shift from laminar to turbulent flow at a crucial Reynolds number of approximately 2000 is consistent with well-established principles of fluid dynamics. This pivotal threshold, extensively documented in literature, signifies a fundamental characteristic of fluid flow phenomena.

Although the experiment successfully showcases the viability of the suggested approach, it's essential to recognize specific limitations. The straightforward nature of the experimental arrangement might limit its suitability for dealing with more complex fluid flow scenarios. Additionally, factors like surface roughness and potential experimental inaccuracies may introduce uncertainties into the measurements.

## 5. CONCLUSION

This research introduces a cost-effective and straightforward method for determining the Reynolds number of water flowing through a cylindrical hole. By using basic laboratory instruments such as stopwatches, measuring cylinders, and plastic bottles, we devised an experiment accessible to various educational settings.

Through measurements of flow rates under laminar and turbulent conditions, it derived average flow rates and calculated mean bulk velocities of the fluid. These values, in conjunction with fluid parameters such as density, viscosity, and characteristic length, facilitated the Reynolds numbers.

The results demonstrate the adaptability and efficacy of our approach. For laminar flow, we obtained a mean flow rate of 6.25 ± 1.30×10−3 m$^3$/s mean bulk velocity of 0.221 ± 0.046 m/s, and a Reynolds number of 1480 ± 310. Conversely, under turbulent flow, the mean flow rate was 37.97 ± 4.33×10−3 m$^3$/s, the mean bulk velocity was 1.344 ± 0.153 m/s, and the Reynolds number was 12760 ± 1440.

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