FLUID MECHANICS
REYNOLDS NUMBER ANALYSIS
REPORT

Objective:
To determine Reynolds Number using water flowing through a cylindrical aperture.

Apparatus:
- 1-liter bottle with 4mm, 6mm, and 8mm diameter holes at the bottom
- 500 ml measuring cylinder
- Stopwatch

Theory:
The Reynolds number (Re) is a useful dimensionless quantity in fluid dynamics which characterizes the stability of a fluid by comparing inertial forces to frictional forces. Laminar flow is characterized by low Reynolds numbers and describes layers of fluids flowing parallel over one another smoothly. Turbulent flow is chaotic and disorderly and is characterized by high Reynolds numbers due to the geometry and physical properties of the fluid. We describe a simple experiment that is accurate enough to give quantitative insight into Reynolds numbers for laminar and turbulent flow.

Formula used:

$$Re = \frac{vl\rho}{\mu}$$

where v = speed of the bulk fluid

l = Hydraulic Diameter

ρ = Density of fluid

μ = viscosity of the fluid

Procedure:

1. The bottom of a 1-litre screw-cap bottle is drilled with a small (6mm) hole.
2. The bottle is filled close to the top with tap water whilst using a finger to keep the water in and the screw-cap is replaced.

3. Gradually open the screw cap to allow the water to exit the bottle, and observe the water flow.
4. Note the point at which laminar flow transitions to turbulent flow, which the change in the flow pattern of the water can identify.
5. Use the screw-cap as the flow rate control, by limiting the rate at which atmospheric air is able to replace the volume of water lost during fluid flow.
6. Mark the closed position of the screw cap and bottle with a small vertical pen mark.
7. Once the laminar (or turbulent) flow has been established, draw two additional vertical pen marks on the bottle, marked ‘L’ for laminar and ‘T’ for turbulent.
8. Measure the flow rate by placing the bottle on top of a 500 cm3 measuring cylinder and starting a stopwatch once the flow appears consistent.
9. Stop the stopwatch after 300 cm3 of water has been collected. Repeat the experiment for the same bottle and take 15 readings of each of the Laminar and Turbulent flows.
10. Repeat the above steps for the bottle with 4mm and 8mm hole bottles.

Observation Tables:

Combined observation table

Calculation:

$$t_{average} = \left(\frac{\sum_{n=0}^{n} t_n}{n} \right)$$

$$dt = \left(\frac{\sum_{n=0}^{n} \left| t_n - t_{average} \right|}{n} \right)$$

Here t = time(s) = $t_{average} \pm dt$

$t_{average}$ = Average time

n = number of observation taken = 21

dt = Deviation(s)

V = Volume = $300 \times 10^{-6}\, m^3$

dV = Volume Error = 0 (V =Constant)

$$Q_{average} = \frac{V}{t_{average}}$$

$$\Rightarrow \quad \frac{dQ}{Q} = \frac{dV}{V} + \frac{dt}{t_{average}}$$

$$\frac{dQ}{Q} = \frac{dt}{t_{average}}$$

$$dQ = Q\left(\frac{dt}{t_{average}}\right)$$

Here Q = Volume Flow Rate = $Q_{average} \pm dQ$

$Q_{average}$ = Average Flow Rate

$dQ = Volume\ Error$

$$v_{average} = \left(\frac{Q_{average}}{A}\right)$$

$$dv = \left(\frac{dQ}{A}\right)$$

Here v = speed of the bulk fluid = $v_{average} \pm dv$

$v_{average}$ = speed of the bulk fluid

dv = speed Error

D = Diameter of Hole

A = Area

$$Re_{average} = \frac{v_{average} l \rho}{\mu} = \frac{v_{average} D \rho}{\mu}$$

$$dRe = \frac{(dv) l \rho}{\mu}$$

Here Re = Reynolds Number = $Re_{average} \pm dRe$

$Re_{average} = Average\ Reynolds\ Number$

dRe = Reynolds Number Error

l = characteristic length of the geometry through which the fluid flows = D

ρ = Density of fluid = $1000\ \frac{kg}{m^3}$

μ = viscosity of the fluid = 8.90×10^{-4}

- Laminar

1. D = Diameter of Hole = $6 \times 10^{-3} m$

$$A = \left(\frac{\pi D^2}{4}\right) = 2.83 \times 10^{-5} m^2$$

$$t_{average} = 56.708571\ s$$

$$dt = 7.011224\ s$$

$$Q_{average} = 5.29 \times 10^{-6}\ \frac{m^3}{s}$$

$$dQ = 0.65 \times 10^{-6}\ \frac{m^3}{s}$$

$$v_{average} = 1.87 \times 10^{-1} \frac{m}{s}$$

$$dv = 2.31 \times 10^{-2} \frac{m}{s}$$

$Re_{average} = 1261.36$

$dRe = 155.95$

t = time(s) = $56.708571 \pm 7.011224\ s$

Q = Volume Flow Rate = $5.29 \times 10^{-6} \pm 0.65 \times 10^{-6}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $1.87 \times 10^{-1} \pm 2.31 \times 10^{-2}\ \frac{m}{s}$

Re = Reynolds Number = 1261.36 ± 155.95

2. D = Diameter of Hole = $4 \times 10^{-3}\ m$

$$A = \left(\frac{\pi D^2}{4}\right) = 1.26 \times 10^{-5}\ m^2$$

$t_{average} = 59.315714\ s$

$dt = 4.315714\ s$

$$Q_{average} = 5.05 \times 10^{-6}\ \frac{m^3}{s}$$

$$dQ = 3.67 \times 10^{-7}\ \frac{m^3}{s}$$

$$v_{average} = 4.02 \times 10^{-1}\ \frac{m}{s}$$

$$dv = 2.92 \times 10^{-2}\ \frac{m}{s}$$

$Re_{average} = 1808.88$

$dRe = 131.61$

t = time(s) = $59.315714 \pm 4.315714\ s$

Q = Volume Flow Rate = $5.05 \times 10^{-6} \pm 3.67 \times 10^{-7}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $4.02 \times 10^{-1} \pm 2.92 \times 10^{-2}\ \frac{m}{s}$

Re = Reynolds Number = 1808.88 ± 131.61

3. D = Diameter of Hole = $8 \times 10^{-3} m$

$$A = \left(\frac{\pi D^2}{4}\right) = 5.03 \times 10^{-5} m^2$$

$t_{average} = 14.353333\ s$

$dt = 2.828888 s$

$$Q_{average} = 2.09 \times 10^{-5} \frac{m^3}{s}$$

$$dQ = 4.11 \times 10^{-6} \frac{m^3}{s}$$

$$v_{average} = 4.15 \times 10^{-1} \frac{m}{s}$$

$$dv = 8.19 \times 10^{-2} \frac{m}{s}$$

$Re_{average}$ = 3737.64

dRe = 736.65

t = time(s) = $14.353333 \pm 2.828888\ s$

Q = Volume Flow Rate = $2.09 \times 10^{-5} \pm 4.11 \times 10^{-6} \frac{m^3}{s}$

v = speed of the bulk fluid = $4.15 \times 10^{-1} \pm 8.19 \times 10^{-2} \frac{m}{s}$

Re = Reynolds Number = 3737.64 ± 736.65

- Turbulent

1. D = Diameter of Hole = $6 \times 10^{-3} m$

$$A = \left(\frac{\pi D^2}{4}\right) = 2.83 \times 10^{-5} m^2$$

$t_{average} = 9.847142\ s$

$dt = 0.957142\ s$

$Q_{average} = 3.04 \times 10^{-5}\ \frac{m^3}{s}$

$dQ = 2.96 \times 10^{-6}\ \frac{m^3}{s}$

$v_{average} = 1.07 \frac{m}{s}$

$dv = 0.1\ \frac{m}{s}$

$Re_{average} = 7264.06$

$dRe = 706.06$

t = time(s) = $9.847142 \pm 0.957142\ s$

Q = Volume Flow Rate = $3.04 \times 10^{-5} \pm 2.96 \times 10^{-6}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $1.07 \pm 0.1 \frac{m}{s}$

Re = Reynolds Number = 7264.06 ± 706.06

2. D = Diameter of Hole = $4 \times 10^{-3} m$

$A = \left(\frac{\pi D^2}{4}\right) = 1.26 \times 10^{-5}\ m^2$

$t_{average} = 20.663571\ s$

$dt = 0.876020\ s$

$Q_{average} = 1.45 \times 10^{-5}\ \frac{m^3}{s}$

$$dQ = 6.15 \times 10^{-7} \frac{m^3}{s}$$

$$v_{average} = 1.15 \frac{m}{s}$$

$$dv = 4.8 \times 10^{-2} \frac{m}{s}$$

$$Re_{average} = 5192.49$$

$$dRe = 220.13$$

t = time(s) = $20.663571 \pm 0.876020\ s$

Q = Volume Flow Rate = $1.45 \times 10^{-5} \pm 6.15 \times 10^{-7} \frac{m^3}{s}$

v = speed of the bulk fluid = $1.15 \pm 4.8 \times 10^{-2} \frac{m}{s}$

Re = Reynolds Number = 5192.49 ± 220.13

3. D = Diameter of Hole = $8 \times 10^{-3} m$

$$A = \left(\frac{\pi D^2}{4}\right) = 5.03 \times 10^{-5} m^2$$

$$t_{average} = 6.727857\ s$$

$$dt = 0.517040\ s$$

$$Q_{average} = 4.45 \times 10^{-5} \frac{m^3}{s}$$

$$dQ = 3.42 \times 10^{-6} \frac{m^3}{s}$$

$$v_{average} = 8.87 \times 10^{-1} \frac{m}{s}$$

$$dv = 6.81 \times 10^{-2} \frac{m}{s}$$

$$Re_{average} = 7973.97$$

$$dRe = 612.80$$

t = time(s) = $6.727857 \pm 0.517040\ s$

Q = Volume Flow Rate = $4.45 \times 10^{-5} \pm 3.42 \times 10^{-6}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $8.87 \times 10^{-1} \pm 6.81 \times 10^{-2}\ \frac{m}{s}$

Re = Reynolds Number = 7973.97 ± 612.80

Results:

a) Laminar Flow

For 4mm:

Q = $5.29 \times 10^{-6} \pm 0.65 \times 10^{-6}\ \frac{m^3}{s}$

Re = 1261.36 ± 155.95

For 6mm:

Q = $5.05 \times 10^{-6} \pm 3.67 \times 10^{-7}\ \frac{m^3}{s}$

Re = 1808.88 ± 131.61

For 8mm:

Q = $2.09 \times 10^{-5} \pm 4.11 \times 10^{-6}\ \frac{m^3}{s}$

Re = 3737.64 ± 736.65

b) Turbulent Flow

For 4mm:

Q = $1.45 \times 10^{-5} \pm 6.18 \times 10^{-7}\ \frac{m^3}{s}$

Re = 5192.49 ± 220.13

For 6mm:

Q = $3.04 \times 10^{-5} \pm 2.96 \times 10^{-6}\ \frac{m^3}{s}$

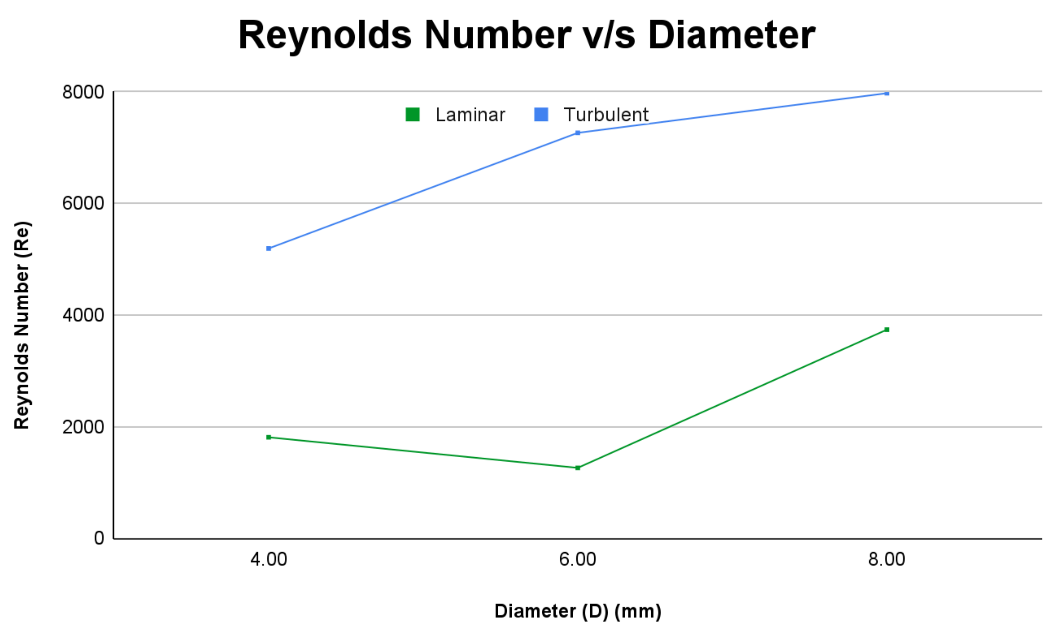
Re = 7264.06 ± 706.06

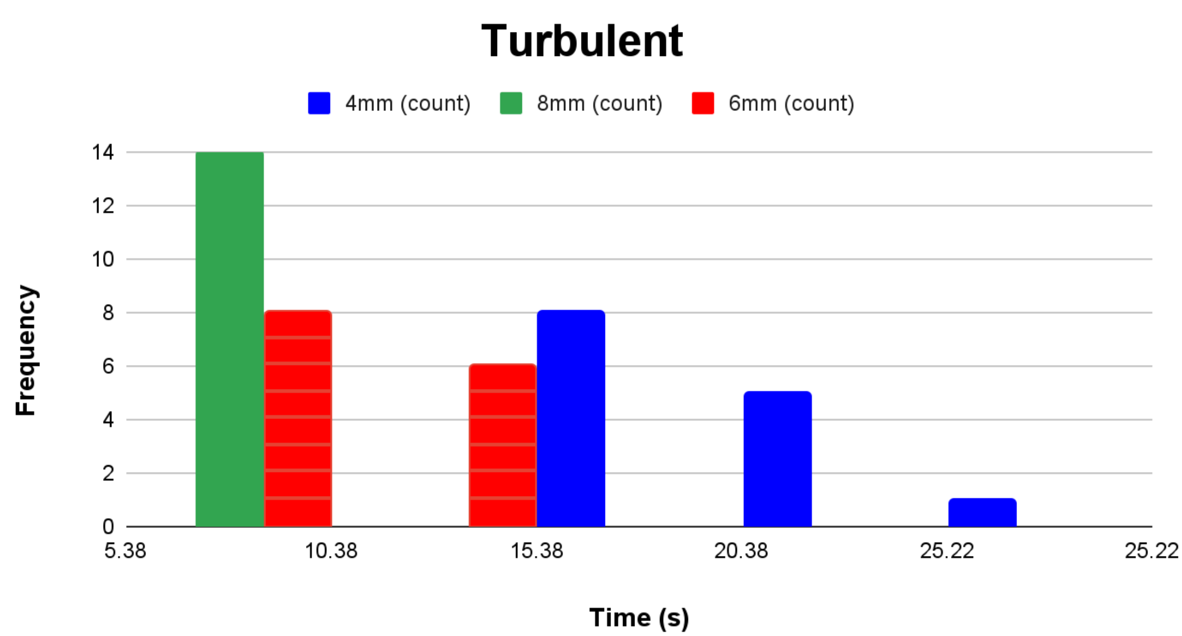
For 8mm:

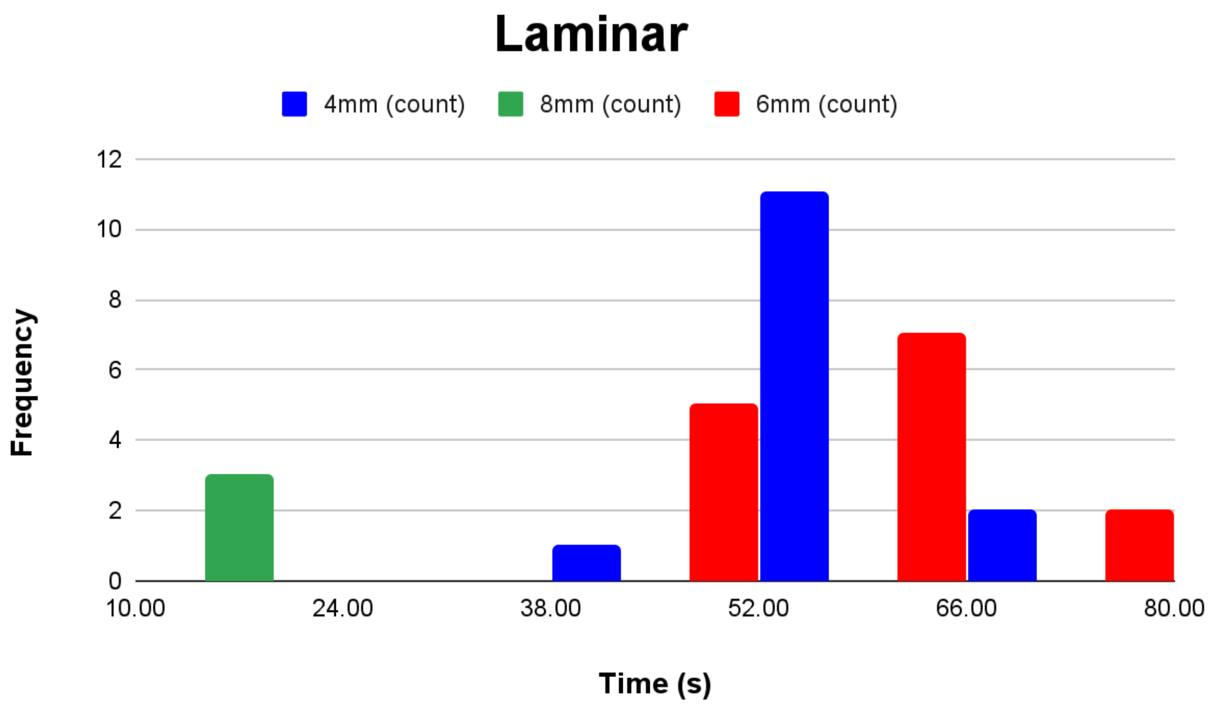
$Q = 6.727857 \pm 0.517040\ s$

$Re = 7973.97 \pm 612.80$

Graphs:





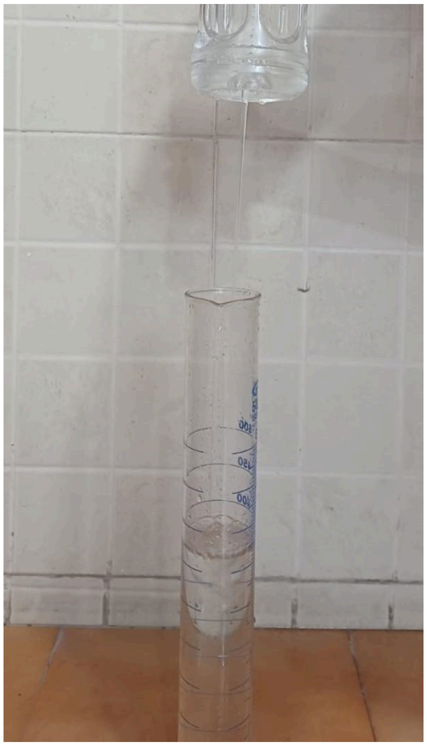


Prototype Diagram:

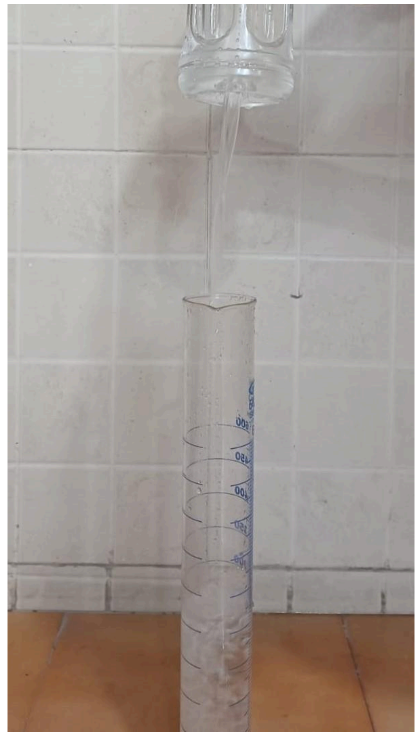
Laminar 4mm

Turbulent 4mm

Laminar 8mm

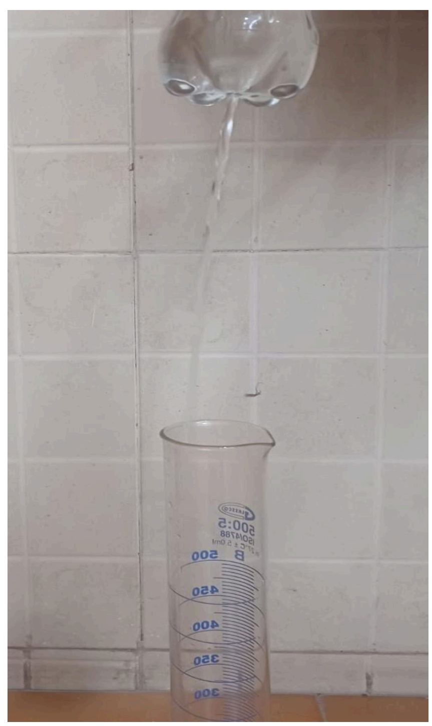


Turbulent 8mm



Laminar 6mm

Turbulent 6mm



Discussion and conclusion:

1. The experiment was conducted using a screw cap bottle with holes of different diameters (6mm, 4mm, and 8mm) and a 500 ml measuring cylinder was aimed at determining the Reynolds number. The results of the experiment showed that the flow regime varied depending on the diameter of the hole.

2. It is being observed that the precise values obtained for the Reynolds number and flow rate may vary depending on the properties of the fluid used, the temperature, and other experimental factors such as variation in pressure. Therefore, repeating the experiment multiple times and taking averages can help to improve the accuracy and reliability of the results.

3. Laminar flow was not observed in the bottle having an 8mm hole at the bottom while it was observed in bottles having 4mm and 6mm diameter holes at the bottom, it may be due to the fact the size of the hole was increased. The larger hole size may have caused the flow to be more turbulent, preventing the formation of smooth, regular flow patterns. Additionally, the shape and roughness of the hole may have contributed to the transient nature of the flow.

4. Overall, the experiment provides a simple and practical way to determine the flow regime of a fluid and the Reynolds number using basic laboratory equipment. This can be useful in a variety of applications, such as in the design of pipes, pumps, and other fluid-handling equipment, where the flow regime and Reynolds number play important roles in determining the performance and efficiency of the system.

Group Members and their Contributions:

1. Jesika Rai (B21CI020)
2. Mamta Kumari (B21CI025)
3. Mohit Bansal (B21CI028)
4. Praveen Kumar (B21CI032)