REYNOLDS NUMBER

Fluid Mechanics

by

Jason Daniel (B21CI019)
Ruchit Kochar (B21CI038)
Manoj Solara (B21CI027)
Divyansh Jain (B21CI017)

Department of Civil and Infrastructure Engineering

Indian Institute of Technology

Jodhpur

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Objective:- To determine Reynolds number.

Apparatus:- Measuring Cylinder (500 ml), Drilling Machine with 4mm, 6mm, and 8mm bits, 1L bottles with 4,6,8 mm holes drilled at the bottom, stopwatch, marker pens

Theory:- Understanding fluid mechanics is important for students studying physics and engineering related disciplines. The Reynolds number is a dimensionless quantity used in fluid dynamics to characterize the stability of a fluid. Laminar flow is characterized by low Reynolds numbers, while turbulent flow is characterized by high Reynolds numbers. The transition between laminar and turbulent flow occurs at a critical bulk speed of the fluid. The article describes a simple experiment that can be performed using basic laboratory equipment to gain insight into Reynolds numbers for laminar and turbulent flow, with opportunities for additional investigation

Formula:

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

Here v = speed of the bulk fluid
l = Hydraulic Diameter
ρ = Density of fluid
μ = viscosity of the fluid

Procedure:- In this experiment:

1) Drill a 6 mm hole into the bottom of a 1-liter screw-top bottle.
2) Fill the bottle close to the top with tap water, using a finger or a suitable alternative to keep the water in and the screw-cap replaced.
3) Open the screw cap a small amount to allow water to exit under laminar flow, and open it much further to allow water to exit under turbulent flow.
4) Draw a small vertical pen mark across the screw cap and bottle to mark the closed position. Draw two additional vertical pen marks on the bottle, marked 'L' for laminar and 'T' for turbulent.
5) Place the marked bottle on top of a 500cc measuring cylinder and start the stopwatch after establishing consistent flow.

6) Stop the stopwatch after collecting 300cc of water. Refill the bottle and empty the measuring cylinder to repeat the experiment (21 times).
7) Repeat the above steps for 4mm and 8mm holes.

Observation Table

READING						
Cat.	Laminar (6mm)	Laminar (4mm)	Laminar (8mm)	Turbulent (6mm)	Turbulent (4mm)	Turbulent (8mm)
S.No	TIME(s)					
1	75.14	52.52	15.86	8.04	18.77	6.21
2	80.43	57.02	12.04	7.9	19.77	6.49
3	48.29	54.78	13.97	8.39	19.28	6.6
4	70.46	80.99	LAMINAR NOT OBSERVED	8.09	19.87	6.45
5	60.86	61.64		8.45	19.53	6.14
6	45.81	66.04		8.17	19.84	6.41
7	31.14	55.32		8.33	19.82	6.46
8	85.9	61.12		8.27	19.48	6
9	34.24	95.25		8.61	19.1	6.23
10	49.57	66.46		9	19.63	6.45
11	74.72	76.5		8.28	19.67	6.15
12	82.01	75.49		8.13	19.8	6.17
13	73.62	86.74		8.34	19.42	6.33
14	57.15	59.71		8.24	20	6.01
15	57.04	69.61		8.57	19.29	6.2
16	43.31	63.1		8.74	19.48	6.45
17	44.36	66.13		8.02	18.96	6.31
18	68.02	68.91		8.11	19.2	6.15
19	63.1	49.33		7.91	19.28	6.33
20	44.11	74.02		7.85	19.42	6.19
21	53.13	77.29		7.6	19.47	6.5

Average time	59.162381	67.522381	13.956667	8.240000	19.480000	6.296667
Average Deviation Time	13.584399	9.247483	1.277778	0.245714	0.248571	0.144444
Volume(V)	.00E-04	.00E-04	.00E-04	.00E-04	.00E-04	3.00E-04
Average Volume Flow Rate(Q)	5.07E-06	4.44E-06	2.15E-05	3.64E-05	1.54E-05	4.76E-05
Volume Flow Rate Error(dQ)	1.16E-06	6.08E-07	1.97E-06	1.09E-06	1.97E-07	1.09E-06
Average Velocity(v)	1.79E-01	3.54E-01	4.28E-01	1.29E+00	1.23E+00	9.48E-01
Velocity Error(dv)	4.12E-02	4.84E-02	3.92E-02	3.84E-02	1.56E-02	2.17E-02
Diameter(D)	6.00E-03	4.00E-03	8.00E-03	6.00E-03	4.00E-03	8.00E-03
Area(A)	2.83E-05	1.26E-05	5.03E-05	2.83E-05	1.26E-05	5.03E-05
Density(ρ)	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03	1.00E+03
Dynamic Viscosity(η)	8.90E-04	8.90E-04	8.90E-04	8.90E-04	8.90E-04	8.90E-04
ρD/η	6.74E+03	4.49E+03	8.99E+03	6.74E+03	4.49E+03	8.99E+03
Average Reynolds Number (Re)	1,209.05	1,589.04	3,843.88	8,680.86	5,507.98	8,520.02
Reynolds Number error (dRe)	277.6	217.63	35 .92	258.86	70.28	195.45

All parameters taken in standard units

Calculation:-

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)

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

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

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

$Q_{average}$ = Average Flow Rate

$dQ = Volume\ Error$

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

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

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

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

Here 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

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

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

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

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

dRe = Reynolds Number Error

l = Hydraulic Diameter = D

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

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

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

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

- **Laminar**

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

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

$$t_{average} = 59.162381\ s$$

$$dt = 13.584399\ s$$

$$Q_{average} = 5.07 \times 10^{-6} \frac{m^3}{s}$$

$$dQ = 1.16 \times 10^{-6} \frac{m^3}{s}$$

$$v_{average} = 1.79 \times 10^{-1} \frac{m}{s}$$

$$dv = 4.12 \times 10^{-2} \frac{m}{s}$$

$$Re_{average} = 1{,}209.05$$

$$dRe = 277.61$$

t = time(s) = $59.162381 \pm 13.584399\ s$

Q = Volume Flow Rate = $5.07 \times 10^{-6} \pm 1.16 \times 10^{-6} \frac{m^3}{s}$

v = speed of the bulk fluid = $1.79 \times 10^{-1} \pm 4.12 \times 10^{-2} \frac{m}{s}$

Re = ***Reynolds Number*** = $1,209.05 \pm 277.61$

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

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

$$t_{average} = 67.522381\ s$$

$$dt = 9.247483\ s$$

$$Q_{average} = 4.44 \times 10^{-6} \frac{m^3}{s}$$

$$dQ = 6.08 \times 10^{-7} \frac{m^3}{s}$$

$$v_{average} = 3.54 \times 10^{-1} \frac{m}{s}$$

$dv = 4.84 \times 10^{-2} \frac{m}{s}$

$Re_{average} = 1,589.04$

$dRe = 217.63$

t = time(s) = $67.522381 \pm 9.247483\ s$

Q = Volume Flow Rate = $4.44 \times 10^{-6} \pm 6.08 \times 10^{-7} \frac{m^3}{s}$

v = speed of the bulk fluid = $3.54 \times 10^{-1} \pm 4.84 \times 10^{-2} \frac{m}{s}$

Re = ***Reynolds Number*** = $1,589.04 \pm 217.63$

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

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

$t_{average} = 13.956667\ s$

$dt = 1.277778\ s$

$Q_{average} = 2.15 \times 10^{-5} \frac{m^3}{s}$

$dQ = 1.97 \times 10^{-6} \frac{m^3}{s}$

$v_{average} = 4.28 \times 10^{-1} \frac{m}{s}$

$dv = 3.92 \times 10^{-2} \frac{m}{s}$

$Re_{average} = 3843.88$

$dRe = 351.92$

t = time(s) = $13.956667 \pm 1.277778\ s$

Q = Volume Flow Rate = $2.15 \times 10^{-5} \pm 1.97 \times 10^{-6} \frac{m^3}{s}$

v = speed of the bulk fluid = $4.28 \times 10^{-1} \pm 3.92 \times 10^{-2} \frac{m}{s}$

Re = ***Reynolds Number*** = 3843.88 ± 351.92

****Laminar was not observed in an 8mm bottle. The closest observed readings fall in the transient section, as the calculations confirm.***

- **Turbulent**

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

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

$$t_{average} = 8.240000\, s$$

$$dt = 0.245714 s$$

$$Q_{average} = 3.64 \times 10^{-5} \frac{m^3}{s}$$

$$dQ = 1.09 \times 10^{-6} \frac{m^3}{s}$$

$$v_{average} = 1.29 \frac{m}{s}$$

$$dv = 3.84 \times 10^{-2} \frac{m}{s}$$

$$Re_{average} = 8680.86$$

$$dRe = 258.86$$

t = time(s) = $8.240000 \pm 0.245714\, s$

Q = Volume Flow Rate = $3.64 \times 10^{-5} \pm 1.09 \times 10^{-6} \frac{m^3}{s}$

v = speed of the bulk fluid = $1.29 \pm 3.84 \times 10^{-2} \frac{m}{s}$

Re = ***Reynolds Number*** = 8680.86 ± 258.86

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

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

$$t_{average} = 19.480000\, s$$

$$dt = 0.248571\, s$$

$$Q_{average} = 1.54 \times 10^{-5} \frac{m^3}{s}$$

$$dQ = 1.97 \times 10^{-7} \frac{m^3}{s}$$

$$v_{average} = 1.23 \frac{m}{s}$$

$dv = 1.56 \times 10^{-2}\frac{m}{s}$

$Re_{average} = 5,507.98$

$dRe = 70.28$

t = time(s) = $19.480000 \pm 0.248571\ s$

Q = Volume Flow Rate = $1.54 \times 10^{-5} \pm 1.97 \times 10^{-7}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $1.23 \pm 1.56 \times 10^{-2}\frac{m}{s}$

Re = ***Reynolds Number*** = $5,507.98 \pm 70.28$

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

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

$t_{average} = 6.296667\ s$

$dt = 0.144444\ s$

$Q_{average} = 4.76 \times 10^{-5}\ \frac{m^3}{s}$

$dQ = 1.09 \times 10^{-6}\ \frac{m^3}{s}$

$v_{average} = 9.48 \times 10^{-1}\frac{m}{s}$

$dv = 2.17 \times 10^{-2}\frac{m}{s}$

$Re_{average} = 8,520.02$

$dRe = 195.45$

t = time(s) = $6.296667 \pm 0.144444\ s$

Q = Volume Flow Rate = $4.76 \times 10^{-5} \pm 1.09 \times 10^{-6}\ \frac{m^3}{s}$

v = speed of the bulk fluid = $9.48 \pm 2.17 \times 10^{-2}\frac{m}{s}$

Re = ***Reynolds Number*** = 8520.02 ± 195.45

Results:

For Laminar Flow:

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

   Re = *Reynolds Number* = $1,209.05 \pm 277.61$

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

   Re = *Reynolds Number* = $1,589.04 \pm 217.63$

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

   Re = *Reynolds Number* = 3843.88 ± 351.92

For Turbulent Flow:

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

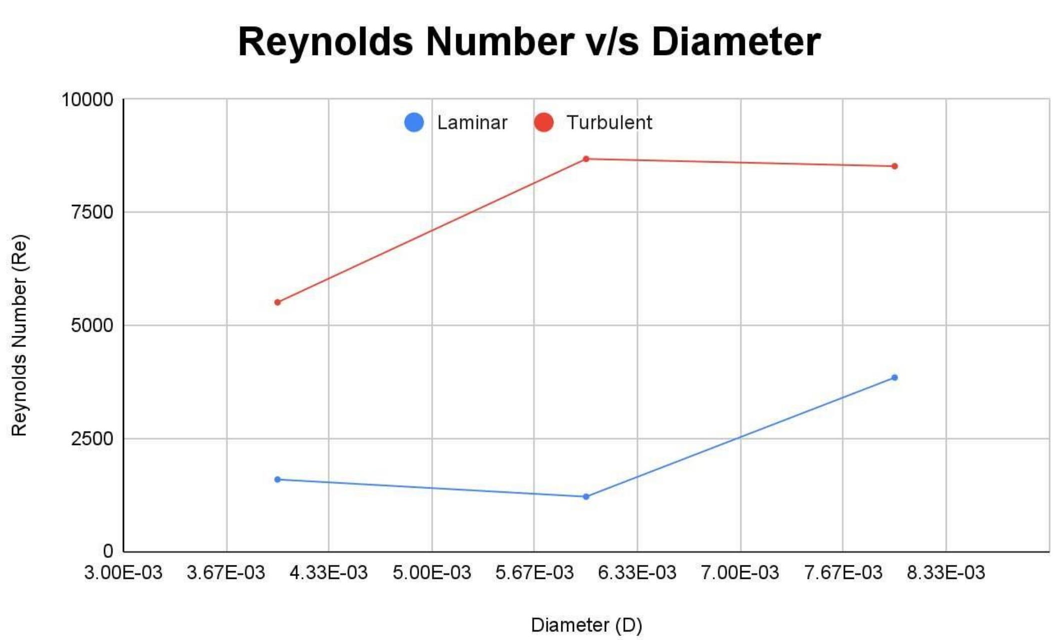
   Re = *Reynolds Number* = 8680.86 ± 258.86

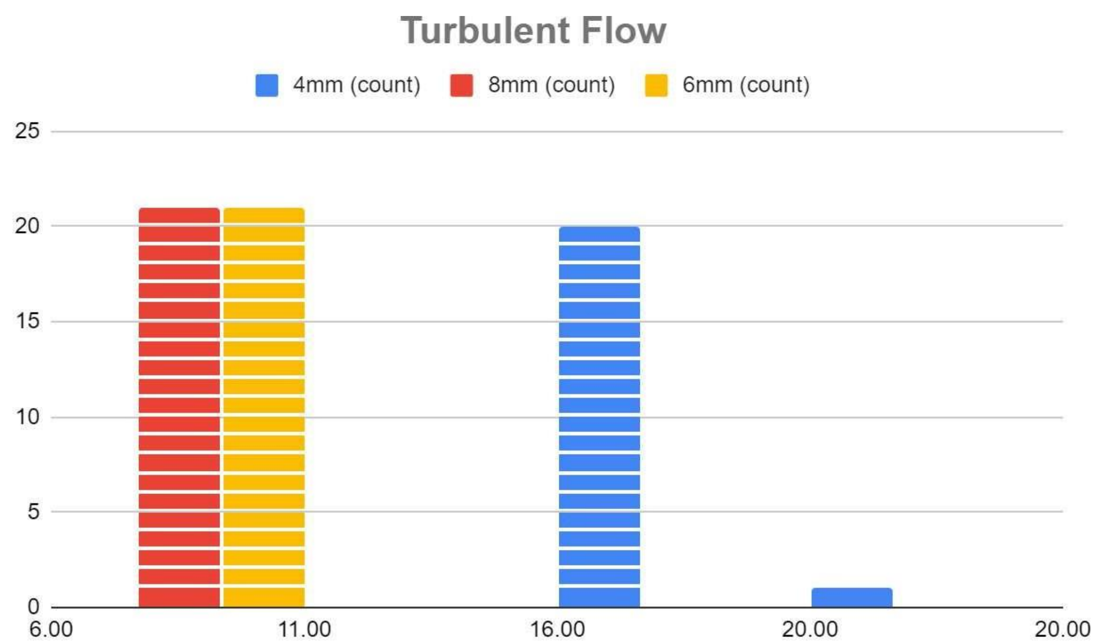
2. D = Diameter of Hole = $4 \times 10^{-3} m$

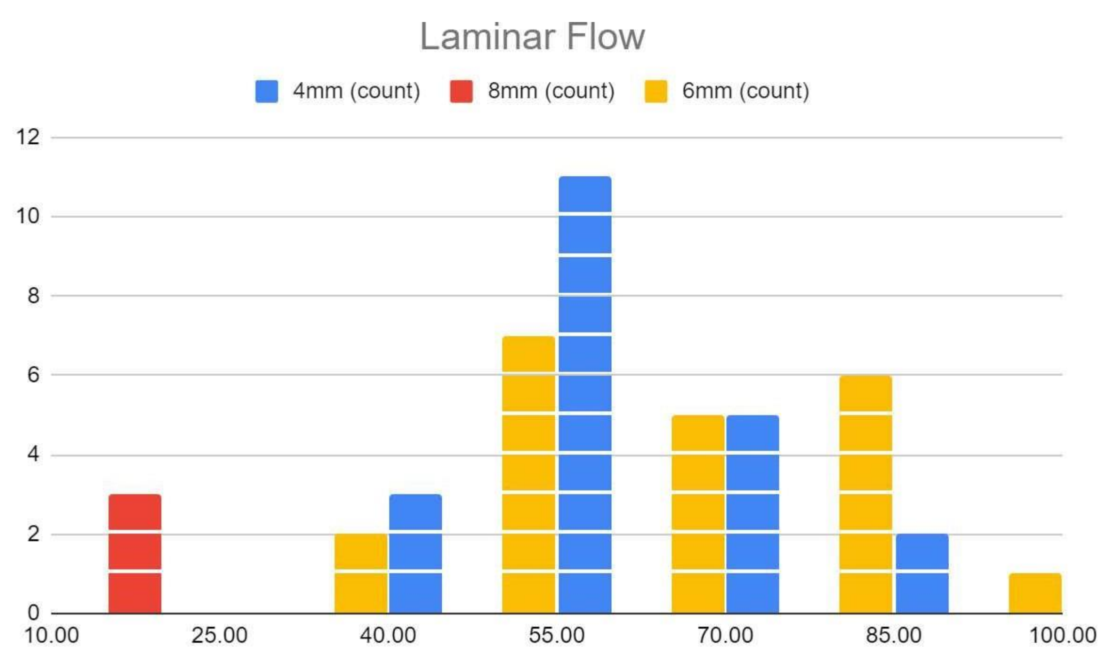
   Re = *Reynolds Number* = $5,507.98 \pm 70.28$

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

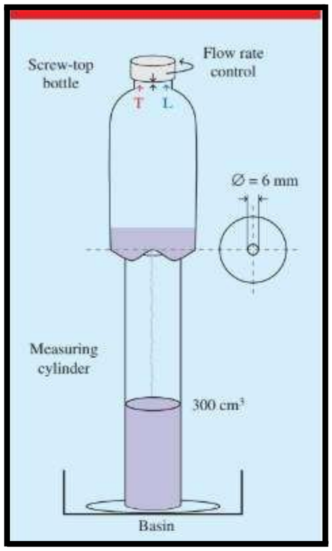
   Re = *Reynolds Number* = 8520.02 ± 195.45




Turbulent Flow
4mm (count)
8mm (count)
6mm (count)
25
20
15
10
5
0
6.00
11.00
16.00
20.00
20.00


Laminar Flow
4mm (count)
8mm (count)
6mm (count)
12
10
8
6
4
2
0
10.00
25.00
40.00
55.00
70.00
85.00
100.00

Prototype Diagram:



Laminar and Turbulent Flow:

+Video Links: [Turbulent] [Laminar]

Discussions and Conclusions:-

1. The transition between laminar and turbulent flow for this geometry and fluid are taken to be within the interval of

   $$2000 < Re < 4000$$

   Reynolds numbers below this transition can be considered more laminar-like and above this value more turbulent-like.

   Slow flows are predictable and well-ordered, while faster flows can dramatically alter the flow behavior due to the increased significance of the fluid's inertia over its viscous forces. In laminar pipe flow, the fluid behaves as if concentric layers are sliding over each other. Whereas in turbulent flow , the flow is very chaotic.
2. 1L bottles were used instead of 750 ml bottles, as we did not observe the flow for its entirety for the 300cm^3 volume in consideration. (Bottles with different characteristic lengths could be constructed and investigated.)
3. The calculations confirm that laminar was not observed in the 8mm reading, and the closest observed readings fall into the transient section as the average Reynolds number came to be 3843.88.
4. Flow rate of fluid increases when we unscrew the cap due to an increase in pressure difference. Therefore the Reynolds number increases.
5. For the bottle with 6mm hole and when laminar flow was observed , the average Reynolds number calculated was 1209.05 which lies in the range 800<Re<1400. When turbulent flow was observed, the average Reynolds number was 8680.86.
6. Turbulent flow, a type of fluid (gas or liquid) flow in which the fluid undergoes irregular fluctuations, or mixing, in contrast to laminar flow, in which the fluid moves in smooth paths or layers. In turbulent flow the speed of the fluid at a point is continuously undergoing changes in both magnitude and direction
7. The number of repeats in this work was 21. This could be decreased to perhaps 5 to provide an estimate of the uncertainty in the measurements.
8. Hold the bottle properly so that the bottle doesn't squeeze by hand, increasing the flow rate. Then Error comes in the time readings of collecting 300cm^3.