Pipe flow, Reynolds number, Forces in Pipe Flow

Lecture 5

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Important Definitions

Pressure Pipe Flow: Refers to full water flow in closed conduits of **circular cross sections** under a certain **pressure gradient**.

For a given **discharge (Q)**, pipe flow at any location can be described by

- the pipe cross section
- the pipe elevation,
- the pressure, and
- the flow velocity in the pipe.

Elevation (h) of a particular section in the pipe is usually measured with respect to a horizontal reference datum such as mean sea level (MSL).

Pressure (P) in the pipe varies from one point to another, but a mean value is normally used at a given cross section.

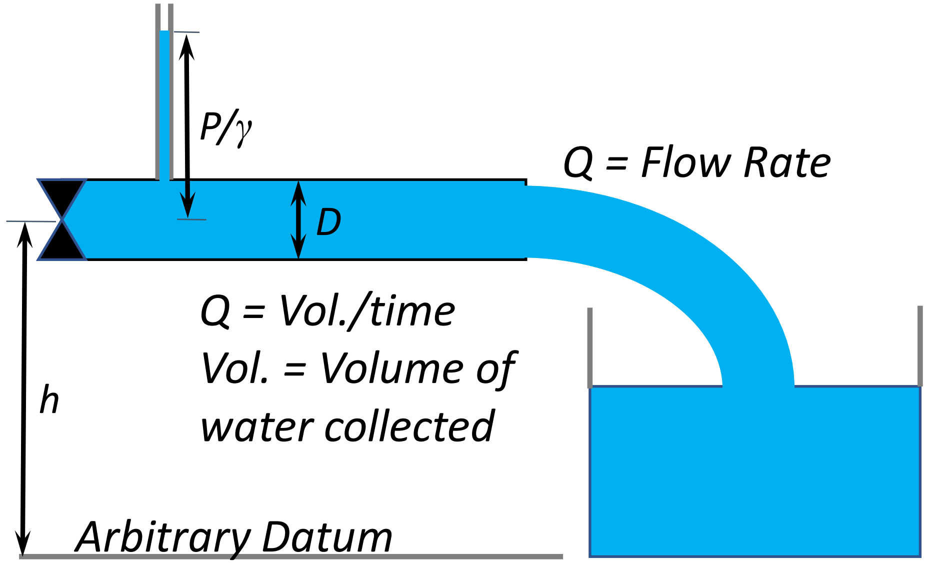
Mean velocity (V) is defined as the discharge (Q) divided by the cross-sectional area (A)

Description of Pipe Flow

Visualization and Analysis

Question: What's the difference between pipe flow and open channel flow? Can you have open channel flow in a pipe?

Visualization: Pipe flow at any location can be described by its discharge or flow rate (*Q*), the pipe elevation (*h*) & cross section area (*A*), the pressure (*P*), and the flow velocity (*V*).



Question: How do you find the **mean velocity** in a pipe given the flow rate (**Q**)?

Reynolds experiment

- Reynolds found that the transition from laminar flow to turbulent flow in a pipe actually depends not only the velocity, but also the pipe diameter and the viscosity of the fluid.

- He also postulated that the onset of turbulence was related to a particular index number.

- The dimensionless ratio ➔ reynolds number (N_R or Re)

$$N_R = \frac{DV}{\nu}$$

D: Diameter, m
V: mean velocity, m/sec
ν: Kinematic viscosity, m^2/sec

Description of pipe flow: Reynolds number

Critical Reynolds number: 2000 → transition from laminar to turbulent flow. It does not happen exactly at 2000. It varies between 2000 to 4000 depending on the experimental conditions.

$Re < 2000$ → Laminar

$2000 < Re < 4000$ → Critical flow

$Re > 4000$ → Turbulent flow

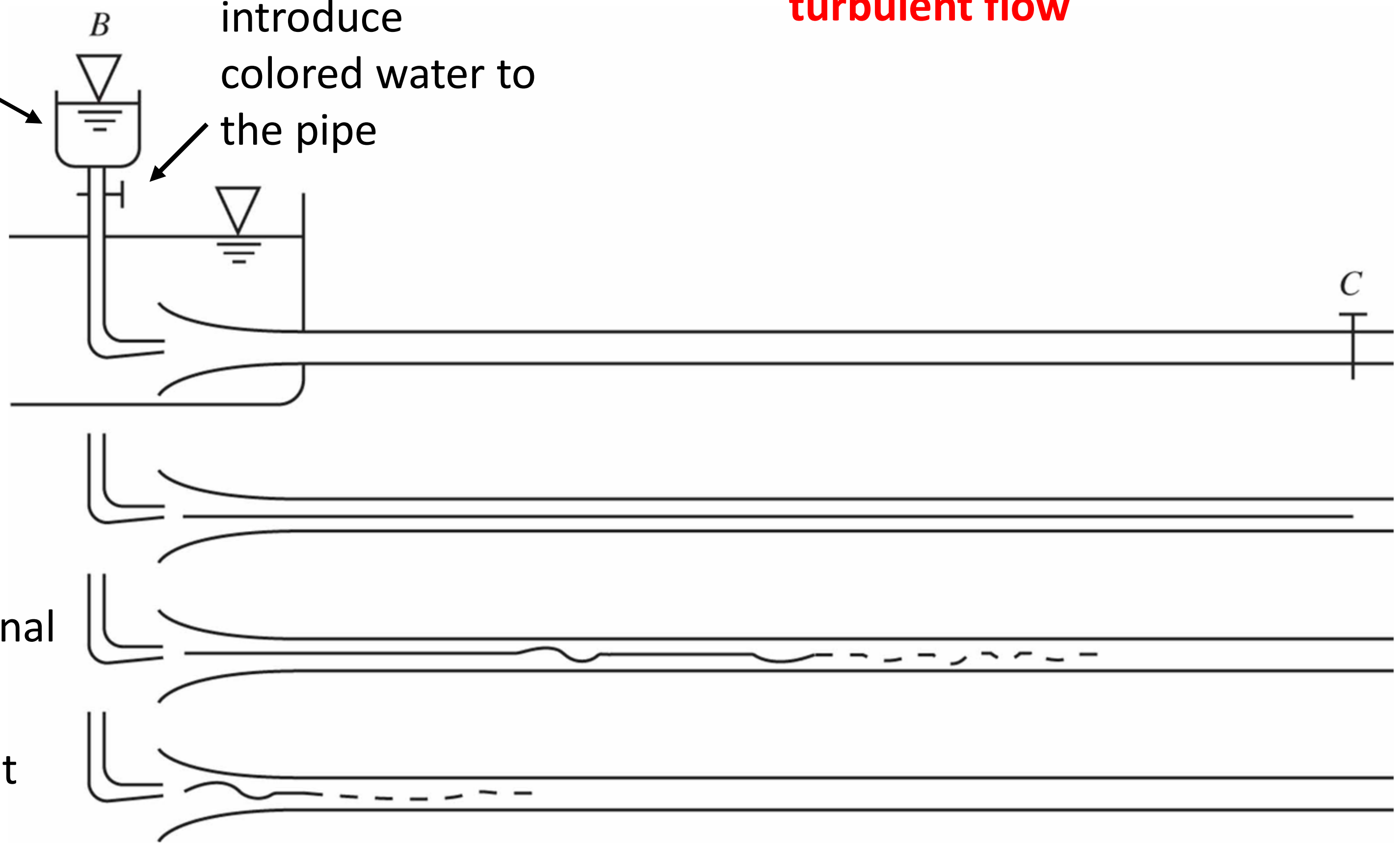
Reynolds experiment

Question: What is the reason of transition from laminar flow to turbulent flow

Figure 3.1 Reynolds' apparatus

Colored water tank

Valve to introduce colored water to the pipe



Valve to control flowrate

Laminar flow

Transitional flow

Turbulent flow

Valve opened partially to allow very slow flow pipe

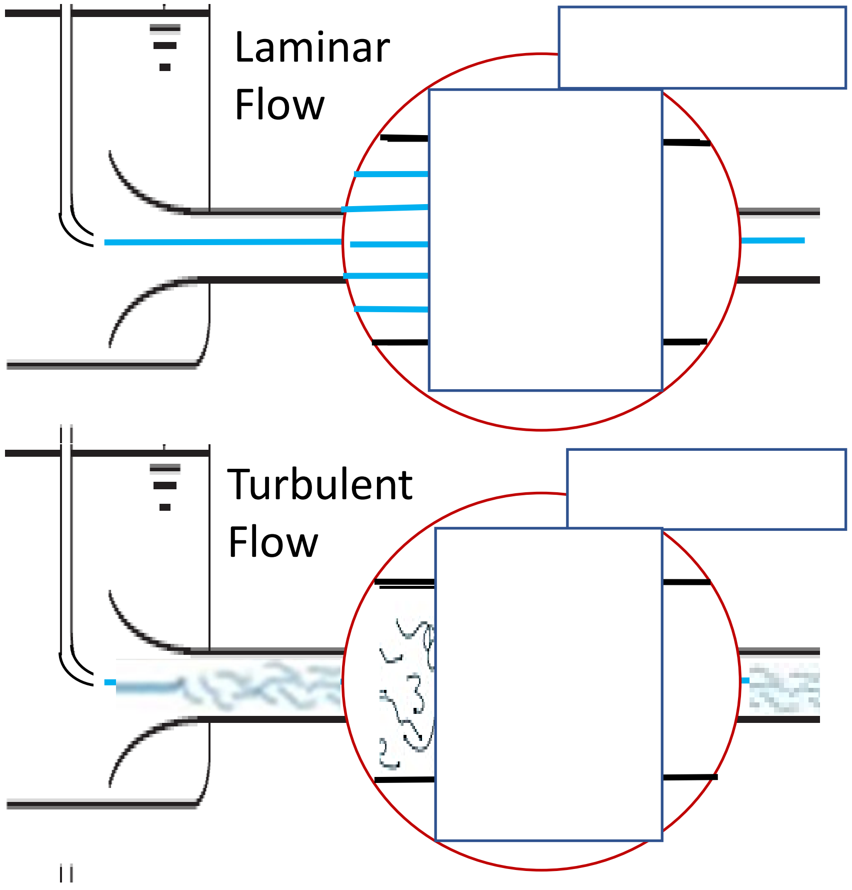
PEARSON

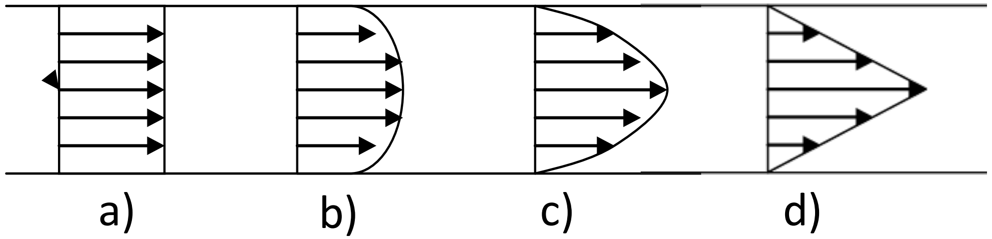
Fundamentals of Hydraulic Engineering Systems, Fourth Edition
Robert J. Houghtalen • A. Osman Akan • Ned H. C. Hwang

Description of Pipe Flow

Visualization and Analysis

Question: Which velocity distribution shown below is laminar and which is turbulent (a, b, c, or d)? Justify your answer.





Question: What parameters (pipe and fluid) influence flow to be laminar or turbulent?

Description of Pipe Flow

Visualization and Analysis

Question: What causes energy to be lost in pipe flow?

Question: What pipe/fluid parameters influence the amount of energy lost?

a)

b)

c)

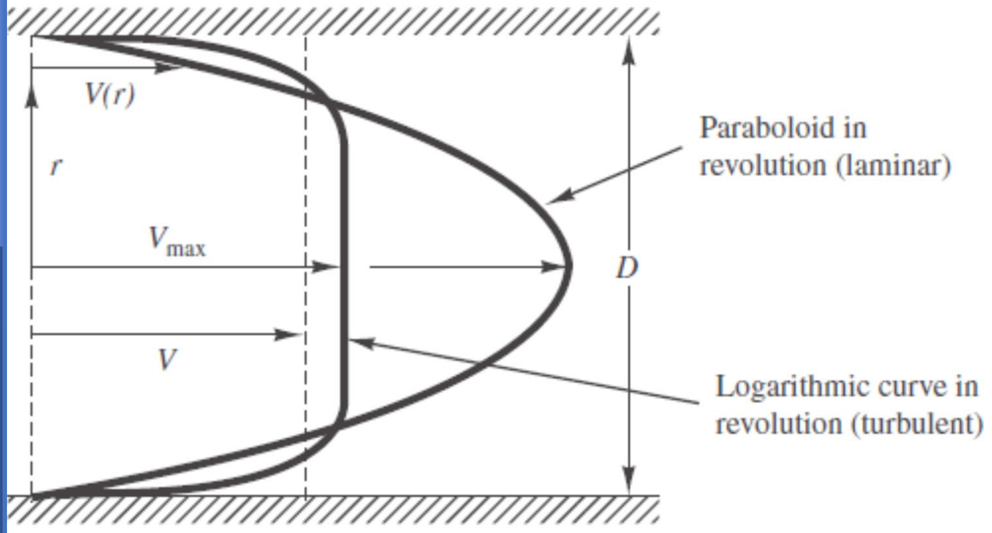
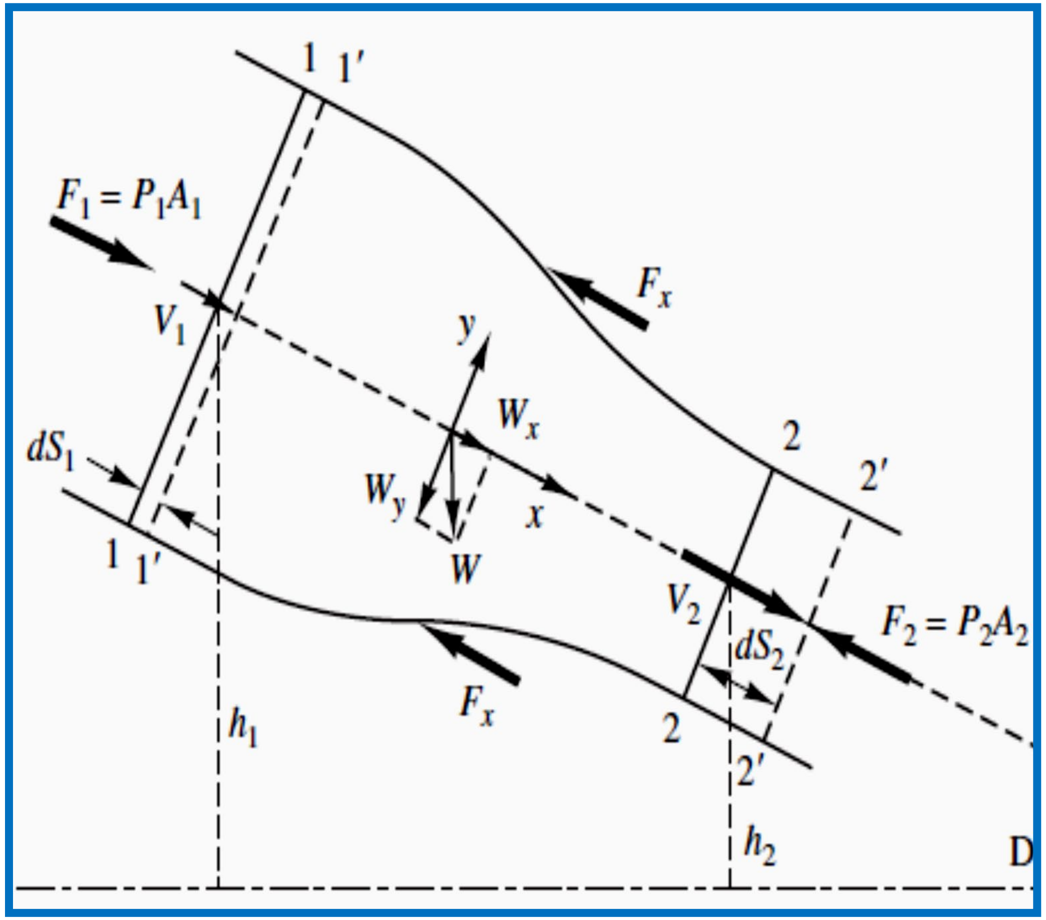


Figure 3.2 Velocity profiles of laminar and turbulent flows in circular pipes

Note: The friction factor (f) depends upon e/D and N_R.

Flow Continuity - Pipe Flow

(Importance: Determining pipe velocities and flows.)



Mass flux in = Mass flux out

$\gamma\ [d(Vol_{1-1'})/dt] = \gamma\ [d(Vol_{2-2'})/dt]$

$\gamma\ A_1[d(S_1)/dt] = \gamma\ A_2[d(S_2)/dt]$

where S = velocity, thus

$\gamma\ A_1(V_1) = \gamma\ A_2(V_2)$

$\mathbf{A_1(V_1) = A_2(V_2)}$

(2nd Key Equation)

The **continuity equation** for steady, incompressible flow.

Forces in Pipe Flow

(Importance: Anchoring pipe bends and nozzles.)

Applying Newton's 2nd Law to the moving mass in the CV:

$$\sum F = ma = m(dV/dt)$$

In finite difference form:
(for convective acceleration)

$$\sum F = (mV_2 - mV_1)/\Delta t$$

but since Mass (m) = γ (Vol);

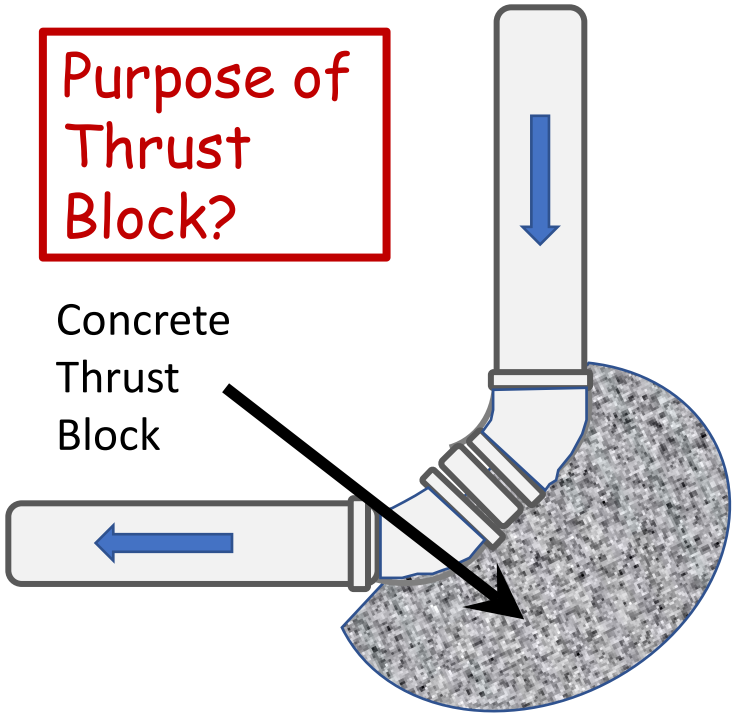
$$\sum F = [\gamma(Vol)(V_2) - \gamma(Vol)(V_1)]/\Delta t$$

and since ρQ = Vol/Δt

$$\sum F = \rho Q(V_2 - V_1)$$

3rd Key Equation

Purpose of Thrust Block?



The **impulse-momentum equation** for steady, incompressible flow.