قسم الهندسة المدنية

المرحلة الثانية

Al-Mansour University College

Civil Eng. Dept.

2nd. Stage

Fluid Mechanics

2022 - 2023

ميكانيك الموائع

Lec.4

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CE 205 Fluid Mechanics

Fundamentals of Fluid Flow

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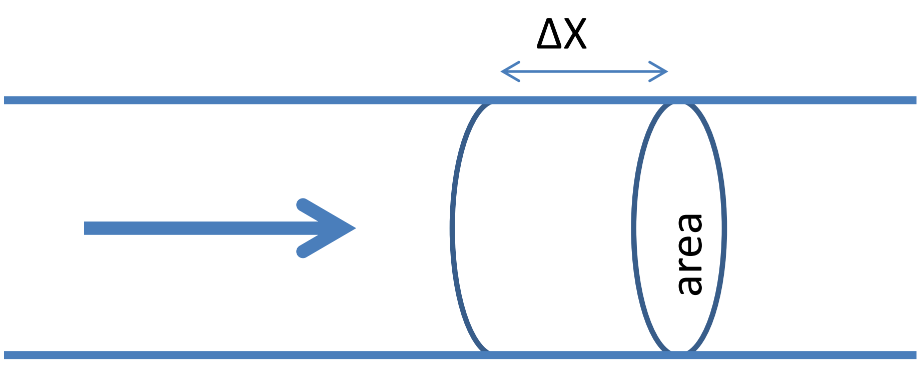
Continuity Equation

Volume flow rate Q = Volume /time (m^3/minute)

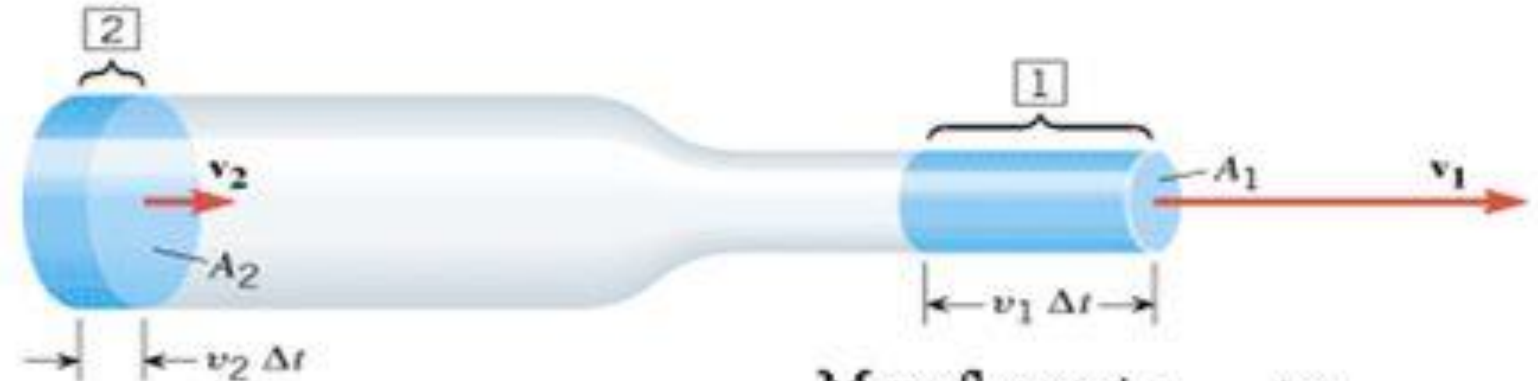
Mass flow rate = ρ.A.v = mass / time (kg/minute)

Weight flow rate = ρ.g.A.v = weight /time (kN/minute



https://www.youtube.com/watch?v=YIXzee3pIng

Equation of Continuity

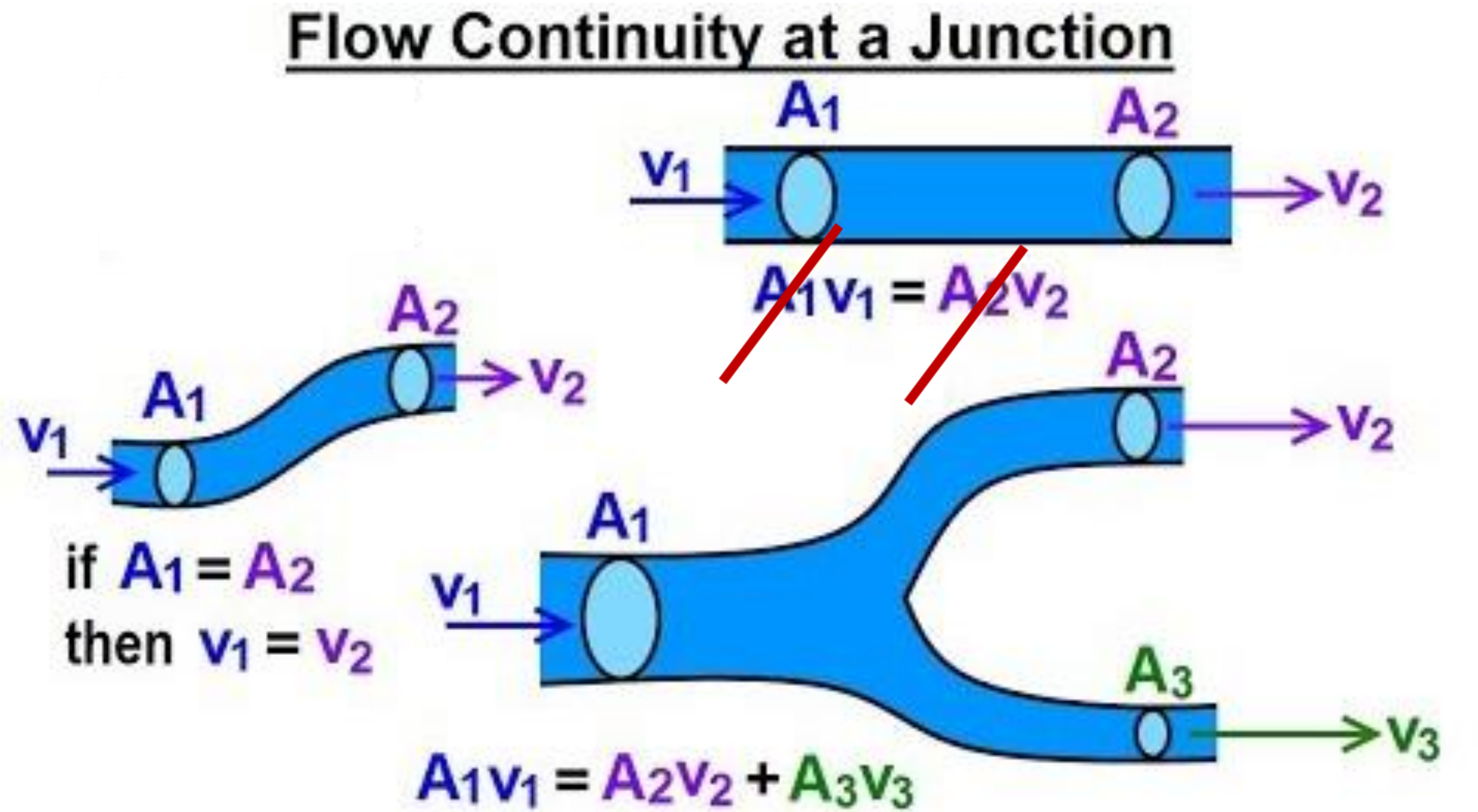


Mass flow rate at position 1 $= \dfrac{\Delta m_1}{\Delta t} = \rho_1 A_1 v_1$

Mass flow rate at position 2 $= \dfrac{\Delta m_2}{\Delta t} = \rho_2 A_2 v_2$

$$\cancel{\rho_1} A_1 v_1 = \cancel{\rho_2} A_2 v_2$$

$$Q = A_1 . v_1 = A_2 v_2$$

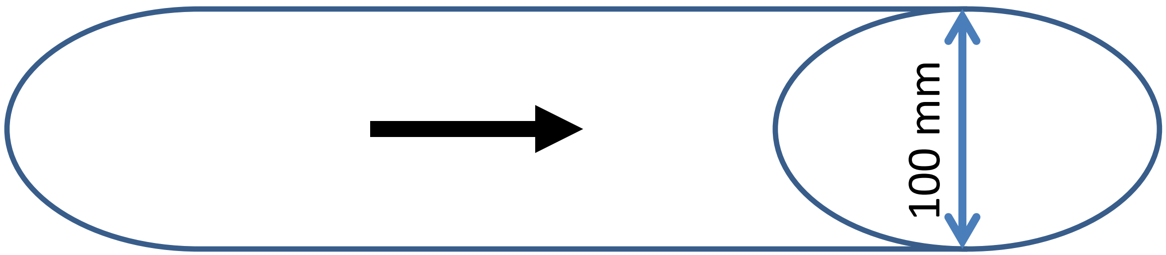

Flow Continuity at a Junction
A_1
A_2
v_1
v_2
$A_1v_1 = A_2v_2$
A_2
A_1
v_1
v_2
if $A_1 = A_2$
then $v_1 = v_2$
A_2
v_2
A_1
v_1
A_3
v_3
$A_1v_1 = A_2v_2 + A_3v_3$

Q in = Q out

Example: Benzene flows through a 100-mm-diameter pipe at a mean velocity of 3 m/s. Find:

-
- Weight flow rate
- Mass flow rate

Note: for benzene $\gamma = 8.62\,\frac{kN}{m^3}$, ρ = 879 kg/m³



Solution

(a) $$Q = Av = [(\pi)(\tfrac{100}{1000})^2/4](3.00) = 0.0236\ \mathrm{m^3/s} = 0.0236/0.00001667 = 1416\ \mathrm{L/min}$$

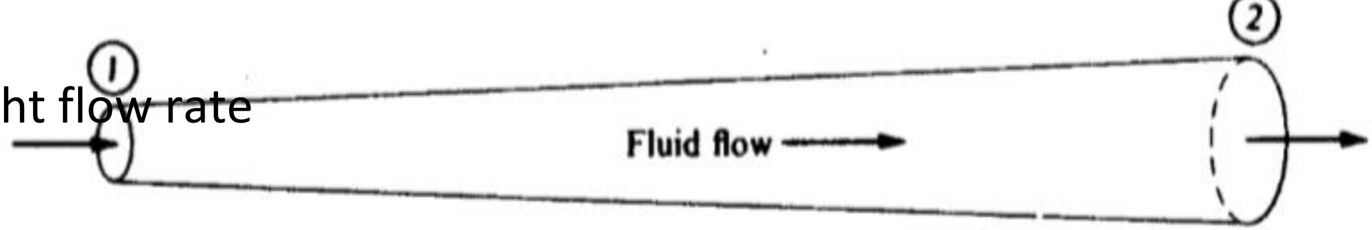
(b) $$W = \gamma Av = 8.62[(\pi)(\tfrac{100}{1000})^2/4](3.00) = 0.203\ \mathrm{kN/s}$$

(c) $$M = \rho Av = 879[(\pi)(\tfrac{100}{1000})^2/4](3.00) = 20.7\ \mathrm{kg/s}$$

Example: Assume the conduit shown in figure below, has (inside) diameter of 12 in and 18 in at section 1 and 2, respectively. If water is flowing in the conduit at a velocity of 16.6 ft/s at section 2, (Note: for water $\gamma = 62.4\ \frac{lb}{ft^3}$).

Find:

-
- Volume flow rate at section 1
- Volume flow rate at section 2
- Weight flow rate



Solution

(a) $A_1v_1 = A_2v_2 \qquad [(\pi)(\frac{12}{12})^2/4](v_1) = [(\pi)(\frac{18}{12})^2/4](16.6) \qquad v_1 = 37.3\ \text{ft/s}$

(b) $Q_1 = A_1v_1 = [(\pi)(\frac{12}{12})^2/4](37.3) = 29.3\ \text{ft}^3/\text{s}$

(c) $Q_2 = A_2v_2 = [(\pi)(\frac{18}{12})^2/4](16.6) = 29.3\ \text{ft}^3/\text{s}$. (Since the flow in incompressible, the flow rate is the same at sections 1 and 2.)

(d) $W = \gamma A_1v_1 = 62.4[(\pi)(\frac{12}{12})^2/4](37.3) = 1828\ \text{lb/s}$

Example: the water tank in figure below filled through section 1 at v1 = 5 m/s and through section 3 at Q3 = 0.12 m³/s. If water level h is constant, determine exit velocity v2.

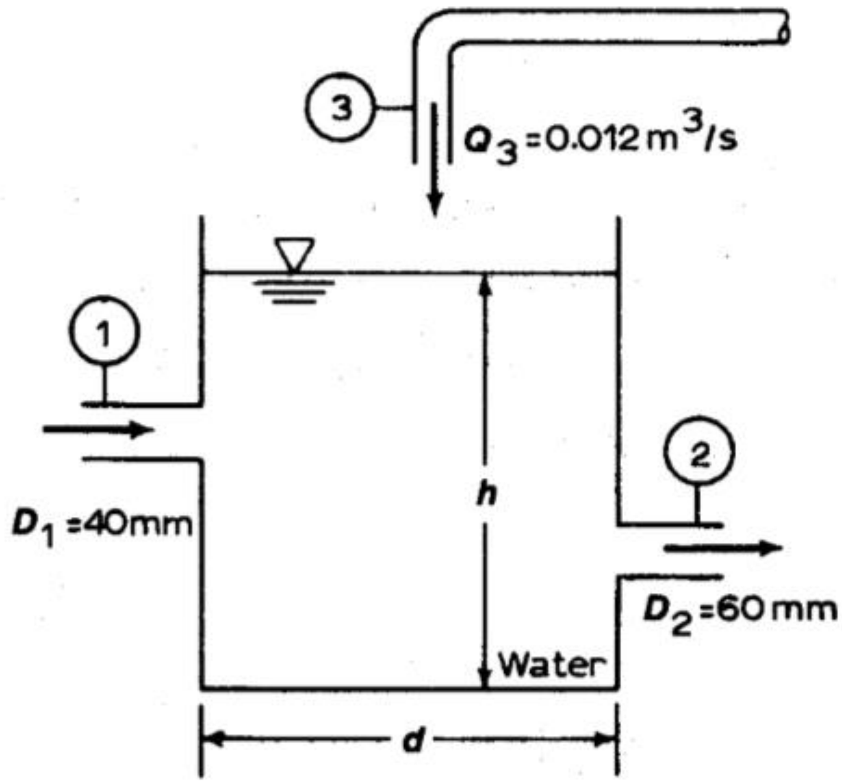


Fig. 8-6

Solution

$$Q_1 + Q_3 = Q_2 \qquad [(\pi)(0.040)^2/4](5) + 0.012 = Q_2$$

$$Q_2 = 0.01828\ \mathrm{m^3/s} \qquad v_2 = Q_2/A_2 = 0.01828/[(\pi)(0.060)^2/4] = 6.47\ \mathrm{m/s}$$

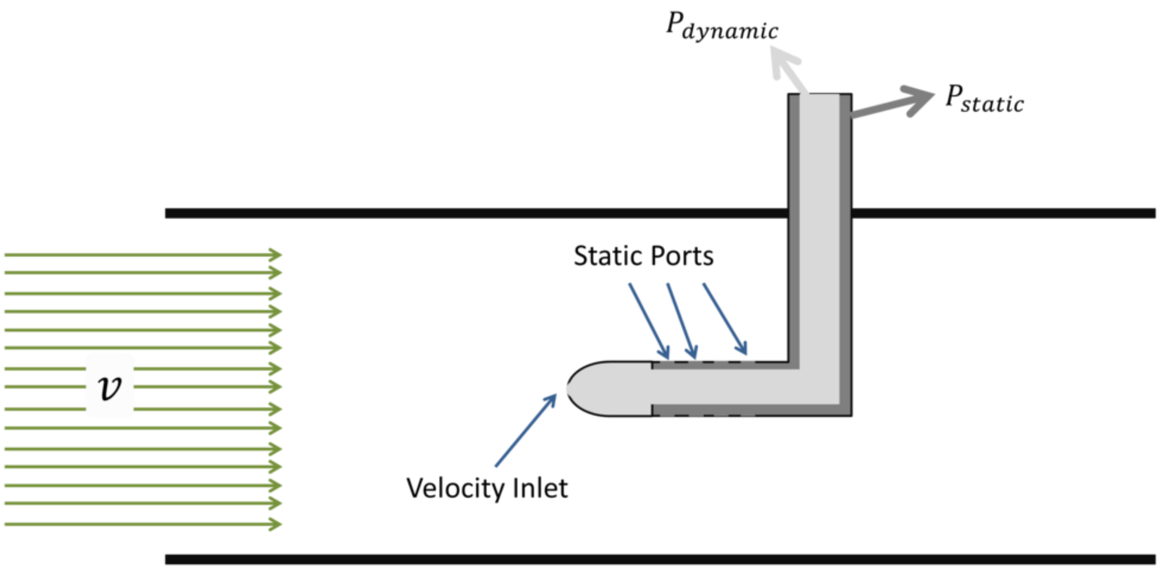
Solution

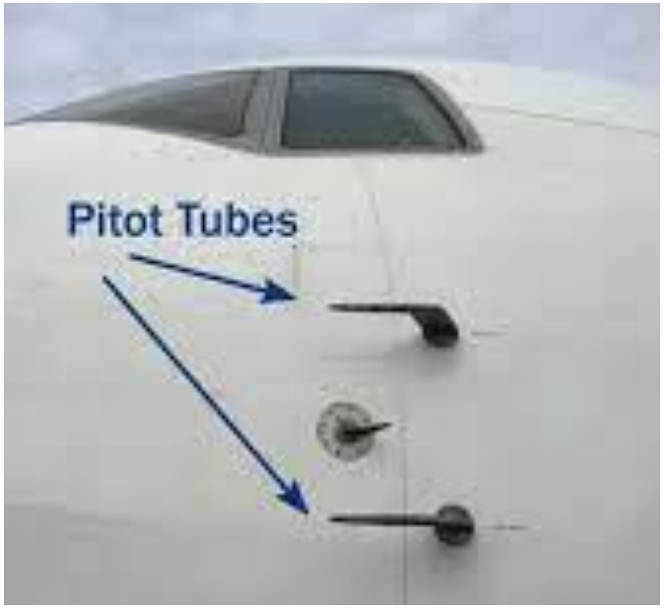
$$Q = V/t = 200.0/[(3)(60) + 21.2] = 0.994\ \text{ft}^3/\text{s}$$

$$v = Q/A = 0.994/[(\pi)(\tfrac{6}{12})^2/4] = 5.06\ \text{ft/s}$$

Pitot Tube for Flow Measurement

- The principle of flow measurement by **Pitot tube** was adopted first by a French Scientist Henri Pitot in 1732 for measuring velocities in the river.
- A right angled glass tube, large enough for capillary effects to be negligible, is used for the purpose. One end of the tube faces the flow while the other end is open to the atmosphere as shown in Figure below.





Such a tube is known as a Pitot tube and provides one of the most accurate of measuring the fluid velocity.

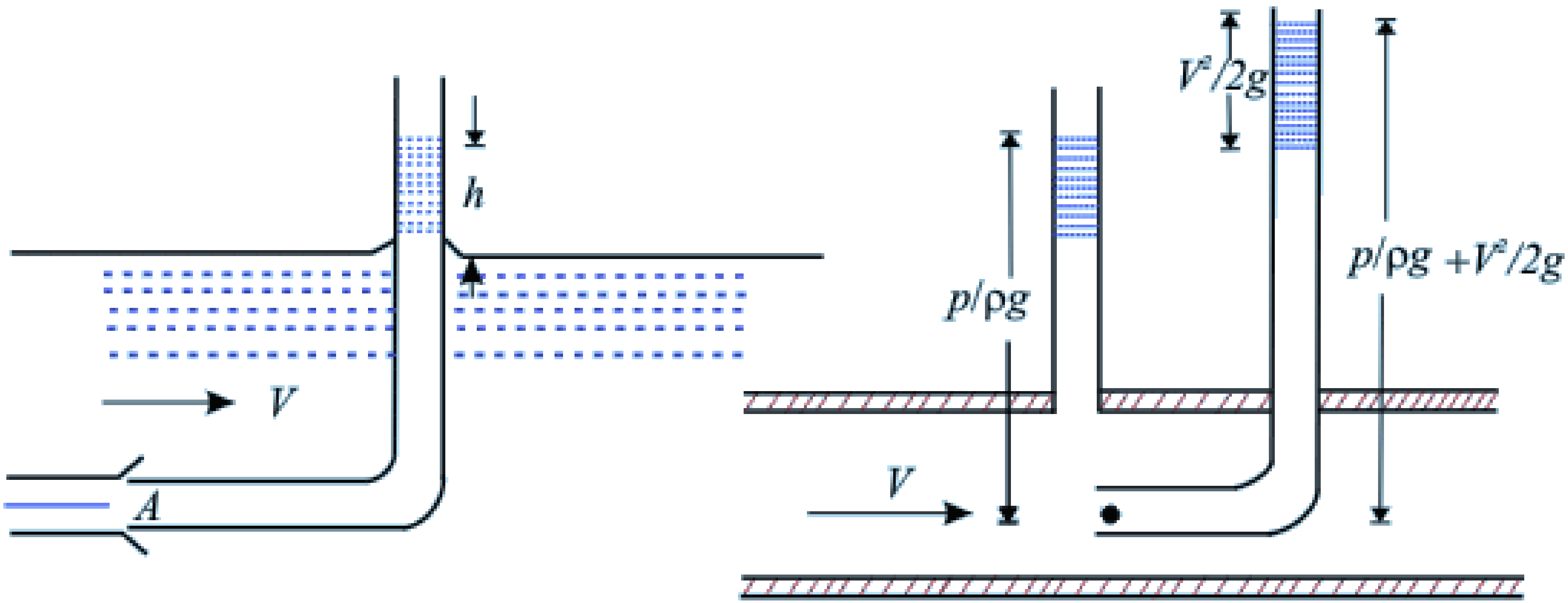


Figure: Simple Pitot Tube (a) tube for measuring the Stagnation Pressure
(b) Static and Stagnation tubes together

- The liquid flows up the tube and when equilibrium is attained, the liquid reaches a height above the free surface of the water stream.
- Since the static pressure, under this situation, is equal to the hydrostatic pressure due to its depth below the free surface, the difference in level between the liquid in the glass tube and the free surface becomes the measure of dynamic pressure. Therefore, we can write, neglecting friction,

$$\boxed{p_0 - p = \frac{\rho V^2}{2} = h\rho g}$$

- where p_0, p and V are the stagnation pressure, static pressure and velocity respectively at point A.

$$\boxed{\mathbf{V} = \sqrt{2gh}}$$

Example: A Pitot tube being used to determine the velocity of flow water in a closed conduit indicator a difference between water levels in the Pitot tube and in the piezometer of 48 mm. What is the velocity of flow?

$$v = \sqrt{2gh} = \sqrt{(2)(9.807)(0.048)} = 0.970 \text{ m/s}$$

Bernoulli equation

The Bernoulli equation states that the sum of the pressure head, the velocity head, and the elevation head is constant along a streamline.

Daniel Bernoulli (1710-1782)

$$\frac{p}{\gamma} + \frac{V^2}{2g} + z = constant$$

$$\frac{p1}{\rho 1.g} + \frac{(v1)^2}{2.g} + \text{z1} = \frac{p2}{\rho 2.g} + \frac{(v2)^2}{2.g} + \text{z2}$$

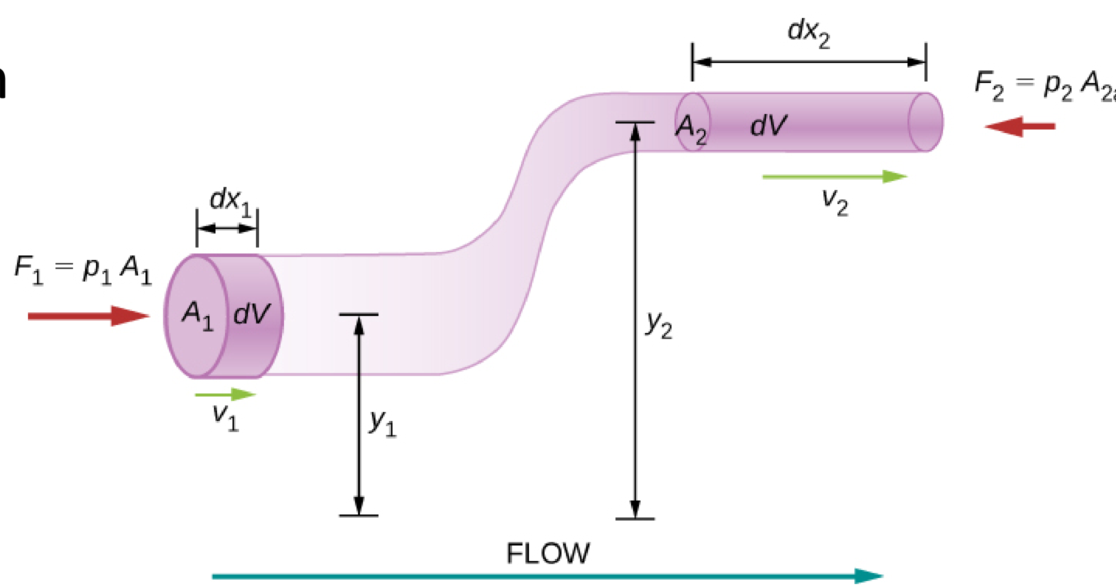
$$\frac{\cancel{kN}/_{m2}}{\cancel{kN}/_{m3}} = \frac{1/_{m2}}{1/_{m3}} = \frac{1/_{1}}{1/_{m}} = \text{m}$$

$$v2/2g = \frac{m^2/\cancel{s^2}}{m/\cancel{s^2}} = \frac{m^2/_{1}}{m/_{1}} = \text{m}$$

Pressure head: $\frac{p}{\gamma}$

Velocity head: $\frac{V^2}{2g}$

Elevation head: z



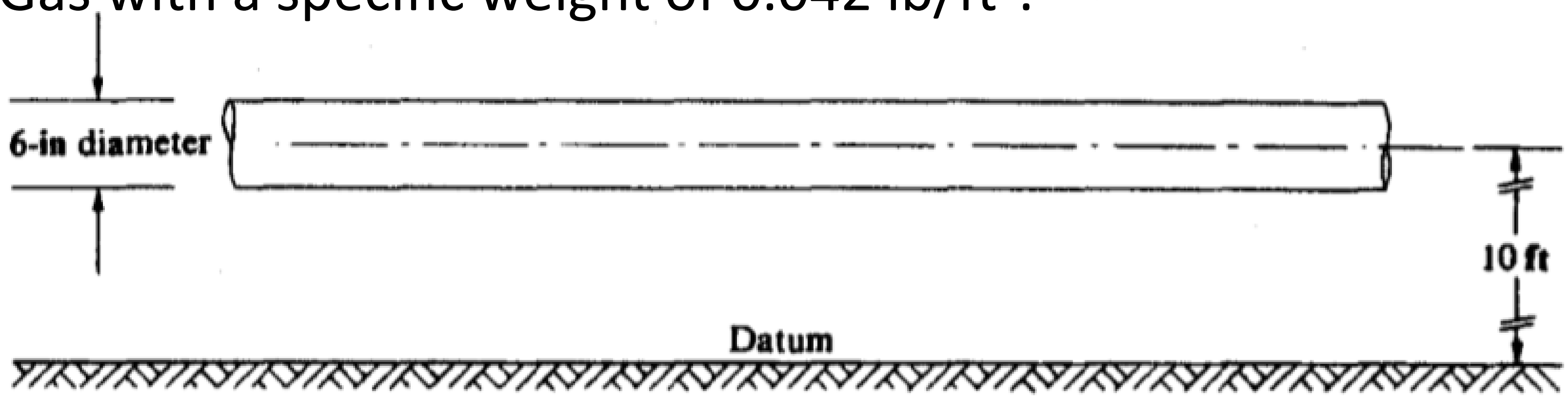
Example: A fluid is flowing in a 6-in-diamter pipe at a pressure of 4.0 lb/in^2 with a velocity of 8 ft/s. as shown in figure below, the elevation of the center of the pipe above a given datum is 10 ft. Find the total energy head above the given datum if the fluid is

(a) Water

(b) Oil with a specific gravity of 0.82

(c) Gas with a specific weight of 0.042 lb/ft^3.

$$\rho_{oil} \cdot g = S.G \times \rho_{water} \cdot g$$



Solution

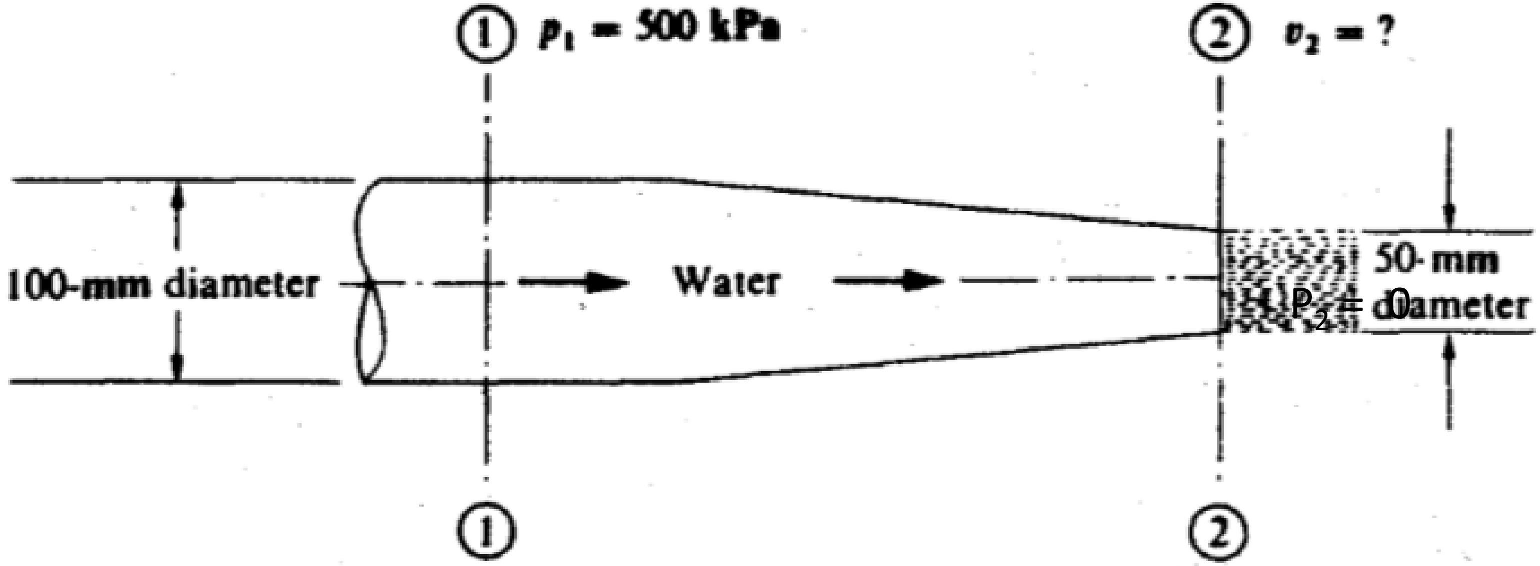
$$H = z + v^2/2g + p/\gamma$$

(a) $$H = 10.0 + 8.00^2/[(2)(32.2)] + (4.00)(144)/62.4 = 20.22 \text{ ft}$$

(b) $$H = 10.0 + 8.00^2/[(2)(32.2)] + (4.00)(144)/[(0.82)(62.4) = 22.25 \text{ ft}$$

(c) $$H = 10.0 + 8.00^2/[(2)(32.2)] + (4.00)(144)/(0.042) = 13\,725 \text{ ft}$$

Example: A nozzle is attached to a pipe as shown in figure below. The inside diameter of the pipe is 100mm, while the water jet exiting from the nozzle has a diameter of 50mm. If the pressure at section 1 is 500 kPa, determine the water jet's velocity, assume head loss in the jet is negligible.

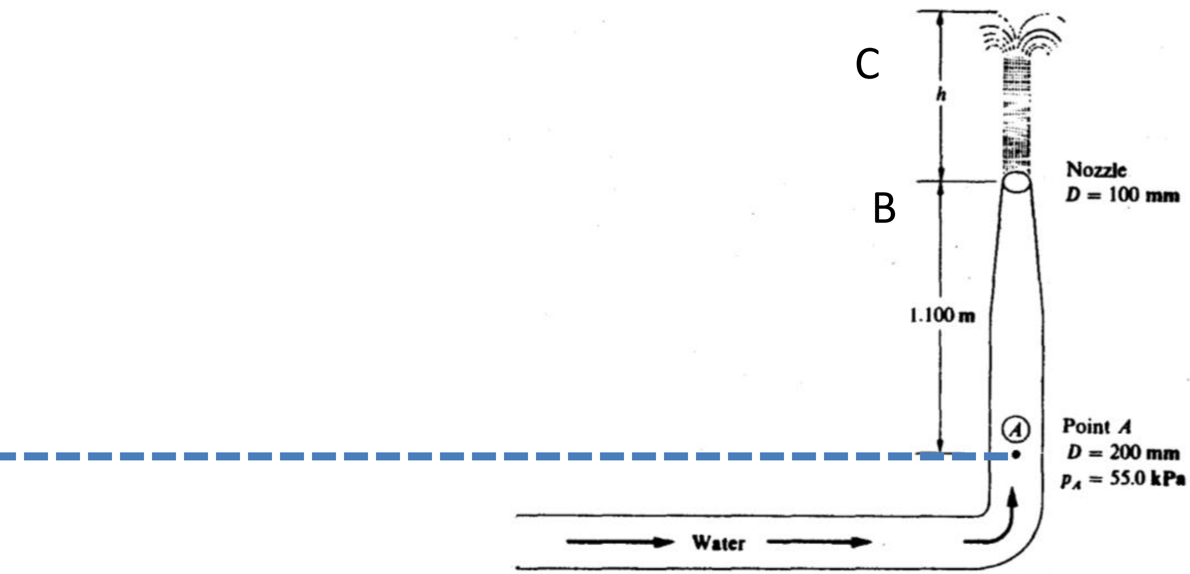


$$Q = A_1v_1 = A_2v_2 \qquad [(\pi)(\tfrac{100}{1000})^2/4](v_1) = [(\pi)(\tfrac{50}{1000})^2/4](v_2) \qquad v_1 = 0.250v_2$$

$$p_1/\gamma + v_1^2/2g + z_1 = p_2/\gamma + v_2^2/2g + z_2 + h_L$$

$$500/9.79 + (0.250v_2)^2/[(2)(9.807)] + 0 = 0 + v_2^2/[(2)(9.807)] + 0 + 0 \qquad v_2 = 32.7 \text{ m/s}$$

Example: For the water shooting out of the pipe and nozzle under the conditions shown in figure below, find the height above the nozzle to which the water jet will shoot. Assume negligible loss.



Solution

$$p_A/\gamma + v_A^2/2g + z_A = p_{top}/\gamma + v_{top}^2/2g + z_{top} + h_L$$

$$55.0/9.79 + v_A^2/2g + 0 = 0 + 0 + (1.00 + h) + 0 \qquad h = 4.518 + v_A^2/2g$$

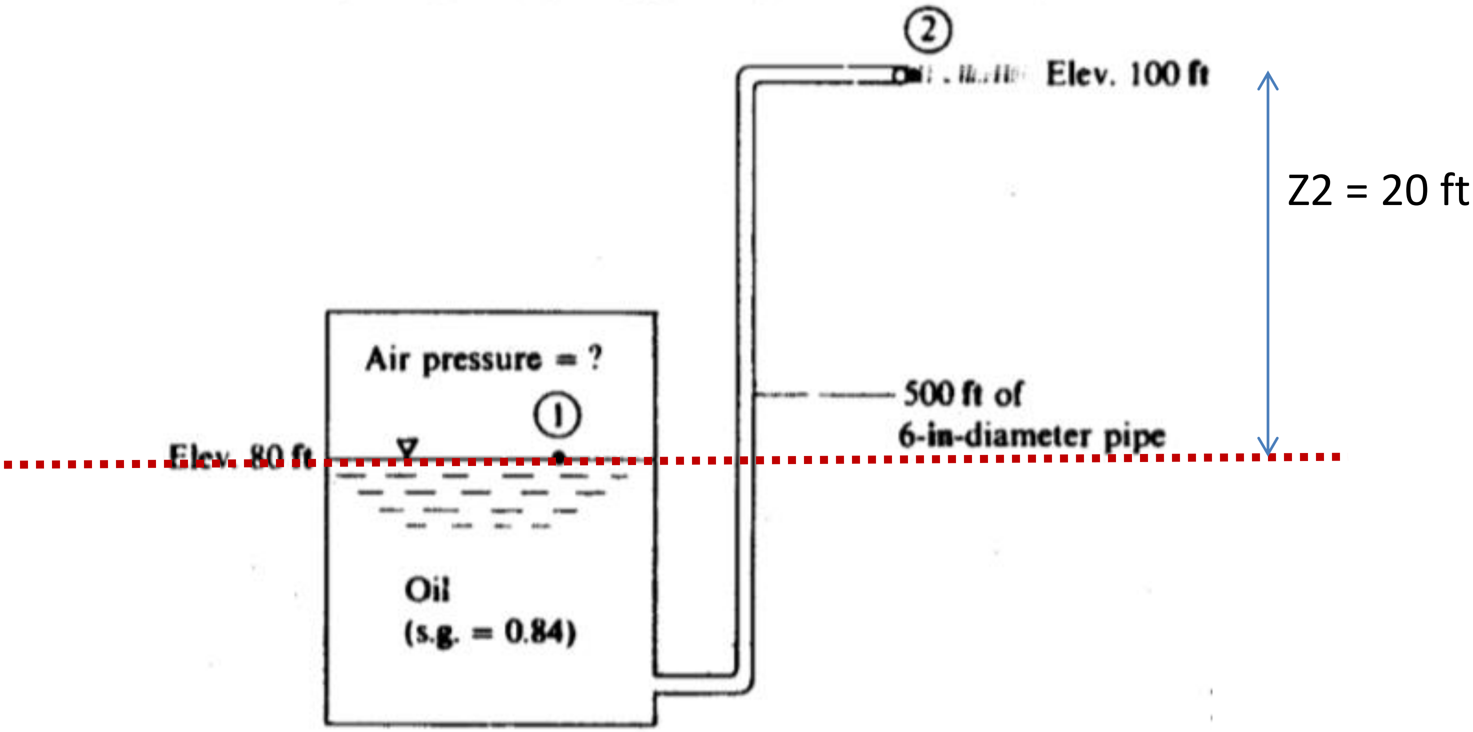
$$p_A/\gamma + v_A^2/2g + z_A = p_{nozzle}/\gamma + v_{nozzle}^2/2g + z_{nozzle} + h_L \qquad 55.0/9.79 + v_A^2/2g + 0 = 0 + v_{nozzle}^2/2g + 1.100 + 0$$

$$A_A v_A = A_{nozzle} v_{nozzle} \qquad [(\pi)(\tfrac{200}{1000})^2/4]v_A = [(\pi)(\tfrac{100}{1000})^2/4]v_{nozzle} \qquad v_{nozzle} = 4.00v_A$$

$$55.0/9.79 + v_A^2/[(2)(9.807)] + 0 = 0 + (4.00v_A)^2/[(2)(9.807)] + 1.100 + 0$$

$$v_A = 2.431 \text{ m/s} \qquad h = 4.518 + 2.431^2/[(2)(9.807)] = 4.82 \text{ m}$$

Example: Oil flows from a tank through 500 ft of 6-in diameter pipe and then discharge into air, as shown in figure below. If the head loss from point 1 to 2 is 1.95 ft of oil, determine the pressure needed at point 1 to cause 0.6 ft^3/s of oil to flow.



Solution

$v_2 = Q/A = 0.60/[(\pi)(\tfrac{6}{12})^2/4] = 3.06\ \text{ft/s} \qquad p_1/\gamma + v_1^2/2g + z_1 = p_2/\gamma + v_2^2/2g + z_2 + h_L$

$p_1/\gamma + 0 + 80 = 0 + 3.06^2/[(2)(32.2)] + 100 + 1.95 \qquad p_1/\gamma = 22.10\ \text{ft of oil}$

$p_1 = [(0.84)(62.4)](22.10)/144 = 8.04\ \text{lb/in}^2$

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CE 205 Fluid Mechanics 2

Flow Regimes

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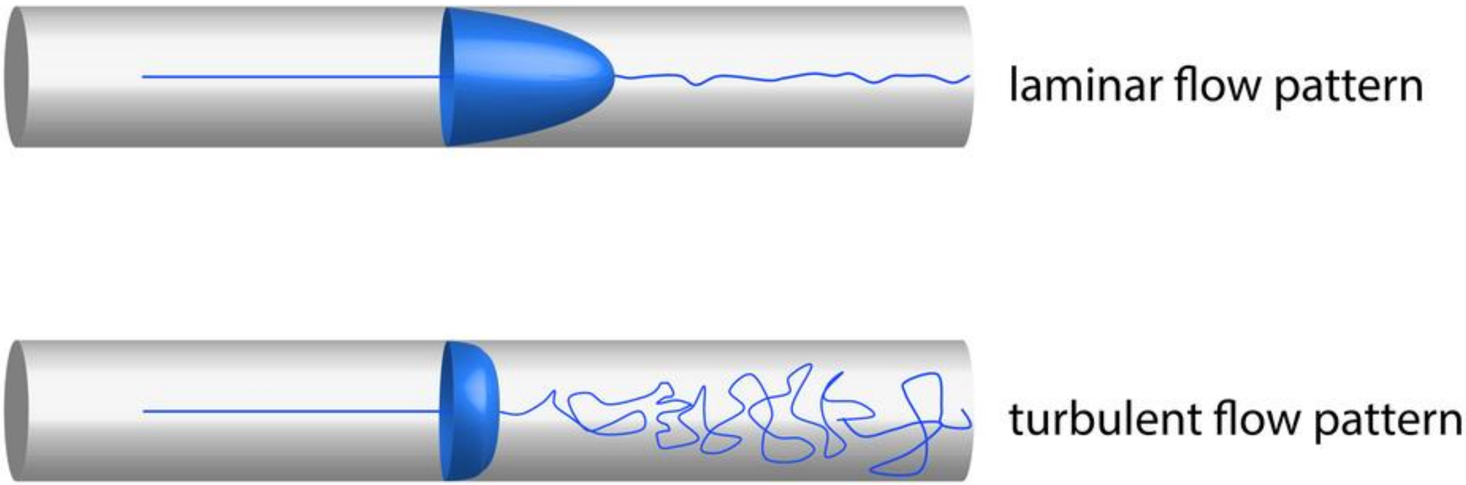
Flow Regimes

-
- These two flow regimes are laminar flow and turbulent flow.
- The flow regime, whether laminar or turbulent, is important in the design and operation of any fluid system.



-
- This is also an important consideration in certain applications that involve heat transfer to the fluid.

Laminar Flow

- Laminar flow is also referred to as streamline or viscous flow. These terms are descriptive of the flow because, in laminar flow,

1. layers of water flowing over one another at different speeds with virtually no mixing between layers
2. fluid particles move in definite and observable paths or streamlines
3. the flow is characteristic of viscous (thick) fluid or is one in which viscosity of the fluid plays a significant part.

Turbulent Flow

-
- There is no definite frequency as there is in wave motion.
- The particles travel in irregular paths with no observable pattern and no definite layers.

Viscosity

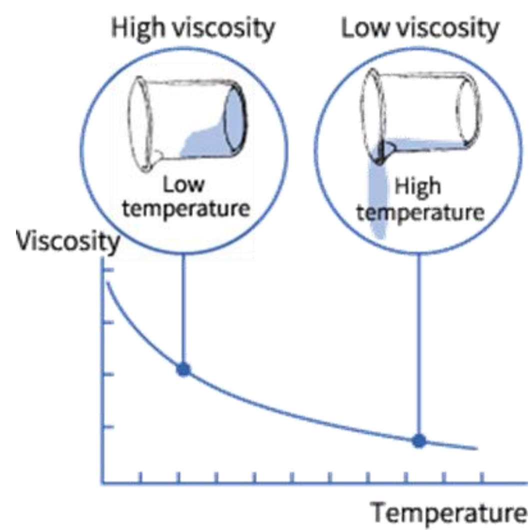
- *Viscosity* is a fluid property that measures the resistance of the fluid to deforming due to a shear force.
- Viscosity is the internal friction of a fluid which makes it resist flowing past a solid surface or other layers of the fluid.
- Viscosity can also be considered to be a measure of the resistance of a fluid to flowing. A thick oil has a high viscosity; water has a low viscosity. The unit of measurement for absolute viscosity is:

μ = absolute viscosity of fluid

-
- The viscosity of a fluid is usually significantly dependent on the temperature of the fluid and relatively independent of the pressure.

- In fluid dynamics, it is common to work in terms of the *kinematic viscosity* (also called "momentum diffusivity"),
- It defined as the ratio of the viscosity μ to the density of the fluid ρ.
- It is usually denoted by the Greek letter nu $\boldsymbol{\nu}$

- For most fluids, as the temperature of the fluid increases, the viscosity of the fluid decreases.
- An example of this can be seen in the lubricating oil of engines. When the engine and its lubricating oil are cold, the oil is very viscous, or thick. After the engine is started and the lubricating oil increases in temperature, the viscosity of the oil decreases significantly and the oil seems much thinner.

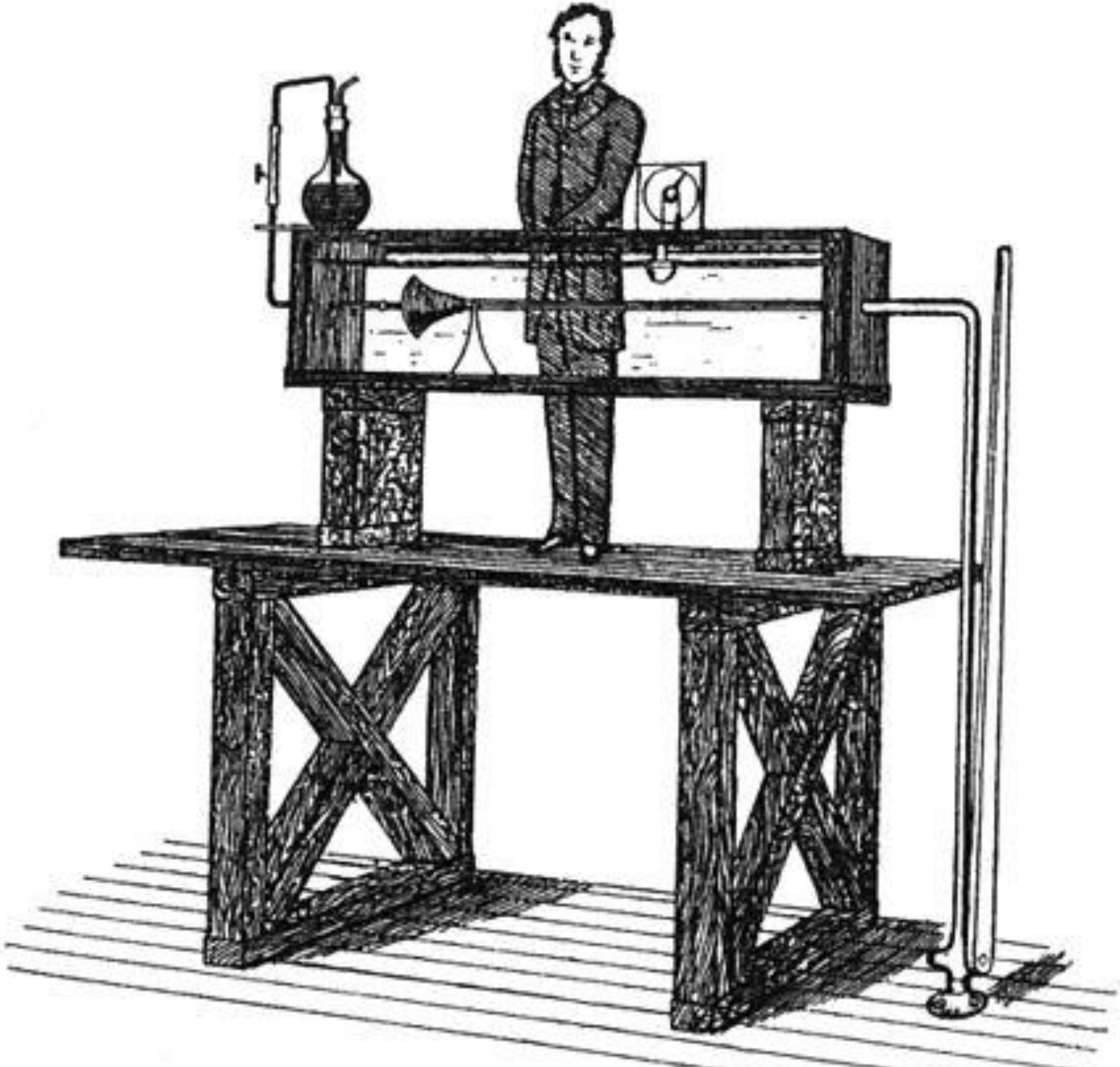


Ideal Fluid

- An ideal fluid is one that is incompressible and has no viscosity.
- Ideal fluids do not actually exist, but sometimes it is useful to consider what would happen to an ideal fluid in a particular fluid flow problem in order to simplify the problem.

Reynolds Number

- The flow regime (either laminar or turbulent) is determined by evaluating the Reynolds number of the flow.
-



$$\mathrm{Re} = \frac{\rho v l}{\mu} = \frac{v l}{\nu}$$

Where:

v = Velocity of the fluid

l = The characteritics length, the chord width of an airfoil

ρ = The density of the fluid

μ = The dynamic viscosity of the fluid

ν = The kinematic viscosity of the fluid

Flow type	Reynolds Number Range
Laminar regime	up to Re ≤ 2300
Transition regime	2300<Re<4000
Turbulent regime	Re>4000

Problem: Calculate Reynolds number, if a fluid having viscosity of 0.4 $N.s/m^2$ (pa.s) and relative density of 900 Kg/m^3 through a pipe diameter = 20 mm with a velocity of 2.5 m/s.

Solution:

$$
\begin{aligned}
Re &= \rho.v.d/\mu \\
&= 900\times2.5\times(20/1000)/0.4 \\
&= 112.5 < 2300
\end{aligned}
$$

So the flow is Laminar

Example: A solution is conveyed by a 23.5 mm pipe has a density of 1017.5 kg/m^3 , viscosity = $1.09\ x\ 10^{-3}$ pa.s. The flow rate is $2.778X\ 10^{-4}$ m/s. What is the Reynolds number? Which type of flow?

$$v = \frac{Q}{A}$$

$$= \frac{2.778\ x\ 10^{-4}}{(23.5/1000)^2\ x\ \boldsymbol{\pi}/4}$$

$$= 0.64\ m/s$$

Force = mass *g

N = kg * m/s^2

$$Re = \frac{\rho v d}{\mu}$$

$$= \frac{1017.5\ x\ 0.64\ x\ 0.0235}{1.09\ x\ 10^{-3}}$$

$$= 14{,}040 > 4{,}000$$

The flow is **Turbulent**