AP®

Fluid Flow

Unit: Fluids & Pressure

NGSS Standards/MA Curriculum Frameworks (2016): HS-PS2-10(MA), HS-PS2-1

AP® Physics 1 Learning Objectives/Essential Knowledge (2024): 8.3.A, 8.3.A.1, 8.3.A.2, 8.4.A, 8.4.A.1, 8.4.A.1.i, 8.4.A.1.ii, 8..A.2

Mastery Objective(s): (Students will be able to…)

- Solve problems involving fluid flow using the continuity equation.

Success Criteria:

- Problems are set up & solved correctly with the correct units.

Language Objectives:

- Explain why reducing the cross-sectional area causes a fluid's velocity to increase.

Tier 2 Vocabulary: fluid, velocity

Labs, Activities & Demonstrations:

- Two syringes connected by tubing

Notes:

flow: the net movement of a fluid

velocity of a fluid: the average velocity of a particle of fluid as the fluid flows past a reference point. (unit = $\frac{m}{s}$)

mass flow rate: the mass of fluid that passes through a section of pipe in a given amount of time. (unit = $\frac{kg}{s}$)

volumetric flow rate: the volume of a fluid that passes through a section of pipe in a given amount of time. (unit = $\frac{m^3}{s}$)

In the United States (where we use Imperial units), the actual volumetric flow rate is measured in cubic feet per minute ($\frac{ft.^3}{min.}$ or CFM). CFM is measured using actual conditions, so it is the flow rate actually observed when using the equipment.

However, in order to compare the output of one air compressor to another, flow rates are given in "Standard Cubic Feet per Minute" or SCFM. SCFM is measured based on "standard" conditions of temperature and pressure. Unfortunately, those "standard" conditions vary. Depending on the manufacturer, standard pressure varies from 14.5 to 14.7 psi, and standard temperature varies from 60 – 68 °F.

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Continuity

If a pipe has only one inlet and one outlet, all of the fluid that flows in must also flow out, which means the volumetric flow rate through the pipe $\frac{V}{t}$ must be constant everywhere inside the pipe.

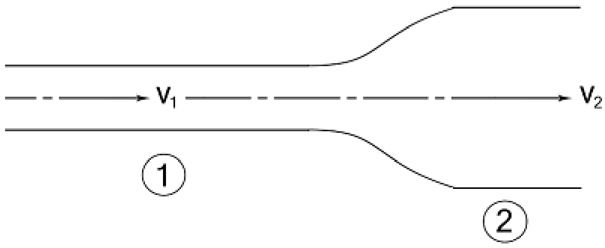
Because volume is area times length (distance), we can write the volumetric flow rate as:

$$\frac{V}{t} = \frac{Ad}{t}$$

Assuming the velocity is constant through a section of the pipe as long as the size and elevation are not changing, we can substitute $v = \frac{d}{t}$, giving:

$$\frac{V}{t} = \frac{Ad}{t} = A \cdot \frac{d}{t} = Av = \text{constant}$$

If the volumetric flow rate remains constant but the diameter of the pipe changes:



In order to squeeze the same volume of fluid through a narrower opening, the fluid needs to flow faster. Because *Av* must be constant, the cross-sectional area times the velocity in one section of the pipe must be the same as the cross-sectional velocity in the other section.

$$Av = \text{constant}$$
$$A_1 v_1 = A_2 v_2$$

This equation is called the *continuity equation*, and it is one of the important tools that you will use to solve these problems.

Note that ***the continuity equation applies only in situations in which the flow rate is constant***, such as inside of a pipe.

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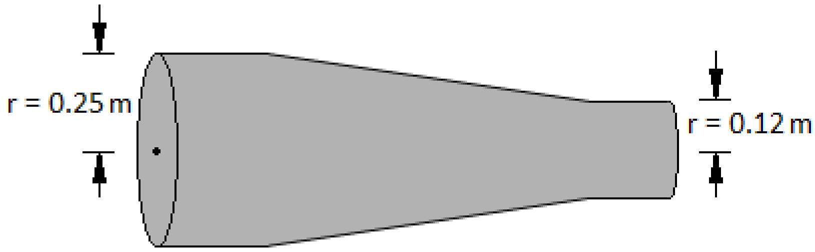
Homework Problem

1. **(M)** A pipe has a radius of 0.25 m at the entrance and a radius of 0.12 m at the exit, as shown in the figure below:



If the fluid in the pipe is flowing at $5.2\,\frac{\text{m}}{\text{s}}$ at the inlet, then how fast is it flowing at the outlet?

(*Hint: the <u>radius</u> of the pipe is given at each end. You will need to use* $A = \pi r^2$ *to calculate the cross-sectional area.*)

Answer: $22.6\,\frac{\text{m}}{\text{s}}$

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