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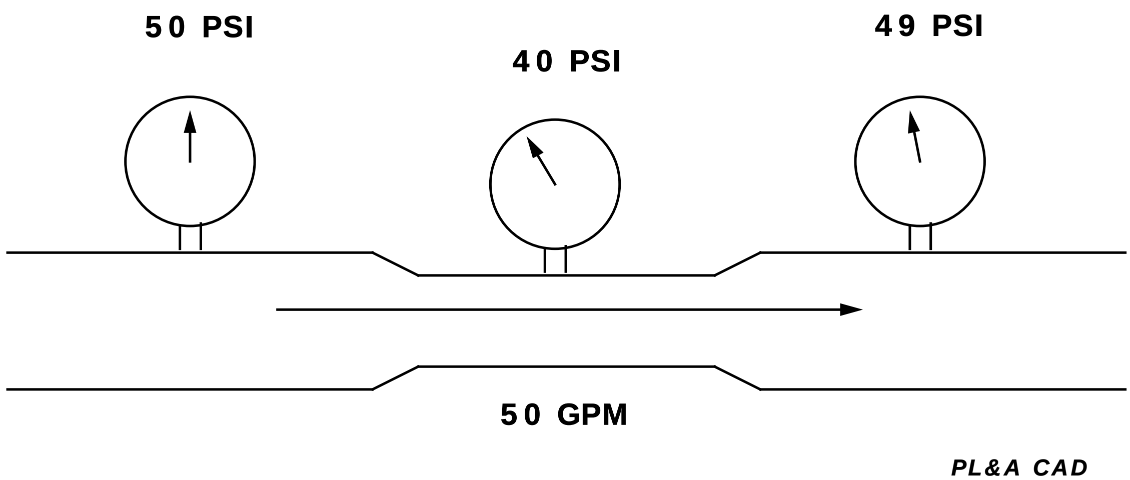
The Restricted Pipe Puzzler



In the pipeline above, water is flowing at 50 gpm. What is the significance of the differing pressure readings among the three gauges? What happens as the water flows from left to right? Who first explained this phenomenon? Is there a simple way to illustrate this mathmatically? Pressures are relative.

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THE RESTRICTED PIPE PUZZLER

THE BERNOULLI EFFECT

Joe Evans, Ph.D

Although we see its consequences daily, we seldom think about the principle described by the Swiss mathematician Daniel Bernoulli (1700-1782). Also known as the venturi principle, it states that the velocity of a fluid increases as it's pressure decreases (and vice versa). It explains many things that occur in nature and is at the core of hydraulics and hydraulic machines.

In the Puzzler fluid enters the larger diameter portion of the tube from the left, traverses a constricted portion, and exits through another increased diameter portion to the right. The rate of flow through the entire tube is constant. After a little thought it becomes fairly obvious that, if the fluid is to maintain it's original rate of flow as it enters a constricted area, it's velocity must increase. We see this in nature when a slowly flowing river becomes a raging torrent as it passes through a narrow gorge. It may not be quite so obvious; however, why there is a corresponding decrease in pressure.

It helps a bit to consider just what causes the fluid's velocity to increase. Newton's first law of motion tells us that a fluid, in and of itself, will never undergo a spontaneous increase or decrease in velocity.[1] Furthermore, his second law states that some force is required to accelerate the fluid to a higher velocity.[2] But, in our puzzler, what is the source of that force? Again, it helps to employ a little classical physics. This time we will call upon the law of Conservation of Energy.[3] For a steady flow of fluid, three types of energy exist within the fluid: 1) Kinetic energy due to motion, 2) Potential energy due to pressure, and 3) Gravitational potential energy due to elevation. In our puzzler elevation does not change, so an increase in velocity would result in an overall increase in energy (a no no in Physics) unless there is a corresponding decrease somewhere else in the system. That "somewhere else" is pressure.

A decrease in pressure provides the force needed to accelerate the fluid to a higher velocity. As it exits the constricted area the process is reversed and velocity decreases due to an increase in pressure (deceleration). The small difference in pressure, shown by the gauges, before and after the constriction is due to friction. More precisely it represents a small reduction in potential energy (in this case, heat due to friction) within the system. Conservation of energy requires that this small reduction in pressure be offset by a small increase in temperature.

A mathematical representation of the three types of energy (kinetic, potential, & gravitational) within a moving stream of fluid is shown below. It takes the form of a conservation equation where the sum of the three variables always equals some constant.

KE + PE + GPE = CONSTANT

Bernoulli's equation also takes the form of the conservation equation. It states:

$$1/2\, mv^2 + pV + mgy = \text{constant}$$

Where:
- m = mass
- v = velocity
- p = pressure
- V = Volume
- g = acceleration due to gravity
- y = elevation

[1] An object in motion (or at rest) will tend to remain in motion (or at rest) in a straight line and at a constant velocity unless it is acted upon by some outside force.

[2] The acceleration produced by a force acting upon a body in motion or at rest is directly proportional to the magnitude of the force and inversely proportional to the mass of the body.

[3] The amount of energy contained within a system is constant. It cannot be created nor destroyed, but it can be transformed from one from to another.

If we express mass in terms of density (d) we will obtain:

$d = m / V$

If we substitute d for m and divide each term by v, Bernoulli's equation takes the form of:

$1/2dv^2 + p + dgy = constant$

Now all have units of pressure. If y does not change, an increase in velocity dictates a decrease in pressure (and vice versa) if the law of Conservation of Energy is to hold true. Bernoulli's equation holds true for the steady, non viscous flow of all incompressible fluids.

The Bernoulli Principle is in action when an airplane flies or a baseball curves. The curved upper surface of an airplane's wing forces the air moving over it to increase in velocity. As a result the pressure in the air near by is reduced thus allowing the higher atmospheric pressure on the bottom of the wing to push it upward. A spinning baseball thrown by a pitcher produces a similar effect. As it spins, friction causes it drag a thin film of air with it. The side of the ball spinning in the same direction as the air moving over it creates a lower pressure than the opposite side which is spinning against the flow. As a result, the ball curves toward the low pressure side.

His principle also holds true at sea. The reason that ships must not pass too closely is that the increased velocity of the water passing between them creates a low pressure area that can cause a sideways collision. For this very same reason, large docks have pilings rather than solid walls.

In the pumping arena, the Bernoulli Principle is the stuff of ejectors, eductors, impellers, and jet pumps. Over time we will cover these in some detail.

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