Bernoulli's Principle

Bernoulli's principle relates the pressure of a fluid to its elevation and speed. It is named after the Swiss scientist Daniel Bernoulli who lived in the 18th century and did experiments looking at how fluids moved. He noticed that as a fluid moves from a wide pipe into a narrower one, it flows more quickly since the volume of the fluid moving over a certain distance within a given time period doesn't change (what goes in must come out). This is also seen in nature when comparing the slow flow of water in a wide section of a river versus the fast flow of the same river in a narrow canyon. Bernoulli understood this to mean that the slower the rate of flow, the higher the pressure, and the faster the rate of flow, the lower the pressure. This formulation was further refined over the years and Bernoulli's equation now provides a valuable way to understand and predict the behaviour of fluids. Mathematically this equation can be written as follows:

$$P_1 + {}^1\!/_2\,\rho V_1^2 + \rho g y_1 = P_2 + {}^1\!/_2\,\rho V_2^2 + \rho g y_2$$

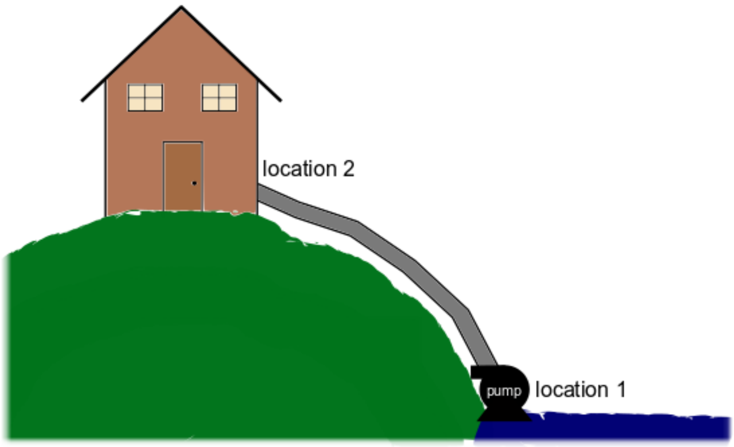
where P refers to the pressure in the fluid, ρ is the density of the fluid, g is the gravitational acceleration, and y is the height of the fluid. Subscripts 1 and 2 indicate two different locations of the fluid in the system, e.g. in the wide section of a river (1) and a narrow canyon of the same river (2). Note that the derivation of the Bernoulli equation assumes that the fluid being considered is ideal. That means the viscosity is zero, the density doesn't change, and the flow of the fluid is steady.

Using this equation, we can calculate an unknown fluid condition (the fluid pressure, velocity, density or height) at one point along a flow streamline, using the conditions at another point along the same streamline.

A simple example

For example, say you have a pipe that transports water from a reservoir in a valley to a house up on the top of a 50 m hill. You'll need a pump to do this and can use Bernoulli's equation to calculate the pressure difference needed to be generated by that pump.

Let's work through it together: We will designate location 1 to be at the reservoir and location 2 to be at the house at the top of the hill, as shown in this diagram.



This means we are trying to calculate P_1, the pressure provided by the pump at the reservoir. We know that acceleration due to gravity is g=9.81 m/s^2, water has density ρ=997 kg/m^3, and the pressure at the top of the hill is P_2=10100 Pa (atmospheric pressure). Therefore,

$$P_1 + {}^1/_2\,\rho V_1^2 + \rho g y_1 = P_2 + {}^1/_2\,\rho V_2^2 + \rho g y_2$$

$$P_1 + \frac{1}{2}(997)(0)^2 + (997)(9.81)(0) = 101000 + \frac{1}{2}(997)(0)^2 + (997)(9.81)(50)$$

$$P_1 = 590{,}000\ Pa$$

That is about 86 psi so it doesn't require a very large pump! For reference, a pump for your shower typically uses a pressure of approximately 44 psi.

Why does my shower curtain attack me?

Bernoulli's principle is a popular explanation given for the shower curtain effect, which is the annoying fact that shower curtains seem to blow in towards the shower, sticking to the person inside. Bernoulli's principle predicts that an increase in velocity results in a decrease in pressure. To explain what is happening in a shower, we anticipate that the water flowing out of a shower head causes the air through which the water moves to start flowing in the same direction as the water. This movement would be parallel to the plane of the shower curtain. If air is moving across the inside surface of the shower curtain, Bernoulli's principle says the air pressure there will drop. This results in a pressure difference between the inside and outside of the shower, causing the curtain to move inward. It would be strongest when the gap between the bather and the curtain is smallest - resulting in the curtain attaching to the bather.

Bernoulli's principle can be used to explore key properties of fluids in many different environments and applications, including:

- Pressure required to pump water up a hill
- Air pressure around an airplane's wing
- Speed of water coming out of the hose in your backyard
- Effect of orifices and contractions in pipe flow
- Force of high winds on a skyscraper
- Pressure through a chemical reactor
- And more…