The different behavior of solids and fluids (the venturi)
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September 2103

Solids and fluids behave very differently. Most of us don't deal with moving fluids on an everyday basis so that certain fluid behaviors appear quite strange and counter-intuitive. Two such behaviors occur with fluids moving in a siphon and a venturi. Let's see what happens in the venturi.
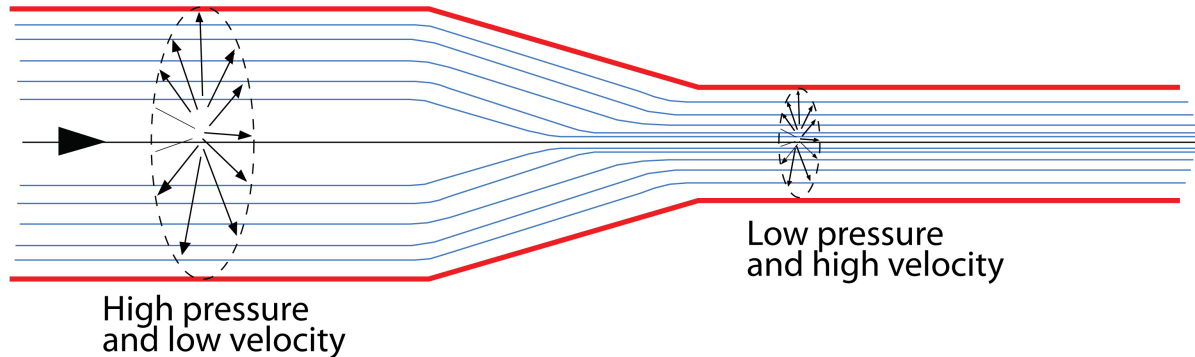

High pressure
and low velocity

Low pressure
and high velocity

Figure 1. The venturi.

Stationary or moving objects can be solid or liquid. To explain the behavior of moving solids we use force (F), mass (m) and velocity. In the case of fluids we don't use force because you can't push on a fluid, by its nature it will just move away, however you can surround a fluid with walls and you can pressurize it. Therefore instead of force we use pressure (p).

The other solids property that is not used for fluids is mass, that's because when we move a fluid through a system, we move large quantities of mass continuously and we don't typically keep track of that mass, therefore it is more appropriate to use density (rho - ρ) which is mass per unit volume.

Lastly we use velocity both for solids and fluids; in the case of fluids we normally consider the average velocity of fluid particles at a specific cross-sectional area of a pipe. We also use flow rate in fluid transfer systems which is the average velocity times the cross sectional area (v x A) divided by unit time often expressed in gallons per minute in Imperial units (v x A/t or volume/t or gpm). This is because for fluids we are not so much interested in the velocity of fluid particles but how much volume per unit time or gallons per minute are transferred, it's more practical.

A venturi is a reduction in a pipe. The liquid is moving at a steady rate or constant velocity in a pipe which is then reduced to a smaller diameter. The interesting thing that happens is that the pressure in the smaller pipe diameter will be less that in the larger upstream diameter. **What's happening?** First of all to get the same flow rate through the smaller diameter the velocity must increase. Right? Why must it increase?

Let's look at the opposite of the venturi, a pipe who's diameter increases, I think it's pretty clear that the velocity will decrease since we have a larger pipe diameter, in other words there is no reason for the flow rate to change but something has to give and that's the velocity.
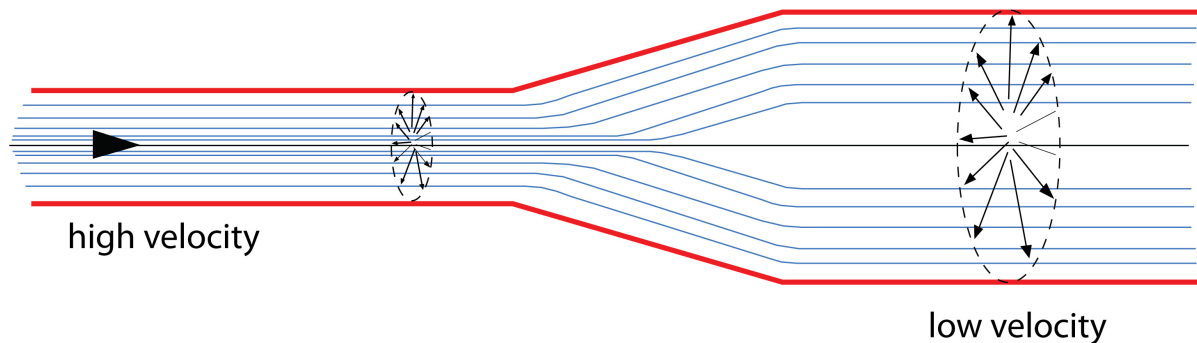
high velocity

low velocity

Figure 2. A reverse venturi.

So it's clear that the velocity will change whether we increase the diameter or decrease it. **Why does it slow down?** The reason is that the flow rate between the area in the small pipe just before the increaser and the flow rate right after the increaser must be equal since there is no where else for the fluid to go. Flow rate is volume per unit time or in Imperial units gallons per minute or gpm. If we have 10 gpm in the high velocity area we will still have 10 gpm in the low velocity area. But since flow rate is v x A /t, if the cross-sectional area goes up then the velocity must go down to maintain the same flow rate.

What affect does this have on other properties of the liquid? There are only 3 properties that need to be considered in the flow of fluid neglecting friction, **pressure, velocity and density**. Density is constant in liquids, therefore only pressure and velocity can affect each other. How?

Both pressure and velocity can be expressed in their corresponding forms of energy, velocity energy is expressed as $\frac{1}{2} mv^2$ and pressure energy as m x p / ρ.

Fluids under pressure have energy, just look at a fire extinguisher, when you clench the handle the fluid under pressure in the reservoir is rapidly expelled though the nozzle. **What about velocity energy?** If you put your hand in front of the nozzle of a typical garden hose you are going to feel a strong reaction on your hand, this is due to the velocity energy of the fluid particles hitting your hand with velocity and mass, not to be confused with pressure, there is no pressure in the water that comes out of the nozzle, only velocity. It's similar to someone throwing a baseball at you.
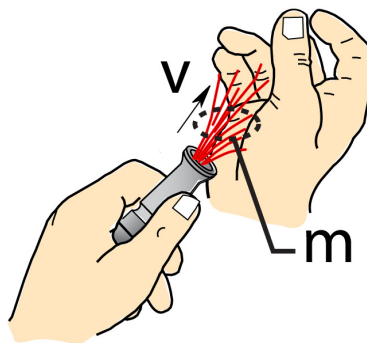
Figure 3. The impact of water on hands.

The principle of conservation of energy tells us that energy can neither be created nor destroyed; it can only be changed from one form to another. In our case this is how pressure and velocity are related, if one changes the other must change in such a way that the total energy remains constant.

$$m \times p / \rho + \tfrac{1}{2} m \times v^2 = 0$$

For liquids the more common way of expressing this relationship is:

$$\frac{p}{g\rho} + \frac{v^2}{2g} = 0$$

These terms are now no longer energy but energy per unit weight of liquid also known as specific energy which is appropriate to the transfer of fluids.

If we apply that to the venturi we see that if the velocity goes up then the pressure must go down to maintain the total energy level, to avoid losing or creating any energy.

The troubling aspect of the venturi is that our common sense experience tells us that if you try to force a fluid through a smaller pipe diameter you will need to exert extra force or extra pressure to get it in there. That's how a solid or semi-solid object would react because you would have to force it in there. A fluid does not behave the same way, instead of reacting by increasing the pressure it will just go faster. **Why is that?** The reason is that a liquid cannot create significant shear forces because the molecules just slip by one another, therefore it cannot resist being pushed forward by counter-acting with increased pressure it can only respond by going faster, and this change is velocity causes the pressure to drop to maintain the balance of energy.

Is there another area of our lives where we see this exchange of energy happen before our eyes, yes! If you've ever ridden a bicycle you will have experienced what happens when you roll down a hill. At the top of the hill you have positional energy or potential energy which is the amount of energy your height gives you with respect to the bottom of the hill. This is because you are attracted towards the ground by gravity, just like when you let go of a ball. You're potential energy is m g h, where h is the height from the top of the hill to the bottom, m is your mass and g the acceleration due to gravity.

On the other hand at the top of the hill you may have zero velocity energy known as kinetic energy. Kinetic energy is $\tfrac{1}{2} m v^2$ where v is your velocity. Think of a football player running down the field for a touchdown he has alot of kinetic energy. The conservation of energy demands that the sum of these two terms must be zero.

$$m \times g \times h + \tfrac{1}{2} m \times v^2 = 0$$

 As you roll down the hill you lose potential energy or height and gain kinetic energy or velocity. .This is the same energy transfer process that we see in the venturi. Pressure energy of fluid particles diminishes and kinetic energy or velocity increases.
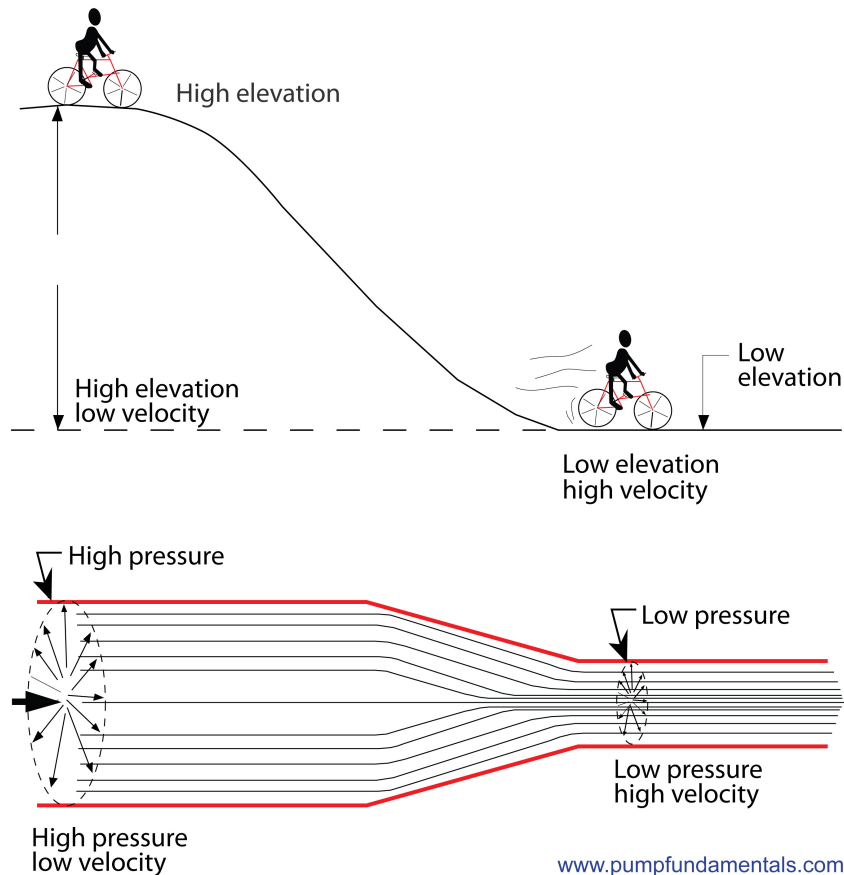
Figure 4. A comparison between two different types of energy exchange.

Seeing is believing. It's easy to demonstrate the venturi effect. You can purchase for low cost a plastic venturi from Fischer Scientific that you can install on your sink tap. Just go to the Fischer Scientific web site and look for the Nalgene aspirator. You will easily detect low pressure at the venturi throat simply by putting your finger on the tube attached to this portion of the venturi. See this video to see how low the pressure can get:

http://www.youtube.com/watch?v=EN2_libETns