The relationship between velocity and flow in a liquid system

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Why does obstructing the end of a pipe increase the velocity of the liquid at the outlet? The velocity is increasing but what happens to the flow rate? Does it stay the same or does it decrease. For example when you put your thumb on the end of a garden hose the velocity increases eat the outlet of the hose, how does this influence the flow rate?

Flow rate is a crucial parameter of a pump system, it determines the velocity in each part of the system and velocity in the various parts will tell us the friction loss. Velocity can change throughout the system because of pipe reductions, partially closed valves or other. But one thing that does not change is the flow rate. This is constant because of the law of conservation of mass, what goes in must come out. This is why the first thing that must be established for a new system is the required flow rate. This will usually depend on production requirements.

The standard answer to the above when applied to a centrifugal pump system is that when the valve is closed the flow decreases because pressure drop across the valve increases; this increase in pressure drop causes the total head of the system to increase which as we know will result in a different operating point on the pump curve. An increase in total head on the pump curve will result in a decrease in flow (see Figure 1).

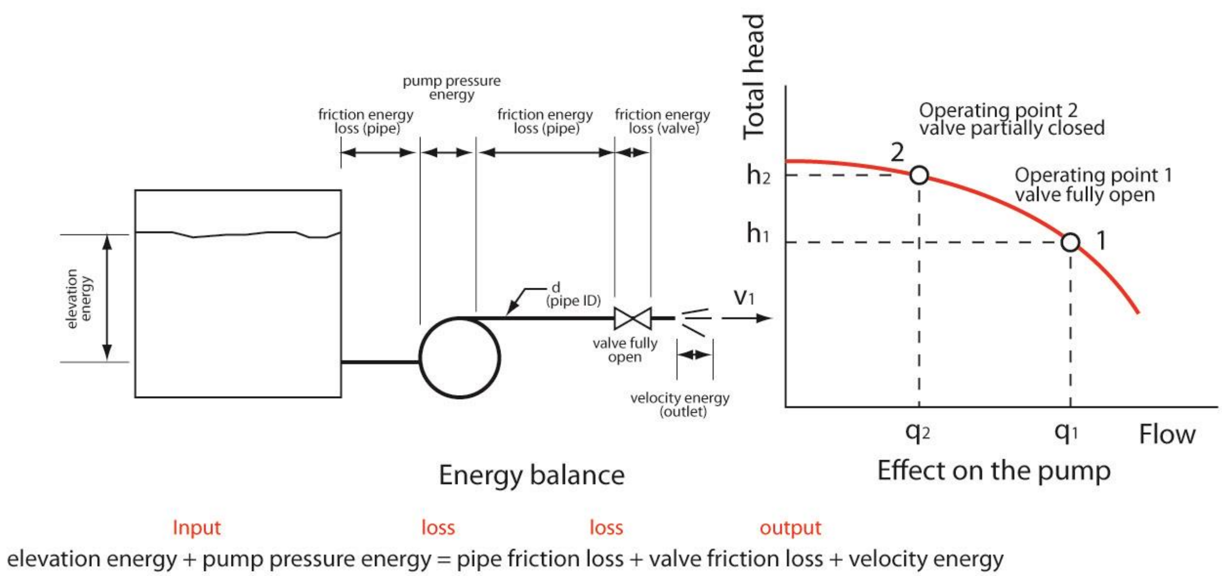

Figure 1. Centrifugal pump system with valve partially closed.

The role of the pump is to provide pressure. What if the system does not have a pump but instead the pressure source is a head tank? The same thing will occur. The source of energy is now potential energy or elevation energy provided by a difference in elevation. The flow rate is the result of the effect of potential energy balancing the friction energy of the system. Energy in (potential energy) is balanced by energy out (velocity energy at the end of the pipe + friction). The only unknown in the system is the velocity at any given moment throughout the different parts of the system. Calculating the velocity is normally an iterative process, one assumes a value for velocity, then a calculation of the friction value is done and if this equals the potential energy then the velocity is correct, if not adjust the velocity up or down until the potential energy is balanced. Knowing the velocity in any part of the system will automatically give us the flow rate.

$$\overset{\text{velocity}}{v\ (\text{ft/s})} = \frac{0.4085 \times \overset{\text{flow rate}}{q\ (\text{gpm})}}{\underset{\text{pipe ID}}{d^2\ (\text{in}^2)}}$$

Figure 2. Flow rate vs. velocity.

If a change is made in the system that increases friction, the potential energy must now be balanced against a different and higher friction energy, this cannot occur because of the principle of conservation of energy. Therefore the friction energy must decrease and this can only be accomplished by decreasing the flow rate. A decrease in flow rate results in a decrease in velocity throughout the main piping system.

A change in the system means that it is essentially a new system; everything is reset to the new conditions.

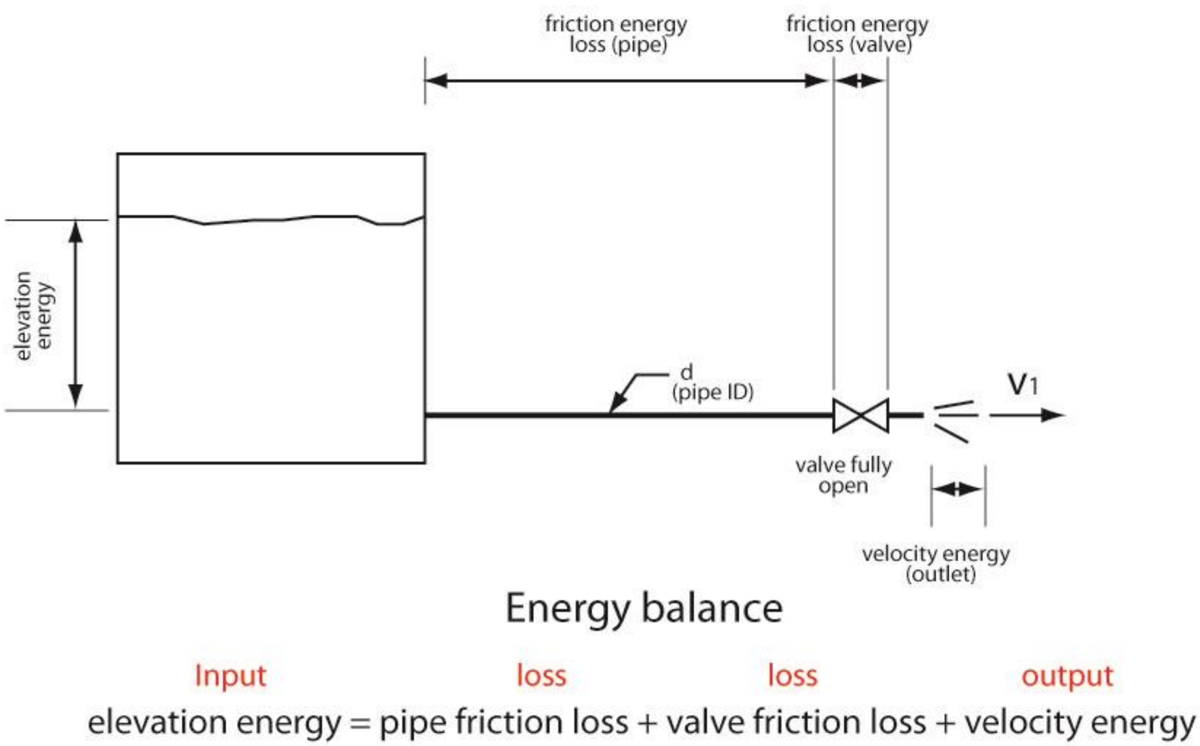

Figure 3. Head tank system.

Therefore if there is a change in the system causing friction to increase, flow rate must decrease. **This is the real answer.** The key is to see that flow rate is the main driver of friction energy. We are not used to seeing flow rate and its partner velocity in that fashion.

This is the energy balance:

elevation energy = friction energy + velocity energy

The velocity energy is the energy velocity of the fluid particles at the end of the pipe; it is normally small compared to the other terms.

An analogy may help view this situation from a different angle. The cyclist is at the top of the hill, she lets herself roll down and gradually the potential energy that she had at the top of the hill is converted to velocity energy. Friction energy (i.e. air resistance, tire to road resistance) also increases limiting the velocity the bike. At the bottom of the hill all the potential energy is converted to velocity energy which is the velocity energy associated with the mass of the bike and cyclist (1/2 m v^2), moderated by the friction energy. We can do the same calculation here for velocity and we will find that there is only one velocity value (at the bottom of the hill) that will satisfy the input energy available (potential energy). How do we increase friction energy in this system? One way is the decrease the tire pressure, this will result in a slower speed at the bottom of the hill. This is another way of thinking of velocity in terms of its effect on friction energy.

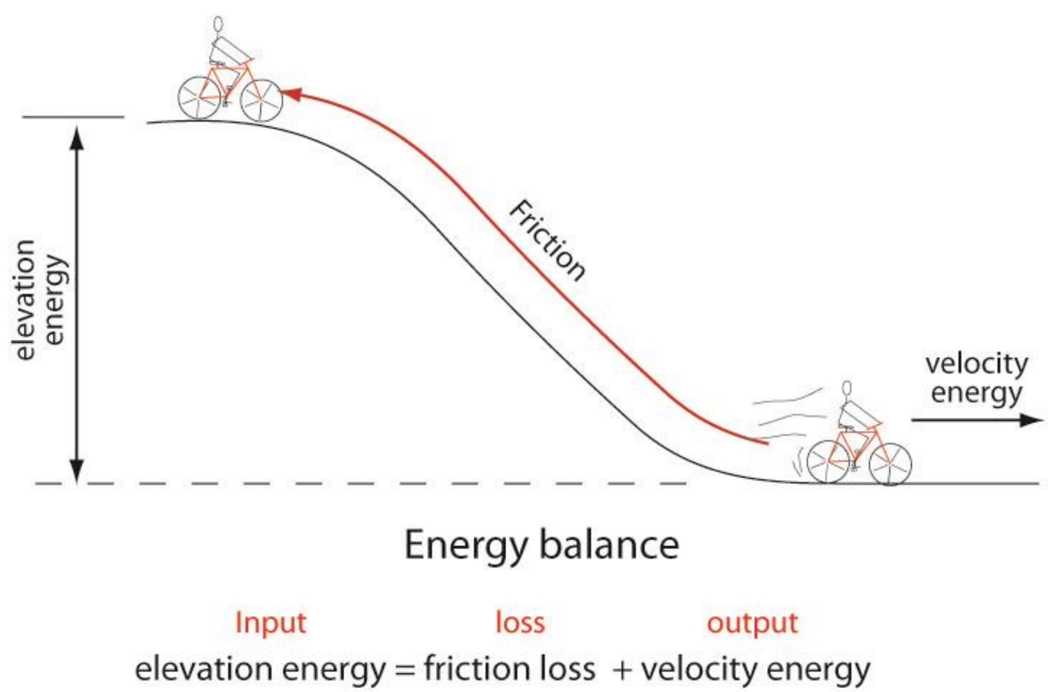

Figure 4. Cyclist converting elevation energy to velocity energy.

Note that when I mention friction or friction loss I mean friction energy and velocity energy is also known as kinetic energy. I sometimes refer to potential energy as elevation energy.

This is the energy balance:

$$\text{elevation energy} = \text{friction energy} + \text{velocity energy}$$

In summary, velocity increases at the end of the pipe because the area available for the liquid to pass through has decreased, just like when we put a reducer in a pipe. We now have a different system, one where the pipe is restricted at its outlet; the effect is to decrease the flow rate which decreases the velocity in the main part of the pipe where most of the friction is generated even though velocity may be higher at the outlet.