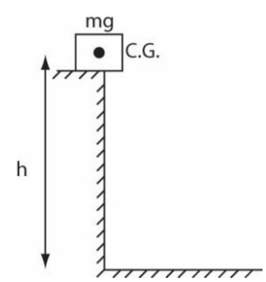
How moving liquids compares to moving solids

Jacques Chaurette, August 2020

I find that most people when they explain pump systems or any type of liquid system often start with stating what the static heads are without giving any background of what it is or where it comes from. Nobody is being devious, it's a short-cut, people are supposed to know; it just seems like a good place to start and I'm equally guilty of this.

Liquids have to be treated slightly differently than solids because they need to be held in a container. It's also how pressure appears, you never hear about pressure in solids because that's not a factor in their movement, they can hold themselves. If you dive in a swimming pool at the deep end and swim to the bottom you will feel pressure on your ear drums and that's the weight of a vertical water column on your ear drums.

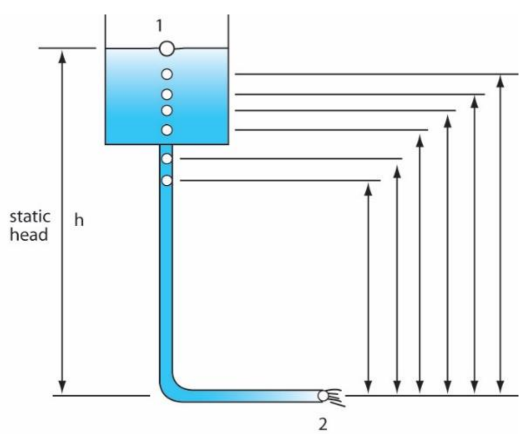
As we will see static head is related to potential energy. It is easy to determine the potential energy of solids, all we need to find is the center of gravity of the object and from there measure the vertical height to the lowest point.




In the case of liquids, we need to figure out how to treat the different parts of the liquid body that is falling towards a low point.

**Static head with the help of velocity head**

Static head is the height of a body of water above a lower point used as a reference. It is in fact potential energy per unit weight of liquid displaced or specific energy. *But which height are we talking about?*

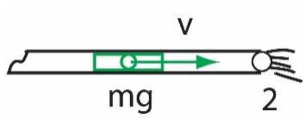


Point 1 is the highest point in the system. Let's assume that the level is remaining constant, the particles around point 1 will eventually make their way out of the system. The height of point 1 with respect to the outlet at point 2 is called the static head of point 1 or if we are connected to a pump or a turbine it would be called the suction static head.

*Why is point 1 so critical? Don't all the other portions of the liquid contribute to this head?*

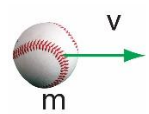
It may be easier to start with some other form of energy such as kinetic energy or velocity energy. Kinetic energy is the energy an object possesses due to it mass and velocity

$$E_K = \frac{1}{2} m v^2$$

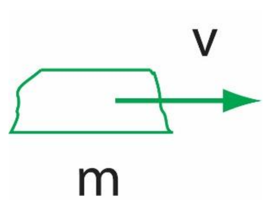



We feel that energy every time we catch a ball. If we look at a certain portion of the tube and we select a volume of the liquid we can determine its kinetic energy.

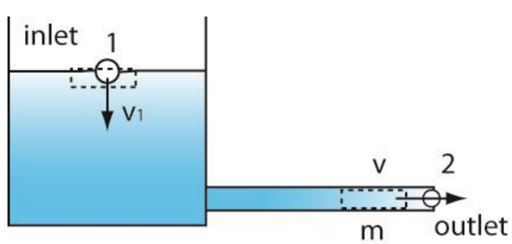
When a solid is moving like a ball, it's easy to identify all the particles of the ball, they are all stuck together.




If we try to move something viscous like putty or jello, it's doable, but we are starting to wonder if it will hold itself together and if the thing should be in a container.




A liquid needs to be in a container, usually not all parts of the liquid are moving at the same velocity and we have to chose which part to consider. For example, the particles on the surface of the tank are moving at a different velocity than those in the pipe – assuming that the level is not constant.




To analyze a system, we look at the energy present at the inlet (point 1) and the outlet (point 2). The difference between these two is the energy that must be supplied, in this case by gravity.

At the inlet we look at a representative small volume and we do the same at the outlet.

In either case we are not being specific about the volumes being considered. What we are really considering is a unit of volume or weight. Let's consider the kinetic energy of a moving object and divide it by a unit weight:

$$E_K / mg = 1/2\ m\ v^2 / mg = v^2 / 2g \qquad \text{(energy / unit weight)}$$

Dividing by weight provides a very useful simplification:

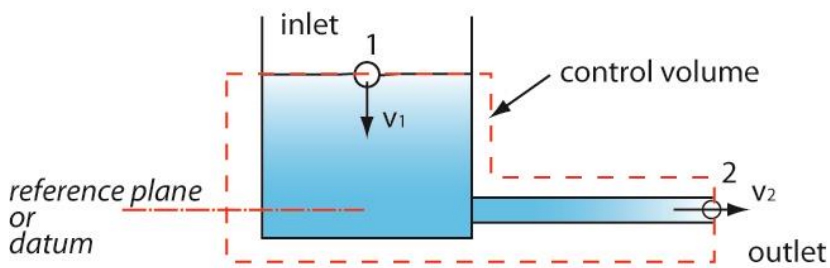
$$v^2\ (ft^2/s^2) / 2g\ (ft/s^2) = v^2 / 2g \qquad (ft)$$

The energy per unit weight or specific energy has a unit of feet (ft) or meter (m) also known as head.

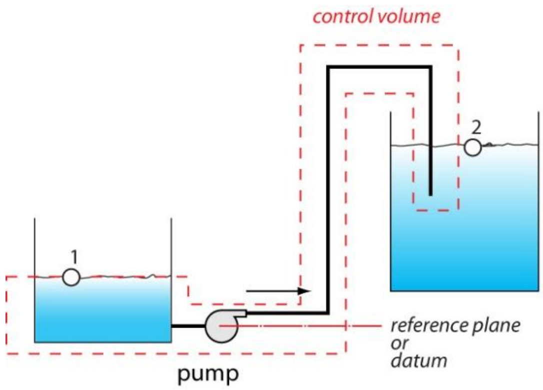
*So how does this apply to our initial situation of a body of water at a height?*

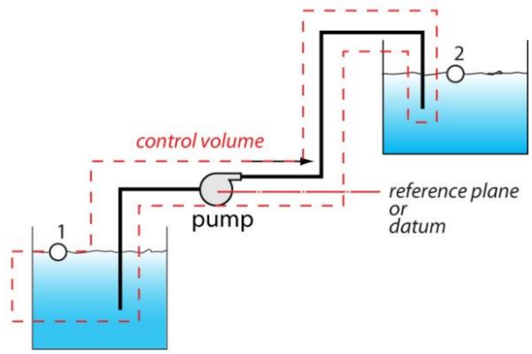
The answer is we need to consider the energy of the fluid particles that are at the inlet of the system, point 1. Those particles will have a potential energy of $E_p$ = mg h. As in the previous situation we divide by a unit weight mg and obtain $E_p$/mg = mg h / mg = h; this is the specific energy or head of the particles at point 1 also known as the static head.

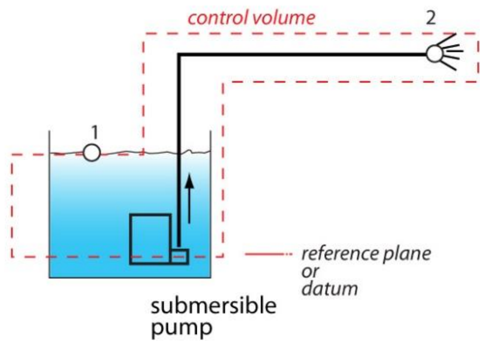
The control volume is what delimits the inlet and the outlet and within this volume we can apply the law of conservation of mass and energy.




Here are some other examples of control volumes. The reference plane does not always have to be the lowest point. In pumping systems, the pump suction centerline is usually taken to determine the reference plane and all the elevations are taken with respect to the suction.



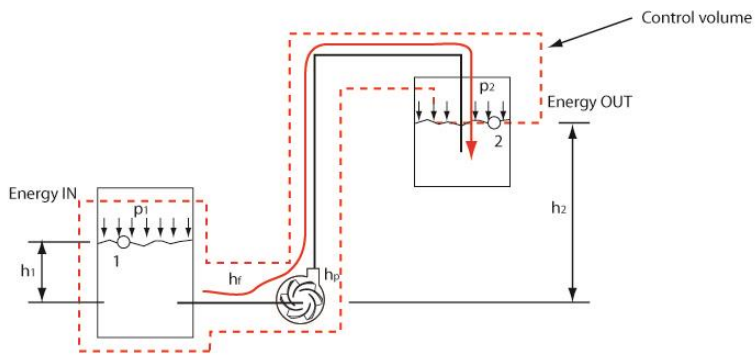



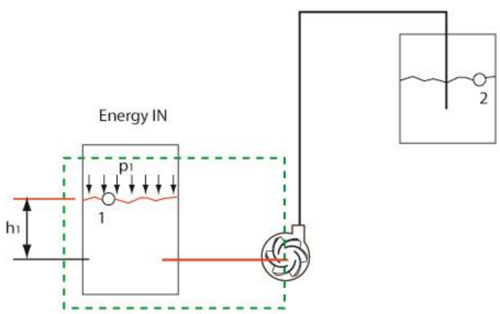

In liquid systems we use the different forms of specific energy or head (i.e. static, velocity, pressure, friction and pump) to describe the energy components and these can be added or subtracted to determine how much energy is required to get the necessary flow rate.

If required, we can determine the pressure or pressure head in any part of the systems by positioning a control volume at the right location.

The next 2 images show the different energies that may occur at the inlet, the outlet and within the system. This can be applied to a great majority of systems if not all.

## Pump system energy balance

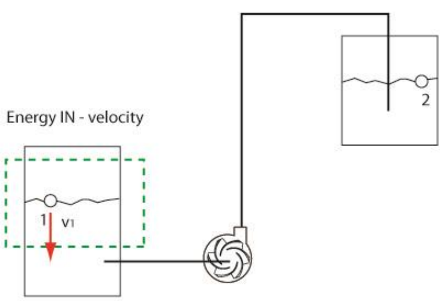



Energy (potential) IN $\quad mg\,h_1 + \frac{p1}{\gamma}$

Head or specific energy $\quad \frac{mg\,h_1}{mg} + H_1 = h_1 + H_1$

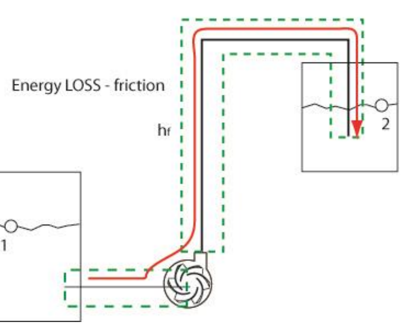
$\gamma$ is density, $H_1$ is pressure head & $h_1$ is static head




Energy (kinetic) IN $\quad \frac{m\,v_1^2}{2}$

Head or specific energy $\quad \frac{m\,v_1^2}{mg\,2} = \frac{v_1^2}{2g}$

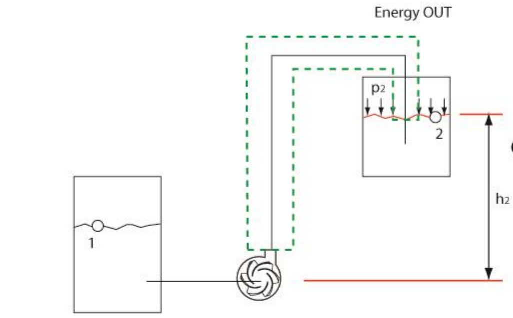
$\gamma$ is density, $H_1$ is pressure head, $v_1$ is velocity & $h_1$ is static head




Energy (friction) LOSS $\quad mg\,h_f$

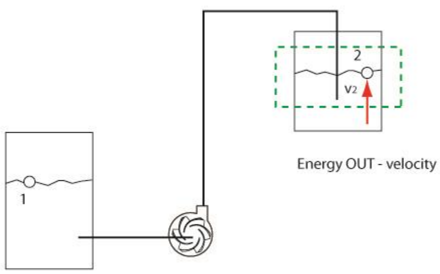
Head or specific energy $\quad \frac{mg\,h_f}{mg} = h_f$

# Pump system energy balance (cont.)



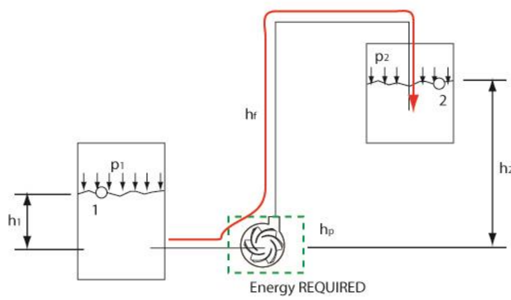

Energy (potential) OUT $\quad mg\,h_2 + \dfrac{p_2}{\gamma}$

Head or specific energy $\quad \dfrac{mg\,h_2}{mg} + H_2 = h_2 + H_2$




Energy (kinetic) OUT $\quad \dfrac{m\,v_2^{\,2}}{2}$

Head or specific energy $\quad \dfrac{m\,v_2^{\,2}}{mg\,2} = \dfrac{v_2^{\,2}}{2g}$




Energy REQUIRED $\quad mg\,h_p$

Head or specific energy $\quad \dfrac{mg\,h_p}{mg} = h_p$

$h_p$ is the pump head or total head

Spec. energy in + Spec. energy pump = Spec. energy loss + Spec. energy out

static head in + velocity head in + Pump head = Head loss + static head out + velocity head out

$$h_1 + H_1 + \frac{v_1^{\,2}}{2g} + h_p = h_f + h_2 + H_2 + \frac{v_2^{\,2}}{2g}$$

$$h_p = h_f + (h_2 - h_1) + (H_2 - H_1) + \frac{(v_2^{\,2} - v_1^{\,2})}{2g}$$