52.5: The Siphon

A siphon (or syphon, from the Greek $\sigma\iota\varphi\omega\upsilon$) is a tube that transfers liquid from a reservoir at higher elevation to a reservoir at lower elevation, without the need for a pump—even though the liquid must travel uphill for part of the journey (Fig. $52.5.1$).

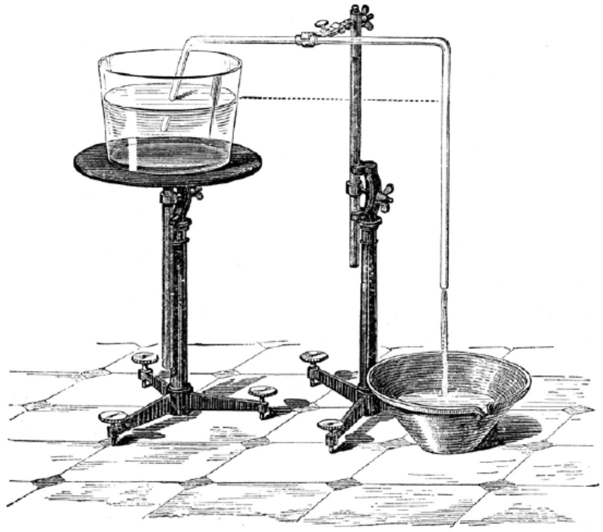

Figure 52.5.1:A siphon. (From Ref. [14])

It is a common misconception that a siphon works by atmospheric pressure pushing the water through the siphon, but this is not correct; siphons have been known to work even in vacuum. It's actually gravity that allows the siphon to work: water in the downward part of the siphon (the downleg) "pulls" the water in the rest of the tube along as it falls under gravity.

Siphons must be started or "primed" by filling the siphon tube with liquid before the siphon works. If the liquid to be moved is clean water, for example, one may sometimes start a siphon by mouth, creating a suction on one end as one would use a drinking straw. Once the tube is filled, you insert one end into the source reservoir, lower the other end into the target reservoir, and the siphon will begin to operate. But you would not want to start a siphon this way with a toxic liquid such as gasoline. (Service stations post a notice near the gasoline pumps, warning “do not siphon by mouth”.)

We can analyze the flow of liquid through a siphon using Bernoulli's equation, Eq. 52.3.1 . Let's let atmospheric pressure be P_0 and the velocity of liquid through the siphon be v. We'll define a coordinate system with the $+y$ axis pointing upward, and with the origin at the surface of the liquid in the higher ("source") reservoir, so all elevations will be measured with respect to this level. As seen in Fig. $52.5.1$, the upper end of the siphon tube is immersed in the liquid; let's say it's at a depth d below the surface of the liquid, so it is at elevation $y=-d$. Let's call the height of the upper horizontal tube above the upper reservoir liquid level h, so it is at elevation $y=h$; and let's call the distance between the upper liquid level and the lower end of the downleg L, so $y=-L$ there. Then applying Bernoulli's equation to various points along
the siphon,

$$\frac{P_1}{\rho g}+\frac{v^2}{2g}-d=k \text{ Upper end of siphon (entrance)} \tag{52.5.1}$$

$$\frac{P_0}{\rho g}+\frac{0}{2g}+0=k \text{ Surface of upper reservoir} \tag{52.5.2}$$

$$\frac{P_2}{\rho g}+\frac{v^2}{2g}+h=k \text{ Top (horizontal) portion of siphon} \tag{52.5.3}$$

$$\frac{P_0}{\rho g}+\frac{v^2}{2g}-L=k \text{ Lower end of downleg (exit)} \tag{52.5.4}$$

Notice that the constant k on the right-hand side is the same for all equations, since the equations all apply to the same siphon. We've used the atmospheric pressure P_0 in Eqs. $52.5.2$ and $52.5.4$, because the surface of the upper reservoir and the exit point are both open to the atmosphere. Note also that the velocity of liquid at the surface of the upper reservoir has been set to zero; this is not strictly true because the liquid level in the upper reservoir is dropping, but the speed with which it drops is very slow compared to the siphon velocity v, so we'll set the liquid level velocity to zero as an approximation. Pressure P_1 is the liquid pressure at the siphon entrance, and P_2 is the pressure in the upper (horizontal) part of the siphon.

Let's try to find the velocity v of liquid through the siphon. Combining Eqs. $52.5.2$ and $52.5.4$,

$$\frac{P_0}{\rho g}+\frac{0}{2g}+0=\frac{P_0}{\rho g}+\frac{v^2}{2g}-L \tag{52.5.5}$$

$$0=\frac{v^2}{2g}-L \tag{52.5.6}$$

or

$$v=\sqrt{2gL} \tag{52.5.7}$$

So the velocity v of liquid through the siphon depends only on the distance L between the upper reservoir liquid level and the exit end of the siphon. [1]

Siphons are more complex than this brief analysis would indicate. Pressures in the tubing above the upper reservoir will be less than atmospheric pressure. As the water rises, gases will be liberated, and with large values of h, the volumetric gas rate will lower the effective density of the water, thereby increasing the maximum siphon height. When the pressure is near the vapor pressure of water, [2] the water will boil and can greatly reduce the effective water density. Under some circumstances, this water vapor can collapse violently in the downleg, causing severe vibration.

There doesn't seem to be a limit to the siphon height h, but $40 \mathrm{ft} (12 \mathrm{~m})$ or more are possible. There is no limit to the length of the downleg L; values as high as $200 \mathrm{ft} (61 \mathrm{~m})$ have been tested.

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[1] It's actually a little more complicated than this, because of inlet losses and pipe friction. When considering just the inlet losses, the liquid velocity is limited to $v_{\max}=\sqrt{gL}$.

[2] The vapor pressure of water depends on temperature; at $20^{\circ} \mathrm{C}$ it is $2339 \mathrm{~Pa}$.
