Does Spout Size Matter for Sap Yield?

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Early research on tap hole size, before vacuum, generally found that bigger was better and yield increased with increasing hole diameter. Over time, a 7/16 inch diameter hole became standard as a compromise involving sap production, reducing damage to the tree, and the effort to create the hole with a hand brace. With vacuum systems, research has demonstrated that hole size could be reduced to 5/16 inch diameter without affecting sap yields and that smaller spouts should be favored because smaller holes damage the tree less and can allow for a better seal between spout and tree.

The size of the hole in the spout itself is not a limitation to sap flow. The main resistance controlling sap flow is within the tree. The sap flow is never fast enough for the hole in the spout to be a limitation, especially when flow is facilitated by vacuum.

Sap is being extracted from the maple tree through the very small tubes, or cells, that constitute the xylem of the tree. Xylem cells in maples have a microscopic diameter, but average 15 centimeters in length. These tubes must be very small in order to allow capillarity, the molecular forces between water and the walls of these tubes, to facilitate water getting to the top of tall trees. The highest resistance to sap movement is at the connections between xylem elements where sap moves through very much smaller holes in the cell walls between the ends of the cells. These small holes are called bordered pits. The interaction between sap and the walls of the xylem tubes create friction when the sap moves through the cells. The basic physics of a fluid moving through a pipe are the same whether the pipe is a xylem cell or a water hose. The factors affecting the rate of sap movement (amount per time) are described in Poiseuille's Law that, in simple form, says that flow rate is a direct function of pressure on the water (sap) column and the size of the tube. In fact, flow rate increases with the 4th power of the radius of the tube, meaning it increases rapidly as these vessel elements increase in size.

The role of internal pressure in the tree and vacuum applied to the tree is to overcome the capillary frictional forces in the small xylem elements that, without this pressure or vacuum, would cause the water to remain in place and not flow.

So what is happening in the tap hole?

Consider first the situation without vacuum. The hole in the tree cuts across and opens up a series of xylem tubes that are running vertically in the tree trunk. So the number of these tubes opening into the hole is proportional to the diameter and depth of the hole. Although sap pressure in the tree probably can push some sap laterally to the cavity, most of the sap is coming from parts of the tree above and below the hole, mostly above the hole. This is why researchers using buckets found that sap volume increased with hole diameter, depth, and number of taps. With increased diameter and depth, there were more xylem tubes supplying sap to the hole. You might think of these xylem tubes as holes in a 2 showerhead; the more holes the more water for your shower. Flow limiters inside water conserving shower heads have the same effect as the small size of the xylem elements and bordered pits in controlling flow to the exit holes.

Vacuum significantly increases the yield of sap from a tap hole. The main effect of vacuum is that pressure within the tree becomes a lot more effective in pushing sap toward the tap hole. Instead of pushing against air pressure, vacuum creates a much greater pressure gradient from inside to outside of the tree. Following Poiseuile's Law, the sap will flow faster into the tap hole.

Another effect of vacuum is that it appears possible to draw sap from a larger area around the tap hole. It may be the case that a single tap hole, given enough time, will draw sap from most of the volume of the trunk surrounding the hole. The resistance within the xylem elements is still significant and will cause the sap to be taken first from areas near the hole and, with time, from areas further and further away. But vacuum eventually will allow the extraction of sap from a larger volume of the tree than will the same size hole exiting to atmospheric pressure.

Other factors will affect the volume of sap exiting a tap hole. One is the amount of time that a tree remains unfrozen. Another is the volume of the trunk that goes through a freeze-thaw cycle. The rate of freezing and the amount of sugar in solution also affect the sap volume.

Because sap moves slowly toward the tap hole, the amount of time between when the trunk thaws and then re-freezes will limit the volume of sap exiting the hole. Freezing shuts off the sap supply and it may do so before all the available sap has made it to the hole. External temperatures also affect the amount of time required for the full volume of the trunk to thaw and yield its sap. It may take 2-3 days for a frozen trunk to thaw deeply enough to be fully available for sap production. This accounts for the common pattern of increasing sap yields over a series of days with the appropriate freeze/thaw cycles.

When the trunk re-freezes a vacuum is created inside the tree that replenishes the sap volume through pulling water and sap from other parts of the tree and the soil. The rate of re-freezing has been shown to affect the volume of replenished sap, the slower the rate of freezing the better.

The pressure built up inside the trunk has an osmotic component, which is where the sugar in solution enters the process. The explanation for this is still pretty new and may change with more research, but the role of sugar seems to be to prolong the time of high pressure. Without sugar, the pressure would be dissipated very quickly and without pressure we get no sap from the tree.

So back to hole size. Given enough time all size holes will empty the "bucket" of sap inside the tree trunk. A large hole will empty the bucket faster and in a restricted period of time will yield more sap than a small hole. But on other days, when there is more time, the yield of different sized holes will be closer to each other. Hole size performance will 3 also change from one sap season to the next because of the weather-dependent processes described. Vacuum reduces the effect of length of thaw period so that 7/16 and 5/16 inch holes perform the same under most conditions. However, below 5/16 inch the size of the hole restricts flow, even under vacuum, and the length of the thaw period becomes a controlling factor.