MAPLES UNDER PRESSURE

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In the sugarhouse at the Champlain Valley Fair, in Essex Junction, Vermont, there is an education booth where visitors are asked to take "the maple quiz." One of the questions has to do with the pressure inside a maple tree during the springtime: is it about equal the pressure of A) a toy balloon; B) a car tire; or C) the space shuttle engines at liftoff. The answer is B). When you consider that car tire pressure is around 30 PSI (pounds per square inch), that's a pretty remarkable statement. As sugarmakers, we sense that the sap is under pressure during a sap run, we can see it leak out of even tiny wounds in the bark (for example squirrel chews in a young tree), but the idea of positive pressure during a thaw is really quite counter intuitive.

Fill a bottle to the top with water and freeze it, and the bottle will break because of the pressure caused by the expansion of ice. When the ice melts, it takes up less room. So why doesn't sap in a maple tree act this way—pressurize the tree during a freeze and relax during a thaw? The simple answer is that the tree is not filled with water like a bottle. The inside of a maple tree has a lot of air space, and as the tree freezes, there are spaces into which the extra volume of ice can expand. Anyone who has watched sap emerge into tubing knows that there is a lot of air that comes out of the tree along with the sap. This air space in maple is what makes the whole sap flow mechanism possible; and impossible in most other tree species that lack this internal arrangement.

Once the winter weather warms enough so that there are cycles of freezing and thawing, pressure measured in one spot on a tree trunk (at a taphole, for example) is not constant, it is dynamic, constantly changing with the weather. It is not always positive—it can be positive, negative, or zero relative to the pressure of the air outside the tree. Why and when is the pressure negative? Mature trees have huge networks of branches, and these are what freeze and thaw during the early spring. Inside each branch, the sap transport vessels are embedded in a dense matrix of tiny fiber cells, each of which is air-filled. During a freeze, ice crystals form in these air spaces, and grow by pulling water out of the vessels. Multiplied a billion-fold, the force of this movement of water from the vessels results in a suction throughout the tree. While the branches are freezing, the negative pressure measured at the taphole can be as low as -7.5 PSI (15 inches of mercury). This force causes roots to suck up more water. This water movement will continue until the branches and the sap transport system becomes frozen solid.

When branches begin to thaw, as the warm spring sun hits them after a cold night, the billions of ice crystals in each fiber cell melt quickly. At this point, the pressure at the taphole will change rapidly from negative to positive, and this is when pressures as high as 30 PSI occur. What causes this high internal pressure? Actually, a combination of factors are at work at this time, and one of the most important is gravity. During the freeze, "additional" water was lifted into the canopy by the ice crystal growth; when thawed, the water causes the tree to act like a standing water pipe. Picture this, a 60 foot tall pipe, filled with water, open at the top. Drill a series of holes every 3 feet up to the top. What you will see is a strong stream shooting out the lowest hole, and successively weaker streams from holes farther up the pipe. This, in fact, is a close analogy to pressure in the trunk of a tree at this time; pressure is highest at the lowest point on the trunk, and progressively less at higher points along the trunk. Sap will drip from a taphole, but the tree does not drain like a pipe with a leak—the wood holds on to most of its water throughout the trunk and branches. Eventually the pressure will diminish to zero, and the sap will cease to flow until another freeze thaw cycle (the reasons why the pressure dissipates are complex).

Going back to the water pipe analogy, the advantage to sugarmakers of positive pressure should be apparent—it is pressure that pushes sap out of the taphole. In fact, the rate of sap flow is very closely tied to the amount of pressure. In a fully thawed tree, the highest pressure, and the highest rate of sap flow, occurs within the first few hours of the sap run.

To see how temperature sap pressure and flow interact in mature trees in Underhill Center, Vermont (and in your own woods), you can visit a webpage that I run every year on the Proctor Maple Research Center website, called TreeMet. Visit www.uvm.edu/~pmrc and click on the button that says “TreeMet is open” There you will find trees that are wired to transmit temperature, pressure and flow data every 15 minutes around the clock for the whole season. Feel free to email me with questions.

During the right conditions in the spring, the pressure inside a sugar maple will cause sap to flow from even small wounds like this one made by a squirrel’s teeth.