Maple Sap Exudation: How it Happens

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There is renewed scientific interest in understanding how maple sap moves in maple trees in the spring. The results of recent investigations at the University of Glasgow (Scotland) and University of Toronto (Canada) are surprising. Many casual visitors to a sugar bush operation might first think that maple sap is pushed up the tree from the roots; apparently this is not true! This is easily shown false by anyone with a spare maple tree that can be sacrificed to curiosity. Next spring, during the sap season, after a freezing night and while the tree is still frozen, cut it down as near the ground as possible. When the temperature rises above freezing you will observe little or no sap flow from the stump of the root stock, but sap will drip from the freshly cut surface of the tree you just felled. The sap that we collect apparently flows from the branches. Of course there can't be an endless supply of sap in the branches. It must first get there from below. So what goes on?

What does happen is this: On frosty cold nights the sap is sucked up the tree as the branches freeze. While the sap is being sucked up all the tap holes are, of course, sucked dry. The tree freezes from the outside in and the smallest branches freeze first. The sap that is sucked up through the portions of the sapwood not yet frozen adds to the ice crystals growing in the colder parts of the tree. If the temperature rises above freezing the next day, the frozen sap melts and falls down the tree under gravity and it is also given a little bit of a shove by compressed air bubbles (see below). How do we know this happens?

A number of scientific observations have been made both in the sugar bush and under well con-trolled laboratory conditions. Measurements of the rate of sap flow into and out of tap holes or into and out of excised branches have been made at the same time as very careful measurements were made of sapwood temperature. It is easy to tell the precise moment that ice begins to form in sapwood, because water does not always start freezing at 0 °C (= 32 °F). Instead water will often "super cool", i.e., drop a few degrees below 0°C before it starts to freeze. When water does freeze an enormous amount of heat is released which very rapidly raises the sapwood temperature to 0°C. This heat is called the latent heat of freezing and the rapid rise in temperature is called the exotherm. Under both field and lab conditions the rate of sap flow has been monitored while the stem temperature was slowly falling. As the temperature approaches and drops below 0°C some sap is slowly sucked in by the stern (or if the tree is already exuding sap then the rate of exudation slows); but at the precise moment of the exotherm (when ice just begins to form), sap is rapidly and vigorously sucked up. Water uptake continues during the full period of the exotherm, i.e., as long as water remains to be frozen.

While the above observations have been repeated many times, they are at the same time puzzling. If you think about it for a moment you will probably remember that water expands as it freezes; that is why ice floats on water. Well, if water expands while it freezes then why isn't sap pushed out of the branches while they freeze? We have in fact observed sap movement in other species of trees. Sap is indeed pushed out during freezing and sucked up during thawing in all the trees we have investigated except for maple which does the opposite!

The reason for the apparently anomalous behaviour of maple trees has to do with the unique properties of maple sapwood. The sapwood of all trees consists of water conduits (called vessels in hardwoods) which provide a path-way for water movement up trees during the growth season. Surrounding these conduits are billions upon billions of living cells and dead wood fiber cells, In most trees the wood fiber cells are all water filled, but in all the maples these wood fiber cells are gas filled. So when maple branches begin to freeze, frost begins to form inside the gas filled spaces of the wood fibers much like frost will form on the inside of the windows of your home on a cold night. Water contributing to the frost comes from the water conduits and is replaced

by the same kind of capillary forces that causes water to flow into a sponge. (In other species of trees where the wood fibers are water filled there is no room for frost formation so as the water freezes the unfrozen portions of the sap are pushed out.) When the maple tree thaws out the next day the excess sap accumulated as frost falls down the tree under the influence of gravity. The sap is also pushed by the pressure of the gas bubbles in the fiber cells. The gas filled spaces are under pressure be-cause as frost forms inside the gas spaces the frozen water displaces and compresses the gas bubbles.

The story is a little more complicated than I have indicated here and there are a few observations in the scientific literature that have yet to be reconciled with this explanation. For example, some older scientific studies conducted at the University of Vermont seem to indicate that sap uptake and exudation occur in maple branches only when maple sugar is present in the sapwood. If the maple sugars are flushed out and replaced by pure water sa.2 movement is much reduced. But frost induced sap uptake occurs even in maple branches collected in the summer when the sugar content is very low. These conflicting results need to be clarified.

These investigations into the basic biology of sap movement in maple trees are of considerable academic interest to biologists, but you might think at first glance that they have little direct application to the sugar bush operator. Fortunately we think that such studies may be of real benefit to the commercial operator. If we can better understand the biological mechanism for sap flow and the climatic conditions under which it occurs we might be able to suggest management techniques to in-crease maple sap yield; or we might be able to predict years when yields might be best. In this regard we do have another relevant observation. When maple trees freeze rapidly the amount of sap sucked up is reduced (if it freezes very rapidly there can actually be a net sap exudation). But when maple trees freeze slowly the volume of sap uptake is greatly enhanced and the yield of sap the next day (if the temperature rises above 0°C) is much greater than when the tree freezes fast. The reason for the reduced sap uptake during a quick freeze is that the sap in the xylem conduits freezes solid and prevents water movement to the wood fibers; so there is not enough time for much frost build up inside the gas filled fibers. Observations of this kind can be used to predict days of good sap yield.