Maple Digest March 2023
62(1): 9-12

Innovations in Maple Sap Collection Systems: Increasing Yield in 5/16” Lateral Line Tubing

Timothy D. Perkins and Wade T. Bosley, University of Vermont, Proctor Maple Research Center

Ongoing research at the University of Vermont Proctor Maple Research Center over the past thirteen years has examined a variety of approaches to increases yield from 5/16” maple tubing systems on vacuum. Several factors are important, including vacuum level (https://mapleresearch.org/pub/m1007sapcollectionvacuumlevel/), spout and dropline sanitation (https://mapleresearch.org/pub/1019sanitation-2/), leak detection and correction (https://mapleresearch.org/pub/4221det/), and tubing system design (https://mapleresearch.org/pub/m0216vacuumtubingresearch/). Large increases in sap yield have resulted, however improvements in the 5/16” lateral line system have proven elusive or have been determined to be cost prohibitive for the gains anticipated.

Sap and gases move together through lateral line tubing under vacuum (https://tinyurl.com/sapflow). As this movement occurs, these two interact with each other and with the tubing in a fashion termed “slug flow,” a highly inefficient mode of liquid transport in pipeline systems. When alone, sap can flow smoothly. When alone, gases will also move freely in tubing. However, when together, the presence of liquid restricts the transit of gases substantially in tubing of this size (which incidentally is one of the reasons 3/16” tubing systems develop natural vacuum well). These gases, if not removed quickly, result in a reduction of vacuum level from the mainline to the end of the lateral line. This drop in vacuum is greatest when sap is flowing strongly and when more tree gases are being produced. This is why keeping lateral lines short and having fewer taps per lateral (introducing air from tree gases and leaks) results in higher vacuum levels and higher yields than lateral lines that are long with many fittings (tees, unions, etc.) on them (https://mapleresearch.org/pub/manual/, Chapter 6). Modeling studies of this problem indicate that that frictional losses in lateral line tubing systems may approach several inches Hg of vacuum depending upon the length of laterals, the number of fittings in the line, sap flow rate, and the presence of microleaks (Perkins unpublished). Reducing friction in the system is therefore a reasonable goal.

Two lines of evidence further suggest that it is possible to get at least 20-25% more sap from maple trees. The first is the high yields from trees in some experimental studies. These setups use canisters connected to vacuum, typically with one tap per lateral with a single dropline. Only the short segment of dropline contains both sap and gases and there are few or no other fittings inline that can restrict sap movement.

Another piece of information comes from dual 5/16" lateral lines, with one serving as a "dry" line and the other as a "wet" (sap) line (https://tinyurl.com/dual-lateral). Both of these types of systems regularly produce high sap yields, a testament to the fact that lateral lines are somehow restricting vacuum and reducing yields. Estimates are that sap yields could be as much as 20-25% higher if these restrictions could be engineered out of the system. While it is unlikely that all restrictions in the system can be eliminated, given the relationship between vacuum and an increase in sap yield of 5-7% for each inch Hg of vacuum (https://mapleresearch.org/pub/m1007sapcollectionvacuumlevel/), reducing restrictions in a labor and cost-effective manner would produce positive results.

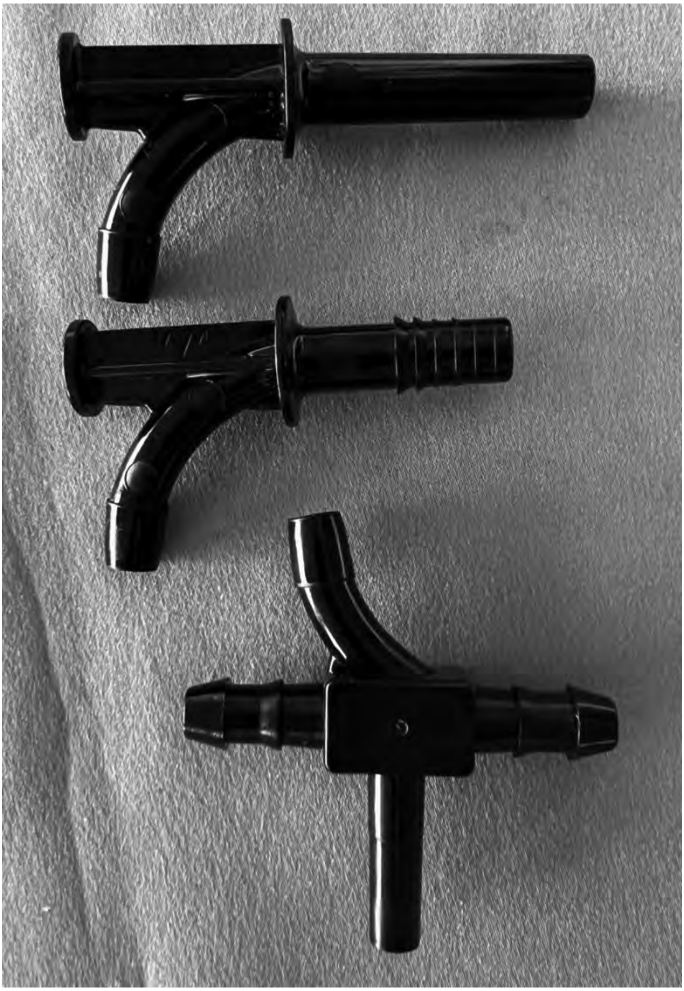

Figure 1. Spout and "tee" designs incorporating the arc-flow design. Standard 5/16" nylon spout (top) with Arc-Flow, Barb-spout with Arc-Flow (middle), and Arc-Flow Tee (bottom). For the Arc-Flow Tee, sap would flow from the lateral line from left to right. The dropline would connect to the curved segment of the tee at the top. The pin is located at the bottom (rather than coming out of the fitting towards the reader) to allow the fitting to be used on either side of the tree either in a normal configuration or in an inverted fashion (tapping below the lateral). University of Vermont Patents Pending.

Considerable experimentation has taken place to get around this problem. Major "losses" in efficiency in hydraulic systems are often solved by making pipes larger and/or smoother. In theory, increasing the diameter of lateral lines larger can reduce the friction of air and liquid movement by allowing room at the top of the tubing for air to slip past the liquid on the bottom, however in practice turns out to be costly (material cost increases rapidly) and difficult to achieve good results given that larger tubing and resultant higher sap weight within that tubing requires laterals be supported on wire to prevent sags and to maintain proper grade (costly in terms of material and labor). An alternative approach using a wet/dry lateral line system akin to the wet/dry dual-mainline system is too costly to be economically viable given current maple syrup prices. Therefore, we have to look to other solutions to reduce vacuum (and thus sap yield) losses in 5/16" maple lateral line systems.

A simple analysis of lateral line systems indicates some possible approaches to reducing friction to gas and liquid flow in lateral line systems. Vacuum and gravity "pull" sap down lateral lines. Friction "uses up" energy. The energy that is lost in this case is vacuum (gravity is constant). Reducing friction in the tubing system preserves energy and preserves vacuum further up the line. If making tubing larger or smoother due to cost or implementation issues, the next best way to reduce friction in tubing is to reduce turbulence, especially at fittings. This can be readily achieved through two simple modifications.

The first method is to incorporate a bevel into the entrance and exit of all fittings (https://tinyurl.com/fittingflow). This simple change "channels" sap flow better by reducing turbulence where tubing meets fittings. If sap encounters a beveled edge, it speeds up and smoothly transits the fitting where it exits smoothly with less turbulence.

The second modification is to incorporate an arc where sap streams meet (https://tinyurl.com/fittingflow). The simplest example is a tee. In most systems, sap flows down the lateral line from trees that are upstream, with sap entering from the dropline into the lateral line through a tee at a 90° angle to the lateral line. This creates a large amount of turbulence at the confluence of the two streams (the sap coming from the dropline and the sap running down the lateral line). This turbulence results in higher friction and reduced vacuum. The simple solution to this problem is to change the geometry of the tee. Y-fittings (30, 45, or 60°) reduce head loss by about 15-18%. Better still is an "arc-flow" fitting configuration (Figure 1), which provides a smoothly curved flow path for sap from the dropline to enter into the lateral line stream. This type of fitting reduces head loss by about 50%. How?

Think of the lateral line as a heavily travelled highway with cars (sap) running down it quickly and smoothly. Air bubbles are the empty spaces between cars. What is the best way for more cars to enter traffic? Obviously, traffic flows better if cars enter via an entry ramp where they can merge smoothly into already flowing traffic. Having cars enter a busy highway at a right angle results in mayhem where all traffic slows down (or stops) and traffic is stop and go (turbulence). A smoothly curved on-ramp greatly reduces the turbulence of cars (or sap) entering the traffic (or sap) flow.

To further the analogy, these frictional losses are additive. Each time sap has to merge (at a tee) or change direction (in a spout, a saddle, etc.), friction reduces the energy in the system, in a similar fashion that a lot of intersections in roads will reduce traffic speed and flow. In other words, the head losses build up and vacuum drops the further you move from the mainline in the lateral line system due to these restrictions.

It is important to note that changing intersections from a right angle to a curve will produce the greatest improvement in head loss. Thus using an arc-fitting wherever sap must change direction (spouts, saddles, etc.) would result in the highest degree of improvement. Liquids tend to flow best in straight lines and create the most turbulence at confluences (tees) and where there is a change in direction. If we're going to incorporate an arc into "tees," then we might as well go full-in and also use the same design principle in all other components of the lateral tubing system (unions, saddles, etc.).

You're probably wondering why hasn't this been done before? We can't say for sure, but it is likely that the main reason is that putting an arc into an injection-molded part is not easy. The engineering to build the tooling is considerably more complicated than building a mold incorporating right-angles. The good news however is that once that design modification is accomplished, that tool can produce the parts for close to the same cost as a simpler tool when spread across millions of individual fittings.

Researchers at the University of Vermont Proctor Maple Research Center (PMRC) have spent a considerable amount of time and energy looking into the various factors involved. Over the past few years we have worked with a highly experienced injection molding company that understands the maple industry. Together we were able to design new fittings incorporating these design elements. Patent applications have been filed to cover these innovations. We anticipate large-scale field testing of the final designs during the 2023 sugaring season at PMRC and other sites across the maple belt. If successful, new fittings incorporating the arc-flow principles will be made available in the fall of 2023.