HIGH VACUUM IN GRAVITY TUBING

By Timothy Wilmot

Many maple producers consider gravity tubing, or tubing without the use of a pump, to be a poor substitute for a modern system with a pump, extractor, and the latest tubing arrangement. Sap yields from gravity systems are often half or less compared to yields of a pumped system. Not everyone, however, can afford the latest technology. Obstacles to the use of modern equipment include the overall expense, difficulty fueling a pump especially where electricity is not available, time needed for maintenance of a pump and extractor, and the impractical nature of adding pumps for separate stands of a few hundred trees each. Thus, gravity tubing systems are widely used in many small to mid-sized operations throughout the maple region. This article summarizes the past 3 years of my research on gravity tubing, or tubing without a vacuum pump. Studies have occurred mostly at the University of Vermont Proctor Maple Research Center (PMRC) in Underhill Center, VT.

Options for achieving high vacuum and high sap yield at low cost are limited. Perhaps the most extensive work available on the subject of "natural" vacuum, or vacuum achieved without a pump, dates from the early 70's, when PVC tubing and less efficient fittings were all that was available. In a summary article based on several years of research, Robert Morrow of Cornell (1) concluded that very high numbers of taps per line (50-100) and relatively shallow slopes (5-15%) were needed to achieve the best vacuum in gravity tubing. The levels of vacuum that Morrow recorded rarely exceeded 10 inches of mercury-which would hardly be considered satisfactory today. Since the theoretical limit of natural vacuum is over 29 inches of mercury at sea level, a more efficient and productive system than the ones described by Morrow must be considered.

To achieve natural vacuum, three things are necessary: 1) a continuous leak-free line, 2) a drop in elevation from the tree to the bottom of the line, and 3) enough sap in the line to create a gravitational pull (suction) on the taphole. Slope is crucial. For producers where an elevation change of 30, 40, 50 or more feet can be obtained between many of the trees and the tank, good natural vacuum is a real possibility.

METHODS

I began experimenting with various sizes of tubing in 2010 and 2011 with the aim of finding a size smaller than the standard 5/16" inside diameter that would maintain a long column of sap on a slope during most sap runs. How would such a system work? When sap is trapped in a tube that is sealed at the top but not the bottom, atmospheric pressure pushing on the bottom of the tube keeps the sap in place. This is assuming that no air (caused by a leak such as a loose spout, a squirrel bite, a poor connection between tubing and fitting) gets into the top of the tube – if it did, then the sap would run down the tube without creating a vacuum. The suspended weight of the sap pulls on the taphole, and as the column of sap lengthens, the vacuum on the taphole increases. As more sap and gas from the tree is added to the tube, the sap moves downhill, but under the right conditions enough stays in the tube to maintain the vacuum. One way to increase the column of sap is to reduce the size of the tube. Tubing that is 3/16" inside diameter has 36% of the volume per inch of 5/16" tubing, and a given quantity of sap will extend in the tubing for almost 2.8 times the length of the same quantity of sap in 5/16" tubing, and thus could exert a proportionally greater suction on the taphole. Given enough sap, high natural vacuum should also be achievable in larger diameter tubing, including standard 5/16" tubing. However, in larger tubing the surface tension at the sap/air interface is lower, and it is more likely that the sap will slip down the tubing without maintaining a long column unless there is a high flow rate.

After experimenting with tubing of different sizes, I chose 3/16" interior diameter, rather than something smaller, or larger, for several reasons: 1) when made of polyethylene with a standard 1/16" wall, similar to most maple tubing, it is strong and stretches very little; 2) it has the capacity to carry high volumes of sap, and 3) fittings for use with this tubing are readily available. Sources for tubing and fittings are shown at the end of this article. Spouts used in all these experiments were standard 5/16" maple spouts from a variety of manufacturers, and they were adapted to 3/16" tubing by connecting a short piece of standard tubing to the spout and using a reducing fitting to connect to the smaller tubing. At the bottom of lateral lines that were connected to mainlines, another fitting was used to connect to 5/16" tubing, which was then connected to the mainline fitting.

A number of experiments have been performed to date to compare vacuum and yield from 5/16" and 3/16" gravity lines on similar slopes and with similar tap counts, as well as other experiments to test the vacuum and yield that can be achieved using gravity on a variety of different slopes and with a variety of different numbers of taps per line.

RESULTS

Vacuum: Experiments performed in 2011 and 2012 using individual lateral lines showed that with 19 or more taps and a vertical drop of 50-100 feet, high vacuum (24-27 inches Hg) could sometimes be achieved in 5/16" lines, especially during periods of high sap flow. In contrast, virtually all 3/16" lines maintained these vacuum levels during periods of high or even minimal flow. For example, in a 2012 experiment in Willison, VT, comparing vacuum in 3/16" and 5/16" lines about 400' long, the best 5/16" line reached 27" of vacuum for a few days, while the best 3/16" line reached 27" vacuum for most of 5 straight weeks. In 2011 several 3/16" lines of varying length with 8-20 taps each reached and maintained vacuum of 24" or more for the entire season that sap flowed, while 5/16" lines reached high vacuum only during strong sap runs. In relatively short lines (approximately 150') and fewer taps, the contrast between vacuum in 5/16" and 3/16" lines was striking, with little or no vacuum in 5/16" lines. Table 1 shows vacuum levels in 10 lines during the hot weather that followed a freeze on March 11, 2012.

Table 1: Daily vacuum readings in 3/16" and 5/16" lines in mid-March, 2012, at the PMRC. The last freeze prior to the dates shown was the night of March 10-11.

Tubing	5/16"					3/16"				
Line #	1	2	3	4	5	6	7	8	9	10
Taps/line	10	5	5	6	8	8	8	6	6	4
	Vacuum (inches Hg)					**Vacuum** (inches Hg)				
3/12	0	0	0	0	0	26	27	23	27	27
3/13	0	0	0	0	0	25	27	23	27	27
3/14	0	1	0	0	1	26	27	23	27	26
3/15	2	1	0	0	1	26	27	23	27	26
3/16	0	2	0	0	0	25	27	23	28	26
3/17	0	0	0	0	0	26	27	23	28	26
3/18	0	0	0	0	0	26	27	23	28	26

Flow Rate: Sap flow rate over a period of 5-10 minutes was recorded daily in 2011 season to estimate comparative yields between 3/16" and similar 5/16" lines. In every instance where the sap was running, sap flow rate in 3/16" lines exceeded the rate in 5/16" lines. The maximum rate recorded during a strong sap run, on a 3/16" line with 22 taps, was equivalent to a rate of over 6 gallons per day per tap, or approximately 1 gallon every 10 minutes through this line. Under these conditions, sap flowed very rapidly through the bottom of the line. It is unclear if this is the maximum rate that could pass through 3/16" tubing – but it is evident from these results that tubing of this size can support a high flow rate. This rate exceeded the maximum rate recorded in any 5/16" tubing with a similar number of taps, although a greater number of taps on a 5/16" line might have resulted in a still higher flow rate.

Sap Yield: Sap yield in gravity lines in 2012 was equivalent in several instances to the yield achieved by the pumped tubing system at the PMRC which used high vacuum Busch rotary claw vacuum pumps and wet/dry conductor lines (Table 2). Although these totals concluded on March 22, which is the last day that sap was boiled at PMRC this year, it is notable that high vacuum levels and high flow rates were again seen in most lines through the second week of April, after freeze/thaw weather resumed.

Table 2: Sap yield from 2/22 through 3/22, 2012, from the PMRC vacuum system and from gravity lines in various locations.

Location:	**5/16" tubing**	**3/16" tubing**
PMRC vacuum system	18.5 gal/tap	
PMRC 150' gravity lines, 4-10 taps/line	4.1 gal/tap	19.8 gal/tap
PMRC 700' gravity lines, 22 taps/line	11.5 gal/tap	18.2 gal/tap
Williston, VT 400' gravity lines, 19 taps/line	7.6 gal/tap	14.8 gal/tap

DISCUSSION

Setting up a gravity system for maximum vacuum and sap yield requires an understanding of some of the differences between this type of system and one that relies on a vacuum pump. In a system where the vacuum is generated by a pump, the maximum vacuum will be closest to the pump, and may diminish with distance from the pump. The whole tubing system, including mainlines, is essentially one unit, and a leak anywhere in the system can affect the vacuum throughout the system. The pumps used in these systems, such as the typical vane or liquid ring pump, generate vacuum by displacing air, and the system must be closed using either an extractor (releaser) or a sealed vacuum tank for sap, in order to allow sap to be collected without breaking the vacuum. In contrast, a gravity line does not rely on air displacement; instead, vacuum is generated in each closed lateral line by the weight of the sap. In a gravity line that is leak free, the highest vacuum is at the top of each lateral line, and diminishes to nothing (atmospheric pressure) at the bottom where the line joins a mainline or empties into a tank. Thus trees lower along any line may be subject to some, but not the maximum possible vacuum, unless there is a significant amount of vertical drop on the line below the tree. For this reason, the ideal arrangement would be a line connecting trees near the top of a slope, and then a stretch of line below these trees continuing down the slope to the tank or mainline. This may not always be possible.

Although great diligence is necessary to keep spouts tight and lines leak free, the advantage of natural gravity vacuum is that each line is independent-unlike vacuum coming from a distant pump, the vacuum is generated in each individual line and a leak in one line does not affect other lines in the system. Mainlines should slope gradually in order to drain the sap into a tank, but mainlines in this system will not be under vacuum and could in fact be open at the far end in order to facilitate flow of sap down their length. Thus, in setting up a system, place the mainlines across the slope at a shallow angle, and run the lateral lines straight up the slope where they will generate the maximum vacuum due to elevation change.

Below is a summary of many of my findings to date concerning gravity tubing, along with some suggestions for a successful gravity layout. Note that this is still a work in progress, and many more suggestions, methods, and improvements may be added in the future.

- For a successful gravity collection, much of what we know about best management under vacuum applies here: good tapping practices, new spouts, good quality materials, diligent checking for leaks.
- A vertical drop below the taphole(s) is necessary in order to generate natural vacuum, although there is no fixed number regarding what this drop should be. A full tube of sap one foot long hanging from a taphole would create 0.88 inches of mercury vacuum; thus a line that descends 20' below a taphole and is completely full would create 17.6 inches of vacuum; however, the line will never be completely full. Even if the line descends only a modest distance below the taphole, some vacuum will be generated in a tight system.
- While the maximum number of taps to put on a 3/16" line is yet to be determined, I have had success with lines up to 22 taps during strong sap runs (see above): under these conditions the sap flows very rapidly through the line, and because of this may arrive cooler at the tank than in a pumped line.
- For high vacuum, the minimum number of taps to place on a 3/16" line approximately 150' long is 4 or perhaps even less; the minimum number of taps on a similar 5/16" line is as yet undetermined, but is greater than 10. This assumes a good vertical drop below most of the trees.
- A long zig zag line has achieved better vacuum and flow in my experiments compared to a branched line. A branched 3/16" line with several taps on each branch seems to become restricted at the Y or T where the two branches meet..
- Line length does not seem to be very important, as I have placed lines as long as 700' with 20 taps and achieved high vacuum and flow. A very long line with very few taps might not achieve the sap column necessary for maximum vacuum. Adding more length to the line without adding slope will not increase vacuum.
- A strong fitting is needed at the top of the lateral line. As I have not found a strong 3/16" fitting that is useful for this, I have used 5/16" tubing on the topmost tree, along with a ring fitting made for this tubing so that the line can be tightened. The line is converted to 3/16" a few feet down slope of this tree. This arrangement will not compromise vacuum, assuming that most of the slope is farther down the line.
- The successful maple tubing arrangement should consist of lateral lines going straight up a slope, and mainlines across the slope at a shallow angle. A possible method to maximize vacuum on a long but shallow slope might be to jump the lateral lines over the closest mainline, and join them to next lowest mainline running across the slope; thus adding a long section of lateral line below every tree in order to gain a long column of sap.

• Checking for leaks is critical with any vacuum system, especially in a system with no pump to overcome leaks. The standard method in a pumped system is to watch for slow sap movement throughout the line, indicating no leaks. Sap movement in a gravity line is different: as more sap is added by successive taps further down the line, the flow speeds up and can become very rapid near the bottom. While it is possible to learn from experience how to spot a leak by observing the rate of flow across a fitting, the most reliable method is to place a vacuum gauge at the top of the line. The amount of vacuum should be approximately the same for lines with the same vertical drop, and the vacuum level obtained should be repeatable daily unless a leak has appeared (Table 1) – thus low vacuum in a 3/16" line or a lessening of the daily vacuum level indicates a line that needs inspection.

• The connection to a vacuum gauge must be tight. A gauge with a 1/8"NPT stem can be screwed onto a piece of tubing (semi-rigid works best) and held tight with a hose clamp. The gauge can be attached to the uppermost part of the line where 5/16" tubing is used, as the larger tubing will help prevent sap from backing up into the gauge when the bottom of the line is frozen. Run a long dropline to the gauge and secure it to the tree in an upright position.

• Obtaining the proper tool for inserting fittings into 3/16" lines is critical. Fittings cannot be forced in by hand. I have found the most versatile tool to be a two-handed tubing tool with screw type adjustment of the vise clamps, used for attaching 3/16" T's and connectors into 3/16" lines, as well as for connecting a 3/16" and 5/16" line via a reducing fitting. The jaws need to be adapted to hold 3/16" tubing, either by grinding them down or building up the jaw by adding masking tape, or with the addition of a half section of 5/16" tubing. Such tools with automatic tension adjustment may or may not grip small tubing – I have found them troublesome when the 3/16" tubing is wet.

Sources for materials: 3/16" tubing can be obtained in 100' rolls from Hudson Extrusions Inc www.hudsonextrusions.com . Specify HDPE with 3/16" interior diameter. At least one maple manufacturer, Dominion & Grimm USA, will produce 3/16" tubing in 500' rolls (contact benjamin@dominiongrimm.ca). The fittings I have used can be obtained from McMaster-Carr www. mcmaster.com. Look for part 5116k15 white nylon single barbed tube fitting Tee for 3/16" tube ID, #5116k42 white nylon coupling for 3/16" tube ID, and #5116K53 White Nylon Single-Barbed Tube Fitting Reducing Coupling for 1/4" X 3/16" Tube ID. This coupling works well to connect 5/16" to 3/16" tubing. All of these materials are food grade.

Future articles will appear with further research on gravity. Feel free to share your own experiments and questions regarding gravity tubing with me - you can find my contact information at http://www.uvm.edu/~pmrc/?Page=PMRCstaf.html

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REFERENCE: 1. Morrow, R.R. 1974. Vacuum and maple sap flow. Maple Syrup Digest 13 (4).