Maple Digest 21A:21-29.

DEVELOPMENT AND TESTING OF THE CHECK-VALVE SPOUT ADAPTER

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INTRODUCTION

Several major changes in sap collection equipment and methods have occurred over the past 10-15 years. The introduction of small spouts, a transition in composition from polyvinyl chloride (PVC) tubing to polyethylene (PE) tubing, and improvements in fittings have occurred. These changes, along with continued modifications in tubing system design, installation, and maintenance as well as alterations in vacuum systems and their operation have led to significant improvements in sap yields for maple producers. The result has been a steady increase in sap yields from those producers adopting this technology and methods to the point where annual yields of 0.3-0.5 gal of syrup equivalent are not uncommon.

Because sap flow reductions and stoppage is ultimately due to taphole drying, which is induced by microbial contamination of tapholes (Naghski and Willits 1955), a significant barrier to sustained high sap yields in tubing systems is related to contamination with various microorganisms. In particular, microbial biofilms develop in sap collection tubing systems as they age (King and Morselli 1983, 1985, Legacé et al. 2006). Despite several research studies and the experience of thousands of sugarmakers, no cleaning methods are clearly capable of returning tubing to the level of sanitation of a new, unused system. The maple industry has responded to this challenge most recently by introducing annually replaceable spouts or spout adapters, which provide a very clean spout-tree interface. Research has demonstrated that these adapters can provide some benefit to sugarmakers in terms of increased sap yield (Perkins, Wilmot, and Stowe unpublished), however they still do not provide an adequate barrier against the migration of microorganisms from the spout stubby, dropline, and lateral line back into the taphole. Thus the use of spout adapters, although helpful, does not completely address the problem of microbial induced taphole drying. The use of vacuum in tubing operations greatly exacerbates this problem by creating a fairly substantial negative pressure within the taphole zone. Under such circumstances, when a leak occurs, or the system is shut-down rapidly, or even when some types of releasers dump their contents by admitting air, this negative pressure in the taphole can cause sap to briefly surge backward in the tubing system towards the tree, carrying microbes into the taphole. The more this backflow of sap occurs, the higher the temperature, and the greater the number of microbes reaching the taphole, the stronger the taphole drying response will be. Eventually sap will cease flowing due to the blockage of vessels resulting from this natural wound response, and the season is over for the sugarmaker.

Decades ago, taphole drying due to microbial contamination was delayed via the use of paraformaldehyde (PFA) pellets in tapholes, resulting in substantially higher sap yields (Sheneman et al. 1959, Costilow et al. 1962, MacArthur and Blackwood 1966). Unfortunately the use of PFA also greatly impeded the ability of the tree to compartmentalize the wound caused by tapping, which resulted in cambial dieback and internal wounds that were much larger in size (Shigo and Laing 1970). Because sustainable maple tapping relies upon the ability of the tree to regrow more wood in the succeeding growing season than is effectively "removed" by tapping, the larger wound due to the use PFA caused a gradual decrease in conductive tissue within trees, eventually resulting in decline and mortality. PFA use was subsequently banned in the U.S. and Canada, with the result that the EPA exemption for PFA use in maple operations was not renewed. Although other taphole sanitizers, including silver, chlorox, and ethyl alcohol among others have been investigated (Sheneman et al. 1959, Perkins unpublished, Perkins and van den Berg unpublished), they are generally not greatly effective, or are not permitted due to various federal, state, provincial food safety regulations. The use of silver or other chemicals added to spouts, incorporated into droplines, or placed into the taphole are unlikely to be permitted under organic certification rules.

The goal of this project was to find alternative ways to reduce microbial contamination of tapholes. One approach we investigated was to use a check-valve to prevent microbial contamination of tapholes by preventing backward movement of sap from the tubing system into the taphole.

2007-2008 PROTOTYPE DEVELOPMENT

During the fall of 2007, we focused on developing a spout that would prevent backflow of sap into tapholes using a check-valve. We investigated a wide variety of commercially available check-valves for their suitability in maple use. Earlier attempts at using valves to prevent microbial contamination of tapholes proved ineffective (Marvin and Greene 1959), and reduced sap yield. However the earlier attempts were done prior to the widespread use of vacuum in tubing systems.

The design goals were to find a check-valve that would operate at very low vacuum levels, that could be fabricated of food-grade materials, and would operate over the range of conditions found in maple tubing (above and below-freezing, and wet or dry). None of the commercial check-valves proved entirely satisfactory, so we fabricated a prototype system using a standard maple stub spout and spout adapter. Although we successfully adapted stubs/spout adapters from several different companies, we eventually standardized on the Leader Evaporator Co. (Swanton, Vermont) for the prototype to be used in field trials.

The prototype was constructed by placing a small ball composed of Buna-N rubber between the spout stub and 5/16" spout adapter. This composition was found to have the proper Durometer "hardness" that would provide a good seal at the expected operating temperatures (30-50°F). A groove was cut on the lower internal part of the spout stub with a fine saw blade. This groove would prevent the ball from moving back (away from the tree) and sealing against the back of the spout stub, thereby providing an outlet for sap to pass through the spout into the dropline. However, the movement of the ball forward (towards the tree) would cause it to seat against the forward inner ring of the spout adapter, thereby preventing sap from moving from the dropline back towards the tree.

2008 PROTOTYPE TESTING

During the spring of 2008, we tested the prototype spouts using vacuum chambers. Chambers were connected to a mainline which was under vacuum via a 5/16" lateral line at the top of the chamber. A 36" used (but cleaned) 30P dropline connected the chamber to the stub spout. Ten standard spout adapters and ten prototype check-valve spout adapters were on individual chambers. Tapholes were placed such that treatment direction alternated. The sap level in each chamber was measured following each sap flow period and the chambers drained. Sap depth was converted to volume using a simple calibration. Sap yield for each period was totaled for the 2008 season.

At two dates near the end of the 2008 sap flow season, sap samples from each chamber were collected for microbial contamination testing using a Charm Sciences, Inc. FireFly ATP Luminometer and Watergiene swabs. This system provides a rapid estimate of the microbial population of liquid samples.

2008 PROTOTYPE RESULTS

Over the course of the 2008 sap-flow season, the control spout produced 14.3 gal sap/tap, while the prototype check-valve spout produced 18.0 gal sap/tap. Thus the check-valve spout produced 26.1% more sap than a standard spout at the same vacuum level.

ATP luminescence showed that microbial contamination was significantly lower in sap collected from chambers with check-valve spouts than control spouts on both collection dates. Sap microbial loads from check-valve spouts were 18% and 31% that of control spouts on 4/4/2008 and 4/9/2008, respectively.

As a consequence of these promising results, a preliminary patent application for the check-valve spout invention was filed by the University of Vermont during the summer of 2008. The patent covers the use of a check-valve anywhere in the lateral line or spout system (from the mainline to the tree). A brief description of this invention was presented at the North American Maple Syrup Council/International Maple Syrup Institute meeting in Amherst, Massachusetts, in October 2008.

2008-2009 LEADER CHECK-VALVE SPOUT ADAPTER DEVELOPMENT

In the fall of 2008, Leader Evaporator Co. signed an agreement which allowed UVM PMRC researchers to discuss in depth the details of this invention and to allow further cooperative research and development of a commercial product to occur. Over several months representatives of Leader and Proctor worked out a design that eventually lead to a test mold for injection molding being produced. The new design incorporated the check-valve concept directly into an annually-replaceable spout adapter (Figure 1) that worked in combination with the Leader Spout Stub. The spout adapter is designed to fit several other (but not all, due to differing stub spout geometries) spout stubs from various maple equipment manufacturers. The ball is captive within a short "straw" within the adapter and is held in place by small projection-like fingers. The straw has openings at the spout stub side which allow sap to pass through under normal operating conditions when the tubing system is under vacuum. When backflow conditions occur, the ball trav-

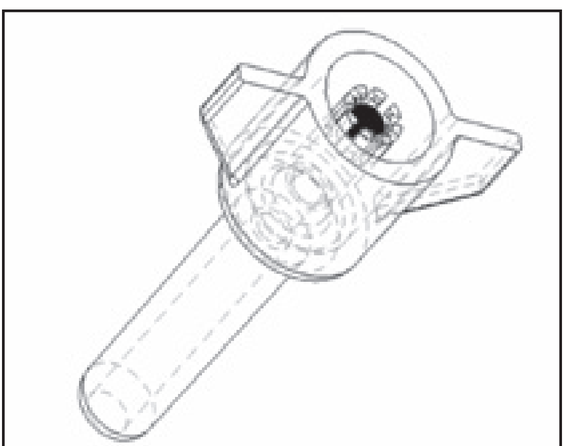

Figure 1. Schematic diagram of the Leader Check-valve adapter based upon the ball check-valve concept.

Errata corrected above

els a very short distance and seals against an inner ring to prevent sap that has already passed through the adapter from moving back into the taphole.

The new design was produced in limited quantities (approximately 15,000) to allow testing at UVM PMRC and by several sugarmakers. Two variants with different ball compositions with the specified "hardness" specification were tested. These were eventually shown to have no difference in functionality or yield, so no further discussion of these will be made.

LEADER CHECK-VALVE SPOUT ADAPTER TESTING AT UVM PMRC

The Leader Check-Valve spout adapter was tested at UVM PMRC in Underhill Center, Vermont, in two separate field trials during the spring of 2009.

In the first study, we utilized vacuum chambers as described in the prototype development, again using standard (non-check-valve) Leader stubs and spout adapters as the control. In both cases, new Leader Spout stubs and spout adapters (non-check-valve and check-valve), and 1-year-old used (but cleaned) 30P droplines were used. A total of 16 chambers were used with eight chambers for each treatment. Average tree diameter (at breast height) was 10.4", and vacuum was operated at an average of -22.5" Hg for the season with all chambers connected to the same vacuum line and pump. Sap depth was measured after each flow period and converted to volume.

Over the 2009 season, sap yield in control spout chambers was 0.81 gal syrup equivalent/tap, whereas sap yield from Check-valve chambers was 1.00 gal/tap, an improvement of 23.5% using Check-Valve spout adapters (Figure 2).

For a larger scale test, we utilized plots that had been retubed prior to the sap flow season in 2004 and operated over the previous five years of operation. Sap yield on a per tap basis from each section was roughly similar (Perkins, Stowe and Isselhardt unpub-

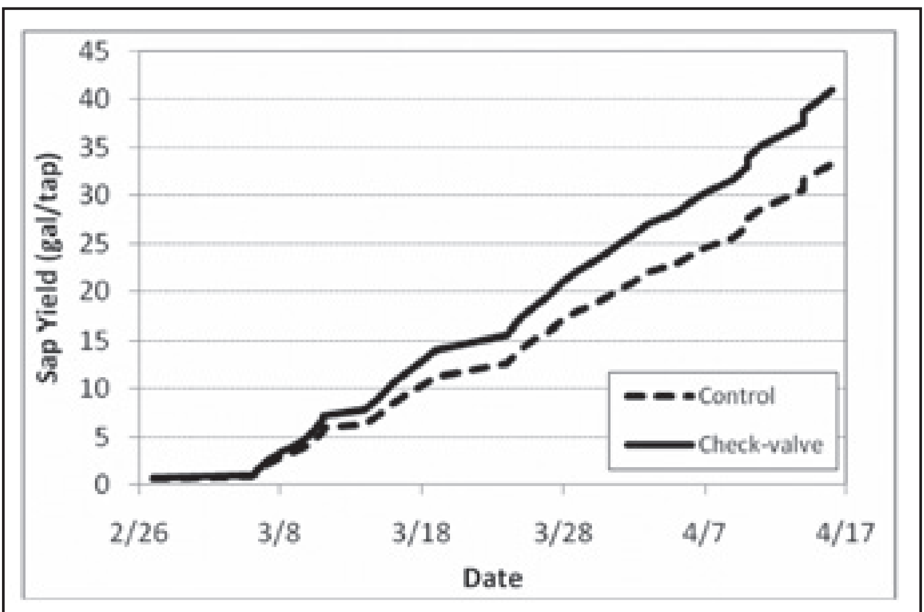

Figure 2. Sap Yield from Leader Check-valve and control spouts during the 2009 maple season (vacuum chamber study).

lished) in these plots, and all systems typically performed quite well, averaging over 0.5 gal syrup/tap throughout testing.

In 2009, one of the tubing sections had all droplines and spouts replaced, two sections had no changes, and the forth section had new droplines with Leader Check-Valve spout adapters installed. Droplines were Flexelene AG (Eldon James Corp), made with anti-microbial silver. All the sections were tapped within a few days of the first sap run in late-February 2009. Each treatment ran through an individual mainline system to a calibrated releaser equipped with an electronic counter system so that the total number of releaser dumps could be tallied. Releasers were calibrated to allow calculation of sap volume collected. All systems were connected to a common vacuum flood pump system which operated at approximately 22.5" Hg at the pump. The pump was turned on whenever the temperature rose to near freezing, and was run for at least 3+ hrs past the time of the final releaser dump. All sections were checked and maintained regularly throughout the entire sap flow season.

All systems performed very well over the 2009 season. Yields were 0.57 and 0.69 gal syrup/tap on the systems that had no changes (Figure 3) and 0.62 gal syrup equivalent/tap on the system with new spouts and droplines installed. The system with new droplines and Check-Valve spout adapters performed exceptionally well (Figure 3, line D), yielding 1.09 gal syrup equivalent/tap, representing a 58.0 - 91.2% increase in yield over the season compared to other sections of the same woods.

Part of the increased yield from the Check-valve section is undoubtedly due to the fact that new spouts and droplines were used. It is clear from ongoing studies that replacing spouts, using a new spout adapter annually, and/or replacing droplines can increase sap yield (Perkins, Wilmot, and Stowe unpublished, Steve Childs - Cornell Maple Program,

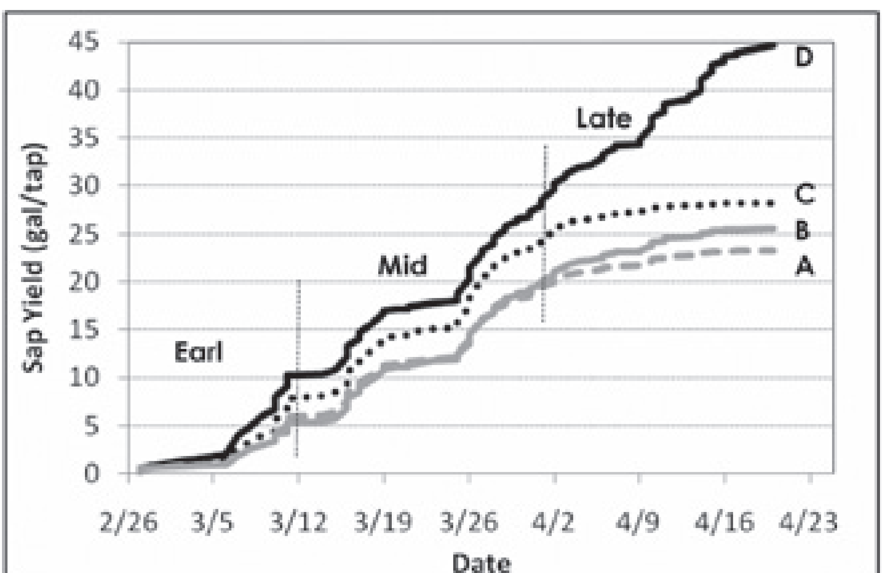

Figure 3. Sap yields from four similar sap collection treatment areas at UVM PMRC in 2009. Sections are: **A.** Dual-line system, six year old droplines and spouts, **B.** Single-line system, new droplines and spouts, **C.** Dual-line system, six year old droplines and spouts, **D.** Dual-line system, new droplines and Check-valve spouts.

personal communication). However, the increases expected from such changes on vacuum systems is typically only about 10-20% (Perkins, Wilmot and Stowe, unpublished). Also, the section where new spouts (non-Check-Valve) and new droplines were installed (Figure 3, line B) did not experience large increases in sap yield, but instead appears to have had only slightly higher flow at the end of the season than the two sections that did not receive new spouts and droplines (Figure 3, lines A and C). Therefore, the bulk of the increase in sap yield observed in the section with check-valves was most likely in large part due to the action of the check-valve itself, and not simply because the spouts and dropline were new. The anti-microbial properties of the droplines appeared to have little effect on sap yield. Yields of chamber studies and field studies were similar, yet chambers did not have anti-microbial silver droplines. This will be discussed in detail in a forthcoming paper on anti-microbial silver in maple operations.

The majority of the increased sap yield from Check-Valve spout adapters occurred during two phases of the season. During short-duration flows in the early season, the Check-Valve spout adapters appears to produce marginally more sap than spouts without check-valves. This is likely due to reduced resorbtion of sap from the dropline as trees go from the positive pressure phase (sap exudation) to the negative pressure (water uptake) phase. Without a check-valve, some sap that had previously been exuded may be sucked back out of the dropline, resulting in slightly lower yields for sections without Check-Valve spout adapters. The average yield from this during testing in the 2009 season was approximately 1 pint of additional sap per Check-Valve adapter per freeze. In controlled experiments, Marvin and Greene (1959) measured sap resorbtion during the uptake phase of approximately 1.5 pints per taphole. Preventing this mechanism appears to roughly increase sap yield by a slight, but noticeable amount over the course of the entire season, but is particularly apparent during the early season when frequent short-duration thaws predominate.

Throughout the mid-part of the maple season, sap yield is essentially equal between control sections and the section equipped with Check-valve spout adapters. In early-April, at what would normally be part of the late season, sap flow from sections that did not have Check-valve spout adapters began to slow abruptly. The section that received new spouts and droplines showed similar patterns, but the decrease was slightly more gradual, and the effective sap flow season lasted about a week longer than the sections without new spout and droplines. The section that received Check-valve spout adapters continued to run well for at least 2.5 weeks beyond the time the other sections had almost completely stopped. Sap sweetness did not drop off appreciably, and the sap did not turn buddy.

A limited number of clear Check-Valve spout adapters were produced for experimental purposes. Using these, we were able to observe that any microbial slime that begins to build up within the spout is removed as the sap flows due to the ball rotating around in the sap flow. This serves to keep the ball relatively clean and prevents clogging of the adapter valve system. In other experiments and observations using dye inserted into the sap column, we were able to observe and confirm that the valve was effective in preventing backflow of sap under most circumstances, whereas tapholes with normal spouts experienced significant backflow under certain conditions.

DISCUSSION

The Check-valve spout concept worked well in both prototype and commercial production versions, increasing sap yields by 23.5 - 26.1% in vacuum chamber studies, and 58.0 - 92.1% in production scale testing. Most of the effect of check-valves is seen in late season sap production through an extension of the sap collection period. Although each year is very different, it seems likely that in most normal seasons, systems employing check-valve spouts should produce more sap than systems without them. These yield results are comparable to those achieved using paraformaldehyde, although, in the current check-valve form, are achieved through mechanical exclusion of microbes from tapholes as opposed to chemical control using PFA or other chemical substances. Unlike PFA or other chemical means, the Check-Valve spout adapter does not require EPA pesticide certification, does not result in further internal damage to the tree, and does not release chemicals into the sap.

Why do we see a smaller effect on sap yield in vacuum chamber studies? There are two possible explanations for this. First, the droplines used in the chamber studies had been used for only 1 year and then cleaned. It is possible that only a slight level of microbial contamination is present in tubing of this age. Other ongoing studies seem to indicate this, and also display a reduced benefit from annually replaced spout adapters (Perkins, Wilmot, and Stowe). Tubing systems become more highly contaminated as they age (Legacé et al. 2006). Despite the relative newness of the used tubing, the Check-Valve spout adapter still increased sap production by 26% and 23% in the two years they were studied with vacuum chambers. Secondly, when used in a vacuum chamber test system, the ONLY source of contamination is the dropline, the spout stub, and the spout adapter (or spout). Contaminated sap cannot move from the chamber to the taphole. In a normal system, sap can flow back from both the dropline and the lateral line. Thus, the potential load of microbial contamination is far more highly restricted with chambers compared to a normal tubing situation, which serves to limit the benefit of the Check-valve to some degree.

Although using check-valves anywhere in the lateral line, dropline, or spout system is technically possible, and may be beneficial to some degree, there are reasons why incorporating it into a spout or spout adapter makes the most sense. Because the spout adapter is replaced annually, it is quite clean (but not completely sterile), whereas the tubing and fittings beyond that point are still contaminated with the microbes that flourish in sap. Putting a check-valve beyond the point where the system is contaminated could allow the taphole to become contaminated more readily. In addition, only a small volume of sap and air is held in the adapter. When the check-valve in the spout functions, there is very little sap or air to flow back. Placing a check-valve further out in the system does allow whatever sap or air is trapped between the taphole and the check-valve to move backward. Any leaks that might occur in the system between the check-valve and the taphole would still result in sap backflow.

One of the possible advantages to using the Check-Valve spout adapter could be in the case of early tapping. Maple producers with large numbers of taps or those with unpredictable early flows must start tapping early. With standard adapters tapholes can begin to dry-out early. By reducing taphole contamination, the Check-Valve spout adapter should reduce the amount of drying experienced and allow for better sap flows through the entire season. This has not yet been experimentally verified, however further research is planned.

How much the Check-Valve spout adapter helps in increasing sap yield is dependent upon a large number of factors relating to tubing system setup, age, and maintenance, as well as vacuum system operation, and prevailing weather conditions during the sap flow season. The following is an initial set of recommendations outlining where Check-Valve spout adapter use should result in the most benefit, and where Check-valve Spout use may result in lesser benefit.

WHERE THE CHECK-VALVE SPOUT WILL HELP THE MOST

1. Older Tubing Systems. Maple tubing systems that are more than a few years old are typically more highly contaminated with microorganisms. Although cleaning will help to keep microbial populations lower, bacterial biofilms develop in tubing systems that are almost impossible to remove, resulting in rapid recolonization of systems.

2. Tubing Systems Using High Vacuum. After a period of time, vacuum within the tubing system extends into the tree. The higher the vacuum level, the greater the potential for sap to flow backward into the taphole.

3. Releasers That Introduce Air When Dumping. The most common releaser design allows air to bleed in to one section of the releaser in order for the releaser to dump its contents. Every time this happens, sap can move backward in the system.

4. Systems with Leaks. Any new leak (heaving spouts, animal chews, vacuum testing, etc.) will introduce air and can result in movement of sap backward in the system. This can be anything from animal damage, wind or snow, or frost heaving of spouts.

5. Warmer Woods. Woods that are characteristically warmer than others will develop tubing system contamination faster than colder woods. The Check-Valve spout adapter reduces microbial contamination of tapholes, thereby extending the flow season.

6. Tapping Early. Producers who tap early due to size of operation or unpredictable weather should experience a longer flow period with Check-Valve spout adapters than with normal spouts.

WHERE THE CHECK-VALVE SPOUT MAY NOT HELP AS MUCH

1. New Tubing System. Tubing systems that are new, or have only been used in one season, have reduced levels of microbial contamination. Sap moving backward in these systems is less damaging to yield, particularly in the first year. Check-Valve spout adapters can produce slight improvements in the first year and result in increasing benefits each year thereafter (spout adapters should be replaced annually).

2. Gravity Tubing or Systems with Low Vacuum Levels in the Woods. In general, the higher the level of vacuum, the greater the potential benefit from Check-Valve spout adapters. Although Check-Valve spout adapters may produce some improvement even under gravity tubing conditions, the potential for backward movement of sap in tubing systems is greater with increased vacuum level.

3. Vacuum Systems That Don't Introduce Air. Releasers that utilize pumps to evacuate the sap from the chamber do not necessarily introduce air into the system, and thus minimize the backward movement of sap. Similarly, producers who collect into bulk tanks and then close off the sap lines when the tanks are pumped out will experience less backward sap movement.

4. Vacuum System Operation. Those producers who keep their vacuum pumps running continuously throughout the maple season until the system is COMPLETELY frozen may experience a reduced level of benefit from Check-Valve spout adapters.

5. Colder Woods. Woods that are normally cold may experience reduced microbial growth in tubing systems, and thus experience a lower benefit from Check-Valve spout adapters.

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ACKNOWLEDGEMENTS - The author thanks Brian Stowe and Tim Wilmot for their many discussions and insights into problems associated with achieving high sap yields. Dr. Abby van den Berg and Timothy Wilmot reviewed earlier drafts of this manuscript. Mark Isselhart, Ben Dana, and Ben Drew assisted with field work. A grant from the USDA funded some of the work on this project.