EFFECTS OF VARIOUS FILTERS ON SAP QUALITY AND CHARACTERISTICS

Simon Lachance[1], Anna Crolla[1], Luc Lagacé[2] and Dave Chapeskie[3]

ABSTRACT

Sap may become contaminated with microorganisms through contact with unclean surfaces. Microbial populations will also build-up in sap as conditions warm-up during the production season. This may cause the production of maple syrup of lower quality in terms of color and flavour. Sap filters can remove residue or debris, which may inadvertently enter the sap through the collection system or during storage. Moreover, filtering may improve the storage potential of maple sap, improve sap quality especially during mid- to late-season and help in keeping the evaporator system clean.

Several commercial sap filters were tested for their efficacy at improving the quality of sap and syrup for the 2005 and 2006 seasons. The diatomaceous earth filter (DE), cylindrical filter with wrapped cloth (cyl./cloth), bag sap filter and a 5 microns polypropylene cartridge filter reduced total particles in sap by 52%, 31%, 23%, and 12%, respectively.

Average reduction of bacteria in the sap was 40%, 26%, 18% and 1% for the DE filter, the cyl./cloth filter, the 5 microns cartridge filter and the bag filter, respectively. Average reduction of yeast and mould was 68%, 47%, 38% and 23% for the DE filter, the cyl./cloth filter, the 5 microns cartridge filter and the bag filter, respectively. The differences are best explained by the pore size of the specific filters, as smaller pores will retain more particles and microorganisms. A stainless steel filter was tested in 2005 only, and due to the limited results from the experiment, the early stage of application in the maple industry and very limited operational experience, further evaluation is recommended. It is important to realize that microorganisms in an ideal environment for growth will show an exponential increase, and counts in the sap may increase very rapidly even after filtration, if sap is not processed rapidly. A pilot scale experiment showed no differences in the colour and flavour intensity of syrup produced from filtered versus non-filtered sap. Filtration must always be accompanied with the application of best management practices throughout the production system. Preventative methods to reduce microbial growth, such as maintaining sap as cool as possible and processing as quickly as possible, are encouraged.

INTRODUCTION

Sap may become contaminated with microorganisms when it comes into contact with unclean surfaces. The invert sugar produced by microbial enzymes in contaminated sap will affect syrup darkening during the heat processing (Morselli et al 1985, Morselli and Whalen 1991). Contamination may occur at the taphole, in the sap collection system and during storage. In order to ensure the production of high quality pure maple syrup, maple producers require management options to maintain the quality of sap and syrup throughout the production process.

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[1]Recherche et transfert de technologie Campus d'Alfred - Université de Guelph Alfred, ON, K0B 1A0

[2]Centre ACER Inc. 3600, boul. Casavant Ouest, St-Hyacinthe, Qc, J2S 8E3 3Ontario Ministry of Agriculture, Food and Rural Affairs ORC Building, P.O. Box 2004 Kemptville, ON, KOG 1J0

[3]Ontario Ministry of Agriculture, Food and Rural Affairs ORC Building, P.O. Box 2004 Kemptville, ON, KOG 1J0

A wide variety of microorganisms can be found in the sap, and 22 different genera were recovered in a recent study (Lagacé et al. 2004). Bacteria are recovered from sap in higher amount than yeast and moulds (Lagacé et al. 2002, Lagacé et al. 2004). When sap comes into contact with contaminated surfaces, it is easily colonized by microorganisms, and the number in sap can increase rapidly. This is particularly true for the sap collection system where a biofilm can build-up on the inner surface of the tubing, increasing the contamination potential and spoilage of the flowing sap (Lagacé et al 2006)

Various methods have been tested to decrease microbial contamination (Lachance and Blais, 2001; Labbe et al., 2001). A growing number of maple producers are filtering their sap once or several times before it is processed into maple syrup. Filtering may be especially beneficial when the quality of sap has deteriorated, such as late in the production season. Deterioration may be due to slow sap flow, extended storage time, warm weather, or unclean sap collection equipment. Sap filters can remove residue or debris, which may inadvertently enter the sap through the collection system or during storage. Filtering maple sap may also increase its storage potential, and may help in keeping the evaporation system cleaner. It is therefore important that the tubing system be cleaned and sanitized as soon as sap collection is completed, but also that the sap be filtered during the season if contamination has occurred.

Four pressure driven filtration processes can be used for water and particle separation (Figure 1). The term filter will usually be limited to structures that separate particles larger than 1 micrometer (μm) (Baker 2000). Yeasts and moulds (fungi) are usually larger than 1 μm. Many bacteria are between 0.1 and 1 μm and could thus be removed only by microfiltration, which removes particles between 0.1 and 10 μm (Baker 2000).

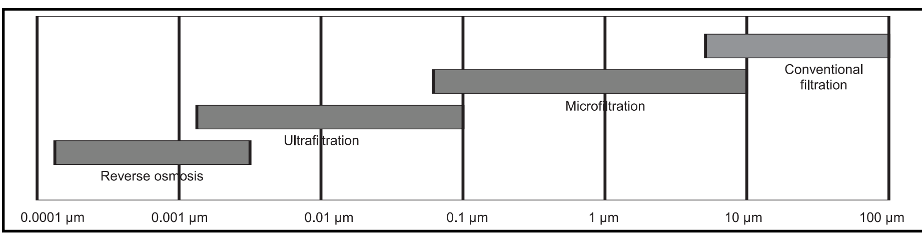

Figure 1. Filtration processes and average diameter pore size.

The decrease in sap quality is not only directly related to the microorganisms present, but to the enzymatic breakdown of sucrose into glucose and fructose by the microorganisms, which can cause darkening of the syrup upon boiling (Lagacé et al. 2004). Therefore, to be the most effective, the microorganisms should be removed from the sap before they have degraded it. Currently, maple syrup producers are choosing their sap filtration equipment based in large part on operational experience and non-scientific recommendations by industry stakeholders. This research project was initiated to provide information on selection criteria for filtration equipment. Selection of filtration equipment should be based on performance in decreasing microbial and physical contamination as well as operational considerations and costs.

PROJECT OBJECTIVES

The general objective of the project was to evaluate and quantify the effectiveness of several commercial sap filters at improving the quality of maple sap and thus maple syrup. The specific objectives were to: 1) evaluate sap microbial contamination levels before and after the use of five different filtration systems [bag filter, line-filter (cylindrical filter with wrapped cloth), pool-filter (diatomaceous earth), 5 microns polypropylene cartridge filter and stainless steel cartridge filter] installed as recommended by the manufacturer; 2) evaluate the effectiveness of five filtration systems at removing physical and biological contaminants (particles and microorganisms) from the sap; 3) complete a cost/benefit analysis for each of the techniques; 4) evaluate some of the operational aspects of filter use and 5) evaluate the potential of maple sap filtering techniques to produce lighter grade syrup.

Materials and Methods

Sampling and Location of Experiment

The research was performed in Eastern and Central Ontario. Five common sap filter types were evaluated by eight maple syrup producers in 2005 (each filter type tested by at least two of the producers). In 2006, three producers were selected to test four filter types (all filter types were installed at all locations).

Filter types evaluated were bag filter, line-filter (cylindrical filter with wrapped cloth), pool filter (diatomaceous earth), stainless steel cartridge filter (only in 2005) and 5 micron polypropylene cartridge filter. Table 1 shows the characteristics of each filter type.

Table 1. Filter characteristics

Type of filter system	Material of filter	Pore size*	Method of operation
Cylindrical filter with wrapped cloth (line-type)	Cloth	5 microns (1 micron available)	Sap flows through a cloth at high pressure
Diatomaceous Earth (DE) sap filter (pool filter type)	Cloth and DE	1-10 microns (depend on quantity of DE added)	Sap flows at high pressure through layers of DE covering a cloth
Bag sap filter	Cloth	50-100 microns	Sap passes by gravity through a cloth
Stainless Steel	Stainless Steel	30 microns as tested	Sap passes through a stainless steel filter encased in a housing at high pressure
Polypropylene cartridge filter	Polypropylene	5 microns (1 micron also available)	Sap passes through a cylindrical filter encased in a housing at high pressure

*Actual (or Absolute): implies that more than 98% of particles will be retained by the filter; Nominal: implies that 60% to 98% of particles are retained by the filter. The stainless steel filter pore size is an actual number; all the other filters are rated using nominal criteria.

Data was gathered by collecting maple sap immediately upstream and downstream the various sap filters. The filters were installed according to manufacturer's recommendations. Samples were collected, by the producers in 2005, during early season, mid-season, and late-season sap runs. Collection dates were at the discretion of the producers and usually were selected during periods of good sap flows. At each of the three periods in 2005 and 2006, 5 sap samples were collected before the filter (non-filtered) and 5 samples were collected after the filter (filtered) for each treatment. The samples were then used for the various laboratory analyses. Each non-filtered and filtered sample were paired and collected at the same time. A new filter was installed before each sap run after samples were collected.

Sterile 250 ml sampling bottles were used to collect the sap, and the same sampling procedure was followed to ensure sterile sap collection. Before the start of collection, the tip of the valve was soaked in alcohol for 15 seconds, and then each valve was opened and the sap was left flowing for at least 10 seconds. The temperature of the sap collected was measured with a Marathon digital thermometer.

After the first sap was discarded from each valve, the sap was collected with the sampling bottles. All samples were frozen immediately after collection in a conventional freezer, to stop growth of microorganisms. Sap samples were later analysed for particle size distribution, bacteria, moulds and yeasts, turbidity, pH and sugar content.

Particle size distribution was analysed using a Lasentec M100 Particle System Characterization Monitor purchased from Lasentec Incorporated (Lasentec Inc., 1994). The Lasentec instrument is attached to a computer which records particle counts at time intervals defined by the users.

Particle size counts were grouped in particle size classes (0.8 to 5 microns, >5 to 11 microns, >11 to 20 microns, >20 to 35 microns, >35 to 57.5 microns, >57.5 to 95 microns, >95 to 230 microns and >230 to 1000 microns) for ease of graphing and interpretation of the data. The results were grouped by sap filter type and compared to one another (stainless steel filter results not presented due to the limited results from the experiment). Total particle count changes (% change after filtration) were used to determine the efficacy of the filter type in decreasing the abundance of particles.

Number of bacteria, yeasts and moulds per millilitre of sap were counted using the appropriate growth nutrient and a plate count of colonies. Counts (Colony Forming Units - CFU) per millilitre before and after filtration were used to determine efficacy of the filter at removing microorganisms.

A paired T-test was used to determine statistical differences between treatments (before and after filtration), using a significance level of 5%. However, it was not always possible to perform a statistical analysis because some of the samples were not collected (missing points) and therefore data points were not numerous enough (indicated as appropriate).

Results

Particle Count for Non-Filtered Sap

The number of particles in the non-filtered sap increased as the season progressed, as shown by the graph for one producer (Figure 2). There were in general less large particles than small particles in the range measured (0.8 to 1000 µm) (Figures 3). This was the case for most of the maple operations. Very few particles were larger than 200 µm.

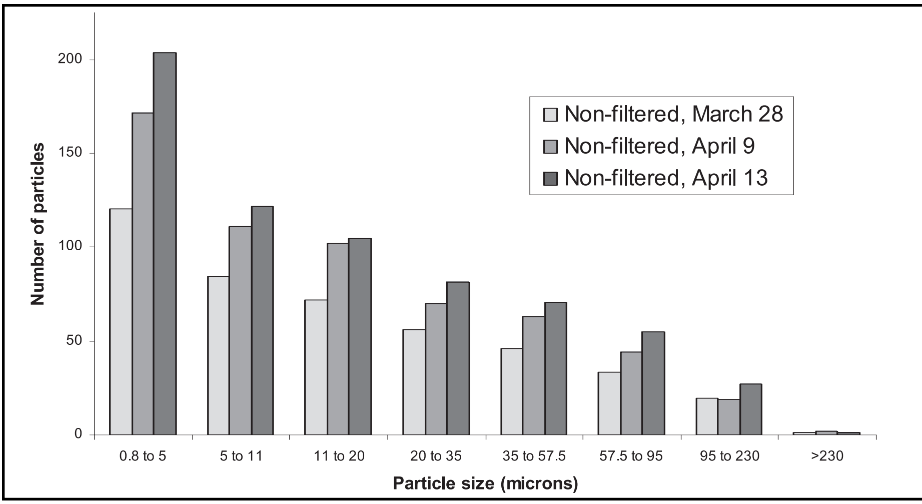

Figure 2. Particle size distribution of non-filtered sap for March 28, April 9 and April 13 at producer #1 (2005).

Particle Count following Filtration of Sap

Figure 4 shows the average percent change in total particle count that was produced by each type of sap filter for both years 2005 and 2006 pooled. The diatomaceous earth filter (DE), cylindrical filter with wrapped cloth (cyl./cloth), bag sap filter, 5 microns polypropylene cartridge filter and a stainless steel (SS) cartridge filter reduced total particles in sap by 52%, 31%, 23%, 12% and 2.0%, respectively (Figure 3). Only the diatomaceous earth filter and the cylindrical filter with wrapped cloth showed a statistically significant ($P<0.05$) reduction in particle count (Figure 4). It is possible that the reduction by the polypropylene cartridge filter was lower because we were starting with a lower amount of particles and microorganisms in the sap than other filters. The results for the Stainless steel filter are not shown in the graph due to the limited results from the experiment, as it was performed only in 2005.

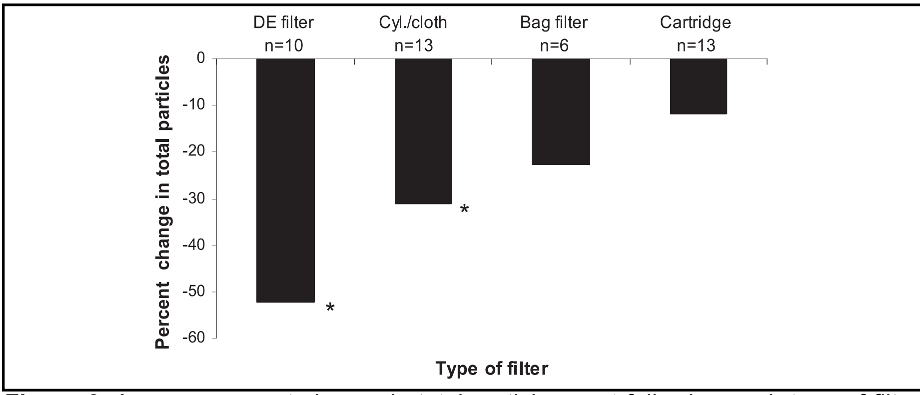

Figure 3. Average percent change in total particle count following each type of filtration, pooled for both years. Asterisks indicate a significant difference in total particle counts from non-filtered sap (P<0.05).

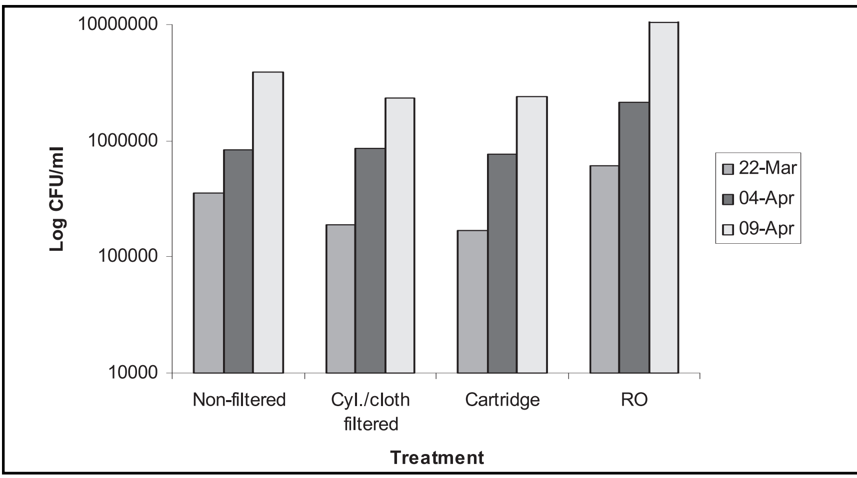

Figure 4. Bacteria in sap for March 22, April 4 and April 9 at producer #7 (2005).

Microbiology of Sap

As expected, the number of microorganisms in the non-filtered sap generally increased as the season progressed, as shown by the results from one producer (Figure 4), including sap that had been processed through Reverse Osmosis.

In 2005, the best reduction in bacterial population (from 375,000 cfu/ml to 134,500 cfu/ml) for a single sample was 64% using the stainless steel filter (although average change with this filter type increased total bacteria counts). In 2006, the best reduction in bacterial population for a single sample was 85% using a DE filter (from 2,560,000 cfu/ml to 383,000 cfu/ml).

Overall reduction in **bacterial population** for each type of filter for both years pooled (2005 and 2006) is shown in figure 5. The cylindrical filter with wrapped cloth, the polypropylene cartridge filter and the DE filter significantly reduced the bacteria number found in the sap by 26%, 18% and 40%, respectively, all being statistically significant (P<0.05). The difference is not statistically significant for the bag filter (reduction of 1%).

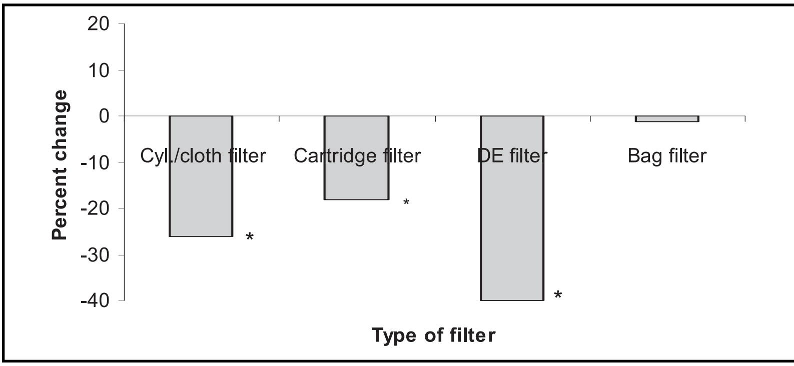

Figure 5. Average percent change in total bacteria count following filtration with each type of filter; both years pooled. Asterisks indicate a significant difference in total bacteria from non-filtered sap (P<0.05).

For yeasts and moulds, the best result for a single sample in 2005 was obtained using the DE filter: yeast and mould counts were reduced by 95% (from 58,500 cfu/ml to 3075 cfu/ml). In 2006, the best result for a single sample was obtained again using the DE filter: yeast and mould counts were reduced by 98% (from 54,000 cfu/ml to 1040 cfu/ml).

The percent change in sap yeasts and moulds populations after the sap was passed through each filter type for both years is presented in Figure 6. There was a reduction of 47%, 38%, 68% and 23% in yeast and mould numbers for the cyl./cloth filter, the cartridge filter, the DE filter and the bag filter, respectively. Only the bag filter was not statistically significant at decreasing yeasts and moulds.

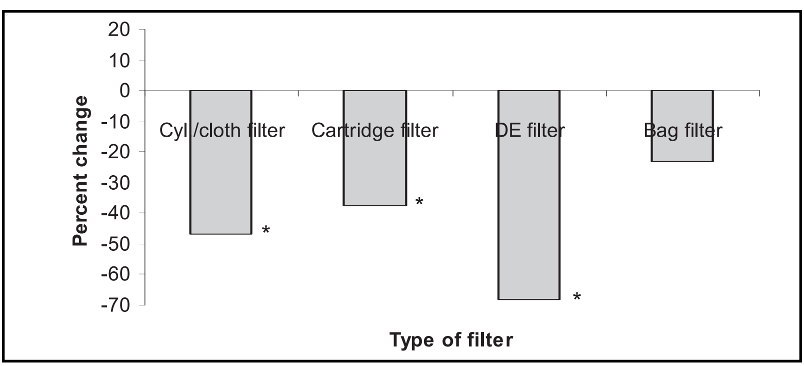

Figure 6. Average percent change in total yeast and mould count following filtration with each type of filter; both years pooled. Asterisks indicate a significant difference in total yeast and mould from non-filtered sap (P<0.05).

Syrup Produced from Non-filtered and Filtered Sap

Seven sets of 18 litre non-filtered and filtered (2 from DE, 2 from cartridge and 3 from cyl./cloth filters) late-season sap were collected, boiled to syrup and compared for grade and organoleptic attributes. Four testers with varying levels of experience rated the syrups for smell, taste and color. The "Flavor Wheel for Maple Syrup", developed by Centre Acer and Agriculture and Agri-food Canada, was used as a guide for taste and odour descriptors.

Syrup produced from non-filtered and filtered sap was identical in color and taste and could not be distinguished from each other. For five of the seven sets, the syrup from filtered sap had fewer odours than the equivalent non-filtered syrup. From these limited tests, it seems that filtering the syrup did not improve the grade of the syrup to a noticeable extent, at least when boiling small quantities of sap to syrup.

We observed a large difference in the cleanliness of the pans after boiling the non-filtered vs. the filtered sap. Most of the time, the sides of the pans used to boil the syrup were much cleaner with the filtered sap than the non-filtered sap, even if only 18 litres were used to produced the syrup. It is expected that the difference may be more observable for large quantities of sap being processed and later in the production season. More tests are needed to draw conclusive results.

Discussion, cost-benefit analysis and operational issues

Based on the results of the experiment, both the diatomaceous earth and cylindrical with wrapped cloth sap filters significantly reduced the amount of particles and microorganisms in the sap. The cartridge filter (5 microns) significantly reduced the abundance of microorganisms in the sap (bacteria, yeast and moulds), but did not show a significant decrease in particle abundance based on statistical analysis. It is not known what caused the discrepancy in these results.

The diatomaceous earth sap filter was the most effective in this experiment. Diatomaceous earth filters can be recommended for efficient sap filtration of particles and microorganisms, provided they are installed and operated properly, as outlined by the manufacturer. The cyl./cloth sap filter was the second most effective at filtering out particles and microorganisms in the sap. The results showed consistent reductions in total particle counts with this 5 microns cyl./cloth filter, except for a slight increase in one trial. A cloth with nominal pore size of 1 micron is now available, showing increased potential for microorganisms filtration. The 1 and 5 microns cloth filters are interchangeable in the system. The polypropylene cartridge filter (5 microns) is also a good choice for producers, as it significantly reduced the amount of microorganisms in the sap.

Some filter types produced variable results among the trials in this experiment. The bag sap filter is desirable to many producers because it is inexpensive and easy to use. This filter provides a desirable filtration option for a producer that simply wants to filter out debris, such as specks of bark or larger particles, with minimum cost and effort. However, smaller constituents, such as microorganisms, are not reduced by this type of filter. The 5 microns cartridge filter is widely distributed in the maple industry as well as for water treatment, and it performed adequately at removing significant amounts of bacteria, yeasts and moulds. The 5 microns cartridge is most often used to remove particles before the sap enters the R.O. machine. The cartridges are also available in the 1 micron pore size, which could improve the filtration potential for microorganisms (especially for bacteria). The stainless steel (SS) filter cartridge is a new alternative and has been designed to work in the same housing as the polypropylene cartridge filter. The SS filter is cleaned after each use, in a boiling water bath or by reverse flow filtration of a sanitizer solution. This filter cannot be recommended for filtering sap at this time, due to the limited results from the experiment, the early stage of application in maple industry and very limited operational experience. It shows potential, but more testing is needed.

Good sanitation procedures related to the use of a filtration system are necessary to avoid any recontamination from unclean surfaces. It is important to clean and sterilize the housing or the devices containing the filter(s), as well as the filter itself, at least for each sap run. Some filtration systems need new filters every time, and this will avoid possible recontamination if the filter is changed often enough. A poorly maintained filtration system may have the opposite effect of how it is designed to perform.

The approximate (2006) cost of installing and running the different filtration systems is presented in Table 2. Most of the systems are fairly inexpensive when averaged over several years of use.

Table 2. Approximate material cost of each filtration system (Based on 5 years of use and a 5000 taps operation - Canadian $).

Filtration system	Unit cost ($)	Filter cost ($)	No. filters used/5 years	Approx. cost ($) for 5 y.
Diatomaceous earth filter	750	40 (50 pounds DE)	10 bags	1150
Cyl./cloth sap filter	450	20	20	850
5 microns cartridge sap filter	70	7	125	945
Bag filer	35	10	30	335
Stainless steel	70	250 (estimate)	1	320

The filters used in the experiment were installed at eight different maple operations in 2005, and variations in the set-up and data collection may have caused some of the inconsistent results. However, the second year of the experiment (2006) showed similar results as 2005 for particles and microorganisms reduction, and has permitted the confirmation of observations regarding filter uses and efficiency.

As expected, the filters were reducing yeast and moulds counts in the sap more efficiently than bacteria, due to the much smaller size of bacteria. The cylindrical filter with wrapped cloth, the polypropylene cartridge filter, the DE filter and the bag filter reduced the bacteria number found in the sap by 26%, 18%, 40% and 1%, respectively, all but the bag filter being statistically significant. In contrast, the reduction of yeasts and moulds was 47%, 38%, 68% and 23% for the same filters, respectively. The average size of bacteria in the sap may be smaller than the average pore size of the filters. It may thus be important and interesting to evaluate other technologies or processes to reduce the population of bacteria in the sap, or to avoid their development, as they are one important contributor to the reduction of sap quality.

The bag sap filter, as with all filters, must be changed (or cleaned) on a regular basis to prevent it from clogging or acting as a source of bacterial contamination. Some filters may be more difficult to be thoroughly cleaned and sterilized, or are time-consuming, and this should be considered in the selection process. It is also important to follow recommendations as to the pressure used to pump the sap through the filters. A high pressure may permit particles to pass through the system and reduce the effectiveness of the filter. The DE filter, although the most efficient, rapidly clogs up when used late in the season when sap is more contaminated, so needs to be de-clogged (cleaned) more frequently. Operational aspects of its use (it may be more time-consuming to run and clean and may clog) and its higher cost may discourage some producers. However, if well installed, it has proven its efficiency in this experiment. Late in the season, when the sap was cloudier, the DE filter was very efficient at clearing up the sap. However, a clear sap does not guarantee that it is not degraded.

It is evident that filtering the sap has an effect on reducing the abundance of particles and reducing populations of bacteria, yeast and moulds (given the appropriate filter type). This will increase the purity of the sap and protect the R.O. machine. However, microorganisms in an ideal environment will show an exponential growth, and counts in the sap may increase very rapidly, even after filtration. Moreover, even given a reduction of hypothetically 75% of microorganisms in contaminated sap, a highly contaminated sample containing 2 000 000 cfu/ml would still contain 500 000 cfu/ml after filtration.

As well, a 50% decrease of the bacterial counts in a sap sample would show a population level comparable to its initial value in less than 60 minutes after the filtration, unless sap is kept very cool. The growth of bacteria can be very fast. A reduction in microorganisms in the sap after filtration, although significant, will not show a real benefit if the sap is not processed rapidly. The invert sugar produced by enzymes released by bacteria in contaminated sap will affect syrup darkening during processing (Morselli et al 1985, Morselli and Whalen 1991). The decrease in sap quality is directly related to the microorganisms present, but even more important, to the enzymatic breakdown of sucrose into glucose and fructose by the microorganisms, which can cause darkening of the syrup upon boiling (Lagacé et al. 2004). Therefore, to be most effective, the microorganisms should be removed from the sap before they have degraded it. A clean tubing system for collecting sap is thus very important in this respect to avoid degradation of the sap prior to filtration. Storing sap for long periods and filtering just before processing may be beneficial in removing particles, yeast and moulds and some bacteria, but the sap degradation process will have already taken place previous to the filtration. Some degradation of the sap will happen prior to filtration, and also after filtration because no system used in the maple industry can completely remove the bacteria from the sap, and because contamination from non-aseptic equipment and material will occur after filtration.

The sap filtration systems used in the maple industry should be food-grade, as the sap is processed into a food product. The bag sap filter, the bag sap filter, the 5 microns cartridge filter and the cyl./cloth sap filter are all specifically designed for the maple industry or are used for potable water, which ensure their safety for use in the food industry. However, the DE filters are designed for pool filtration, and food-grade standards are not yet met, although food-grade DE powder is available.

An increase in particle counts and microorganisms was observed as the season advanced, which is likely related to the decrease in syrup grade as the season advances. Fewer particles and fewer yeast and moulds in sap will result in an improved colour of syrup. However, none of the filtered sap samples collected during late-season sap runs and processed to syrup produced lighter colour syrup than the non-filtered equivalents. Although the sample size was limited, the decrease in microorganisms was most likely not enough to account for a quality increase in syrup grade. However, we observed a large difference in the cleanliness of the pans after boiling non-filtered vs. the filtered sap. Most of the time, the sides of the pans used to boil the syrup batches were much cleaner with the filtered sap than the non-filtered sap, even where only 18 litres of sap were used to produced the syrup for this particular experiment. It is expected that the differences would be more observable for larger quantities of sap being processed. Another benefit of sap filtration is the increase in storage time, provided it is filtered as soon as possible when collected.

It was observed that the temperature of the sap can increase 3-4 degree Celsius after filtration, depending on the operational set up of the producer. This may be due to the pumps warming up the sap, or environmental conditions which are warmer around the filtration system(s). This increase in temperature will likely accelerate degradation of the sap, and reduce any benefits the filtration may have. More research on techniques to keep sap cool must be done in order to evaluate its effectiveness at reducing microorganisms in the sap and its effect on syrup quality.

Filtration of the sap will not solve any degradation problems that may arise upstream or downstream from the filter due to poor management upstream to the filtration system or later in the processing. Filtration must always be accompanied with the application of best management practices throughout the production system, and preventative methods to reduce microbial growth, such as a clean tubing system, maintaining sap as cool as possible and processing it as quickly as possible. These preventative methods may be more important than filtration for the production of improved quality of syrup.

ACKNOWLEDGEMENTS

Sincere thanks are due to the 8 producers participating in the project and helping to collect data. Moreover, we would like to thank the following people for helping with the technical aspects of the project: Don Dodds (OMSPA), Dario Falsanisi (McGill University), Crystal Ernst and Michel Laviolette from Campus d'Alfred. Angela Wheeler's (Wheeler Maple Products, Lanark County) contribution to writing and editing the report is greatly appreciated. Funding was provided by the Ontario Maple Syrup Producers Association (OMSPA), Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), Agricultural Adaptation Council (AAC) through the Canada-Ontario Research and Development program (CORD) and North American Maple Syrup Council (NAMSC).

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