A Promising Alternative to Defoamers for Maple Production

Nathalie Martin, Fadi Ali, Jessica Houde, Stéphane Corriveau
Centre de recherche, de développement et de transfert technologique acéricole Inc. (Centre ACER), Québec, Canada

In North America, the sap of maple trees is collected in the spring to be processed into maple syrup. During the harvesting period, the composition of the sap will change depending on many factors such as the metabolism of the trees and the action of microorganisms that colonize the collection tubing system and processing equipment. Sap is composed of several organic and inorganic compounds such as sugars, organic acids, phenolic compounds, amino acids, and minerals (Perkins et al., 2006; Perkins and Van den Berg, 2009; Lagacé et al., 2015). Their presence in higher concentrations, combined with a higher load of microorganisms towards the end of the season (Lagacé et al., 2015), makes the sap more prone to excessive foaming and overflow when boiled for syrup production.

Foam development in the evaporator is a phenomenon often encountered in maple production (Martin, 2011). As it passes through the evaporator, the boiling sap can begin to foam quickly, especially at a later stage of the production season. When excessive foaming occurs, the use of a foam control agent, commonly called "antifoaming agent" or "defoamer" in the maple syrup industry, sometimes becomes necessary to avoid problematic overflows (low productivity, loss of product, cleaning challenges, safety, etc.).

Foaming is not exclusive to maple production, and the use of defoamers is generally of technical and economic interest in the food industry, as they are inexpensive, effective, and easy to use (Bensouissi, 2007). Defoamers are considered food processing aids in maple syrup production and are currently tolerated in the industry under certain conditions, given the strict standards governing the purity of maple products. Only trace amounts of defoamer should be used during the production process and only when really needed. Although this type of intervention significantly reduces the quantity of defoamer added, the maximum concentration allowed for a processing aid can easily be exceeded when important foaming occurs, leading to quality problems. This is particularly problematic for organic maple productions, which require that certified organic products, mostly cooking oils (safflower, canola, and sunflower), be used as defoamers. These oils are not strictly speaking defoamers and are much less effective (Martin 2016 and 2017 a,b; Van den Berg, 2020). The quantity added is therefore often excessive, leading to quality problems such as an oily texture and off-flavors.

In this context, the development of a foam control technique that does not require the use of a defoamer is an interesting way to maintain and ensure the purity of maple syrup. The aim of this proof-of-concept study was therefore to develop and test a system to control foaming in maple syrup production that is efficient, easy to use, and inexpensive, and which does not require the use of defoamer.

ANTIFOAMING PROTOTYPE DESIGN

The work conducted in this proof-of-concept study aims to evaluate the potential of an alternative method for controlling foaming in a maple syrup evaporator. But in order to do this, we had to investigate the basic concept behind foam formation and put it in the context of maple syrup production. In summary, when a liquid is heated, the energy supplied raises its temperature until it reaches the boiling state. During boiling, the liquid undergoes a transition to the gas phase; saturated vapor bubbles form and rise to the surface (Blander, 1979). If the liquid, such as a maple aqueous solution, contains surfactant molecules, like sugars, amino acids, proteins and protein fragments, these will be adsorbed at the gas/liquid interface to lower the surface tension (Bensouissi, 2007; Drenckhan et al., 2015). The vapor bubbles are then "trapped" and the foam is created (Garrett et al., 2014; Drenckhan et al., 2015).

Foams are desirable in several food and cosmetic applications, in hygiene and cleaning products, in pharmaceuticals, etc. In other applications, foaming is detrimental and must be controlled. To avoid the addition of a defoamer, mechanical devices have been developed in other industries. Of these, the most widely used is a rotating device equipped with disks or various arrangements of rotating blades. The main disadvantages of their use are their high operating costs, complex design and limited effectiveness (Vardar-Sukan, 1992 et 1998). When foaming is excessive and intense, they must often be used in combination with a defoamer.

In our previous studies, some of these techniques were adapted and tested in laboratory-scale experiments to evaluate their potential to control foaming in maple syrup production (Martin et al., 2017a). These involved spraying water, applying a jet of compressed air or using a rotating device. In all cases, the boiling was so intense that it was not possible to effectively control the foam with these techniques. Further work led us to the development of a new device, the proposed prototype, which uses the circulation of cold water to control foam formation.

The prototype was made of stainless steel SS316 piping network designed to provide the best possible surface coverage in each pan without affecting the evaporation process (Figure 1). This food grade steel material was chosen for its high resistance to acids, alkalis, and chlorides (such as salt). The height of the prototype above the liquid was adjustable. The flow of liquid passing through the pipes (potable water) could be controlled for each pan individually and was activated only when needed. The device operates in a closed system (Figure 2) and there is no direct contact between the circulating fluid of the device and the sap. The device was equipped with a cooling tank (with agitation) to maintain water at targeted temperatures, a flow meter, to evaluate the volume of water used during the tests, and temperature sensors to evaluate the heating of the water in the prototype after circulation in the evaporator.

Figure 1. Design and layout of the prototype in the evaporator (top: sap pans; bottom: syrup pans).

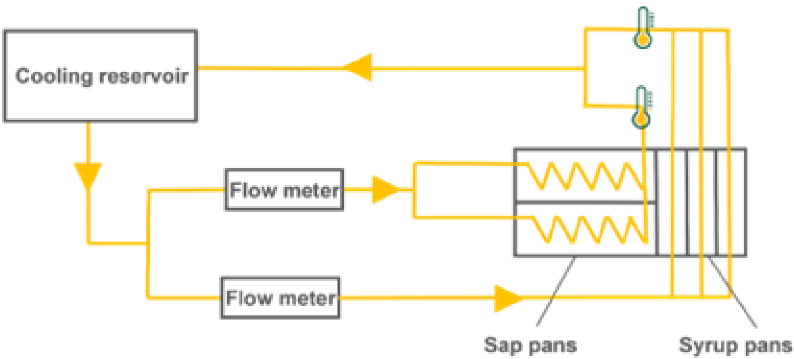

Figure 2. Diagram of the water supply circuit of the prototype during testing.

EXPERIMENTAL DESIGN AND TESTS

Concentrated sap

Sap from Centre ACER sugar bush (Saint-Norbert-d'Arthabaska, Québec, Canada) was collected at the end of 2017 and 2018 sugaring seasons to ensure foaming material during syrup production. The sap was concentrated at 15 oBrix and kept frozen at -18oC until needed. Sap was preheated to 70oC before treatment in the evaporator.

Maple syrup production

A small commercial-scale 19 in. x 48 in. evaporator (2 sections sap pan, and 3 sections syrup pan, Mini-Pro evaporator, Les Équipements Lapierre, Québec, Canada) placed on propane stoves equipped with height 30 000 BTU burners was used for the experiments. Evaporator settings were optimized to promote excessive foaming (near overflow) and monitored to ensure they were the same for each experiment so that the tests were comparable. The level of sap was maintained at 2 in. in the sap pans and 2 in. in the syrup pans. Production parameters (e.g., evaporation rate) were continuously monitored. The syrup was filtered at the end of each test, and samples were placed in a freezer until further analysis. The equipment was cleaned between each test. A total of 11 productions (n=7 with 2017 sap and n=4 with 2018 sap) were carried out with the prototype in different conditions of use. No defoamer was used during testing with the prototype. Two (n=2) control tests were conducted with a defoamer.

Control tests with defoamer

The efficacy of the prototype to control foaming was determined by comparing it to a defoamer. Two tests were carried out under the same production conditions, but where foaming was controlled only with Atmos 300K (Corbion), a commercial liquid defoamer commonly used in the maple industry. The liquid defoamer was used in the following two modes:

-Adding the defoamer manually and in the smallest quantity possible to control foaming at the predetermined marked height of 2 in. above the liquid in the sap pans and 1 in. in the syrup pans (n=1 production).

-Adding the defoamer in continuous mode using a peristaltic pump-type automatic liquid defoamer dispenser at a rate of 4 mL/h (not recommended). The device was installed in the sap pan according to the manufacturer's recommendations and defoamer was added manually in the syrup pans as needed (n=1 production). This test was done to completely avoid the formation of foam and to allow evaluation of the extent to which the presence of foam influences the process.

Prototype operation

The operating parameters of the prototype during testing are described in Table 1. They were chosen to represent extreme conditions in order to test the limits of the process.

Table 1. Experimental operating conditions of the prototype during testing

	Sap pans	Syrup pans
Height of the prototype above the liquid*	0.5, 1, 2 and 3 in.	0.5, 1 and 3 in.
Water flow rate in the prototype (low and high flow)	168 and 480 L/h (44 and 127 gal US)	135 and 384 L/h (36 and 101 gal US)
Water temperature in the prototype	4, 12 and 20 ºC (39, 54 and 68 ºF)	

*A height of 3 in. in the sap and syrup pans did not allow for good control of the production process. Therefore, this trial was excluded from the study.

Analysis

For the prototype performances, many parameters were followed such as the temperature and volume of circulating water into the prototype as well as processing rate, syrup draw-off and evaporation rate.

Each maple syrup produced was sampled and analyzed for its soluble solids content (oBrix), pH, conductivity, color (light transmittance at 560 nm), and flavor. Maple syrup flavor was evaluated by certified inspectors at ACER Division Inspection Inc. using the standard classification protocols and criteria used for bulk maple syrup quality control in Québec.

RESULTS AND DISCUSSION

Tables 2 and 3 respectively present the total volume of water used during the tests and the temperatures measured during the operation of the prototype. As seen in Table 2, the total amount of water per test required to control the foam level to the desired target is relatively high, even at low water flow, hence the need to operate in a closed system. The prototype was put into operation in the sap pans at the very beginning of each test when the foam reached the overflow point. In the syrup pans, the system generally had to be activated just before the first maple syrup draw-off to control the foam level to the desired height. The heating intensity in the evaporator was so high, and the quality of the sap was so prone to foaming, that the prototype had to be kept running continuously in both types of pans until the end of the tests. No defoamer was needed during testing with the prototype. Table 3 shows the temperature of the water circulating in the prototype during the tests. As expected, the water heats up and the warming was slightly higher at the sap pans exit. In general, the warmer the water enters the device, the warmer it will come out, maintaining the same defoaming effectiveness. The difference between the water outlet and inlet temperatures was also influenced by the flow rate and height of the prototype (not shown). The conditions that favor greater heating of the water in the prototype are a low flow rate and a lower height of the device. This would need to be confirmed with further tests.

Table 2. Average total volume of water used in the prototype during the tests

Water flow	Total volume of water (L/test)	
	Sap pans	Syrup pans
Low (168 and 135 L/h; n = 6)	619 ± 45	350 ± 23
High (480 and 384 L/h; n = 4)	2 061 ± 267	1 084 ± 133

Note: The data presented are an average of all conditions of use of the prototype and defoamer, and not of actual repetitions.

Table 3. Average temperature of the water circulating in the prototype during the tests

Targeted temperature	Measured temperature (°C)			Temperature increase (°C)	
	Inlet	Outlet Sap pans	Outlet Syrup pans	Sap pans	Syrup pans
Trials at 4 °C (n = 2)	4.8 ± 1.8	15.7 ± 2.7	12.9 ± 3.1	10.9 ± 4.5	8.1 ± 4.9
Trials at 12 °C n = 4)	12.6 ± 1.1	24.1 ± 3.4	20.0 ± 2.2	11.5 ± 4.0	7.4 ± 3.0
Trials at 20 °C n = 4)	20.0 ± 0.1	31.7 ± 4.7	28.8 ± 2.4	11.7 ± 4.7	8.8 ± 2.4

Note: The data presented are an average of all conditions of use of the prototype and defoamer, and not of actual repetitions.

Foam control efficacy

Evaporator operating parameters have been adjusted to promote excessive foaming. In Figure 3, the left panel shows the sap pans at the beginning of a trial before putting the prototype into operation: foaming is at the overflow point. The right panel shows that the foam level drops as soon as water begins to circulate in the prototype. This effect was observed under all operating conditions of the prototype in this study (regardless of water temperature and flow rate or height above liquid). In all cases, the foam was never eliminated, but its level could be maintained at the targeted height.

Figure 3. Effectiveness of the prototype to control foam formation in sap pans (left: prototype off; right: prototype on).

Although some subtleties may remain to explain the mechanisms underlying the control of the foam by the prototype, hypotheses can already be put forward based on empirical observations and the available scientific literature. The observed effect seems to be highly related to the temperature difference between the vapor contained in the gas bubbles and the “cold” air around the tube. This “thermal shock” phenomenon may cause part of this vapor to condense, creating a vacuum that deforms the bubble and causes it to implode. This will then cause the structure of the underlying foam bubbles to rupture (Yanagisawa and Kurita, 2019). The thermal shock phenomenon proposed may be similar to the “water hammer” observed in steam circuits or in pumping systems under the effect of cavitation (Farajisarir, D. 1993; Feng et al., 2000). When vapor suddenly condenses on contact with a lower temperature liquid in the pipes, its volume is instantly and violently reduced.

Effects on syrup Production

Table 4 presents some of the results obtained for production parameters evaluated during the tests. Overall, we observed a slight slowdown of the production process with the use of the prototype (e.g., longer production time, lower evaporation rate) compared to the defoamer. This is probably due to a slight cooling effect of the sap in the evaporator caused by the prototype.

Table 4. Production parameters

	Defoamers (n=2)	Prototype (n=10)
Processing rate (Imperial gal/h)	7.66 ± 0.68	6.13 ± 0.40
Syrup draw-off (Imperial gal/h)	1.69 ± 0.12	1.06 ± 0.14
Evaporation rate (Imperial gal/h/pi^2)	0.36 ± 0.05	0.30 ± 0.02

Note: The data presented are an average of all conditions of use of the prototype and defoamer, and not of actual repetitions.

Although the results obtained with the prototype are relatively similar for all conditions of use, it is possible to identify general trends. A low foam level allows for better control of the evaporation process. The settings of the prototype that seem to show the closest performance to the manually added defoamer are:

- Height of the prototype above the liquid: 1 in. in both sap and syrup pans.
- Water flow rate in the prototype: 168 and 135 L/h in the sap and syrup pans respectively (low flow)
- Water temperature in the prototype: 20°C

Maple syrup quality

Besides the fact that the sap at the end of the season generally produces lower quality syrup, the quality of maple syrup was relatively similar in all tests except for color. The syrup had a lower transmittance (darker syrup) with the prototype (36.1 ± 1.4%, n=7 sap 2017) compared to the defoamer added manually (40.2%, n=1 sap 2017). This is in agreement with the slowing down of the evaporation process observed with the prototype. The major effect on the maple syrup flavor was observed while using the defoamer in continuous mode. An off-flavor and a greasy texture related to defoamer were detected.

CONCLUSION

The aim of this project was to develop a system to control foaming in maple syrup production that is efficient, easy to use and inexpensive, and that does not require the use of a defoamer. This proof-of-concept study showed that it was possible to control foaming by circulating a cool fluid through a network of stainless-steel pipes placed above the boiling sap in the evaporator pans despite a certain slowdown of the process. These results were obtained even though extreme conditions (low quality sap and high evaporation temperatures) were used in our trials. Different results are therefore to be expected in different operation conditions.

Thus, more work is needed to optimize the system, and the integration of the process into maple syrup manufacturing operations is required (e.g., preheating the sap or R.O. filtrate for equipment cleaning, use of heat exchanger). It is important to emphasize that this promising technique preserves the purity of maple syrup, as nothing is added to the sap or sap concentrate during processing. Centre ACER is interested in continuing its development.

ACKNOWKEDGEMENTS

We thank the maple advisors of the Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec for their advice and support in this work. This research was supported in part by a grant from the Ministère de l'agriculture, des pêcheries et de l'alimentation du Québec and by Centre ACER.

LITERATURE CITED

Bensouissi. A. 2007. Auxiliaires technologiques utilisés en sucrerie de betterave et qualité du sucre blanc. Centre de recherche en physioco-chimie et biotechnologie agroindustrielle : Europol-Agro., Université de Reims Champagne-Ardenne, 239 pp.

Blander, M. 1979. Bubble nucleation in liquids. Adv. Colloid Interface Sci., Vol. 10(1) : 1-32.

Drenckhan W. and Saint-Jalmes A. 2015. The science of foaming, Adv Colloid Interface Sci. Vol. 222: 228-259.

Farajisarir, D. 1993. Growth and collapse of vapour bubbles in convective subcooled boiling of water (thesis). University of British Columbia.

Feng, H., Jinglong, Y. and Xuefang, W. 2000. Condensation-induced steam bubble collapse in a pipeline. Tsinghua Sci. and Technol.. 5. 424-427.

Garrett, P.R. 2014. The Science of Defoaming-Theory, Experiment and Applications, CRC Press, FL, USA, 598 pp.

Lagacé, L., Leclerc, S., Charron, Sadiki, M. 2015. Biochemical composition of maple sap and relationships among constituents. J. Food Comp. Anal., 41 :129–136.

Martin, N. 2011. Ce qu'il faut savoir sur le contrôle du gonflement dans les casseroles par les antimousses, InfoSirop Hiver 2011, p.6-7.

Martin, N. 2016. Essais et validation de deux nouveaux produits antimousses en production acéricole. Centre de recherche, de développement et de transfert technologique acéricole inc. Rapport Final 4010170-FIN-300916.

Martin, N. 2017a. Optimisation du contrôle du moussage dans les casseroles de l'évaporateur en production acéricole. Centre de recherche, de développement et de transfert technologique acéricole inc. Rapport Final 4010117-FIN-1102 V.2.

Martin, N. 2017b. L'état de la recherche sur les agents antimoussants, InfoSirop Hiver 2017, p.15.

Perkins, T.D., Morselli, M.F., van den Berg, A.K. and Wilmot, T., 2006. Annexe 2 - Maple chemistry and quality. In: North American Maple Syrup Producers Manual. 2nd ed. Heiligmann, R.B., Koelling, M.R., Perkins, T.D. (Eds.), p. 291-299.

Perkins, T.D. and van den Berg, A.K. 2009. Maple syrup-production, composition, chemistry, and sensory characteristics. Adv. Food Nutr. Res. 56: 101–143.

Van den Berg, A., and Perkins, T.D. 2020. Identifying an Effective Defoamer for Certified Organic Maple Production, Maple Syrup Digest, 59(1): 8-23.

Vardar-Sukan, F. 1992. Foaming and its Control in Bioprocesses, In: Recent Advances in Biotechnology, F. Vardar-Sukan and S.S. Sukan Editors., Springer, Dordrecht Publisher, 558 p.

Vardar-Sukan, F. 1998. Foaming: consequences, prevention and destruction. Biotechnology Advances. Vol. 16(5/6): 913-948.

Yanagisawa, N. and Kurita, R. 2019. In-situ observation of collective bubble collapse dynamics in a quasi-two-dimensional foam. Sci. Rep. 9, 5152: 1-9.