Spray drying of fruit juices project

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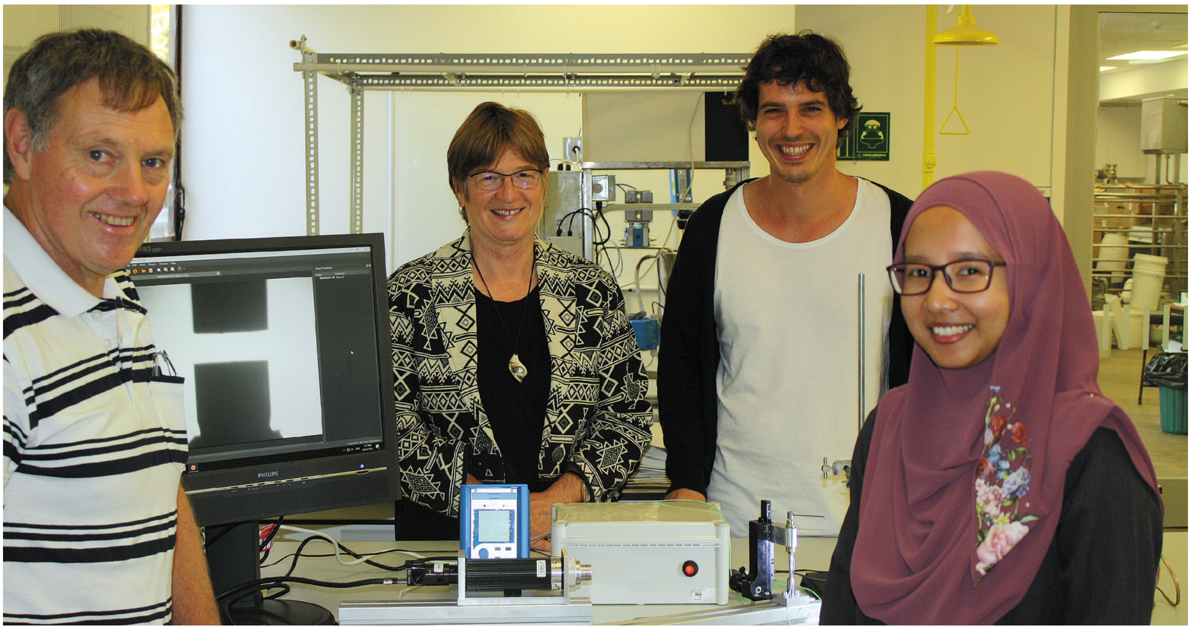

The team, left to right, Tony Paterson, Lee Huffman, Sebastian Linnenkugal, Siti Mohd Rozali

Introduction

This project has its basis on an approach that was made to Massey University, in 2014, to spray dry lemon juice.

The spray drying of most fruit juices is very difficult to impossible to achieve due to the sugar composition within most fruit juices. Typically, the sugars (mono-,di-, polysaccharides) and organic acids make up about 90% of the total solid weight of the juice and the final chemical composition differs for each fruit and depends on the level of treatment. There is also the complication of fruit acids or sugar alcohols such as malic acid and sorbitol in the mix [5], [6] . These components make it hard to impossible to dry as they have very low glass transition temperatures.

Effects of glass transition temperature

When a liquid, such as a juice, is rapidly dried, as happens in spray drying, the molecules of the solids in the liquid do not have time to crystallise before the solution becomes so thick that the molecules can no longer move past each other. When this happens the solid that is formed is said to be in a glass form. If this solid is heated, or allowed to adsorb moisture, then a point will be reached where the molecules can start to move past each other in a time frame that is noticeable. This point is known as the glass transition temperature of the substance. When it is exceeded, either due to the powder being exposed to a higher temperature, or due to having its glass transition temperature depressed by the adsorption of water into the powder, then the glass form undergoes a transition into a thick, rubbery like fluid which will flow and cause caking. When drying from a solution, there is a point when the droplets move from being a sticky powder to being a non sticky powder and this usually occurs when a powders surface falls below about 22°C above the glass transition temperature of the powder [7]. In order to be able to spray dry a liquid, the surface of the particles must be dry enough so that the glass transition temperature of the powder is high enough at the outlet of the spray dryer so that the powder particles do not stick to the walls.

Understanding this gives us a target for the conditions at the outlet of the dryer if we are to be successful in spray drying a particular substance. Namely, the powder needs to be dry enough by the time it reaches the wall so that it is no longer sticky, which can be approximated to having a surface below 22 °C above the glass transition temperature. If we apply this principle, along with a mass and energy balance around the spray dryer so we can predict the outlet air temperature and relative humidity, then we can predict where the optimum conditions for running the spray dryer should be.

The glass transition temperatures of pure, completely dry fructose and glucose powders are 11 and 31 respectively[10]. Thus, even at room temperature the glass transition temperature of the powders that are not completely dry is likely to be exceeded. Also, given that the lowest possible temperature that the outlet air temperature from a spray dryer can normally be run at is 50 to 80 °C,[11], it is obvious that it is impossible to spray dry a fruit juice without some sort of drying aid being added.

Demand for spray dried fruit juices

World wide there is a demand for being able to dry all sorts of fruit juices and, here in New Zealand, there is potential in black currant, lemon, apple and kiwi fruit juice powders. The usual method is to add a maltodextrin as a drying aid with the aim of raising the glass transition temperature of the resultant powder so that a dry fruit juice powder can be obtained from a spray dryer [1], [2], [3], [4], [8], [9], [11]. The amount of maltodextrin added has varied from 45 to 70% making the powder essentially spray dried maltodextrin with a fruit juice additive.

The lemon juice enquiry that started the project started with predicting the glass transition temperature of the powder based on its composition. This was found to be about 30°C different to the measured powder at any given water activity of the powder after it was produced and this showed that the current methods of predicting the glass transition temperatures of sugar mixtures and sugars with maltodextrins was inadequate[9]. Also, Cheuyglintase (2009) had shown that adding carrot fibre enabled apple juice concentrate to be successfully spray dried. From these works, it was conceived that it might be possible to spray dry fruit juices using fibres made from the pomace of the fruit, provided it was possible to spray the fibre suspensions. Because every juice has its own composition, it was desirable to take a holistic approach by first finding a better way of predicting the glass transition temperature of mixtures of sugars and maltodextrins and finding out what the best way of atomising fibre suspensions.

A work in progress

Thus, the spray drying of fruit juices FIET programme was born, with the first three years being devoted to understanding the science so it can be applied in the last three years of the project. At present Sebastian Linnenkugel and Siti Mohd-Rozali have completed the first two years of their PhD projects looking at predicting the glass transition temperature of sugar mixtures and understanding the rheology of fibre suspensions. To date we have succeeded in finding a better method of predicting the glass transition temperature of sugar mixtures. We also now understand why so much maltodextrin needs to be added to produce a successful powder from a spray dried fruit juice.

The issues of maltodextrin DE 9-13 and other high molecular weight drying aids is that there is a huge difference in size between the main solid components in the fruit juices (sugars and organic acids). By adding maltodextrin, the molecules in the system will interact with each other, but the overall structure of the system and therefore the glass transition temperature will only be modified slowly due to the large difference in quantity and size between the molecules. In the case of blackcurrant juice, by considering the interaction of the main solids, fructose, citric acid and glucose with maltodextrin DE 9-13 the overall anhydrous glass transition temperature for different ratios of maltodextrin DE 9-13 can be well predicted.

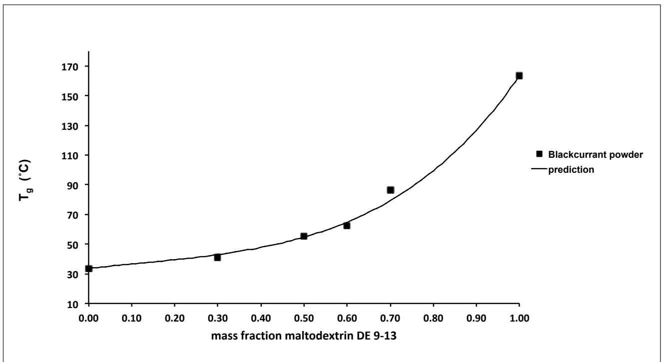

Figure 1. Glass transition temperature of anhydrous system of different mixture of blackcurrant with maltodextrin DE 9-13

The overall approach for drying a fruit juice was tested when we were approached to produce blackcurrant and grape juice powders for an industrial company. In this case it was permitted to use maltodextrin. We applied our method for predicting the glass transition temperature and the optimisation of the spray dryer operation and we successfully produced good powder on the first runs.

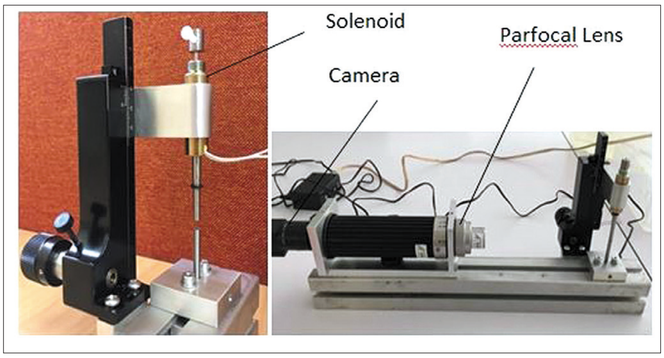

Figure. 2 (left) Close-up view of the portable extensional rheometer (right). Photograph of the whole setup including camera, lens and the portable extensional rheometer

Rheology of fibre suspensions

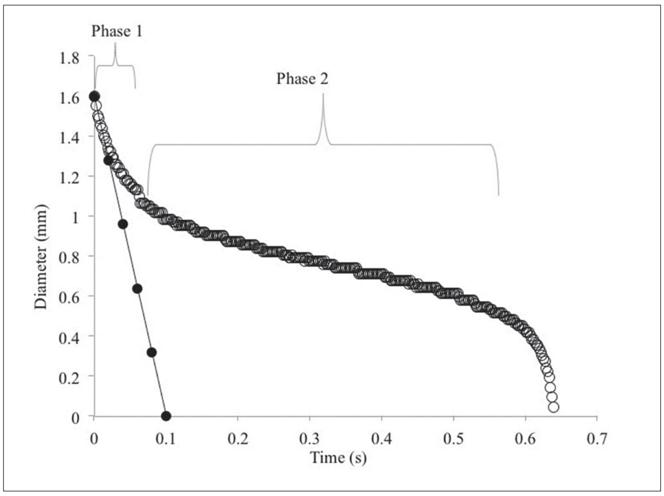

Figure 3. Filament diameter profile of apple juice (●, filled symbols) and 7 wt% citrus fibre suspensions (○, open symbols) showing the extensional behaviour of the fibre suspensions relative to the Newtonian behaviour of the pure apple juice

The rheologyof fibre suspensions has now been measured. To do this we built a capillary breakup extensional rheometer, (CaBER), shown in Figure 2 and, as shown in Figure 3, the fluids with fibre added show extensional rheological properties.

First trials with atomisation have shown that these extensional properties result in long filaments being formed under conditions sufficient to atomise the concentrated juice equivalent (Figure 4) used in the experiments and that more energy intensive methods must be used to successfully atomise fibre suspensions.

This work is continuing.

Fig4 - Left: Spray pattern for water with no fibres at the nozzle for Pa=1 bar: ligaments break and disperse into droplets. Right, Spray pattern for 5 wt% wheat fibres in an apple juice concentrate at the nozzle with PA= 1 bar: ligaments remain intact

Looking forward

We are also investigating alternative drying aids to raise the glass transition temperature of these mixtures, but it is too soon to know whether this will succeed or not.

With the results from these PhD's, the next stage will be to test the theory on different fruit juices using both fibres derived from the fruit pomaces and/or, possibly, the addition of alternative drying aids if they can be shown to increase the glass transition temperature of sugar mixtures with low percentage additions. The aim is to start with blackcurrant juice as an exemplar and then to find other juices that people would like to turn into powders. Any industry that has a potential juice they are interested in should contact the authors.

Acknowledgements

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References

1. Adhikari, B., Howes, T., Bhandari, B. R., & Truong, V. (2001). Stickiness in foods: a review of mechanisms and test methods. *International Journal of Food Properties,* 4(1), 1-33.

2. Adhikari, B., Howes, T., Bhandari, B. R., & Truong, V. (2004). Effect of addition of maltodextrin on drying kinetics and stickiness of sugar and acid-rich foods during convective drying: experiments and modelling. *Journal of Food Engineering,* 62, 53-68. doi:org/10.1016/S0260-8774(03)00171-7

3. Bhandari, B. R., Datta, N., Crooks, R., Howes, T., & Rigby, S. (1997). A semi-empirical approach to optimise the quantity of drying aids required to spray dry sugar-rich foods. Drying Technology, 15(10), 2509-2525.

4. Cheuyglintase, K. (2009). Spray drying of fruit juice with vegetable fibre as a carrier. (PhD), University of Canterbury, Christchurch.

5. Dolinsky, A., Maletskaya, K., & Snezhkin, Y. (2000). Fruit and vegetable powders production technology on the bases of spray and convective drying methods. *Drying Technology,*18(3), 747-758.:doi: 10.1080/07373930008917735

6. Elkins, E. R., Matthys, A., Lyon, R., & Huang, C. J. (1996). Characterization of Commercially Produced Apple Juice Concentrate. *Journal of Food Composition and Analysis,* 9(1), 43-56. doi: http://dx.doi.org/10.1006/jfca.1996.0006

7. Foster, K. D., Bronlund, J. E., & Paterson, A. H. J. (2006). Glass transition related cohesion of amorphous sugar powders. *Journal of Food Engineering,* 77(4), 997-1006.

8. Jaya, S., & Das, H. (2004). Effect of maltodextrin, glycerol monostearate and tricalcium phosphate on vacuum dried mango powder properties. *Journal of Food Engineering,* 63, 125-134.

9. Paterson, A. H. J., & Bröckel, U. (2015). Caking Development in Lemon Juice Powder. *Procedia Engineering,* 102(0), 142-149. doi:http://dx.doi.org/10.1016/j.proeng.2015.01.117

10. Schenz, T. W. (1997). Glass Transitions and Product Stability - An Overview. Food Hydrocolloids, 9(4), 307-315.

11. Shishir, M. R. I., & Chen, W. (2017). Trends of spray drying: A critical review on drying of fruit and vegetable juices. Trends in Food Science & Technology, 65, 49-67. doi:https://doi.org/10.1016/j.tifs.2017.05.006

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Food Industry Enabling Technologies

Food Industry Enabling Technologies (FIET) is funded by the Ministry for Business, Innovation and Employment and its purpose is to support new process developments that have the potential to add significant value to our national economy. The programme has six partners, Massey University (the host), Riddet Institute, University of Auckland, University of Otago, Plant and Food and AgResearch. Funding is $18m over six years (2015-2021) and targets pre-commercialisation activities. If you are interested in more information, then please contact either Dr Jo Kerslake, FIET Programme Director, (j.i.kerslake@massey.ac.nz) or Professor Richard Archer, Chief Technologist, (R.H.Archer@massey.ac.nz).