(Section 11.8), poor conching results in big differences between the up and down measurements of a viscometer. Further details concerning the effect of conching parameters on chocolate viscosity are given in Chapter 10.

In addition to coating particles, conching also removes moisture from the chocolate mass, which also has a big effect on viscosity.

11.9.5 Moisture

If a small percentage of moisture is added to chocolate it will become very thick. Indeed if as little as 0.3% extra moisture is left within the chocolate, it will be necessary to add another 1% of cocoa butter to restore the viscosity to what it should have been. This is probably in part due to water on the surface of the sugar particles, sticking them together and impeding the flow. Where lecithin is also present this is less likely to happen and indeed chocolates containing this emulsifier can have more water present and yet retain their correct flow properties. However, lecithin can have a negative effect during conching as its hydrophilic properties will reduce the amount of water evaporating from the mass.

Below the 1% level, however, most of the moisture is bound into the ingredients, for example as water of crystallisation in lactose, and so has little effect on the flow properties.

11.10 Advanced methods to characterise chocolate flow behaviour

Advanced methods to characterise the viscosity behaviour of chocolate include nuclear magnetic resonance (NMR) and ultrasound. These methods are not designed for routine laboratory analysis but have research and trouble-shooting applications.

Gotz *et al.* (2005) applied NMR T1 and T2 relaxation time measurements to chocolate model suspensions composed of fat blended with different emulsifiers, sucrose and skimmed milk powder. T2 was found to be more sensitive to the addition of solid material than T1. Only a small impact of emulsifier on the relaxation times was noted. The relaxation times were reported to correlate with zero shear and infinite shear viscosity determined with rotational and capillary rheometry.

Ouriev *et al.* (2003) described an industrial non-invasive trial which measured ultrasound velocity profiles and pressure differences (UVP-PD) in an untempered chocolate. The velocity profiles were fitted to a power law model and wall shear stress calculated from the pressure difference measurement. Good agreement was obtained with laboratory viscosity data and the UVP-PD method was also able to generate information on processing behaviour that could not be obtained by other techniques.

Conclusions

The flow properties of chocolate are very complex. However, an understanding of both flow property measurement and the factors affecting the flow can greatly help trouble-shooting and plant optimisation.

It is always important to measure the flow properties of chocolate under conditions that are as close as possible to those under which it is being processed. Where faults occur, corrective action should be taken according to the flow parameter that is incorrect, for example add PGPR for a high apparent viscosity at a low shear rate (Casson yield value), or cocoa butter for a high reading at a high shear rate (Casson plastic viscosity).

Acknowledgements

The author wishes to acknowledge that the basis of this Chapter has been Chapter 10 of the fourth edition of this book, kindly made available by Stephen Beckett.

References

Aeschlimann, J.M., Beckett, S.T. (2000) International inter-laboratory trials to determine the factors affecting the measurement of chocolate viscosity, *Journal of Texture Studies*, **31**(5), 541–576.

Arnold, G., Schade, E., Schneider, Y., Friedrichs, J., Babick, F., Werner, C., Rohm, H. (2014) Influence of individual phospholipids on the physical properties of oil-based suspensions, *Journal of the American Oil Chemists Society*, **91**(1), 71–77.

Beckett, S.T. (2001) Casson model for chocolate, friend or foe? *The Manufacturing Confectioner*, **5**, 61–66.

Beckett, S.T. (2008) *The Science of Chocolate*, RSC, Cambridge.

Beckett, S.T. (2009) Chocolate flow properties. In: *Industrial Chocolate Manufacture and Use*, Blackwell Publishing, London.

Carvalho-da-Silva, A.M., Van Damme, I., Wolf, B., Hort, J. (2011) Characterisation of chocolate eating behaviour *Physiology and Behavior*, **104**(5), 929–933.

Carvalho-da-Silva, A.M., Van Damme, I., Taylor, W., Hort, J., Wolf, B. (2013) Oral processing of two milk chocolate samples, *Food and Function*, **4**(3), 461–469.

Chevalley, J. (1991) An adaption of the Casson equation for the rheology of chocolate, *Journal of Texture Studies*, **22**(2), 219–229.

Chevalley, J. (1999) Chocolate flow properties. In: *Industrial Chocolate Manufacture and Use*, Blackwell Publishing, London.

De Graef, V., Depypere, F., Minnaert, M., Dewettinck, K. (2011) Chocolate yield stress as measured by oscillatory rheology, *Food Research International*, **44**(9), 2660–2665.

Dhonsi, D., Stapley, A.G.F. (2006) The effect of shear rate, temperature, sugar and emulsifier on the tempering of cocoa butter, *Journal of Food Engineering*, **77**(4), 936–942.

Finke, H. (1965) *Handbuch der Kakaoerzeugnisse*, Springer, Berlin.

Goodwin, J.W., Hughes, R.W. (2008) *Rheology for Chemists*, RSC Publishing, Cambridge.

Gotz, J., Balzer, H., Hinrichs, R. (2005) Characterisation of the structure and flow behaviour of model chocolate systems by means of NMR and rheology, *Applied Rheology*, **15**(2), 98–111.