The viscosity of supersaturated aqueous glucose, fructose and glucose-fructose solutions

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Keywords:

supersaturation, glucose, fructose, viscosity

Abstract. The viscosity of supersaturated aqueous glucose-fructose solutions has been measured, using flow curves on an Anton Paar RheolabQC rotating viscometer. Three different concentration (85%, 83%, 81%) and five different glucose:fructose ratios (60:40, 55:45, 50:50, 45:55, 40:60) has been selected in a similar composition to honey. Measurements were taken at temperatures ranging from +10 to +50 °C.

All systems exhibited Newtonian behaviour, meaning that the viscosity is independent of the shear rate. The viscosity of the supersaturated solutions was decreasing with increasing temperature and increasing with increasing the concentration. Aqueous solutions of fructose are somewhat more viscous than glucose solutions. For aqueous glucose-fructose solutions, the increase of fructose concentration increases the solutions viscosity.

INTRODUCTION

Viscosity is widely acknowledged as a key physical property in understanding the flow of raw materials, processing intermediates and final products (Ferry, 1980). Aqueous solutions of glucose and fructose at different temperatures and concentrations are found in several food processes and basis to formulation of a number of food products or ingredients in the bakery, ice cream, and confectionary industries (Telis et al., 2007). The confectionary products as well as honey contain high amount of sugar and knowing the flow properties of supersaturated sugar solutions are important in designing industrial processes like pumping, filtration, mixing and packaging.

There have been several studies looking at viscosities of aqueous sugar solutions. The viscosity-temperature relationship in aqueous sugar amorphous phases in partially frozen systems has been evaluated by Maltini & Anese (1995) and in liquid supercooled pure sugar systems has been evaluated by Kerr & Reid (1994). Several studies have been performed with solutions of sucrose, glucose and/or fructose in a range of temperatures and concentrations with objective of comparing different models (Arrhenius, Williams-Landel-Ferry (WLF), Vogel-Taumman-Fulcher (VTF), and power law) to fit experimental data (Recondo, et al., 2006; Quintas et al., 2006; Telis et al., 2007). All the models can be employed quite satisfactorily to describe the experimental behaviour. However, the Arrhenius model predicts the lower temperature dependence, while the WLF predicts the higher temperature dependence close to the Tg value (Telis et al., 2007).

There is a lack of data on supersaturated aqueous sugar systems similar to honey. The aim of the present work was to determine experimental values of viscosities for supersaturated aqueous glucose-fructose solutions as a function of temperature and concentration.

MATERIALS AND METHODS

Supersaturated solutions of glucose, fructose and glucose-fructose were prepared by appropriate amounts of glucose (Cargill) and fructose (Cargill), up to complete dissolution in distilled water at 95 °C. Three different concentration (85%, 83%, 81% w/w) and five different glucose (G):fructose (F) ratios (60:40, 55:45, 50:50, 45:55, 40:60) has been selected in a similar composition to honey.

Flow properties of samples at temperatures in the range of 10 – 50 °C at 10 °C intervals were measured with a RheolabQC rotating viscometer (Anton Paar, Germany) fitted with CC27 system, with temperature controlled water bath. The apparent viscosity η was measured as a function of shear rate $\dot{\gamma}$ (1 – 100 s^{-1}). Moreover, the apparent viscosity was measured as a function of shear time (2 minutes), while keeping the shear rate constant (50 s^{-1}). Samples were allowed to rest for about ten minutes before to measuring their rheological properties. All determinations were performed in triplicate.

RESULTS AND DISCUSSION

All systems exhibited Newtonian time independent behaviour in the whole domain of temperature, meaning that the viscosity is independent of the shear rate. This is according to other published works, sugar solutions as well as honey are reported to be Newtonian fluids (Recondo et al., 2006; Telis et al., 2007; Lazaridou et al., 2004).

The supersaturated 83% glucose solution showed the low viscosity 2.14 ± 0.30 Pa*s at 20 °C compared to other tested solutions. The supersaturated 83% fructose solution had viscosity 9.27 ± 0.23 Pa*s and 83% glucose-fructose solutions had slightly higher viscosity values than fructose solutions, ranging from 11.0 ± 0.3 Pa*s (G50:F50) to 13.15 ± 1.32 Pa*s (G40:F60) at 20 °C. The viscosity of supersaturated 83% glucose-fructose solutions increased with an increase in fructose content (Figure 1). This is in agreement with Sopade et al. (2004) work. Glucose and fructose are chemically different. Fructose is a ketose sugar, while glucose is an aldose sugar, and the positions of the hydroxyl groups in these sugars can influence hydrogen bonding with water.

The viscosity of the supersaturated solutions was decreasing with increasing temperature (Figure 2a). As temperature increases, viscosity falls, due to less molecular friction and reduced hydrodynamic forces (Mossel et al., 2000). The value of viscosity had a dramatic decrease in the low range of temperature. Similar results have been obtained in different studies (Recondo et al., 2006; Sopade et al., 2004; Telis et al., 2007). Generally, at a low temperature, the viscosity of materials is usually very high as they tend towards the glassy state (Rahman, 1995).

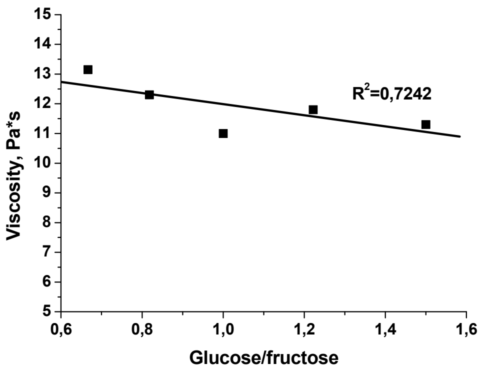

Figure 1
Viscosity of supersaturated 83% glucose-fructose solution
as a function of glucose-fructose ratio at 20 °C

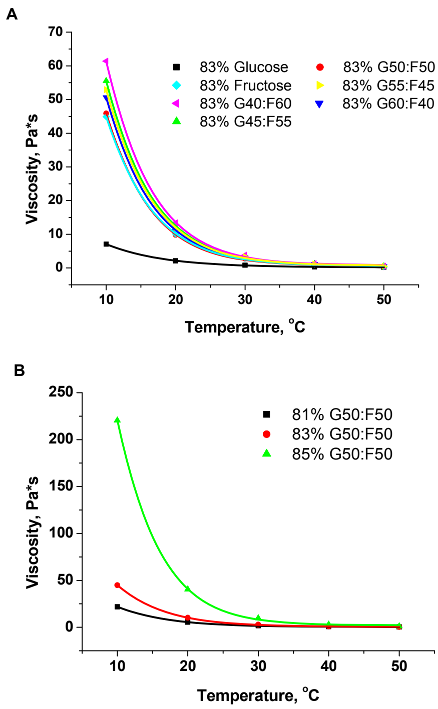

Figure 2
Viscosity of sugar solutions as a function of temperature (a) and solid content (b)
at shear rate 50 s^{-1}.

Increase in moisture content (decrease in solids) (Figure 2b) exponentially reduce the viscosity of aqueous supersaturated glucose/fructose solutions. This is in accordance with published studies on honeys and other foods (Munro, 1943; Sopade et al., 2004). The temperature have more effect on more concentrated solutions.

CONCLUSIONS

Supersaturated aqueous glucose, fructose and glucose-fructose solutions showed Newtonian time independent behaviour. The glucose solution showed the low viscosity compared to other tested solutions. Increases in moisture, glucose and temperature reduced the viscosity while the increase in fructose content increased the viscosity of supersaturated glucose-fructose solutions.

ACKNOWLEDGEMENTS

This work was supported by the institutional research funding IUT (1927) of the Estonian Ministry of Education and Research and by the EU Regional Development Fund (project EU29994).

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