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Predictive model of viscosity for a caramelization reaction

Vincent CAQUERET, Imelda Elizabeth ORTIZ-CERDA, Jean-Louis HAVET

CNAM, 2 rue Conté, 75003 Paris – Université Paris-Saclay, INRAE, AgroParisTech, UMR Sayfood, 91120 Palaiseau - France

Introduction

Dynamic viscosity is essential for design and scale-up of industrial processes. The formation of di-fructose dianhydrides (DFAs) in fructose caramel can be obtained by operating at temperatures between 70 and 90°C. Under these conditions, the caramelization reaction needs to be initialized by acid catalysis. The use of solid catalyst induces strong rheological constraints.

The objective of this study was to **calculate apparent viscosity in different homogeneous and heterogeneous samples**.

Experimental section

Products and materials	Caramelization set up	Density measurements	Viscosity measurements (rheometer)	Viscosity measurements (viscometer)
Caramelization Anhydrous D-fructose 99% Ion exchange resin Lewatit 2328 (catalyst) Strongly acid, macroporous Particle size 400 – 500 nm Density 1100 kg.m ⁻³ Catalyst activation/deactivation Aqueous HCl 1M Aqueous NaCl 1M Deionized water	1 L double jacketed stirred glass vessel with reflux system Temperature control by Pt100/cryothermostat Stirring system : motor and blade anchor	Graduated cylinder hermetically sealed (+/- 1 mL) Alcohol thermometer (+/- 1 °C) Thermostatically controlled bath Precision scale (+/- 0,1 g)	MCR302 Rheometer (Anton Paar) Cone-plate measuring geometry Temperature control by peltier hood C-PDT200 (Anton Paar) Rheoplus/32 v3.61 software (Anton Paar)	In situ viscosity measurements Digital rotational DV-E viscosimeter (Brookfield) Test with pure glycerol

Viscosity measurement and modelling for fructose syrups

Viscosity measurements (expressed in Pa.s)

Temperature (°C)	Fructose mass fraction		
	0.7	0.8	0.9
70	51 ± 4	143 ± 6	1251 ± 19
80	39 ± 4	106 ± 7	646 ± 3
90	36 ± 4	95 ± 6	449 ± 16

Viscosity decreases with the increase in temperature.

Viscosity increases with the fructose mass fraction in the syrup.

Prediction of fructose syrups' viscosity

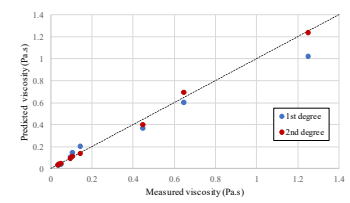
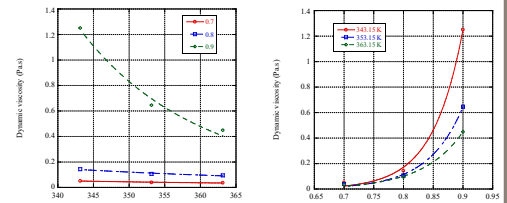
Temperature dependence of viscosity (Arrhenius type equation)

$$\mu = \mu_{\infty} \times \exp\left(\frac{E_a}{RT}\right) = \exp\left(\ln\mu_{\infty} + \frac{E_a}{RT}\right)$$

E_a/R and $\ln\mu_{\infty}$ were correlated with fructose mass fraction using first- and second-degree polynomial equations

$$\mu = \exp\left(a_1 x_F + b_1\right) + \frac{(a_2 x_F + b_2)}{T}$$

$$\mu = \exp\left((a'_1 x_F^2 + b'_1 x_F + c'_1) + \frac{(a'_2 x_F^2 + b'_2 x_F + c'_2)}{T}\right)$$



Apparent viscosity measurement and modelling for heterogeneous mixtures

Apparent viscosity measurements (expressed in Pa.s)

Resin proportion (w/w)	Temperature (°C)		
	70	80	90
0.09	3 563 ± 66	1 465 ± 57	763 ± 65
0.18	4 286 ± 51	1 721 ± 17	756 ± 10
0.27	5 988 ± 146	2 181 ± 38	1 030 ± 36

(Fructose mass fraction 0.9)

Apparent viscosity decreases with the increase in temperature.

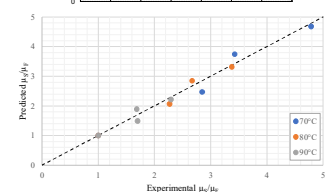
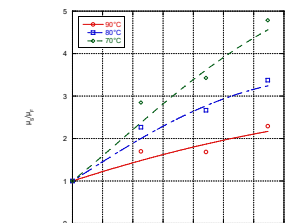
Apparent viscosity increases with the fructose mass fraction in the syrup.

Modeling the apparent viscosity of heterogeneous samples

Apparent viscosity of a liquid-solid mixture depends on the dynamic viscosity of the carrier fluid, temperature and the solid volume fraction

$$\frac{\mu_S}{\mu_F} = (1 + a_3 C_V + b_3 C_V^2)^p \quad (\text{Vand})$$

$$\frac{\mu_S}{\mu_F} = \left(1 + \frac{C_V}{a_4}\right)^q \quad (\text{Krieger-Daugherty})$$



Conclusion

Fructose syrups, with or without catalyst particles, were characterized in term of viscosity and density in the range of fructose mass fraction between 0.7 and 0.9, temperatures between 70 and 90 °C and catalyst proportion between 0.09 and 0.27 w/w.

For fructose syrups, viscosity was correlated as a function of temperature and fructose mass fraction with Arrhenius model.

The apparent viscosity of fructose syrups with catalyst particles were correlated with derivative Vand model.

By using this equation, a prediction of the viscosity of fructose caramels can be proposed depending on the caramelization temperature and fructose concentration in the initial syrup.