

Predictive model of viscosity for a caramelization reaction

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Dynamic viscosity is related to transport properties and therefore, is essential for industrial design and scale-up of many industrial processes. The preparation of caramel uses simple raw materials (sugars, water and sometimes a catalyst) and has been the subject of several studies in the literature. To obtain the formation of DFAs in fructose caramel, it is necessary to operate at temperatures between 70 and 90°C. Under these conditions, the caramelization reaction needs to be initialized by acid catalysis. Some authors use acid reagents in liquid form (homogeneous catalysis). Others use solid catalyst (heterogeneous catalysis), inducing strong rheological constraints. Despite the vast amount of experimental data for homogeneous catalysis, a lack of data can be noticed for heterogeneous catalysis.

The objective of the present work was to calculate apparent viscosity in heterogeneous samples. Experimental data for fructose syrups were first modeled as a function of temperature and fructose mass fraction using an Arrhenius-type equation (Eq. (1)).

$$\mu = \exp\left((a_1 x_F^2 + b_1 x_F + c_1) + \frac{(a_2 x_F^2 + b_2 x_F + c_2)}{T}\right) \quad (1)$$

Experimental data concerning heterogeneous mixtures were then used to test Vand equation (Eq. (2)) to express apparent viscosity as a function of dynamic viscosity of the carrier fluid and solid fraction.

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

For fructose syrups and fructose syrups/catalyst mixtures, dynamic or apparent viscosity measurement were performed in a MCR302 rheometer (Anton Paar). The caramelization reaction was carried out in a 1 L thermostated double jacketed stirred glass vessel with a reflux system. During caramelization process, in-situ apparent viscosity measurements were performed with a digital rotational viscosimeter (Brookfield DV-E).

The lines in Figure 1A represent the predicted viscosity values of fructose syrups using Eq. (1). The experimental values are also included in these plots. Figure 1B presents the evolution of fructose syrup viscosity as a function of fructose mass fraction.

In Figure 1A, the results show an acceptable correlation of the experimental viscosities with the Arrhenius equation. In Figure 1B, viscosity rises exponentially with increasing fructose concentration, though the trend is less pronounced at higher temperatures.

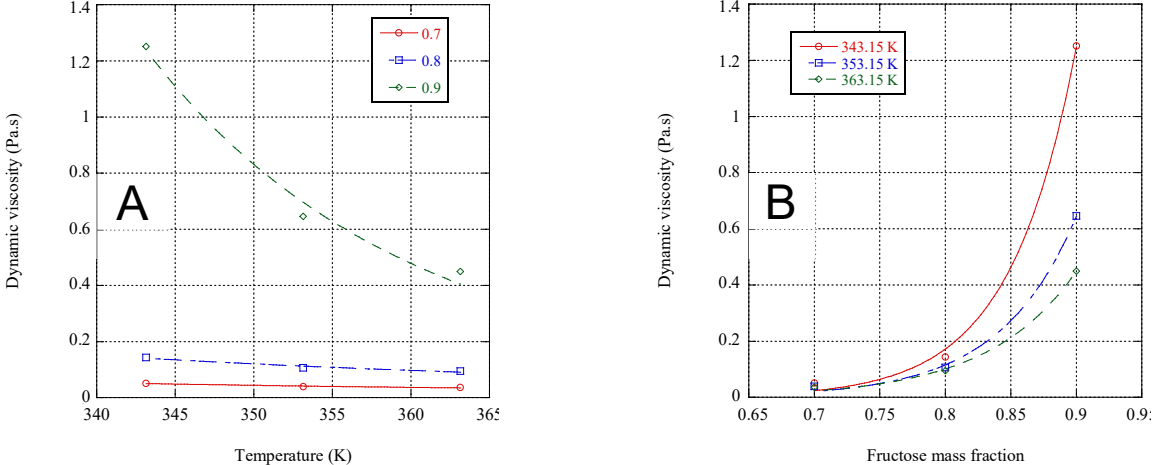


Figure 1. Viscosities of fructose syrups A: vs. temperature for different fructose concentrations, B: vs. fructose mass fraction for each temperature studied.

Vand equation was fitted to experimental data to describe the dependence of the mixture viscosity on the solid volume fraction. Fitting curves are presented in Figure 2. The results revealed a good ability of the Vand model to describe experimental data.

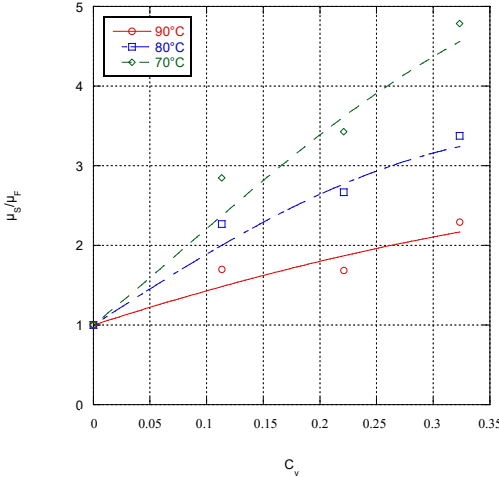


Figure 2. Viscosities of fructose syrup/catalyst mixtures as a function of solid volume fraction for different temperatures.

Finally, from the model used for caramelization in heterogeneous phase, it is possible to predict dynamic viscosity of the homogeneous caramel (without catalyst).