In-line Low Field Magnetic Resonance Reveals Inversion State of Inverted Syrups

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Introduction

- Sugar syrups play a vital role in the food and beverage industries contributing sweetness, texture, flavor profile, and preservation properties to the end product.
- They are frequently combined with acidulating agents like citric acid to enhance flavor and extend shelf-life [1].
- Sucrose, the primary sugar in many syrups, experiences inversion when exposed to heat and acid, breaking it down into glucose and fructose, leading to changes in the physicochemical properties of the syrup.
- There remains a lack of understanding regarding this process.
- Here we monitor how T_2^{eff}, a parameter that provides vital insights into molecular mobility within a solution varies as sucrose syrups are inverted.
- Furthermore, we present this using a system developed to allow measurements during flow to demonstrate applicability to in line processes.

Figure 1: Left, Simulation of Halbach array. Centre, photograph of constructed magnet arrangement with copper shielding. Right, Peristaltic pump.

Methodology

Experiment 1

- A 70% sugar syrup is prepared, to which 2% citric acid was added to catalyze the inversion process.
- Heat treatment is applied and Brix, viscosity and T_2^{eff} measured after 1 hour, 2 hours, and 4 hours.
- The sugar content was measured using Brix, while viscosity was used to understand the flow characteristics of the syrup at different stages of the experiment.
- T_2^{eff} was measured to determine if it would reveal the inversion state.
- NNLS T_2^{eff} relaxation spectra were acquired, providing the distribution of the relaxation times for the different sugar molecules. This has proven effective in quantitatively elucidating complex characteristics in similar systems [2].

Experiment 2

- The impact of pump speed (RPM) on the T_2^{eff} relaxation times is assessed for sugar-citric acid syrup solutions with different Total Soluble Sugar contents (70%, 71%, and 72%).
- Solutions were circulated at 0, 25, and 55 RPM giving flow rates of 0, 165 and 356 mm/min. Continuous measurements were taken and the Mean T_2^{eff} plotted in Figure 4.

Results and Discussion

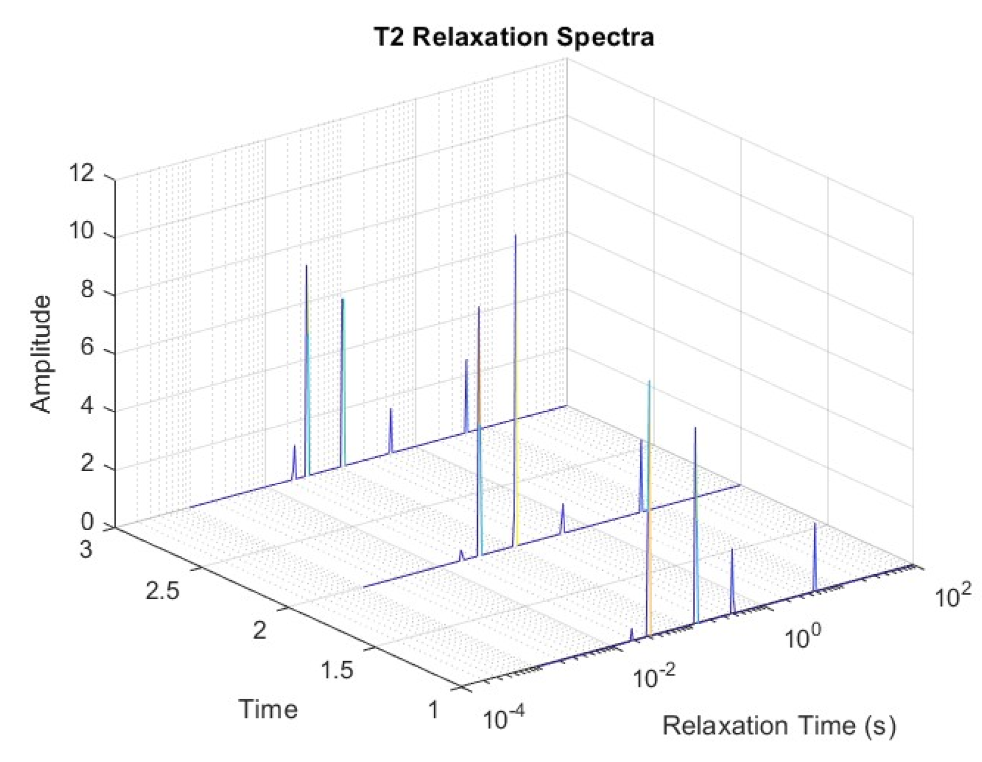

Figure 2: NNLS Spectra from experiment 1

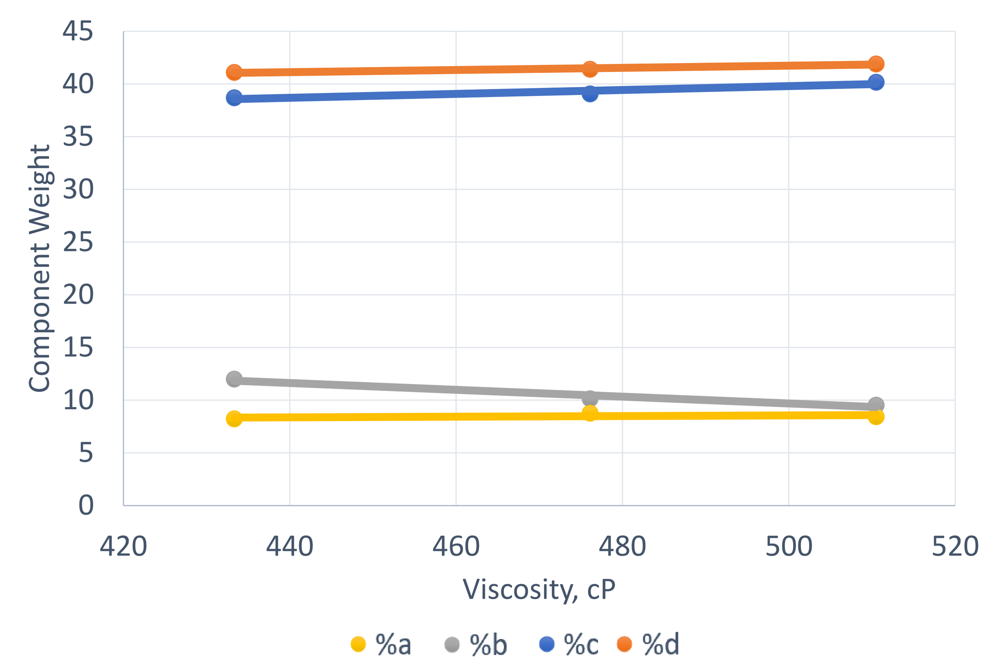

Figure 3: Viscosity vs weight of most prominent NNLS components

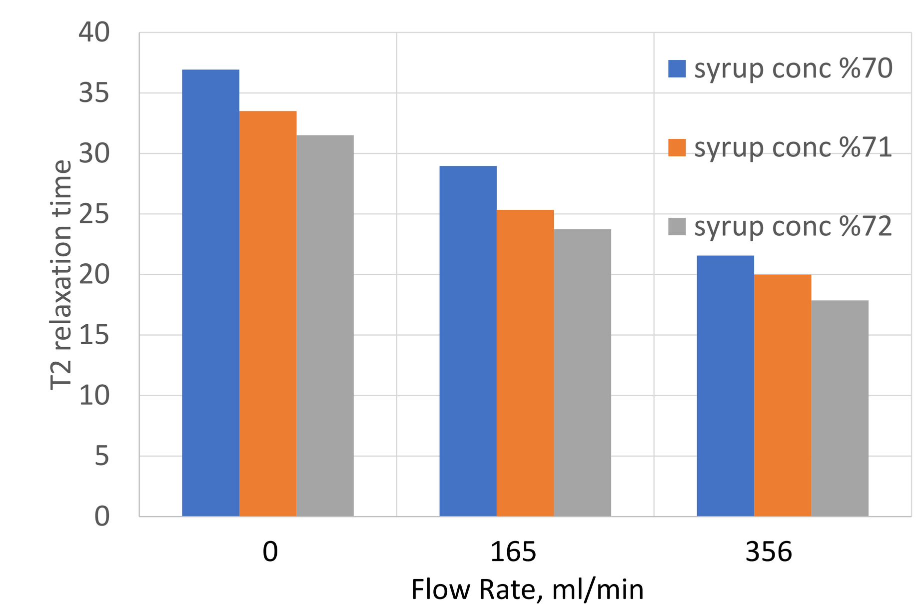

Figure 4: Effect of flow rate on T_2^{eff}

- Relative weights of T_2^{eff} NNLS components (Figure 2) shifted significantly with the heat treatment. As seen in figure 3, the weights of components associated with longer relaxation times, such as 'a' and 'd', decreased while those associated with shorter relaxation times, such as 'b' and 'c', increased.
- This suggests a conversion from a less inverted to a more inverted state with increased heat treatment as would be expected in an acidic environment.
- The differences in T_2^{eff} for the three difference sugar concentrations (Figure 4) remain well resolve. regardless of pump speed which holistically shortens T_2^{eff}.
- This shortening may be caused by the sample experiencing a wider range of magnetic fields effectively increasing G.
- However, measurements which are dependent on T_2^{eff} remain possible even at high flow rates.

Parameter	Value
Repetition Time	500 ms
Echo time	100 µs
Number of Echoes	128
Averages	64

Table 1: Pulse sequence parameters for CPMG sequence used to measure T_2^{eff}

Conclusion

- T_2^{eff} relaxation times are dependent on heat treatment time and inversion state.
- The observed decrease in T_2^{eff} as the viscosity increases suggests changes in molecular mobility and texture.
- The ability to monitor these changes in a flowing fluid is valuable to the food and beverage industries which has been shown to be possible with the design presented up to 350ml/min.

Acknowledgments

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