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Rheological Behavior of Blood Orange Juice Concentrated by Osmotic Distillation and Thermal Evaporation

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Abstract:
Fruit juices concentrated by osmotic distillation are characterized by higher organoleptic and sensorial properties than those of juices concentrated by thermal evaporation as confirmed by several research studies. On the other hand, no literature is readily available about the rheological characterization of juices concentrated by osmotic distillation. This work aimed at investigate the rheological behavior of the concentrated blood orange juice prepared from the clarified juice by using thermal evaporation and osmotic distillation processes as a function of solids concentration in the range 115 – 614 g/kg of total soluble solids (TSS) within a range of 20 – 70 °C. The effect of the temperature and concentration on the juice viscosity was studied. Arrhenius-type correlation equations for viscosity were used to represent the temperature dependence of viscosity. Values of the Arrhenius equation parameters (flow activation energy) were calculated for the measured viscosities of juices as a function of concentration. Results indicated no significant differences in the rheological behavior for orange juices concentrated with both methods. The juices exhibited a Newtonian behavior regardless of the concentration method.

Key words:
Blood orange juice, thermal evaporation, osmotic distillation, rheology

1 INTRODUCTION

The blood orange juice is a typical Italian product characterized by the presence of huge amounts of health promoting substances such as ascorbic acid, hydroxycinnamic acids and anthocyanins [1]. Three types of this product are mainly present on the European market: fresh juices, obtained by simple squeezing and mild pasteurization (fresh squeezed), not from concentrate juices (NFC) obtained by freezing after squeezing and juices reconstituted from concentrate (RFC). A large part of the market is based on the latter products, as the concentration process (up to 600 g/kg final concentration of dissolved solids) allows to reduce storage volumes (thus reducing transport and storage costs) and to facilitate preservation. Nevertheless, when concentration is carried out by traditional multistep vacuum evaporation, a severe loss of the volatile organic flavor/fragrance components occurs, as well as a partial degradation of ascorbic acid and natural antioxidants, accompanied by a certain discoloration and a consequent qualitative decline [2]. These effects are mainly due to the heat transfer to the juice during the evaporation.

Compared with traditional juice processing methods, membrane processes are low-cost and athermal separation techniques which involve no phase change or chemical agents. These features are becoming very important factors in the production of new fruit juices with natural fresh tastes and additive-free. Membrane concentration processes, such as reverse osmosis, membrane distillation, and osmotic distillation present some attractive potentials to overcome limitations associated with vacuum evaporation [3]. In particular, osmotic distillation is an athermal membrane-separation process in which the driving force of the process is given by a water vapor pressure gradient across a macroporous hydrophobic membrane separating two aqueous solutions having different solute concentration: a dilute solution on one side and a hypertonic salt solution (concentrated brine stripper) on the opposite side. The water vapor pressure gradient determines a water vapor transfer across the membrane pores from the high-vapor preswhere η is the viscosity (Pas), η_0 a constant (Pas), E_a the activation energy (kJ/mol) for flow, T is the absolute temperature (K), and R the gas constant (kJ/(molK)). Therefore, the experimental data were used to derive mathematical models describing the relation between parameters such as viscosity, concentration, temperature and activation energy. Such models are useful in engineering applications that are related to proper design and unit operations, as well as for the understanding of the transport process. The Arrhenius plots obtained for both osmotic distillation and thermal evaporation samples are reported in Figures 5a and 5b, respectively. Results for both samples are summarised in Tables 2a and 2b. The activation energy increased with an increase in soluble solids concentration. For the clarified juice concentrated by osmotic distillation it increased from 17.35 to 47.86 kJ/mol as soluble solids content increased from 155 to 700 TSS g/kg, respectively. A similar trend was observed for the thermally evaporated juice where the activation energy increased from 15.31 to 47.11 kJ/mol in the same investigated TSS range. Similar results were found for clarified juices [7, 21, 26, 27], liquorice extract [22], mango juice [23], mulberry pekmez [24] and Gaziantep pekmez [25]. The difference between viscosity and activation energy values for samples concentrated by osmotic distillation and thermal evaporation was statistically insignificant revealing that various concentration methods did not change the flow behavior.

4 CONCLUSIONS

Blood orange juice was concentrated from the ultrafiltered juice by using thermal evaporation and osmotic distillation. The rheological behavior of both juices was studied as a function of solids concentration in the range 155 – 700 g/kg at 20 – 70 °C by using a strain-controlled rheometer. The fresh juice showed its pseudo plastic flow behavior. The ultrafiltered juice and concentrated juices exhibited Newtonian behavior. Differences between viscosity and activation energy values for both concentrated juices were statistically insignificant, revealing that various concentration methods did not change the flow behavior. Useful flow parameters were derived for modeling and optimization of juice processing.

TSS (g/kg)	T (°C)	η (mPas)	E_a (kJ/mol)	r^2
700	20.0	450.0	48	0.9946
	30.0	200.0		
	40.0	110.0		
	50.0	63.0		
	60.0	36.1		
	70.0	25.2		
614	20.0	70.0	33	0.9792
	30.0	39.0		
	40.0	23.6		
	50.0	15.9		
	60.0	11.9		
	70.0	10.0		
565	20.0	33.9	30	0.9918
	30.0	19.5		
	40.0	13.4		
	50.0	9.5		
	60.0	7.2		
	70.0	5.4		
450	20.0	9.6	23	0.9960
	30.0	6.6		
	40.0	4.9		
	50.0	3.7		
	60.0	3.0		
	70.0	2.4		
265	20.0	3.0	19	0.9984
	30.0	2.3		
	40.0	1.8		
	50.0	1.4		
	60.0	1.2		
	70.0	0.9		
205	20.0	2.2	18	0.9985
	30.0	1.7		
	40.0	1.4		
	50.0	1.1		
	60.0	0.9		
	70.0	0.7		
155	20.0	1.9	17	0.9997
	30.0	1.5		
	40.0	1.2		
	50.0	1.1		
	60.0	1.1		
	70.0	0.8		

Table 2a: Total soluble solids, temperature, viscosity, and activation energy values for orange juice samples concentrated by osmotic distillation.

TSS (g/kg)	T (°C)	η (mPas)	E_a (kJ/mol)	r^2
700	20.0	422.0	48	0.9920
	30.0	190.0		
	40.0	97.0		
	50.0	58.0		
	60.0	35.2		
	70.0	24.7		
614	20.0	71.6	34	0.9917
	30.0	38.0		
	40.0	25.3		
	50.0	17.0		
	60.0	12.2		
	70.0	9.0		
565	20.0	33.9	30	0.9931
	30.0	20.7		
	40.0	13.6		
	50.0	9.5		
	60.0	7.1		
	70.0	5.6		
450	20.0	9.4	23	0.9961
	30.0	6.4		
	40.0	4.7		
	50.0	3.7		
	60.0	2.9		
	70.0	2.3		
265	20.0	3.0	19	0.9824
	30.0	2.2		
	40.0	1.8		
	50.0	1.4		
	60.0	1.3		
	70.0	0.9		
205	20.0	2.3	18	0.9975
	30.0	1.7		
	40.0	1.4		
	50.0	1.1		
	60.0	0.9		
	70.0	0.7		
155	20.0	1.8	15	0.9812
	30.0	1.4		
	40.0	1.2		
	50.0	0.9		
	60.0	0.8		
	70.0	0.6		

Table 2b: Total soluble solids, temperature, viscosity, and activation energy values for orange juice samples concentrated by thermal evaporation.

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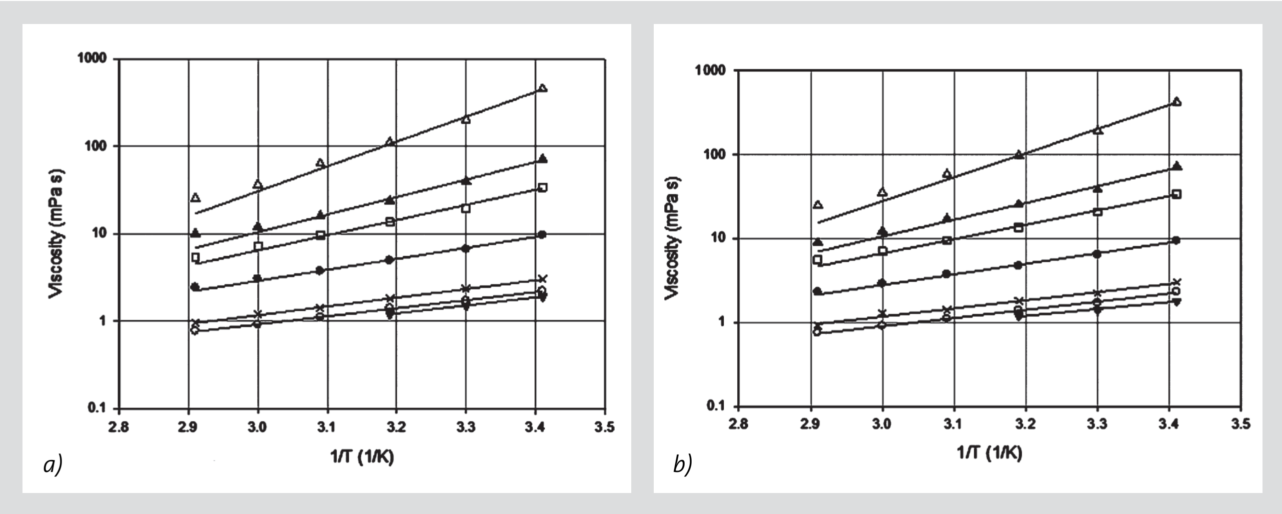

Figure 5: Arrhenius curves for samples coming from a) osmotic distillation and b) thermal evaporation (legend same as in Figure 4).

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