VISCOSITY AND PARTICLE SIZE DISTRIBUTION OF CONCENTRATED APPLE JUICE PRODUCED BY SPINNING DISC REACTOR (SDR)

VISKOSITAS DAN DISTRIBUSI UKURAN PARTIKEL KONSENTRAT JUS APEL YANG DIPRODUKSI MENGGUNAKAN SPINNING DISC REACTOR (SDR)

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ABSTRACT

This research explored the potential use of the spinning disc reactor (SDR), a novel processing technique used for the production of concentrated apple juice. The apple juice was passed over the SDR disc spinning at 2000 rpm, heated at various temperatures (90 °C, 100 °C, 110 °C, and 120 °C), and at a flow rate of 7 ml/s. The effect of SDR-processing on viscosity and particle size of the apple juice concentration, was investigated. The SDR-concentrated apple juice exhibits narrow particle size distribution (average particle size in the range of d_{32} = 0.1-0.2 µm and d_{43} = 4-12 µm) and shear-thinning behaviour in the range of shear rates from 0.1 – 200 s^{-1}, in which the viscosity decreases with increasing the shear rate. The reconstituted samples show similar viscosity with its original counterpart. The increase of the processing temperature allows a reduction in the processing time. The results reveal that the SDR is capable of producing the concentrated apple juice.

Keywords: *concentrated apple juice, viscosity, particle size distribution, SDR-technology.*

INTRODUCTION

Evaporation is a separation method of a volatile solvent from a non-volatile solute based on the vaporization principle. Evaporation is conducted by vaporizing a portion of the solvent (liquid), mostly water, at the boiling point of the solution or dispersion's boiling point, from a thin (low density) feed material to produce a concentrated solution or thick product (Ramaswamy and Marcotte, 2006; Valentas *et al*., 1997; Earle, 1983). The feed could be a solution, slurry, or suspension of solid materials in a liquid. Evaporation process involves energy transfer (heat for vaporization and condensation), mass transfer (the removal of the moisture).

Fruit juices, such as apple juice, are concentrated by evaporation techniques to reduce packaging costs, needed area for storage, transportation costs, and to increase the shelf life. However, this technology affects the nutritional value of the concentrated fruit juices. Most of the volatile flavor compounds contained in raw juice can be damaged during concentration processes by evaporation. Those compounds, known as essence, are vaporized together with water during processing. To generate a flavorful product, they must be recovered and added back to the concentrate (Arthey and Ashurst, 1996; Johnson *et al*., 1996).

There are three main technologies commonly used in the production of concentrated fruit juice: heat evaporation, membrane concentration, and cryoconcentration. Heat evaporation, the technology that commonly used in the food industry, is more effective to produce clear juices with low viscosity. The product quality produced by this method is influenced by temperature gradient between product and heat exchanger. Product can undergo local degradations due to a great gradient, particularly the liquid with intense contact with the heat exchanger. Although this problem can be minimised by using vacuum technology, however, a thermal pre-treatment at 85-95 °C is still needed for inactivation of enzymes and to prevent the degradation of some fruit juice compounds (Aider and Halleux, 2008).

Early evaporators had demonstrated that high-vacuum low temperature processing generated concentrate of good flavour quality, but it was discovered that the heat treatment was insufficient to deactive pectin methylesterase. This cause gelation in the final products. The effect was not immediately apparent , but took place after few weeks of storage (Ashurst, 2005).

The membrane concentration technology can be used to produce concentrated fruit juices, with low energy consumption at an ambient temperature. Depending on the size of the pore membranes and the applied pressure, membrane filtration processes can be divided into several types, including microfiltration and ultrafiltration for the fruit juice clarification. Reverse osmosis, membrane distillation and osmotic distillation are the concentration techniques. Reverse osmosis is used as pre concentration technique as the water is separated from the juice but the high osmotic pressure limits the removal of water (Kozak *et al*., 2008). Osmotic distillation, also called isothermal membrane distillation, is a newly developed concentration process. The solutions to be concentrated are separated using a microporous hydrophobic membrane from an extraction medium, usually a hypertonic solution e.g. a brine. The penetration of water into the membrane pores interior is prevented by the hydrophobic nature of membrane. The driving force for mass transfer in this process is the concentration difference across the membrane (between juice and brine solution). The water removal through the membrane can be summarised in three steps: water evaporation at the dilute solution/membrane interface, the diffusion of the water through the membrane pores, and the condensation of the water vapor at the membrane/brine interface (Hongvaleerat *et al*., 2008; Cassano *et al*., 2003; and Kozak *et al*., 2008).

However, due to high pressure for filtration of the concentrated solution, fouling of membrane and the membrane integrity deterioration can occur. Therefore, cleaning periodically and membrane replacement are needed (Aider and Halleux, 2008).

In addition, Su and Wiley (1998) reported that flavor components of apple juice might be lost during ultrafiltration . Factors such as pumping, membrane absorption, fouling, machine adsorption, material absorption, vaporization, etc might have detrimental effects on juice flavors. The loss of flavor components including hexanal and ethyl 2-methyl butyrate in concentrated apple juice during the reverse osmosis process has also been reported.

Another technology used for the production of concentrated fruit juice is cryoconcentration (freeze concentration), in which water is removed not as vapour, but as ice. This technology is performed at low temperatures, which means that it suits to preserve the heat-sensitive liquid food compounds, retaining the nutritive value of the food and volatile aromatics in the product. However, It can not substitute products with large diffusion evaporative concentration, such as citrus juices, because they need a considerable consumption of energy. Moreover, the obtained concentration (approximately 40 g / 100 g) is lower than the level achieved by evaporation (Aider and Halleux, 2008; Aider and Halleux, 2009).

Other technologies have been developed for production of the fruit juice concentration because of the limits and disadvantages of the reported technologies. The technologies should be environmentally friendly, effective and lower the consumption of energy, retain high nutrition and sensory qualities of the final product, and require low maintenance cost .

Spinning disc reactor (SDR) technology could be an alternative technology to produce fruit juice concentration. The processing is conducted in a rotating disc, using thin fast-moving films. The liquid flows over spinning discs as thin falling films. They form complex dynamics through large-amplitude waves formation. These waves increase an intense mixing environment in the film that rises considerably the heat and mass transfer rates. The body force in the flow over spinning discs varies radially and has a component of azimuthal, which causes better flow control. The spinning disc reactor can be used in many applications, for example in conducting fast reactions of gas-liquid and homogeneous, crystallization, heat treatment, and heterogeneous catalysis (in this case, the disc itself acts as the support of the catalyst) (Matar and Lawrence, 2006).

In this work, the effect of SDR-processing on viscosity and particle size of the apple juice concentration, which are important physical properties of liquid foods in many areas of food processing, was investigated.

METHODOLOGY

One liter of non-concentrated pure apple juice aseptically packed in a carton was purchased from Sainsbury's supermarkets Ltd., in Leeds, United Kingdom. Apple juice come from carefully selected fruits that are picked at the peak of their ripeness, then squeezed, pressed, and pasteurised.

A. Production of Concentrated Apple Fruit Juice Using Spinning Disc Reactor (SDR) Technology

The spinning disc reactor (SDR-type P201) is designed by Triton Chemical System Ltd., and commercialized by Protensive Ltd., Bioscience Centre, Newcastle, United Kingdom. The system possesses an extensive heating and cooling facility to set the disc temperature in the range of +200 °C to -20 °C by using heat transfer fluids in a water bath. The speed range of the spinning disc is 100 to 3000 rpm with the range of flow rate 0.5 to 7 ml/s. The main vessel could mechanically withstand pressure of up to 5 bar. In addition, there are two standard pumps (Micropump © model 185 gear pumps) which have been connected into the main controller to be used depending on the viscosity of the used material.

The principle of the SDR technology is that liquid passes across the metal disc surface which can be programmed to spin, heat, and cool at optimum speeds depending on the requirements. In this study, the disc was heated at various temperatures. The SDR technology provides great accuracy and high speed to mix the liquid and creates a thin film (typically 10s of microns) for low viscosity fluids. It also possesses the ability to strip water from substances and the high temperature that can be reached. Liquid is fed into the rotating disc centre, and then the centrifugal forces drive the liquid as a very thin film (in µm), which enables very high heat transfer coefficients between the disc and the liquid, as well as very high mass transfer between the liquid and the gas over the liquid. The liquid completely wets the surface of the metal disc and the liquid film creates small intense waves. The residence time on the disc is short, mainly seconds, so operational time is shortened.

Apple juice sample was collected initially before passing through the reactor. The disc temperature was set for various temperatures (90 °C - 120 °C) and the wall was maintained at room temperature. A 500 ml apple juice was passed over the disc running at 2000 rpm, flow rate of 7 ml/s, and temperature 90 °C. When it reached 350 ml, about 50 ml sample was collected for the analysis. Then the process was continued until it reached 150 ml of concentrated apple juice. The produced samples were collected in glass tubes. The same procedure was repeated for each temperature setting (100 °C - 120 °C). The samples were covered airtight stored in a fridge at 5 °C for further analysis, including rheology and particle size.

In order to investigate the effect of the SDR-processing on the reconstitution of the juice samples, 10 ml of the produced samples was reconstituted with 60% of water (a 15 ml of water was added to 10 ml of the sample). Then it was compared to the original/fresh juice in terms of viscosity.

B. The Analysis of Concentrated Apple Juice

1. Rheological measurement

Steady-state viscosity of concentrated apple juice sample was measured using a Bohlin rheometer CVOR (Malvern Instruments Ltd, Worcester, United Kingdom) at controlled shear rate with C25 cup and bob geometry. The gap size for plates was set to 0.1 mm. The sample was poured into the cell of the rheometer, surrounded by a temperature controlled vessel, and allowed to reach 5 °C for approximately 10 min prior to the measurement. During the tests, the shear rate was increased step-by-step over the chosen range of shear rates and a steady state was obtained at each measurement. Apparent viscosity was determined at shear-rates in the range of 0.1 – 200 s^{-1} using continuous shear, with a 30 s delay time and a 30 s integration time at 5 °C. The viscosity data reported is the average of the two sets of experimental results.

2. Particle size analysis

The particle size distribution of the concentrated apple juice sample was determined using a Malvern Mastersizer MS2000 (Malvern Instruments Ltd, United Kingdom) laser light-scattering analyser with absorption parameter value of 0.001 and refractive index ratio of 1.53. The sample was dispersed in water (RI 1.33) at ambient temperature, then it was subjected to gentle stirring with ultrasonic dispersion for about 2 min in order to disperse particles. The particle size measurements are reported as the volume-weighted mean diameter (d_{43}) and the surface-weighted mean diameter (d_{32}), which can be defined as follows:

$$d_{43} = \frac{\sum_i n_i d_i^4}{\sum_i n_i d_i^3} \qquad d_{32} = \frac{\sum_i n_i d_i^3}{\sum_i n_i d_i^2}$$

where n_i is the number of particles of diameter d_i.

The d_{43} value was used to monitor changes in the particle-size distribution of concentrated apple juice.

RESULTS AND DISCUSSION

A. Rheology of Concentrated Apple Juice

The viscosity of fresh and concentrated apple juice using the SDR has been investigated over a wide range of shear rates from 0.1 – 200 s^{-1} at 5 °C. The results show that both fresh and concentrated apple juice samples exhibit shear-thinning behaviour over the entire range of shear rates, in which the viscosity decreases with increasing the shear rate. This results are consistent with the general observation that concentrated fruit juices are one of non-Newtonian fluids which will display shear-thinning behaviour (Fellows, 2009; Fryer *et al*., 1997). Shear-thinning behaviour is a common type of flow in food systems, which is possibly because of a break down of structure under the influence of the shear force (Rao *et al*., 2005).

The viscosity, as a measure of flow resistance, can be influenced by concentration (Figure 1, 2, 3, and 4) and varying the processing conditions such as processing disc temperature (Figure 5).

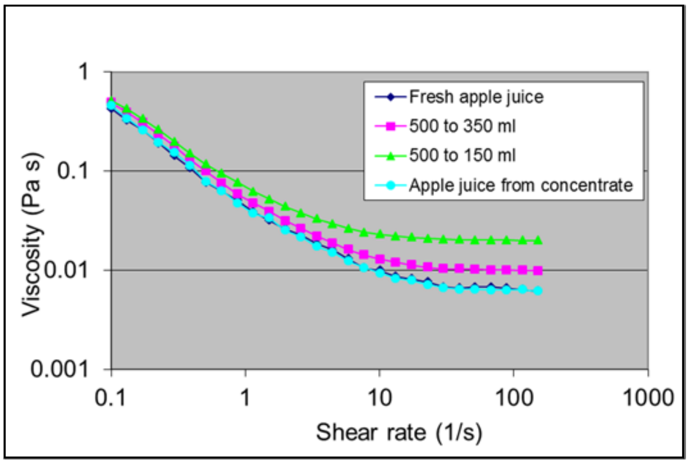

Figure 1. The viscosity of concentrated apple juice processed at 90 °C.

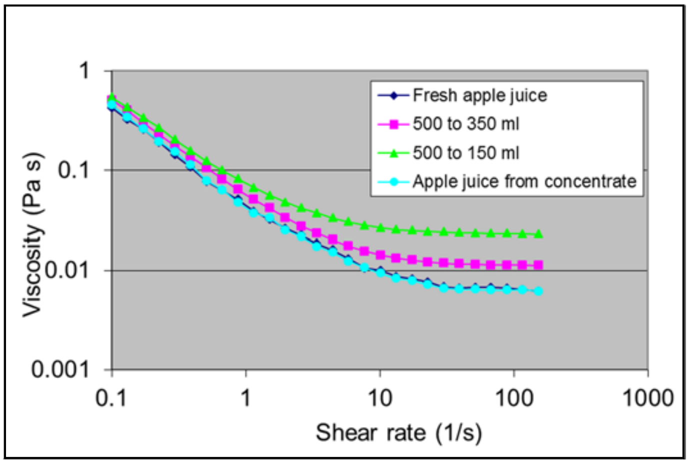

Figure 2. The viscosity of concentrated apple juice processed at 100 °C.

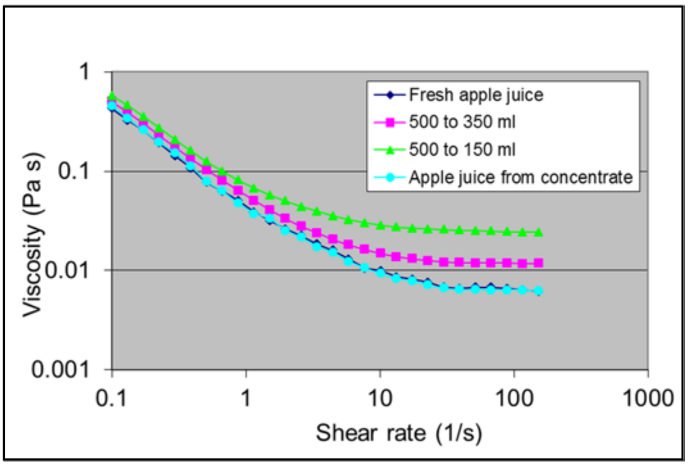

Figure 3. The viscosity of concentrated apple juice processed at 110 °C.

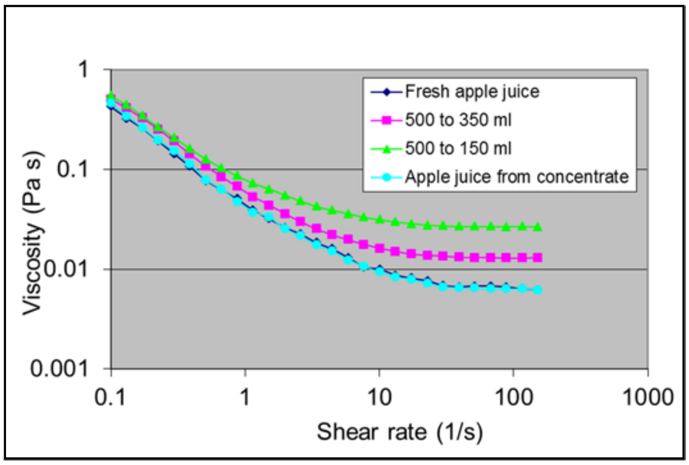

Figure 4. The viscosity of concentrated apple juice processed at 120 °C.

The Figures show that the viscosity of concentrated apple juice increases as the concentration of the fluid flow is increased. The pattern is similar for all processing temperatures (90 °C – 120 °C). The increase in the viscosity of concentrated apple juice samples is possibly due to the removal of the free water present in the fruit juice during processing. As the amount of free water being removed from samples increases, the relative solid content of samples also increases, so the samples become more concentrated and more resistance to flow, resulting in an increase in the viscosity.

The effect of processing temperature on viscosity of the concentrated apple juice are shown in Figure 5 and 6.

The results suggest that the concentrated apple juice viscosity goes up slightly with the processing temperature. However, the increase of the viscosity profiles was not significant. It is caused by the amount of evaporated water during processing which is approximately the same for all temperature processing. All samples were concentrated from 500 ml to 350 ml and 150 ml. The processing temperature only affects the processing time. The processing time is shorter with the increase of the processing temperature.

The produced apple juice concentration was then reconstituted to the original strength of fresh juice by adding 60% of water. The viscosity profiles as a function of shear-rate for the reconstituted apple juice which was processed using the SDR at different processing temperature are shown in Figure 7. It illustrates that there are no significant differences in the viscosity of reconstituted apple juice at all processing temperature and those of fresh apple juice and apple juice from concentrate. It suggests that the concentration process using the SDR can produce the similar viscosity of reconstituted samples with its original/fresh state.

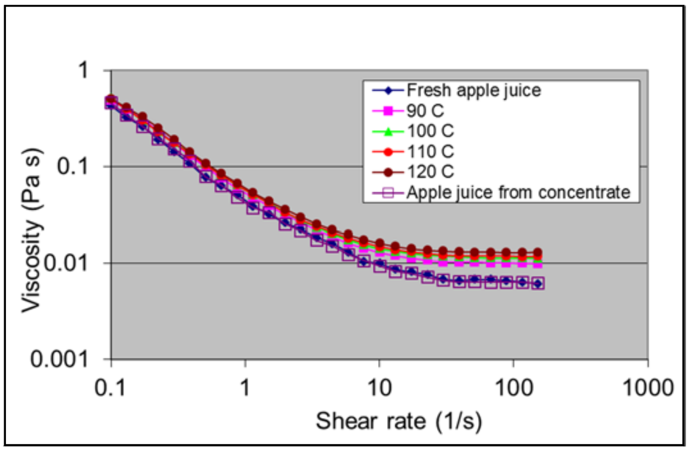

Figure 5. The viscosity of concentrated apple juice from 500 to 350 ml at different temperatures

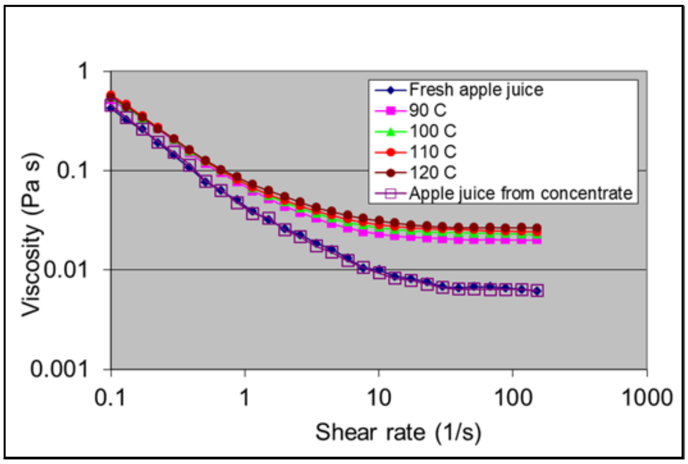

Figure 6. The viscosity of concentrated apple juice from 500 to 150 ml at different temperatures

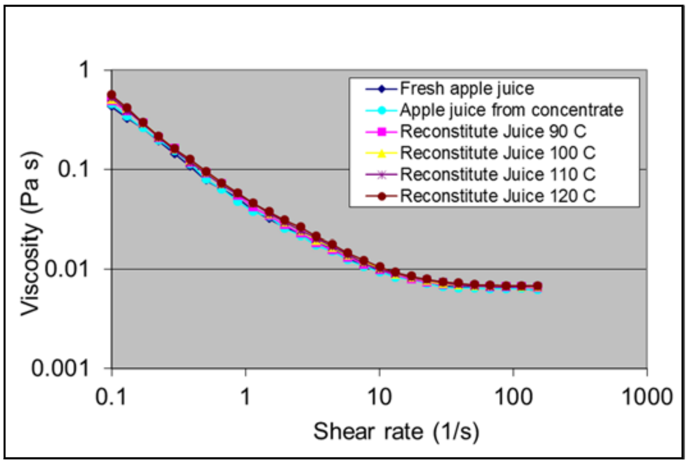

Figure 7. The viscosity of reconstitute concentrated apple juice

B. Particle-size Distribution of Concentrated Apple Juice

The particle-size distribution is an important factor determining the stability of concentrated fruit juice. Particles in a cloudy juice can adhere together and form aggregates of increasing size (flocculation) which may settle because of gravity. Flocs might undergo coagulation and produce a much denser form, which is an irreversible process. One of the main problems in production of cloudy juice is the assurance of cloud stability (Genovese *et al*., 1997; Genovese and Lozano, 2000).

Rheological behavior of dispersed systems depends on the characteristics of both the liquid and the solid phase. Concerning the last one, particle size distribution and volume fraction influence the stability of colloidal system such as concentrated fruit juice (Genovese and Lozano, 2000; Rao, 2006).

The particle-size distributions (volume fractions against particle size) of the fresh and concentrated apple juice samples are given in Figure 8.

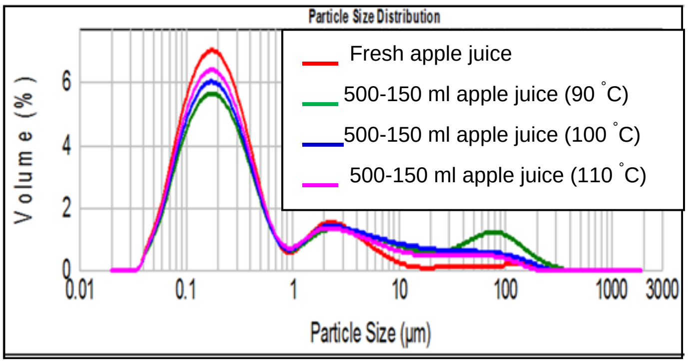

Figure 8. The particle size distribution of the fresh and SDR-concentrated apple juice samples at different processing temperatures.

Both fresh and the SDR-processed apple juice concentration at different temperatures show fairly narrow distributions with the average particle size in the range of d_{32} = 0.1-0.2 µm and d_{43} = 4-12 µm. The particle size distributions of the SDR-processed apple juice concentration samples are similar to that of fresh apple juice. It means that the concentration process using SDR does not affect the particle size distribution of the product. The results also indicate that the different processing temperature has no effect on the particle size distribution of the concentrated apple juice.

CONCLUSION

The novel Spinning Disc Reactor (SDR) technology has been successfully employed to produce a very acceptable concentrated apple juice. The residence time of samples on the SDR disc was very short. The juice was heated as a very thin film due to the centrifugal forces created during SDR processing. Therefore, it allows more efficient heat transfer and minimises the heat damage to the product. The different processing temperatures influence on the processing time of the SDR-concentrated apple juice. As the processing temperature increases, the processing time is shorter. The reconstituted sample also has the similar viscosity with its original/fresh state. In addition, the SDR can produce uniform particles with narrow particle size distribution. A further investigation has to be carried out for optimising the use of SDR in production of concentrated fruit juice and the effect of SDR processing on nutrient quality.

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