Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

Maejo International Journal of Science and Technology

ISSN 1905-7873
Available online at www.mijst.mju.ac.th

Full Paper

Freeze concentration of lime juice

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Received: 17 July 2008 / Accepted: 3 November 2008 / Published: 10 November 2008

Abstract: The main objective of this research was to study the effects of processing conditions, i.e. cooling medium temperature (-6, -12 and -18°C) and scraper blade rotational speed (50, 100 and 150 rpm) on the freeze concentration of lime juice. The initial soluble solid content of lime juice was 7.6° Brix. Results showed that soluble solid content of lime juice increased as cooling medium temperature decreased while scraper blade rotational speed increased. It was also found that the processing condition with -18˚C cooling medium temperature and 150 rpm rotational speed of the scraper blade was the best among all studied conditions, although the loss of the soluble solids with ice crystals during ice separation was relatively high at 35%.

Keywords: simulation, aeration, silica gel, paddy, silo

Introduction

Lime is one of the major economic plants of Thailand. Lime juice, which is extracted from lime by squeezing, provides sour taste and pleasant flavour and aroma. Thai people use lime and lime juice as flavouring in food and drink products as well as a component in cosmetics and cleaning products. Lime can grow in every region in the country and bears its fruits throughout the year. Due to the shortage of lime in the dry season, especially from March to April, its price increases five to ten times that of the usual price. Therefore, it is necessary to extend the shelf life of lime or lime juice for utilisation during the shortage period. Several methods include, for example, covering lime with sand, coating lime, storage in controlled atmosphere or modified atmosphere, adding food preservatives in

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

lime juice, and so on. However, these methods require large storage space. Thus, concentrated lime juice is considered as a preferable alternative method.

There are three concentration processes feasible for selective dewatering: evaporation, membrane and freeze concentration [1]. In evaporation technique, the volatile compounds are lost quantitatively with water vapour. This agrees with the research of Chaisawadi et al. [2], who found that there were a lot of changes in the flavour of lime juice after the evaporating process. In membrane method, such as reverse osmosis, the concentration level of liquid depends on membrane pore size. If the needed solute has smaller molecular weight than water, it will pass through the membrane. During this process, the loss of flavour and aroma can occur [3]. In freeze concentration, the water is separated from the aqueous solution by crystallisation and then ice crystals are removed from the concentrated liquid thus avoiding the loss of volatile compounds. The freeze concentration process is, therefore, suitable for the concentration of heat sensitive liquid foods containing volatile compounds. Moreover, freeze concentration has less energy costs when compared with the evaporation method. In addition, the freeze concentration has been applied to produce concentrated liquid foods such as fruit juices, coffee, tea and dairy products. This method is, therefore, very interesting and considered as one of the most suitable methods to preserve lime juice while maintaining its strong flavour and aroma [4-5].

Materials and Methods

Raw material

Lime was purchased from Talad Thai market, Pratumthani province of Thailand. It was then washed, squeezed and stirred in order to obtain equalised soluble solid of lime juice. The lime juice was kept in refrigerator at approximately 4˚C. Before each experiment, the lime juice was taken from the refrigerator and then left at ambient temperature (approximately at 25˚C).

Batch crystalliser

A batch crystalliser (Figure 1.) consisted of a cubic freezer box with inner dimension of 48 cm x 48 cm x 48 cm, a cylindrical vessel, a scraper blade, a 0.5 hp motor, and a temperature controller. In the batch crystalliser, the cylindrical vessel (15 cm in diameter x 25 cm in height) made of stainless steel was maintained in a refrigerated NaCl solution bath at a constant temperature. The lowest temperature of this batch crystalliser was approximately at –20 ºC using 22% (w/w) NaCl solution as a cooling medium. The scraper blade was mounted on a rotating shaft, constantly removing frozen material from the surface of the container during the processing and providing agitation for crystal contacts.

Experimental method

In each experiment, 3,000 g of lime juice sample at ambient temperature was used and concentrated in the batch crystalliser. The experiments were performed at the temperature of -6, -12 and -18ºC with rotation speed of the scraper blade at 50, 100 and 150 rpm for 30 min. Every 5 min during the experiment, approximately 40 g of slurry was taken and centrifuged at 7500 rpm for 10 sec

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

in order to separate ice crystals from concentrated lime juice. The schematic diagram for the freeze concentration process is shown in Figure 2.

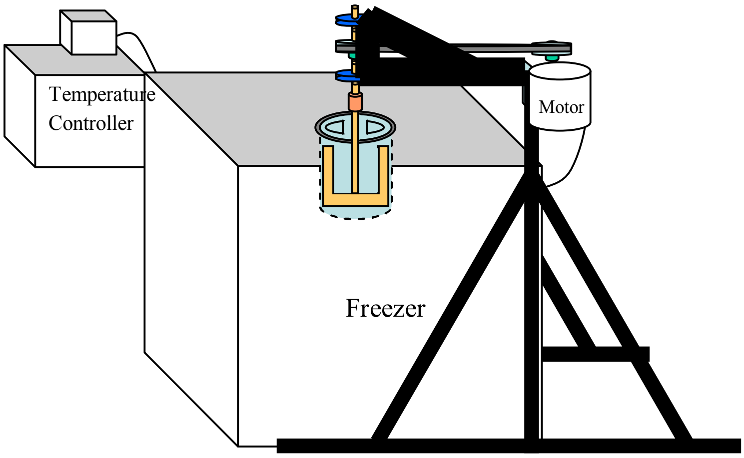


Figure 1. Batch crystalliser

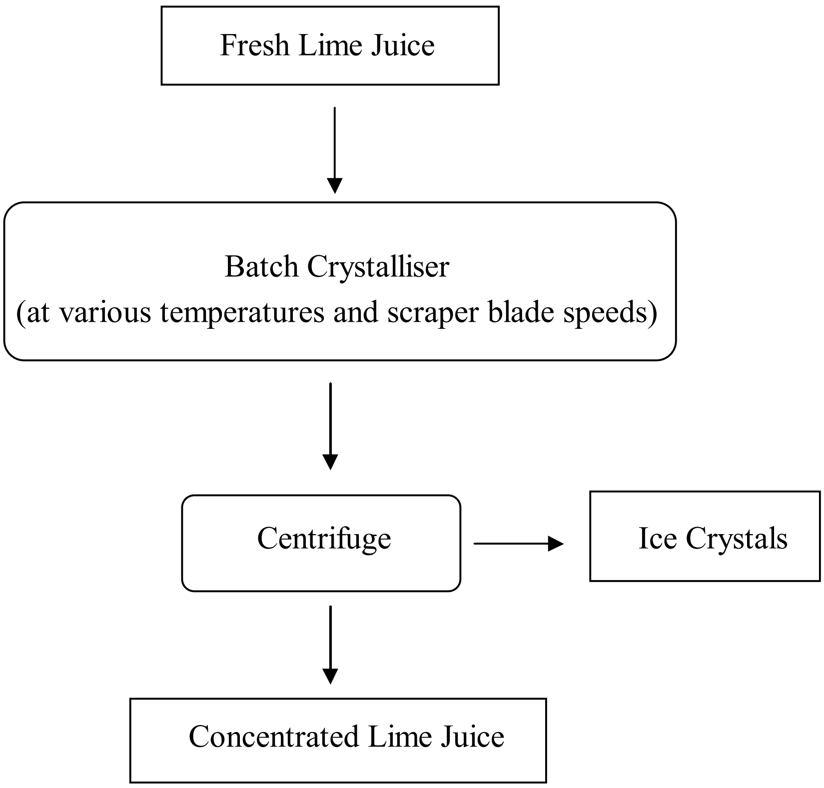


Figure 2. Schematic diagram for the freeze concentration process

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

Total soluble solid

The concentrated lime juice was analysed for total soluble solid content using a hand refractometer (N-1α, Atago, Japan) of which the brix scale (°Brix) between 0-32 could be read in 0.2 increments. To measure the liquid concentration, one or two drops of the specimen fluid were placed in a designated window. The refractometer was calibrated with distilled water before each measurement.

Viscosity

The viscosity (mPas) was measured using a rotational concentric cylinder viscometer (HAAKE VT500, Germany). A 9-ml sample was put in a coaxial cylinder sensor and maintained at 25°C by the thermostat bath. The sample was then sheared at an increasing rate of 0 to 300 s^{-1} within 2 minutes.

Experimental design

The experiments were performed at 3 levels of cooling medium temperature (-6, -12 and -18 ºC) and 3 levels of rotation speed of the scraper blade (50, 100 and 150 rpm) for 30 minutes. A 2-factor factorial design was used in scheduling of the experiments with three replications in each case.

Data analysis

All statistical analyses related to the experimental data were done using Microsoft Excel and carried at a significant level of 0.05.

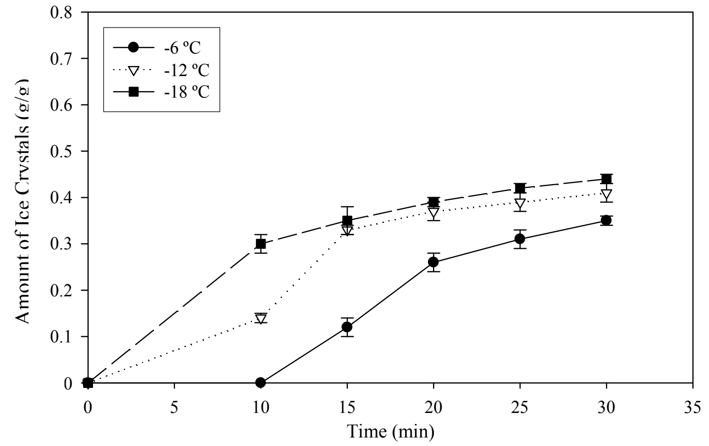
Results and Discussion

Effects of cooling medium temperature and scraper blade rotational speed on the amount of ice crystals

The initial total soluble solid of lime juice was found to be 7.6˚Brix. Figures 3 and 4 reveal that at a particular time the amount of ice crystals increased as the cooling medium temperature decreased and the speed of scraper blade increased. This may be due to the fact that the lower medium temperature causes more nuclei during the primary nucleation step of freezing. The rate of primary nucleation depends on the cooling medium temperature. As the cooling medium temperature is lowered, the primary nucleation rate is increased accordingly [6]. In addition, the higher speed of the scraper blade also causes more nuclei during the secondary nucleation. The new crystal nuclei are formed due to the crystal-scraper blade and crystal-crystal collisions. Russell et al. [6] and Windhab and Bolliger [7] reported that an increase in the amount of crystals with increasing rotational speed in an ice cream freezer is related to a higher rate of secondary nucleation.

It was also found that the rate of ice crystal formation for all studied conditions was reduced after 15 min of freezing. Table 1 shows the results of the effects of processing conditions on the amount of ice for a processing time of 30 min.

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37



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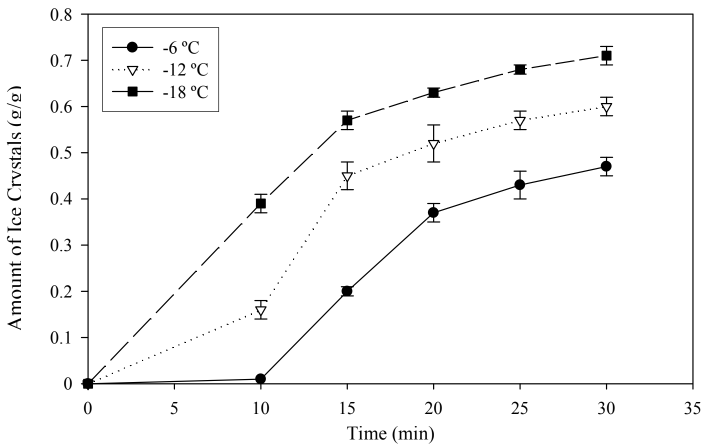

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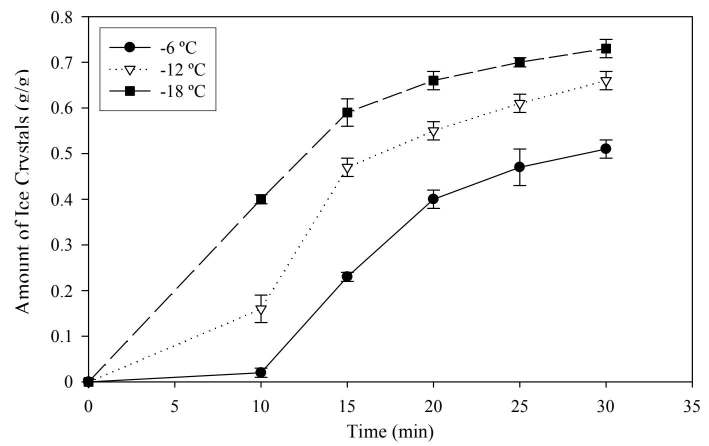

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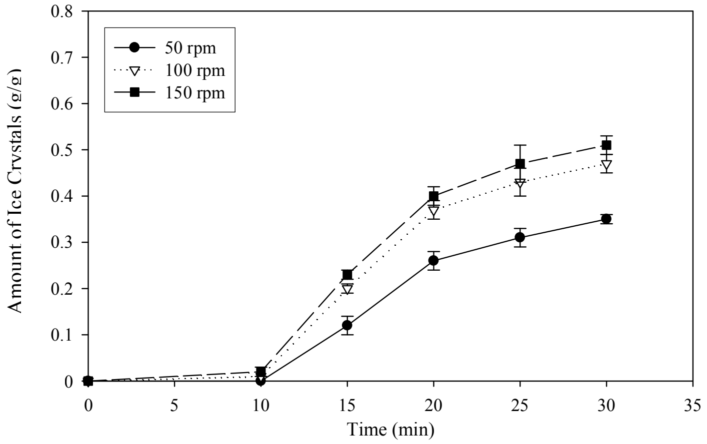
Figure 3. Effect of cooling medium temperature on amount of ice crystals at various rotational speeds: (a) 50 rpm (b) 100 rpm (c) 150 rpm

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37



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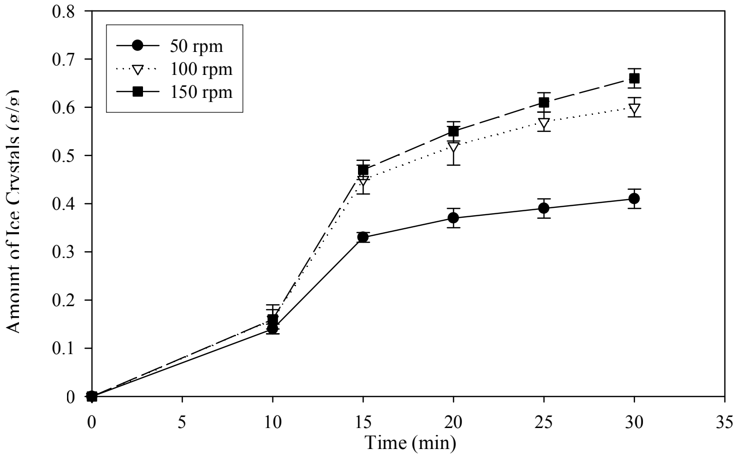

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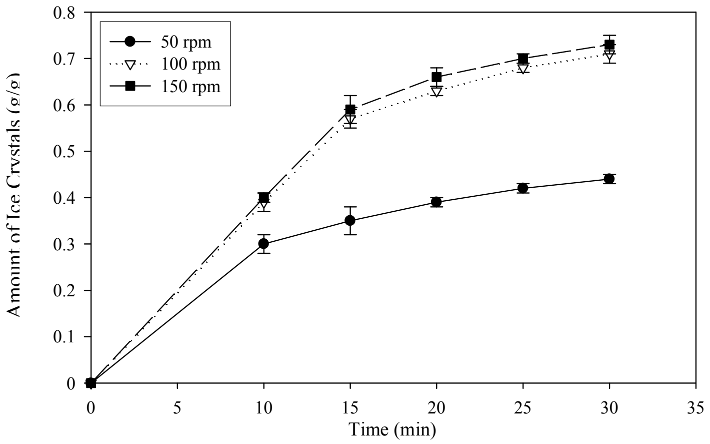

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Figure 4. Effect of rotational speed on amount of ice crystals at various cooling medium temperatures: (a) -6°C (b) -12°C (c) -18°C

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

Table 1. Effect of processing conditions on amount of ice crystals for processing time of 30 minutes

Rotational speed (rpm)	Amount of ice crystal (g/g)		
	Temperature (°C)		
	-6	-12	-18
50	$0.35{\pm}0.01^{a,A}$	$0.40{\pm}0.03^{a,B}$	$0.44{\pm}0.01^{a,C}$
100	$0.47{\pm}0.02^{b,A}$	$0.60{\pm}0.02^{b,B}$	$0.71{\pm}0.02^{b,C}$
150	$0.51{\pm}0.02^{c,A}$	$0.66{\pm}0.02^{c,B}$	$0.76{\pm}0.02^{c,C}$

Note : Different lettercase superscripts in the different columns mean that the values are significantly different at 95% confidence level ($\alpha = 0.05$)
Different capital letter superscripts in the different rows mean that the values are significantly different at 95% confidence level ($\alpha = 0.05$)

Effects of cooling medium temperature and scraper blade rotational speed on the total soluble solid of lime juice

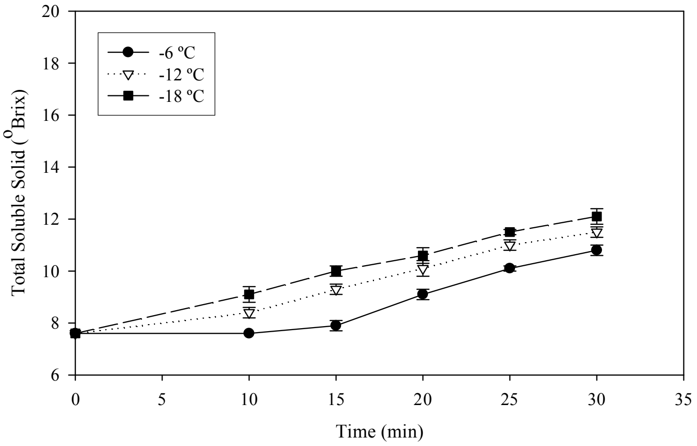
Figures 5 and 6 show that the total soluble solid of lime juice increased as the cooling medium temperature decreased and the rotational speed of scraper blade increased, apparently because the soluble solid could be easily attached to the surface of the ice crystals. This corresponds to the higher amount of ice crystals which were removed afterwards. Table 2 shows the results of the effect of processing conditions on the total soluble solid of lime juice for a processing time of 30 min.

Based on the experimental results in this research, the highest level of concentrated lime juice was obtained at the lowest cooling medium temperature of -18°C and the fastest rotational speed of the scraper blade at 150 rpm. The concentration level was related to the amount of ice crystals produced during the freeze concentration process. Thus, under the processing conditions that enhanced more ice crystals, a higher level of concentration could be achieved.

Effect of viscosity on loss of soluble solid

From Figure 7, it was found that the concentrated lime juice with higher total soluble solid had higher viscosity, resulting in higher loss of total soluble solid on the surface of the ice crystals. The viscosity results showed the same tendency as those reported by Shamsudin et al. [8] who studied the effect of concentration on apparent viscosity of guava juice.

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37



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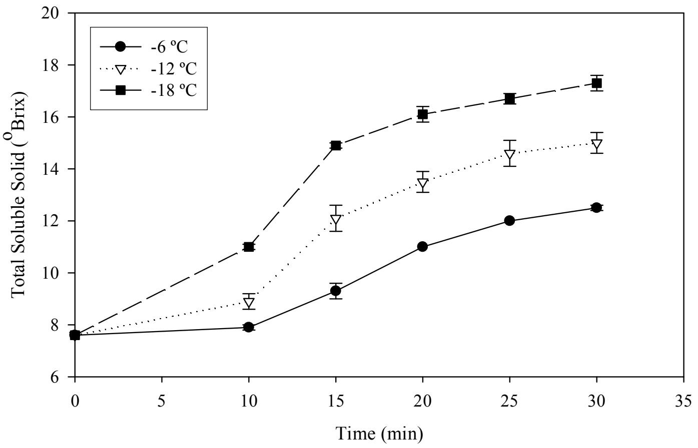

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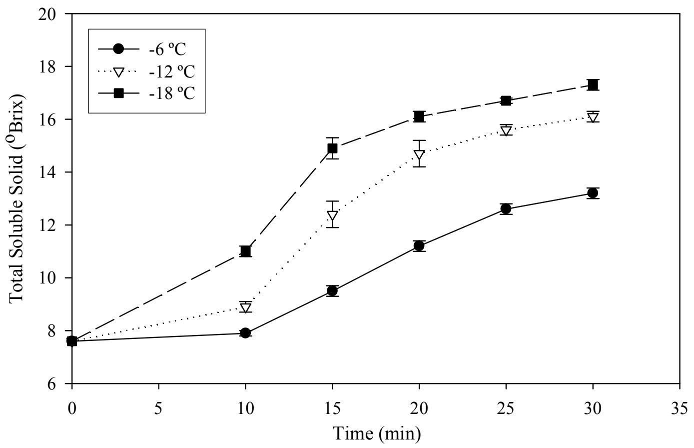
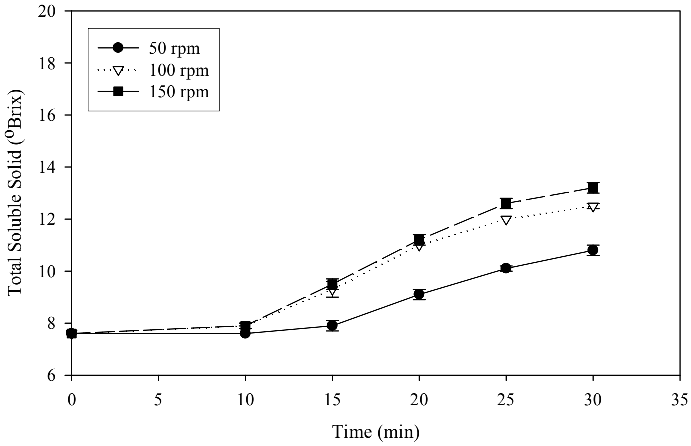


(c)

Figure 5. Effect of cooling medium temperature on total soluble solid of lime juice at various rotational speeds: (a) 50 rpm   (b) 100 rpm   (c) 150 rpm

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37



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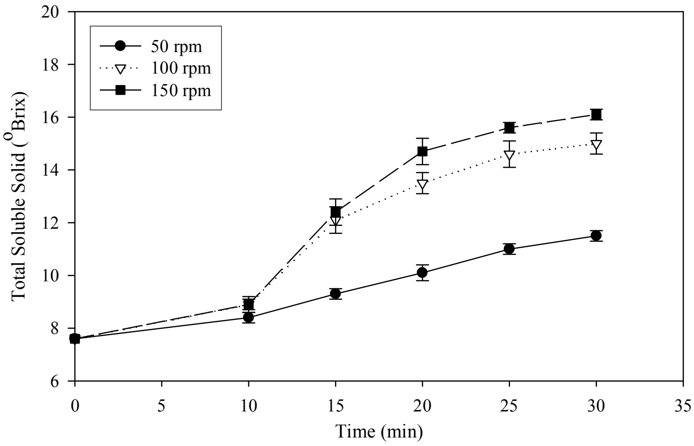

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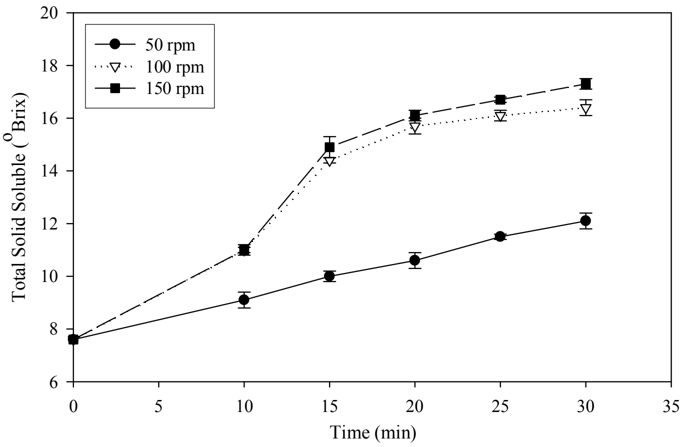

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Figure 6. Effect of rotational speed on total soluble solid of lime juice at various cooling medium temperatures: (a) -6°C (b) -12°C (c) -18°C

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

Table 2. Effect of processing conditions on total soluble solid of lime juice for processing time of 30 minutes

	Total soluble solid of lime juice (°Brix)		
Rotational speed (rpm)	Temperature		
	-6 °C	-12 °C	-18 °C
50	$10.8\pm0.2^{a,A}$	$11.5\pm0.2^{a,B}$	$12.1\pm0.3^{a,C}$
100	$12.5\pm0.1^{b,A}$	$15.0\pm0.4^{b,B}$	$16.4\pm0.2^{b,C}$
150	$13.2\pm0.2^{c,A}$	$16.1\pm0.2^{c,B}$	$17.3\pm0.3^{c,C}$

Note : Different lettercase superscripts in the different columns mean that the values are significantly different at 95% confidence level (α = 0.05).
Different capital letter superscripts in the different rows mean that the values are significantly different at 95% confidence level (α = 0.05).

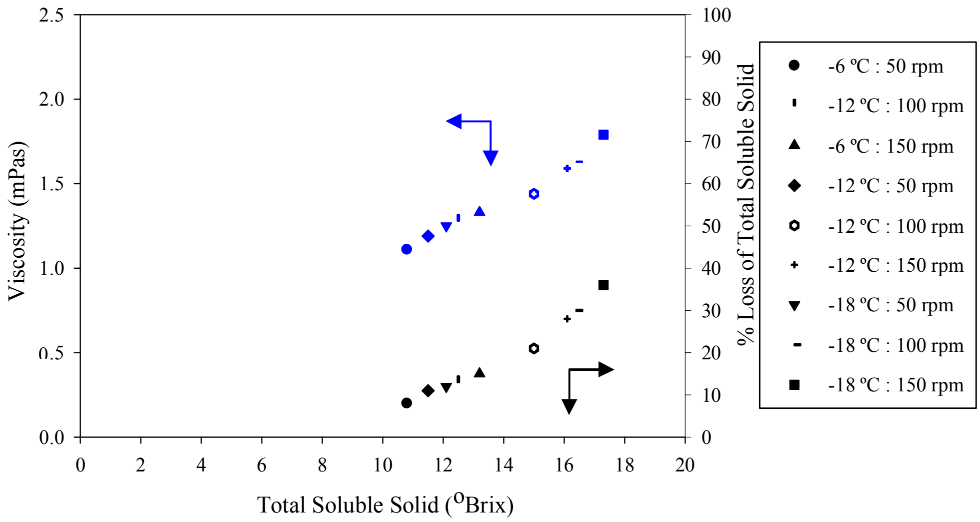

Figure 7. Effect of processing conditions on viscosity and percentage of loss of soluble solid of lime juice

Conclusions

In this research, the optimum conditions for freeze concentration of lime juice from 7.6˚Brix to 17.3˚Brix within 30 minutes were found at cooling medium temperature of -18˚C and scraper blade rotational speed of 150 rpm. The highest amount of ice crystals and the highest total soluble solid of lime juice were achieved at this optimum conditions. However, at the optimum conditions, the concentrated lime juice had the highest viscosity, which resulted in 35% loss of the soluble solid with the removed ice crystals. A study of reduction of loss of total soluble solid of lime juice undergoing freeze concentration is recommended for future work.

Mj. Int. J. Sci. Tech. **2008**, *1*(Special Issue), 27-37

Acknowledgements

The authors express their sincere appreciation to the Office of the National Research Council of Thailand (NRCT) for financial support and Thailand Institute of Scientific and Technological Research for supporting the lime juice squeezer for this research.

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