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Research Article

Keywords: Reverse osmosis, watermelon juice, concentration, modelling, lycopene, antioxidant activity

Posted Date: March 30th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1487272/v1

FLUX DECLINE AND FOULING ANALYSIS IN REVERSE OSMOSIS OF WATERMELON JUICE

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Abstract

In this paper, the concentration of watermelon juice by HR98PP membrane was investigated at 30 and 40 bar of operating pressure. The semi-empirical model of permeate flux was determined. The predominant fouling mechanism in the concentration was found to be complete blocking by Hermia's model. Recovery yield and content of total solid, lycopene and antioxidant capacity in concentrate was analyzed. Results indicated that, concentration of watermelon juice by HR98PP at 40 bar exhibited the higher effectiveness than that at 30 bar. At 40 bar and 2.25 of CF, contents of total sugar (TS), lycopene and antioxidant capacity in concentrate were 171.31 g/L, 83.9 mg/L and 124.74 mg TEAC/L, respectively. Recovery yields of TS, lycopene and antioxidant capacity in concentrate were 98.67. 90.03 and 82.39 %, respectively. Maximum CF value of concentration at 40 bar of operating pressure was 2.64. The mathematical model was built for estimation of the change in the contents of lycopene and TS versus time. Maximum theoretical content of lycopene and TS at 40 bar were estimated as 185 mg/L and 341 g/L, respectively. The cleaning procedure with NaOH solution at pH10 could fully recovery permeate flux after the concentration. Results imply that, concentration of watermelon juice by HR98PP was feasible.

Keywords: Reverse osmosis; watermelon juice; concentration; modelling; lycopene; antioxidant activity.

1. Introduction

Watermelon (*Citrullus lanatus*) is a fruit with high content of lycopene: 8.20 – 59.17 mg/100 g watermelon flesh (Oberoi and Sogi 2017). Due to richness of lycopene, watermelon juice exhibits the high antioxidant capacity (Neglo et al. 2021). Di Mascio et al. (1991) and Ribaya-Mercado et al. (1995) reported that lycopene exhibits the quenching capacity of singlet oxygen in vitro with quenching constant being 2 and 10 times higher than that of β – carotene and α – tocopherol. Lycopene-rich foods are considered to relate to a lower risk of some degeneration diseases (Liang et al. 2019). Lycopene plays roles as a chemopreventive agent of digestive-tract cancers, lung cancer and prostate cancer (Anlar and Bacanli 2020; Bano et al. 2020; Mirahmadi et al. 2020; Qi et al. 2021). However, thermal processes cause the isomerization, consequently, reduction of biological activity of lycopene (Gupta et al. 2010; Murakami et al. 2018; Saini et al. 2019). Watermelon juice is also a source of citrulline with content being 1.1 – 4.7 g/kg in flesh (Tarazona-Díaz et al. 2011). Citrulline is precursor for arginine for human (Bahadoran et al. 2020). In addition, watermelon juice contains many nutritious constituents, such as: vitamins (A, B1, B2, B6, C, E) and minerals (Maoto et al. 2019). In general, watermelon juice is an extremely valuable source of nutrition for human health.

Recently, watermelon juice has been consumed in form of fresh juice, concentrate and instant powder. In concentrate and instant powder production juice, the concentration is one of the most important steps because it determines quality and energy consumption. Recently, concentration of juice has been conducted by vacuum evaporation. However, thermally sensitive constituents are destroyed by influence of high temperature. With lycopene, thermal processes cause the isomerization and oxidation, consequently, reduction of biological activity (Colle et al. 2013; Murakami et al. 2018; Saini et al. 2019). In addition, sensory properties of juice, especially flavor, is significant change under thermal processing (Pendyala et al. 2020). Consequently, it leads to decrease in quality of final products.

Reverse osmosis (RO) is membrane separation process with pressure driving force. The mechanisms of separation are based on sieving and diffusion effects (Wenten and Khoiruddin 2016). This process can be conducted at ambient temperature, thus remains the thermally sensitive compounds (W. Barker 2011). Besides, RO process consumes lower energy than the evaporation (Cassano et al. 2021). In addition, the RO system is also low capital cost, easy to install, operate and maintain (Anis et al. 2019). Because of these advantages, RO process has been used to concentrated a variety of juices, e.g. apple (Ahmad et al. 2020), orange (Destani et al. 2020), pomegranate (Bagci et al. 2020), etc. Dos Santos Gomes et al., 2011 evaluated the concentration of watermelon juice by polyamide composite

RO membrane. The results showed that the process concentrated juice from 6.5 to 24 °Brix and increased lycopene content 3.1 times. However, this study did not clearly show the impact of operating condition and kinetic in process of concentrating watermelon by RO membrane. Meanwhile, these information help to easily optimize the operation process.

The objective of this research was to investigate the application of RO for concentration of watermelon juice. Influence of operating pressure on performance of process was studied. The recovery yield of total sugar (TS), lycopene, and antioxidant capacity in concentration by RO membrane was also determined. The determination of predominant fouling mechanisms and the mathematical models were also investigated to describe the watermelon juice concentration by RO membrane. We aim to assess the feasibility of RO process for concentration of watermelon juice.

2. Materials and methods

2.1. Materials

Watermelon juice: Watermelon (*Citrullus lanatus*) fruits were purchased from a local market in Ho Chi Minh City (Vietnam). Their weight was 3 – 4 kg per fruit, with total red flesh. The fruits were clean by water. Then, it was peeled, followed by recovering flesh. The flesh was crushed by a steel sieve with 1 mm of mesh to obtain the juice. The juice was stored at 4 °C and using in 24 hours.

2.3. Membrane

Reverse osmosis membrane was HR98PP, a composite membrane made from polypropylene, manufactured by Alfa Laval (Denmark). NaCl rejection by this membrane is higher than 96% at 2,000 ppm of NaCl, 15.5 bar of operating pressure and 25 °C of operation temperature (information supplied by manufacturer). Prior to use, membrane was cleaned as following procedure: Flush with clean water with approximately 5 times of the system hold up volume; then, flush by full recirculation of NaOH solution (pH10) in 30 min without applied pressure and 15 L/min of feed flowrate; finally, flush with clean water at 5 bar of applied pressure until pH of permeate and retentate reached 6.0 – 7.0.

2.4. Membrane apparatus

The Labstak M20, a plate and frame system manufactured by Alfa Laval (Denmark) was used to carry out the concentration of watermelon juice (**Fig. 1**). The unit consisted of 4 couples of membrane sheets with 0.144 m^2 of active area (0.018 m^2/sheet). The pressure was supplied by Hydra – Cell pump, a piston pump manufactured by

Wanner Engineering Inc. (USA). The operating temperature was at ambient. The system was operated as concentration mode with full recirculation of retentate (**Fig. 1**). Feed flow rate was 15 L/min. In this research, the operation pressure was investigated at 30 and 40 bar to evaluate the effects of operating pressure on the RO filtration. All experiments of concentration were in duplicate with difference in permeate flux being lower than 5%.

Concentration factor (CF) was expressed as the ratio of initial volume of feed (V_F, L) to the volume of the retentate (V_R, L):

$$CF = \frac{V_F}{V_R} \tag{1}$$

The recovery yield of component i in retentate side (Y) was expressed as the following formula:

$$Y_i = \frac{C_{R,i}V_R}{C_{F,i}V_F} \tag{2}$$

Where, $C_{R,i}$ and $C_{F,i}$ were contents (g/L) of component i in retentate and feed, respectively.

After each run of RO, crossflow membrane system was cleaned as the following procedure:

- Flush with clean water with approximately 5 times of the system hold up volume.
- Recirculate clean water in 30 min at 5 bar of applied pressure and 15 L/min of feed flowrate.
- Recirculate NaOH solution (pH10) in 30 min without applied pressure and 15 L/min of feed flowrate.
- Flush with clean water at 5 bar of applied pressure until pH of permeate and retentate was 6.0 – 7.0.

2.5. Fouling mechanisms analysis

In this work, the fouling mechanism was determined using the models described by Hermia (Equation (3) and **Table 1**). The equation was determined by nonlinear regression, the coefficient of determination (R^2) and the root mean square deviation (RMSE) was used to find out the mechanism for each assay evaluated.

$$\frac{d^2t}{dV^2} = k_n\left(\frac{dt}{dV}\right)^n \tag{3}$$

Where, n: blocking index, t: filtration time (h), V: accumulated permeate volume (L), k_n: resistance coefficient.

Besides that, fouling and cleaning effectiveness in NF were evaluated by fouling and recovery indices and expressed as the following equations:

Fouling index:

$$FI = 100\frac{PWP_{final}}{PWP_{initial}} \tag{4}$$

Where, $PWP_{initial}$ (L.m^{-2}h^{-1}) and PWP_{final} (L.m^{-2}h^{-1}) were the initial pure water permeability of membrane and the pure water permeability when NF was completed.

Recovery index:

$$RI = 100\frac{PWP_{cleaning}}{PWP_{initial}} \quad (5)$$

Where, $PWP_{initial}$ (L.m^{-2}h^{-1}) and $PWP_{cleaning}$ (L.m^{-2}h^{-1}) were the initial pure water permeability of membrane and the pure water permeability when the cleaning was completed.

2.7. Mathematical model

In order to model the permeate flux in concentration of watermelon juice by RO process, the following equation was applied:

$$J_v = k.\ln(\frac{\alpha}{CF}) \quad (6)$$

Where, J_v: permeate flux (L.m^{-2}.h^{-1}), k: representative of mass transfer in boundary layer on membrane surface (L.m^{-2}.h^{-1}) and α: considered as maximum of CF value.

This semi – empirical model derived from osmotic pressure model (Nabetani et al. 1995). In osmotic pressure model, permeate flux is limited by difference in osmotic pressure between two sides of membrane. When CF reaches α value, the difference in osmotic pressure between two sides of membrane equals to transmembrane pressure, consequently, permeate flux is zero. This model was successfully applied for modeling permeate flux in concentration chicken extract (Nabetani et al. 2012) and nanofiltration for concentration of fish sauce (Lai and Nguyen 2021), coffee extract (Pan et al. 2013).

The variation of retentate volume (V_R, L) during the concentration by membrane filtration:

$$\frac{dV_R}{dt} = -AJ_v \quad (7)$$

Where, A: the membrane area (m^2), J_v: permeate flux (L/m^2.h)

According to the mass balance, the following equation describes the relationship between individual solute variation in retentate flows:

$$\frac{d(V_R C_{R,i})}{dt} = -AJ_v C_{R,i}(1 - R_i) \quad (8)$$

Where: R_i: solute retention (-); R_i, A, V_R and $C_{Ro,i}$ were determined from experimental data. The set of equations (equation (7) and equation (8)) were solve by the fourth order Runge – Kutta method in Matlab software (version

R2018a). This mathematical model has been successfully applied in modeling in concentration waste fresh tea leaf extract by RO (Lai et al. 2021), as well as purification and concentration rice protein by ultrafiltration (Doan and Lai 2021).

2.6. Analytical methods

Total sugar (TS) content of watermelon juice was determined by using sulfuric acid to form furan compounds, then adding phenol as indicator. The absorbance at 490 nm of wavelength was measured (Nielsen 2010).

Lycopene: Total lycopene were analyzed by spectrometric method (Fish et al. 2002). 10 mL of n-hexane was delivered into a tube. Then, adding 5 mL of ethanol 95% (v/v) and 5 mL of BHT 0.05% (w/v) in acetone. The mixture was vortexed. A given weight (approximately 0.5 gram) of watermelon juice was added into the mixture and shaking at 180 rpm in 15 min. Then, 3 mL of distilled water was added and shaking at 180 rpm in 5 min. After shaking, the tube was remained in 5 min for phase separation. Three mL of upper layer (n-hexane) was taken to determine the absorbance at 403 nm of wavelength. All steps were conducted at 20 ºC. Content of lycopene was calculated by the following equation:

$$Lycopene\ (mg/kg) = \frac{A_{503} x 31.2}{m_{juice}(g)} \quad (9)$$

Antioxidant capacity of watermelon juice was determined as the scavenging capacity of 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Oms-Oliu et al. 2009). Watermelon juice was centrifuged at 6000g for 15 min at 4 ºC. Then, 0.01 mL of the supernatant was added to 3.9 mL of 0.025 g/L of DPPH in methanol. Then, adding 0.090 mL of distilled water. The mixture was vortexed and kept in 30 mins in darkness. Then, the absorbance was determined at 515 nm of wavelength. Blank was methanol. AC was estimated as mg/L of Trolox equivalent antioxidant capacity (TEAC).

3. Results and discussion

3.1. Permeate flux

Permeate flux in concentration of watermelon juice by HR98PP was showed in **Fig. 2**. Permeate flux declined with increase in CF. Due to higher driving force, at same CF value, permeate flux at 40 bar was higher than that at 30 bar of operating pressure. At initial point, permeate flux at 40 bar was 19.74 $L.m^{-2}.h^{-2}$; whereas, that at 30 bar was 13.54 $L.m^{-2}.h^{-2}$. The curves of permeate flux at 30 and 40 bar of operating pressure was nearly offset. It means that the difference in permeate flux decline between at 30 and 40 bar of operating pressure was insignificant during the concentration. It implies that, based on resistance series model, influence of operating pressure on fouling in concentration by HR98PP was also insignificant (W. Barker 2011). It also implies that, increase in total solid in retentate insignificantly influenced on concentration polarization due to the high turbulence of fluid on membrane surface. Thus, the decline of permeate flux with increase in CF can be explained by increase in osmotic pressure, which caused by increase in total solid in retentate.

Based on equation (6), the linear regression was applied for modeling of permeate flux. Result in **Fig. 2** and **Fig. 3** and the approximate 1.0 of R^2 indicates that model exhibited the good agreement with experimental data. The estimation of value in concentration of watermelon juice by HR98PP was stated in **Table 2**. The mass transfer (k) value at 30 bar was lower than that at 40 bar. Wijmans et al. (1984) proved that increase in operating pressure leads to increase in mass transfer in boundary layer on membrane surface. And result in **Table 2** also indicates that higher operating pressure lead to higher maximum value of CF due to higher transmembrane pressure.

The statistical analysis results are summarized in **Table 3**. The resistance coefficient (k_n), coefficient of determination (R^2) and the root mean square deviation (RMSE) were used to compare the numerical predictions and the experimental data, and to choose the best fit mechanism for fouling and permeate decline over time evaluation. The results showed that blocking models were better correlated with experimental results than cake filtration models. This was completely consistent with the explanation for flux variation as a function of concentration factor. At both survey pressure conditions, the complete blocking model had the highest R^2 value, and best fit to the experimental data. On the other hand, the standard blocking mechanism had the highest resistance coefficient indicating that it was the most important fouling mechanism. For standard blocking the R^2 was about 0.986 and 0.946, respectively, at 30 and 40 bar that also showed the good agreement between the model and the experimental data. This is explained that the watermelon juice is a complex solution containing solutes of varying sizes, the multiple pore blockings mechanisms can occur simultaneously. This phenomenon reported in concentration of strawberry juice by Arend, Rezzadori, et al. (2019). However, due to the molecular weight of components in the watermelon juice, as well as the high operating pressure (30 – 40 bar), the foulants were less likely to enter the pore and reduce diameter. Therefore, the standard pore blocking did not occur significantly. This was also observed in several other studies (Lamdande et al. 2020; Lin 2017).

The resistance coefficient of the cake filtration mechanism was extremely low, indicating that there was no boundary layer formation in the concentration of watermelon juice. This reaffirmed that, as total solid concentration increased, concentration polarization had no significant effect on permeate flux. This suggested that the complete blocking mechanism is dominant during concentration of watermelon juice. Both complete pore blocking and cake filtration mechanism occur when the sizes of most solute molecules in watermelon juice were greater than the membrane pore size. As results, particles are unable to enter into the pore and permeate through the membrane (Khan et al. 2020). However, cake layer occurs in the presence of factors such as high concentration and binding of molecules, binding to the membrane and they can deposit on the membrane surface. It has a great influence on the permeate flux. While, in the case of the complete blocking mechanisms, a molecule never settles on another molecule that has previously deposited on the membrane surface (Vela et al. 2008). It is easily eliminated by strong impacts such as high pressure or turbulent flow, and it has little effect on permeate flux. These prove that HR98PP membranes were suitable for watermelon juice concentration. Furthermore, the resistance coefficient was greater at 40 bar of operating pressure than at 30 bar. This suggested that the increased pressure was responsible for the increase in turbulent flow, thereby reducing fouling phenomena. The complete blocking mechanism has also observed in many concentration processes by RO, such as waste fresh tea leaf extract (Lai et al. 2021), skim milk (Arend, Castoldi, et al. 2019).

3.2. Recovery yields and contents of components in retentate

Content in retentate and recovery yield of TS in concentration of watermelon juice by HR98PP is showed in **Fig. 4**. Relationship between TS content and CF was linear. It means that, rejection of TS was insignificant change in concentration of the juice. However, slope of TS content versus CF at 30 bar was slightly lower than at 40 bar. It implies that rejection of TS at 30 bar was lower than that at 40 bar. Tsuru et al. (1991) proved that, increase in operating pressure leads to increase in rejection in RO process. Comparing to at 40 bar, at 30 bar, the lower rejection of TS led to the lower recovery yield. At 40 bar, recovery yield was 98.6% when reaching 2.25 of CF; whereas, at 30 bar, the one was 90.7% when reaching 1.78 of CF. Ratio of C_R/C_F to CF at 40 bar was approximately 1.0. It means that, rejection of TS at 40 bar was approximately 100%. Whereas, that ratio at 30 bar was higher than 0.92, implies that rejection of TS at 30 bar was higher than 92%. The high rejection of TS also led to low concentration of TS in permeate (**Fig. 5**). Result in **Fig. 5** indicates that, content of TS in permeate was very lower than one in retentate. At 40 bar of operating pressure and 2.25 of CF, TS content in permeate was 2.41 g/L. The one at 30 bar of operating pressure and 1.79 of CF was 1.93 g/L. At same CF value, TS content in permeate at 30 bar of operating pressure was higher than that at 40 bar because that, rejection of TS at 30 bar was lower than that at 40 bar.

Estimation based on equation (6) indicates that, maximum of CF in retentate could reach 2.6 folds higher than that in feed. Dos Santos Gomes et al. (2011) reported that, when concentrating watermelon juice by RO membrane at

60 bar, CF and TS content can reach 4.4 and 30 ºBrix, 3.2 folds in relation to feed. The CF and TS content in that work was higher than ones in our work. Nevertheless, the process carried out by Dos Santos Gomes et al. (2011) was conducted at higher operating pressure and recovery of TS was lower, in comparing with present work.

Content and recovery yield of lycopene in concentration of watermelon juice by HR98PP is showed in **Fig. 6**. Rejection of lycopene in RO process insignificantly changed due to linear relationship between lycopene content and CF. Result also indicates that, lycopene in permeate was not detected. At 2.25 of CF and 40 bar of operating pressure, recovery yield of lycopene was 90%. Whereas, at 1.79 of CF and 30 of operating pressure, the one was 86.8%. It means that, there was the loss of lycopene by oxidation resulted in a reduction in recovery yield along with increase in CF. Comparing at 40 bar, the recovery yield of lycopene at 30 bar was lower due to operating time at 30 bar was longer. The loss of lycopene by oxidation and isomerization reactions was also observed in report by Dos Santos Gomes et al. (2011). However, the loss of lycopene in membrane process was not much as comparing to concentration by evaporation. The concentration of watermelon juice from 8 ºBrix to 30 ºBrix at 50 ºC and 100 mg Hg of pressure in rotary vacuum evaporator, 33.7% of lycopene was degraded (Jaju et al. 2017).

The processing properties of watermelon juice in concentration at 30 and 40 bar based on proposed mathematical model are presented in **Fig. 7**. The theoretical results are given from mathematical models that were well consistent with the experimental data. The content of lycopene and TS at 40 bar was higher than that at 30 bar due to the faster concentration process caused by the higher permeate flux. It implies that, at 40 bar, the concentration of watermelon juice was more effective compared to at 30 bar. In mathematical model, rejection was assumed to be constant and estimated as mean of experimental rejection, and permeate flux varied linearly with CF, but experimental rejection and permeate flux slightly changed. As a result, there is a discrepancy between calculating data and measured data. However, they fluctuated slightly and asymptotically around the predicted value. The reasons for this were the fouling phenomena that cough occur after a time of operation and increase in the viscosity of the retentate. Thus, the predictive model can be used to predict the time operation for a target solutes concentration at the end of the concentration. From the mathematical model, the maximum theoretical value of lycopene content at 30 and 40 bar were 172 and 185 mg/L, respectively, increased by 4.5 and 3.5 folds, with operating time of 36.8 and 27.1 hours. Along with that, the maximum of TS content was 245 and 341 g/L, respectively. It implies that, the concentration of watermelon juice was more effective at 40 bar, due to shorter time and higher of molecules content. Compared with other studies on applying RO for concentration, the maximum theoretical value of TS content obtained at 40 bar in watermelon juice concentration by HR98PP membrane is significantly higher than soluble solids content obtained in concentration by RO membrane of orange juice (30 ºBrix at 60 bar, (Jesus et al. 2007), apple juice (28.1 ºBrix at 60 bar, (Aguiar et al. 2012)), chokeberry juice (24.9 ºBrix at 55 bar, (Pozderović et al. 2016)), pomegranate juice (18 ºBrix at 30 bar, (Bagci et al. 2019)). The maximum theoretical value of lycopene and TS content in watermelon juice obtained by concentration with HR98PP membrane suggests that, the concentrate exhibited a good recovery particles which could be used in another process without concentrated process more. However, more research is necessary to identify the optimal multi-stage RO system for a watermelon juice product with high concentration of bioactive compounds and soluble solids.

Summary of concentration of watermelon juice by HR98PP was stated in **Table 4**. Result in **Table 4** indicated that the antioxidant capacity of watermelon juice was lost 29.89 and 17.61% when concentration by RO at 30 bar, 1.79 of CF and 40 bar, 2.25 of CF, respectively. Result also indicated that, the fouling in RO process with HR98PP at 30 bar of operating pressure was more severe than that at 40 bar. FI values of RO process at 30 bar and 40 bar were 67.11 and 76.64% . However, the cleaning as proposed procedure was eliminated fouling. RI values of RO process with HR98PP at 30 and 40 bar of operating pressure were higher than 95%. It means that, permeate flux was fully recovered.

4. Conclusions

Results indicated that the concentration of watermelon juice by HR98PP at 40 bar of operating pressure was more effective than that at 30 bar. The semi-empirical model has shown good performance when used to simulate permeate flux. The complete blocking mechanism was observed to be the reason causing fouling phenomena and the decline in permeate flux in concentration of watermelon juice by HR98PP. Theoretical maximum value of CF was 2.64. Recovery yields of TS, lycopene and antioxidant at 40 bar of operating pressure and 2.25 of CF were 98.67, 90.03 and 82.39, respectively. Result showed that, at 40 bar, the maximum contents of lycopene and TS increased up to 4.5 folds. TS and lycopene contents at that conditions of RO process were 171.31 g/L and 83.90 mg/L, respectively. From mathematical model, the theoretical permeate flux, content of compounds in retentate over time were observed, and they were in good agreement with the experimental data. The fouling in RO process were severe; however, cleaning with NaOH solution at pH10 was fully eliminated fouling. It is feasible to utilize HR98PP membrane for concentration of watermelon juice.

ACKNOWLEDGEMENT

We acknowledge the support of time and facilities from Ho Chi Minh City University of Technology (HCMUT), VNU–HCM for this study.

CONFLICT OF INTEREST

None

ETHICAL APPROVAL

Ethics approval was not required for this research.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

AUTHOR'S CONTRIBUTION STATEMENT

Q.D.L and H.D.N designed and directed the project. Q.D.L and N.T.T.D. wrote the main manuscript text. N.T.T.D. processed the experimental data, performed the analysis. All authors reviewed the manuscript.

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FIGURE LEGENDS

Fig. 1. Schema of flat and frame pilot LabstakM20 system. 1: feed tank, 2: pump, 3: pressure gauge, 4: membranes, 5: permeate tank, 6: flowmeter

Fig. 2. Permeate flux against CF in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; Solid line: estimation, spot: experimental data)

Fig. 3. Permeate flux against Ln(CF) in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; Solid line: estimation, spot: experimental data).

Fig. 4. Content and recovery yield of TS in retentate in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; filled spot: recovery yield, non-filled spot: content)

Fig. 5. Content of TS in permeate in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar)

Fig. 6. Content and recovery yield of lycopene in retentate in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; filled spot: recovery yield, non-filled spot: content)

Fig. 7. Content of lycopene and TS in retentate vs. operating time in concentration of watermelon juice by HR98PP. Plot: experiment (at 40 bar, ○: lycopene, Δ: TS; and at 30 bar, □: lycopene, +: TS). Line: calculation (at 40 bar: ———: lycopene, — — — : TS; at 30 bar, --------: lycopene, — · — ·: TS)

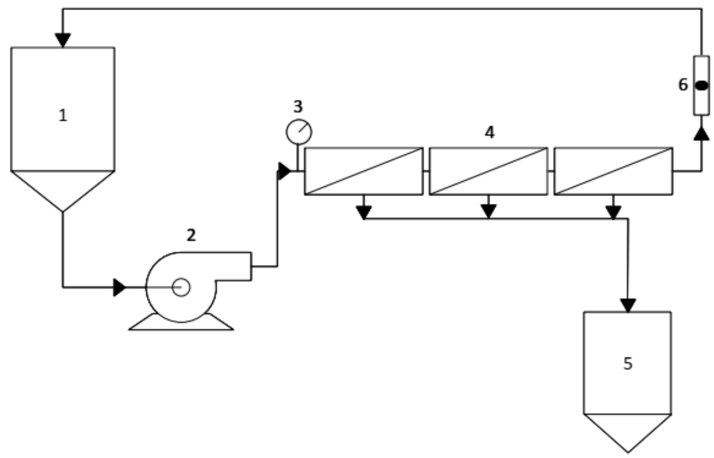

Fig. 1. *Schema of flat and frame pilot LabstakM20 system. 1: feed tank, 2: pump, 3: pressure gauge, 4: membranes, 5: permeate tank, 6: flowmeter*

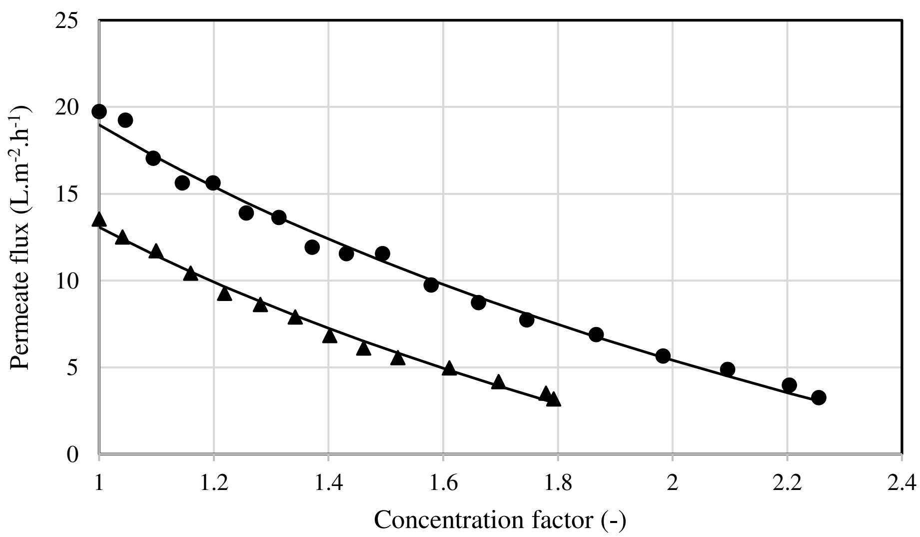

Fig. 2. *Permeate flux against CF in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; Solid line: estimation, spot: experimental data)*

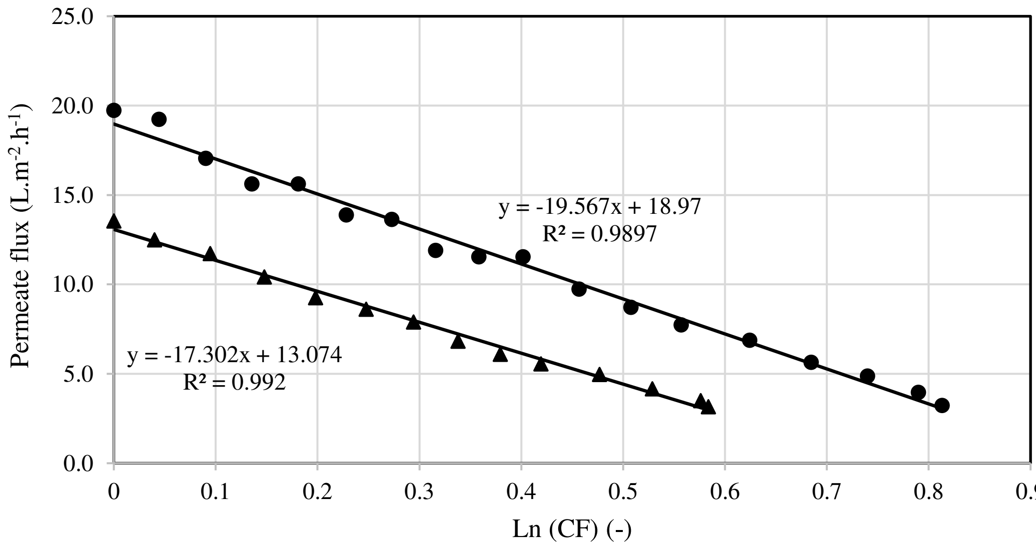

Fig. 3. *Permeate flux against Ln(CF) in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; Solid line: estimation, spot: experimental data).*

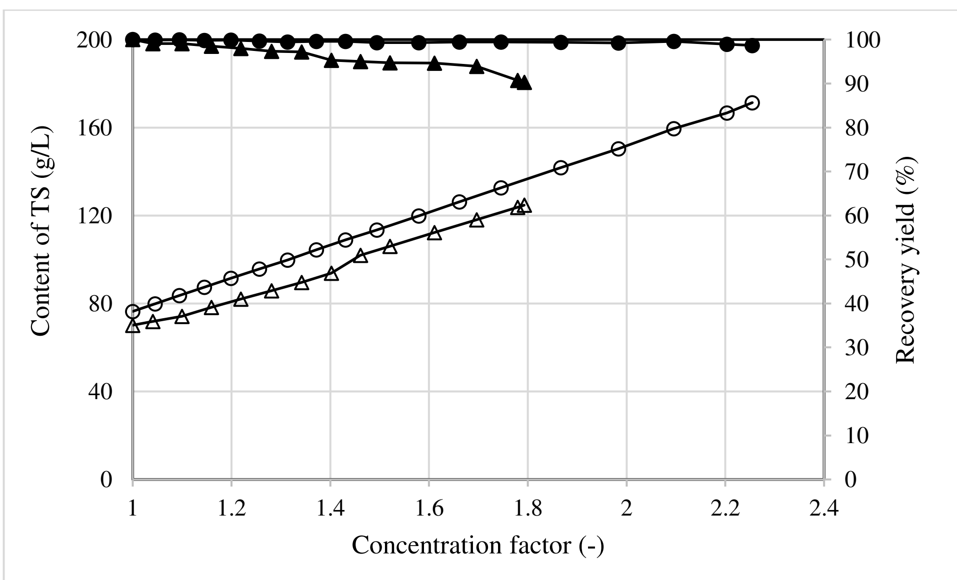

Fig. 4*. Content and recovery yield of TS in retentate in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar; filled spot: recovery yield, non-filled spot: content)*

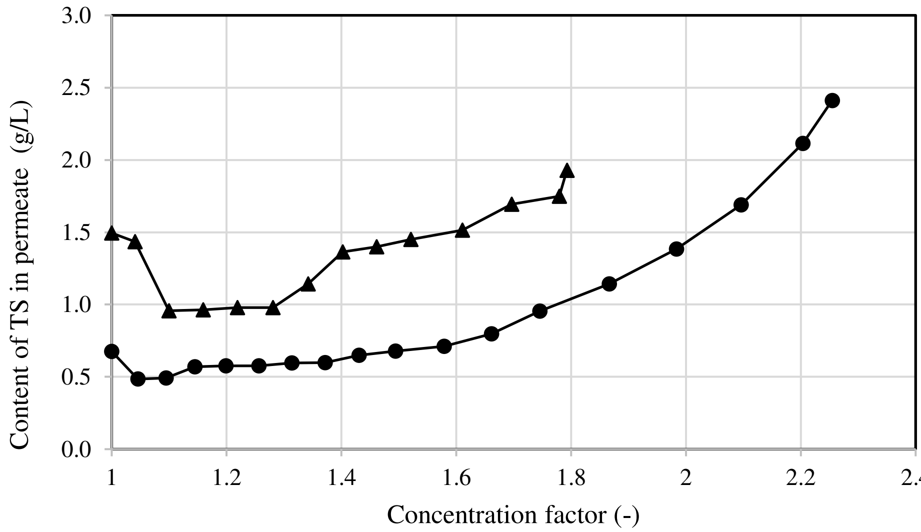

Fig. 5. *Content of TS in permeate in concentration of watermelon juice by HR98PP (●: 40 bar, ▲: 30 bar)*

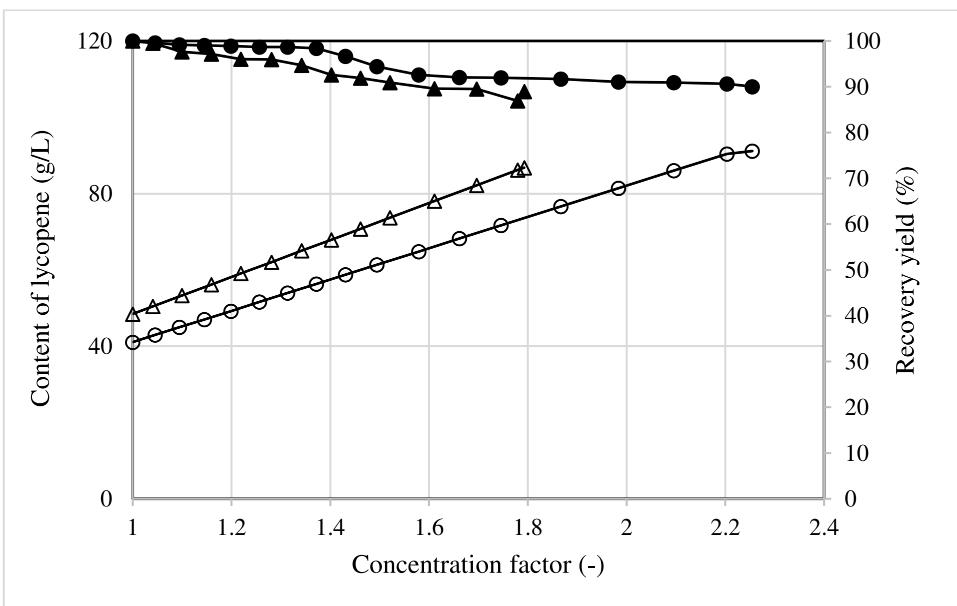

Fig. 6. *Content and recovery yield of lycopene in retentate in concentration of watermelon juice by HR98PP*

(●: 40 bar, ▲: 30 bar; filled spot: recovery yield, non-filled spot: content)

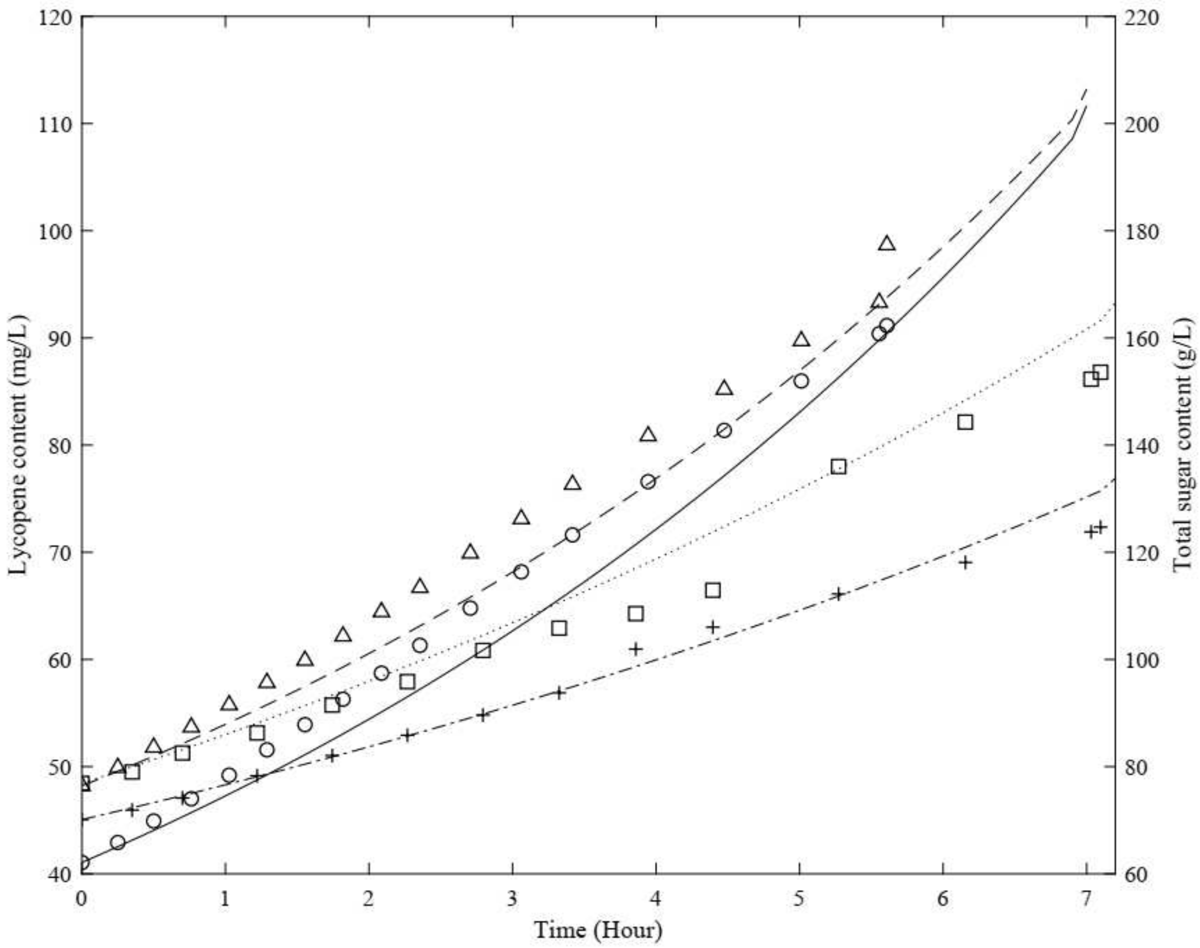

Fig. 7. *Content of lycopene and TS in retentate vs. operating time in concentration of watermelon juice by HR98PP. Plot: experiment (at 40 bar, ○: lycopene, Δ: TS; and at 30 bar, □: lycopene, +: TS). Line: calculation (at 40 bar: ——: lycopene, — — — : TS; at 30 bar, --------: lycopene, —·—·: TS)*

TABLE LEGENDS

Table 1. Flux expressions of Hermia models

Table 2. Estimation of parameters of model of permeate flux in concentration of water melon juice

Table 3. Models fitting accuracy for concentration of watermelon juice by HR98PP

Table 4. Summary of concentration of watermelon juice by HR98PP membrane.

Table 1. Flux expressions of Hermia models

Fouling mechanism	n value	Derivative equation
Complete pore blocking	2	$\ln(J^{-1}) = \ln(J_0{}^{-1)} + kt$
Standard pore blocking	1.5	$J^{-0,5} = J_0{}^{-0,5} + kt$
Intermediate pore blocking	1	$J^{-1} = J_0{}^{-1} + kt$
Cake formation	0	$J^{-2} = J_0{}^{-2} + kt$

J and J_0 (L/m^2h) are the permeate flux at t (h) of operating time and initial time, respectively.

Table 2. *Estimation of parameters of model of permeate flux in concentration of water melon juice*

Operating pressure (bar)	k **($L.m^{-2}.h^{-1}$)**	α	R^2	**RMSE**
30	17.302	2.13	0.992	0.2921
40	19.669	2.63	0.9898	0.5061

Table 3. *Models fitting accuracy for concentration of watermelon juice by HR98PP*

Pressure		Cake filtration	Intermediate blocking	Standard blocking	Complete blocking
30 bar	k_n	0.00006	0.0023	0.2024	0.0385
	R^2	0.8568	0.9557	0.986	0.9964
	RMSE	4.6947	1.4839	0.4437	0.1524
40 bar	k_n	0.00003	0.0019	0.2740	0.0169
	R^2	0.7164	0.8806	0.9462	0.9856

RMSE	4.8326	6.995	1.7959	0.5889

Table 4. *Summary of concentration of watermelon juice by HR98PP membrane.*

Operating pressure (bar)	Fresh juice			Concentrate juice			Recovery yield			CF	*FI*	*RI*
	TS[a]	Ly[b]	AC[c]	TS[a]	Ly[b]	AC[c]	TS[a]	Ly[b]	AC[c]			
30	70.12	48.46	70.81	114.53	76.54	88.86	90.32	86.90	70.11	1.79	67.11	95.72
40	76.41	41.05	67.83	171.31	83.90	125.74	98.67	90.03	82.39	2.25	76.64	96.12

a: g/L, b: mg/L, c: mg TEAC/L