The Effect of Magnetic Field on Efficiency and Fouling Mechanisms During Membrane Clarification of Pomegranate Juice

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ABSTRACT: *Microfiltration can be used to clarify Pomegranate Juice (PJ); however, it is fouled by charged particles. The magnetic field was coupled with microfiltration to reduce the membrane fouling. Results showed that the magnetic field halved the total resistance; since it increased the permeate flux. The most efficient application of the magnetic field in the membrane clarification was achieved at the high intensity of the magnetic field, low level of the feed flow rate, and the direction of the magnetic field from the feed to the permeate side. Evaluation of the fouling mechanisms showed that with the increase in the intensity of the magnetic field, at the beginning of the process, the intermediate and standard blockings were dominant mechanisms, but over time, the formation of the cake became more important. Scanning Electron Microscope (SEM) showed that the layer of the cake deposited on the membrane surface in the absence of the magnetic field, inverse mode with the magnetic field was very dense. On the other hand, the total monomeric anthocyanin content and the antioxidant activity of PJ increased; pH and total phenolic components were constant, and the total soluble solid content, turbidity, and acidity were reduced.*

KEYWORDS: *Fouling; Magnetic field; Microfiltration; Membrane; Pomegranate.*

INTRODUCTION

Pomegranate (*Punicagranatum L.*) in both fresh fruit and juice forms has a nutritional value that makes it a desirable food throughout the world [1-4]. Clarification of pomegranate juice is an important pretreatment before its concentration avoiding the destruction of concentrated juice color and flavor. Nowadays, the application of enzymes and filter press is a conventional clarification method in the food industry, which requires expensive enzymes and spending considerable time [3,4]. Membrane technology is an interesting alternative to clarify fruit juice which

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has important benefits such as low initial investment, ease of application, and relatively low energy consumption compared to traditional methods. Microfiltration is a pressure-driven membrane process that can successfully clear the fruit juices [4-6]. One of the most important problems in the membrane processes is the fouling phenomenon [3, 7, 8]. Membrane fouling reduces permeate flux and productivity, as well as increases production costs and consumer health, which is threatened by the detergent remaining in the final product. There are several types of research focusing on the improvement of the performance of the membrane clarification of juices. Pomegranate Juice (PJ) was successfully clarified using membrane processing [4, 9-11]. Results showed that both microfiltration and ultrafiltration can reduce the PJ turbidity; however, there is no difference between their effects on the juice turbidity. In another study, the effect of membrane clarification on the physicochemical properties of PJ was studied by *Mirsaeedghazi et al.* [4]. Results showed that the antioxidant activity, acidity, soluble solids content, total solids, and the total phenolic content of PJ decreased after the membrane clarification process. *Espamer et al.* [12] studied the clarification of lemon juice using the membrane process and showed that the permeate flux is decreased in the early stages of the process mainly due to the concentration polarization phenomenon and the spreading of the gel layer on the membrane surface.The authors concluded that the properties of the clarified juice were not dependent on the pressure of the process. The effect of several pretreatments on the permeate flux during the membrane clarification of orange juice was studied by *Rai et al.* [13]. They concluded that using bentonite could affect the obtained maximum permeate flux.

Membrane clarification of tomato juice was studied by *Razi et al.* [14]. In their study, the effect of the transmembrane pressure, feed temperature, and flow rate on the permeate flux and juice physicochemical properties were studied. Results showed that the flow rate has a significant effect on the permeate flux; however, operation parameters don’t affect the physicochemical properties of the juice. *Aliasghari Aghdam et al.* [3] evaluated the effect of ultrasonic waves on the permeate flux during the membrane clarification of PJ. They concluded that the permeate flux increased by application of the ultrasonic treatment due to the cake layer reduction. *Vedadghavami et al.* [15] introduced the electric field as a useful method that can reduce the concentration polarization layer and fouling phenomenon. *Zin et al.* [16] used a permanent magnetic field (max. 0.7 T) to improve the permeation performance and permeability recovery during ultrafiltration of Bovine Serum Albumin (BSA) and the milk. They used a 50 kDa hydrophilic polyethersulfone membrane and resulted that both the permeate flux and the recovery of hydraulic permeability increased by application of the magnetic field. *Woo et al.* [17] modified polytetrafluoroethylene (PTFE) Micro Filtration (MF) membrane with magnetite nanoparticles and concluded that the resistance of the membrane to the fouling increased under a rotating magnetic field and water permeate flux increased by 50% in these conditions. *Yu et al.* [18] used a magnetic field in the preparation of the membrane to enhance the permeability and antifouling property of the resulted membrane. They got positive results from their research.

The charge in the number of particles that causes the fouling and its effect on this phenomenon is an important point that was not evaluated before. In PJ, pectin has a negative charge that caused the most percent of membrane fouling during microfiltration [19, 20]. Also, phenolic components have a negative charge; however, protein in juice pH has a positive charge [19]. In this study, the effect of the charge of particles on the fouling phenomenon was evaluated with the application of the magnetic field along with the microfiltration process. Also, the effect of such coupled process on the permeate flux and physicochemical properties of PJ was studied.

In previous research, reduction of the membrane fouling was evaluated on the following two bases:

1) After fouling, it is removed or reduced by various physical and chemical methods

2) By some methods such as increasing the flow rate, and changing the pressure and vibration of the membrane surface, particle sedimentation on the membrane surface is prevented, and thus fouling is reduced.

The technique used in the present study differs from all previous approaches. In this method, the chemical nature of the particles causing fouling (their pure chemical charge) is used to prevent its deposition on the membrane surface. Therefore, the novelty of the present study could be the use of an electromagnetic phenomenon with a focus on the chemical properties of the particles that cause fouling to prevent the deposition of these particles on the membrane surface.

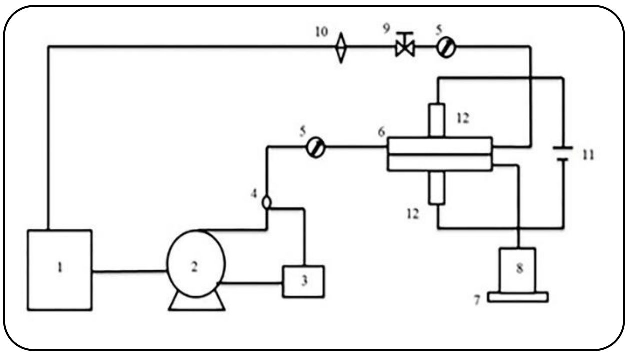

Fig. 1: Membrane unit coupled with the magnetic field (1: feed tank; 2: pump; 3: inverter; 4: transmitter; 5: pressure meter; 6: membrane module; 7: balance; 8: permeate tank; 9: valve; 10: flow meter; 11: electric power supply; 12: poles of magnetic field).

EXPERIMENTAL SECTION

Juice extraction

Pomegranate (variety Malaise Saveh) was prepared from the local market (Saveh, Iran), washed, peeled, and lathery skin was removed. After extraction of Pomegranate Juice (PJ) by manually pressing, large particles were removed from the fresh juice using a 2 mm mesh filter. The juice was stored in PET bottle at -25℃ to be used in any experiment. Before testing, all samples were agitated.

Magnetic field-membrane unit

Mixed cellulose ester flat sheet membrane (Millipore, USA) with pore size 0.22μm and active area 78 × 10^{-4} m^2 was used to clarify PJ at the room temperature ~20℃ and the transmembrane pressure 50662.5 Pa. A flat sheet membrane module made of stainless steel was selected with a thickness 0.01 m per plate. It was placed between poles of the magnetic field-producing system that can produce a magnetic field intensity 0-600 mT. The pomegranate juice was pumped from the feed tank (with an initial feed volume of 0.005 m^3 to prevent the significant effect of batch mode on feed characteristics) to the membrane module using a rotary van pump (PROCON, Series 2, Milano, Italy). The permeate tank was placed on a digital balance to calculate the permeate flux and the retentate was recycled to the feed tank. A transmitter (WIKA, type ECO-1, Klingenberg, Germany) coupled with an inverter (LS, model sv015ic5-1f, Kyonggi-Do, Korea) was used to adjust the constant pressure at different feed-flow rates (Fig. 1).

Evaluation of the physicochemical properties of PJ

The physicochemical properties of the samples were determined before and after the microfiltration in both without the magnetic field and with the magnetic field processes.

Radical scavenging properties of PJ were evaluated using 2,2-diphenyl-1picrylhdrazyl (DPPH) method to determine the antioxidant activity of PJ [4]. In this method, 3.9 mL of methanol solution of DPPH (25 mg/L) was mixed with 0.1 mL of the juice and its absorbance was measured using a UV-Vis spectrophotometer at 515 nm (Photonix Ar2015, Iran) which was reported as $[DPPH]_t$. The test was repeated with methanol instead of PJ to measure the value of DPPH at t = 0. The remaining DPPH was calculated according to Eq. (1).

$$DPPH_{rem} = \frac{[DPPH]_t}{[DPPH]_{t=0}} \tag{1}$$

The concentration of the juice sample which can remain 50% of DPPH was expressed as EC50.

To determine the content of phenolic compounds in PJ, 1 mL of the juice was added to 1 mL of HCL (6M) and 5 mL of methanol in a water solution (75% v/v). The final solution was placed in a water bath (Serology Water Bath, SHSWB25, IRAN) at 90 ℃ and was stirred for 2 hours; then, its temperature was decreased to 25℃. The volume of this solution was adjusted to 10 mL and 1 mL of the last solution was added to 5 mL folin which had been diluted 10 times and 15 mL of Na_2Co_3 (0.07 kg/L) and its volume was brought to 100 mL. The absorbance of the solution was measured using a UV-Vis spectrophotometer at 760 nm against a control sample in which distilled water was used instead of PJ. Also, gallic acid was used as the standard and the total content of phenolic components was measured and expressed as mg gallic acid per 100 mL of juice [3].

The Total Anthocyanin Content (TAC) of PJ was measured using pH differential method. According to this method, 3.6 mL of KCl (0.025 M, which was adjusted to pH = 1 with HCl) was added to 0.4 mL PJ and its absorbance was measured at 510 and 700 nm and reported as A_1 and A_2, respectively. The test was repeated with sodium acetate (0.4 M that was adjusted to pH = 4.5 with acetic acid) instead of KCl and its absorbance at 510 and 700 nm was expressed as A_3 and A_4, respectively. TAC (mg cyanidin-3, 5-diglucoside/100 mL juice) was calculated with Eq. (2) [3, 6].

$$TAC = \frac{A \times MW \times DF \times 100}{MA} \quad (2)$$

Where *MW* and *MA* are molecular weight and molar absorptivity of cyanidin-3-glucoside, respectively, *DF* is the dilution factor and *A* is the total absorbance, which was measured according to Eq. (3.)

$$A = (A1 - A2) - (A3 - A4) \quad (3)$$

The total acidity was measured using a titration of 2.5 g of PJ that has been diluted 10 times with NaOH (0.1 N) in presence of phenolphthalein until the stable pink color was achieved and it was measured according to Eq. (4).

$$A = \frac{A \times 0.0064 \times 100}{W} \quad (4)$$

Where *A* is total acidity (g citric acid/100g juice), M is the volume of NaOH (mL) and W is the weight of the juice sample (g).

The turbidity was measured by a digital turbid meter (TU-2016, TAIWAN) and was expressed as NTU. pH of PJ was measured using a pH meter (Metrohm-821 model, Switzerland). Total Soluble Solids (TSS) of PJ was measured using a digital refractometer (Atago, Japan) and expressed as °Brix.

CALCULATIONS

Calculation of permeate flux

The permeate flux (kg/m^{2}s) was calculated according to Eq. 5.

$$Flux = \frac{W_2 - W_1}{(t_2 - t_1) \cdot A} \quad (5)$$

Where *A* is the membrane active area (m^2), W_2 and W_1 are the permeate weights (kg) in time t_2 and $t_1(s)$, respectively. Permeate difference flux was calculated according to Eq. (6.)

$$\Delta F = F_1 - F_2 \quad (6)$$

Where ΔF, F_1, and F_2 are the permeate difference flux, the permeate flux in with magnetic field mode, and the permeate flux without magnetic field mode.

The Volume Concentration Factor (VCF) was calculated according to Eq. (7.)

$$WCF = \frac{V_0}{V_0 - V_p} \quad (7)$$

Where V_0 and V_p are the initial volume of juice and permeate volume, respectively.

Calculation of the fouling resistances

The membrane cleaning process was performed with distilled water, NaOH solution (%0.5w/w), and HCL solution (pH=1) at the maximum flow rate and the minimum transmembrane pressure, respectively. Total resistance was calculated according to Eq. (8)[3, 7, 21].

$$R_t = R_m + R_c + R_{frev} + R_{firrev} \quad (8)$$

Where $R_{t,}$ R_m, R_c, R_{frev} and R_{firrev} (1/m) are total, membrane, cake, reversible and irreversible fouling resistances, respectively. These resistances can be calculated by Eqs. 9-12.

$$R_m = \frac{1}{L_p^0 \cdot \mu} \quad (9)$$

$$R_m = \frac{1}{L_p^1 \cdot \mu} \quad (10)$$

$$R_{frev} = \frac{1}{L_p^2 \cdot \mu} - R_m - R_{firrev} \quad (11)$$

$$R_{firrev} = \frac{1}{L_p^4 \cdot \mu} - R_m \quad (12)$$

Where μ (Pas) is the water viscosity and L_p^n (m/Pas) is the hydraulic permeability of membrane which was calculated according to Eq. (13).

$$L_p^n = \frac{\text{water permeate flux}\left(m^3/m^2s^1\right)}{\text{transmembrane pressure(Pa)}} \quad (13)$$

L_p^0, L_p^1, L_p^2 and L_p^4 are the hydraulic permeability in the new membrane, after the juice treatment, after washing with water, and after washing with the acid solution, respectively.

Evaluation of the main mechanism of fouling

Hermia's model was used to determine the fouling mechanism as follows [22].

● When the curve of *t*/*v* versus *v* is linear, cake formation is the dominant mechanism of fouling.

● When the curve of *t*/*v* versus *t* is linear, standard blocking is the dominant mechanism of fouling.

● When the curve of ln(t) versus *v* is linear, intermediate blocking is the dominant mechanism of fouling.

On the other hand, the moment of creating any fouling mechanism can be determined using Eq. 914) [22].

$$\frac{d^2t}{dv^2} = k\left(\frac{dt}{dv}\right)^i \tag{14}$$

Where *t*, *v*, *k* and *i* are the time, permeate volume, resistance coefficient, and the blocking index, respectively. When blocking indexes are 0, 1, 1.5, and 2, cake formation, intermediate blocking, standard blocking, and complete blocking would occur, respectively.

Cross-sections and surfaces of new and used membranes in the presence and absence of the magnetic field were studied using scanning electron microscopy (EM3200, KYKY, China) to confirm the fouling mechanism predicted by Hermia's theory. The samples were first coated with gold using the physical vapor deposition method with a sputter coater (SBC-12, KYKY, China).

RESULTS AND DISCUSSION

The effect of magnetic field on the efficiency of membrane clarification

The effects of magnetic field intensity, its direction, and the feed flow rate on the process performance during the membrane clarification of PJ were evaluated in this section.

Microfiltration was performed at different magnetic field intensities 100, 300, and 500 mT. Results showed that the minimum permeates flux was achieved when the membrane clarification of PJ was performed without a magnetic field and the flux increased with increasing the intensity of the magnetic field, especially by applying 500 mT (Fig. 2). Studies have shown that magnetic fields can interfere with intermolecular reactions and increase the wettability of polymeric surfaces. As a result, the hydrophilic property of the membrane surface increases due to the application of a magnetic field, which ultimately leads to an increase in permeate flux [23]. On the other hand, *Silva et al.* [24] believe that reducing the interaction between the solute and the membrane surface increases the permeate flux in the membrane processing of bovine serum albumin. This fact seems to be true in the present study. PJ contains about 85 percent water [25] which is diamagnetic and is affected by a magnetic field [26-28]. The magnetic field changes the PJ molecular structure [29, 30] and converts it to small particles; on the other hand, the intermolecular force between the molecules of water increases [28, 31-35], and it affects the PJ flow rate [30]. Also, the magnetic field can reduce the viscosity of materials in their liquid state [36, 37]; since the permeate flux of PJ increases during the membrane clarification. On the other hand; increasing the intensity of the magnetic field increases its power (F_B) according to Eq. (15).

$$F_B = q \cdot v \cdot B \cdot \sin\theta \tag{15}$$

Where *q(c)* is the charge of particles, v (m/s) is the velocity of particles, and *B(T)* is the magnetic field intensity. Consequently, increasing the field intensity increases the effect of the magnetic field on PJ [38].

Carlesso et al. [39] obtained the same results during ultrafiltration of synthetic textile effluent. They concluded that the application of a magnetic field in the ultrafiltration of the model textile wastewater containing CMC and sodium sulphate can improve hydraulic permeability recovery. Also, *Zin et al.* [16] obtained the same results during ultrafiltration of bovine serum albumin and milk and improved both permeate flux and hydraulic permeability recovery by application of the magnetic field. *Yu et al.* [18] had a similar experience in using magnetic fields to increase membrane permeability.

Evaluation of total resistance showed that the magnetic field decreased during the microfiltration of PJ. Microfiltration with high intensity of the magnetic field had the least total resistance (Fig. 3). *Woo et al.* [17] obtained the same results when they concluded that the application of magnetic nanoparticles in the production of PTFE membrane under the rotating magnetic field increased the resistance of membrane to fouling.

The clarification process was performed in the membrane unit coupled with horizontal and vertical magnetic fields to evaluate the effect of magnetic field direction on the performance of membrane processing. Also, the vertical magnetic field was designed in the feed to permeate (F to P) and the permeate to feed (P to F) directions. Experiments were performed at a feed flow rate 10 mL/s,

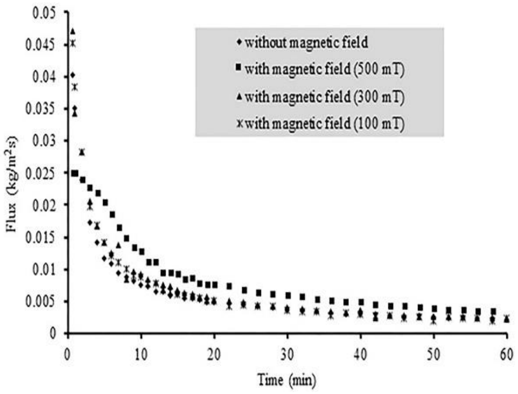

Fig. 2: Effect of the intensity of magnetic field on the permeate flux during membrane clarification of PJ (pressure of 0.5 bar; flow rate of 10 mL/s and direction of F to P).

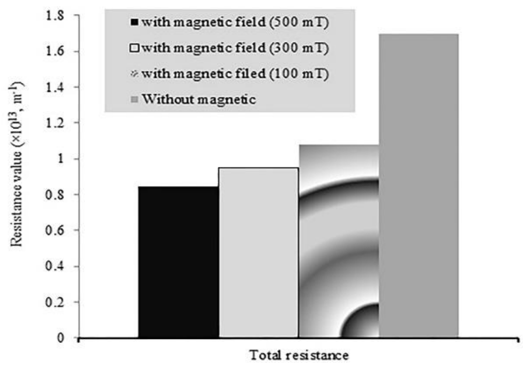

Fig. 3: Effect of the intensity of magnetic field on the total resistance during the membrane clarification of PJ (pressure of 0.5 bar; flow rate of 10 mL/s and direction of F to P).

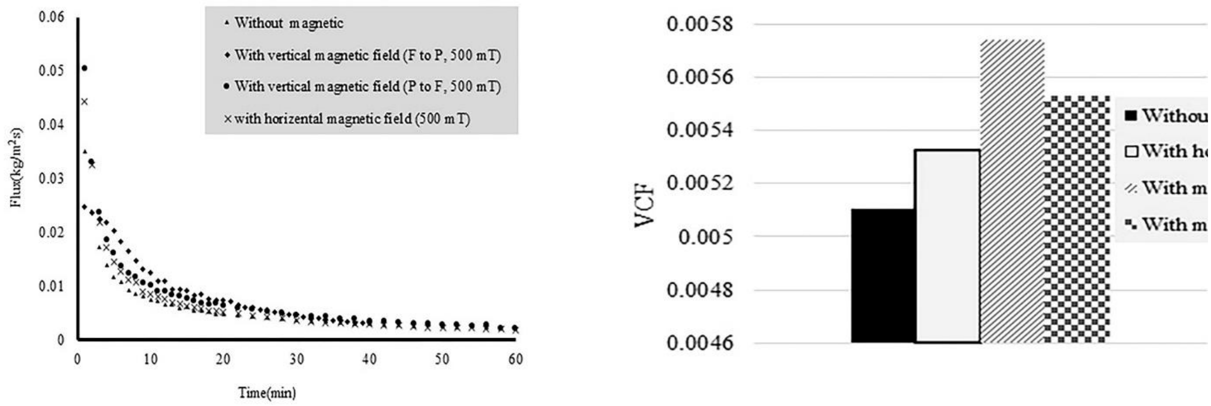

Fig. 4: Effect of magnetic field direction on the permeate flux and Volume Concentration Factor (VCF) during the membrane clarification of pomegranate juice (feed flow rate = 10mL/s, transmembrane pressure = 0.5 bar, magnetic field intensity = 500 mT).

transmembrane pressure 0.5 bar and magnetic field intensity 500 mT. Results showed that the membrane clarification of PJ in the presence of a magnetic field with a direction of F to P had the most permeate flux and the least total resistance (Figs. 4, 5). On the other hand, in this case, the amount of VCF was almost twice the VCF obtained in the process mode without the presence of a magnetic field, which was consistent with the results of the total resistance. (Fig. 4, 5). Evaluation of different fouling resistances showed that the irreversible and the cake resistances showed the maximum reduction in this configuration. In P to F and horizontal modes, the reduction of total resistance was mostly due to reduced cake resistance and irreversible fouling did not change in these modes.

The reason for this is the opposition of the direction of the magnetic field to the direction of the permeate flow, which prevents the deposition of large particles on the membrane surface. In addition, research has shown that pectin, proteins, and tannins are the most important constituents of turbidity in juices [40] and in pomegranate juice, the role of pectin in creating turbidity is significant [41]. Research has shown that the predominant charge of pectin is negative [42]. Fig. 6 shows the direction of field polarity in different modes. As can be seen in the F to P mode, the N is up (feed side) and the S is down (Permeate side). On the other hand, the N pole has a positive charge and as a result, can absorb turbidity-causing particles that have a predominantly negative charge and prevent them from flowing to the surface of the membrane.

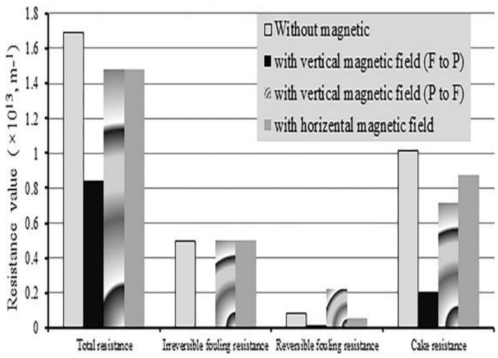

Fig. 5: Effect of the direction of magnetic field on the different fouling resistances during the membrane clarification of pomegranate juice (feed flow rate = 10mL/s, transmembrane pressure = 0.5 bar, magnetic field intensity = 500 mT).

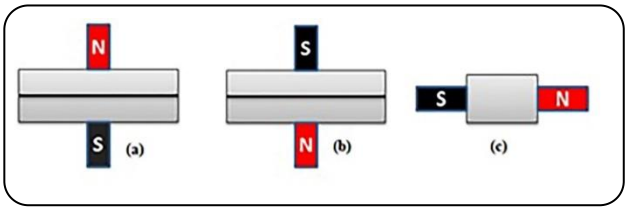

Fig. 6: The direction of field polarity in different modes (a: F to P; b: P to F; c: horizontal).

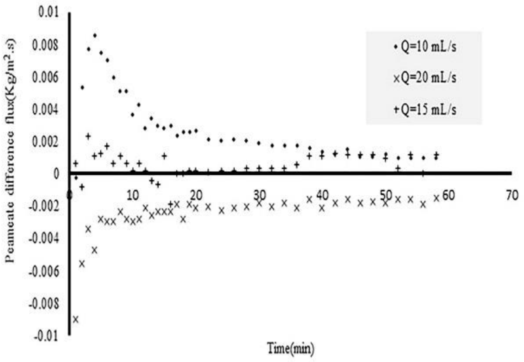

Fig. 7: Effect of the direction of magnetic field on the different fouling resistances during the membrane clarification of pomegranate juice (feed flow rate = 10mLs^{-1}, transmembrane pressure = 0.5 bar, magnetic field intensity = 500 mT).

As a result, in this case, the amount of fouling of the system decreases, and consequently the permeate flux increases.

The effect of the magnetic field in P to F mode on different resistances was similar compared to the effect of ultrasound on these resistances during membrane clarification of pomegranate juice at low flow rates [3]. The results were in consist with those of *Samieirad et al.* [43], who concluded that the use of an electric field followed by a magnetic field in a vertical mode could increase the water permeate flux in forwarding osmosis by almost 6 times the value without these fields.

Membrane clarification was performed at three feed flow rates 10, 15, and 20 mL/s to evaluate its effect on the intensity of the efficiency of the magnetic field. Results showed that the effectiveness of the magnetic field in the membrane clarification of PJ increased with the reduction of the feed flow rate; since in the low feed flow rate, the residence time of juice in the magnetic field increases and the magnetic field has more time to affect the juice; so the permeate flux increased gradually (Fig, 7).

Effect of magnetic field on membrane fouling mechanism (transmembrane pressure = 0.5 bar, magnetic field intensity = 500 mT)

Evaluation of the relation between permeate volume (v) and the processing time (t) showed that according to Hermia's model the curve of t/v versus v and t/v versus t were more linear than in the other case; therefore, cake formation and standard blocking could be considered as the main fouling mechanisms (Table 1).

The study of blocking index in 10 mL/s showed that in a process without a magnetic field, and also with a magnetic field 100 mT, this index was between 0.2 and 0.6 (Figs. 8a). This indicates that the cake formation was the dominant mechanism in the whole process. However, with increasing the intensity of the magnetic field, the mode of change of the blocking index varied; so that at the beginning of the process, the index had values of about 1 to 1.2, gradually falling to about zero. This shows that, at the beginning of the process, the intermediate and standard blockings were the dominant mechanisms, but over time, the formation of the cake became the dominant mechanism. On the other hand, by increasing the magnetic field intensity, the time of cake formation was postponed. It also started by changing the direction of the magnetic field with a complete blocking mechanism and then other mechanisms occurred. All observations showed that by applying the magnetic field and increasing its intensity, the importance of the cake layer, possibly due to its thickness reduction, was reduced. Similar conditions were observed at feed flow rates 15 and 20 mL/s (Figs. 8b, c).

Table 1: R^2 of different curves of permeate volume (v) versus time (t) with the linear curve (FVV= Feed Volumetric Velocity; F = Feed; P = Permeate).

Process			Value of R^2		
FVV (mL/s)	Intensity (mT)	Field direction	t/v versus v	t/v versus t	Ln(t) versus v
5	0	--	0.961	0.983	0.978
	500	F to P	0.947	0.991	0.977
10	0	--	0.984	0.978	0.955
	100	F to P	0.964	0.988	0.974
	300	F to P	0.971	0.987	0.969
	500	F to P	0.968	0.996	0.959
	500	P to F	0.973	0.986	0.967
	500	Horizontal	0.957	0.991	0.978
15	0	--	0.979	0.968	0.949
	500	F to P	0.989	0.971	0.946
20	0	--	0.971	0.986	0.972
	500	F to P	0.992	0.977	0.953
	500	P to F	0.949	0.991	0.978

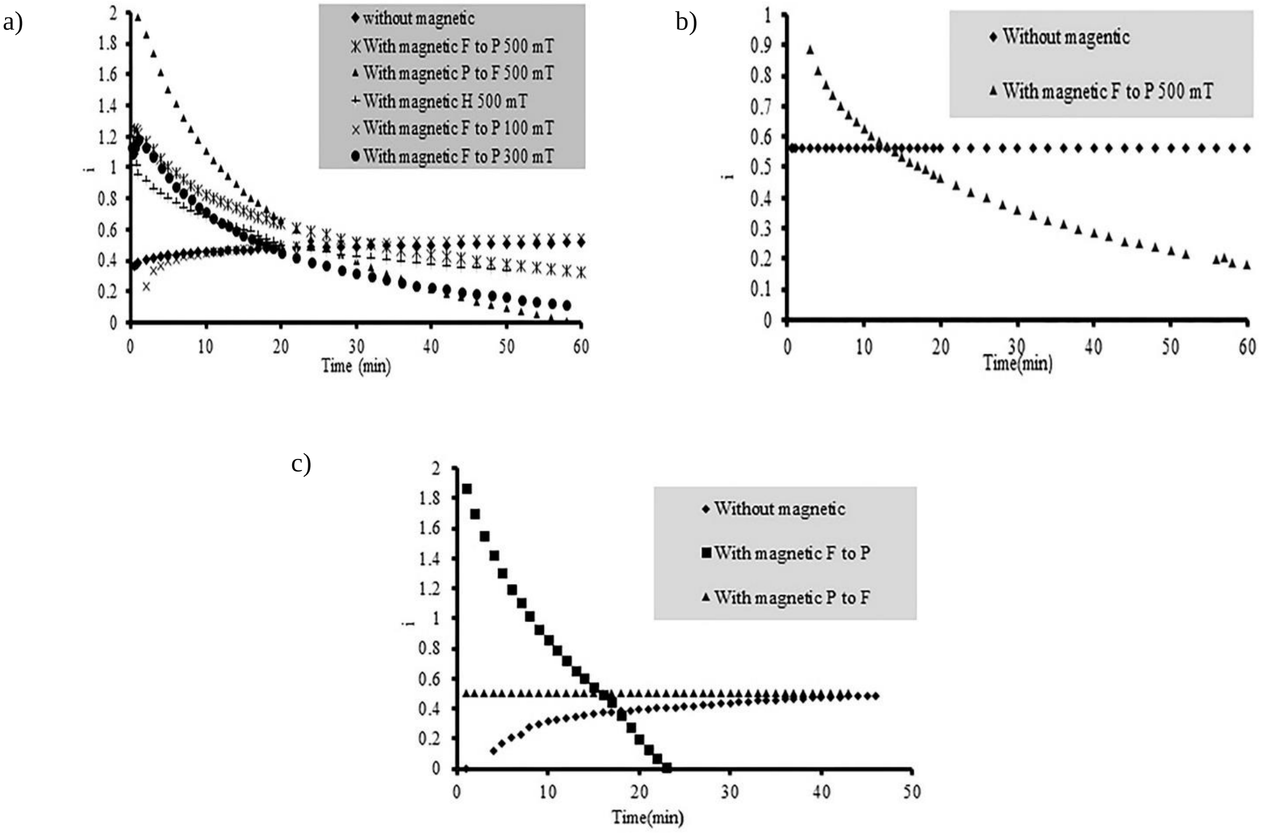

Fig. 8: Change in blocking index during membrane clarification of pomegranate juice under magnetic field (a: 10 mL/s; b: 15 mL/s; c: 20 mL/s, 500 mT; F = Feed; P = Permeate).

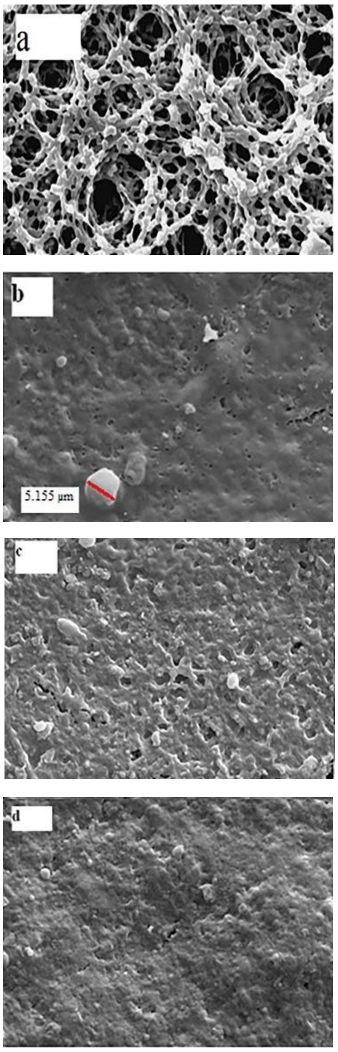

Fig. 9: ***Scanning electron microscopy images of membrane surface (×2500, a: new membrane, b: after pomegranate juice treatment without magnetic field, c: after pomegranate juice treatment with the magnetic field at 10 mL/s; d: after pomegranate juice treatment with the magnetic field at 20 mL/s).***

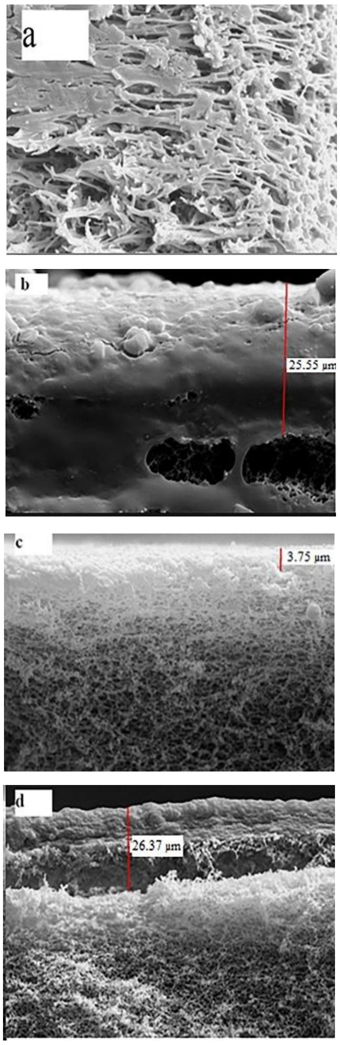

Fig. 10: ***Scanning electron microscopy images of membrane cross-section (×2000, a: new membrane, b: after pomegranate juice treatment without magnetic field, c: after pomegranate juice treatment with the magnetic field at 10 mL/s; d: after pomegranate juice treatment with the magnetic field at 20 mL/s)***

In order to confirm the results of the permeate flux and Hermia's model, the surface of new and treated membranes was evaluated using SEM. As seen in Fig. 9, the layer of the deposited cake on the membrane surface in absence of a magnetic field was very dense. But, this layer was very soft in the presence of the magnetic field at 10 mL/s. The condition at the flow rate 20 mL/s was between these two modes. These observations were fully consistent with the permeate flux observations in which the highest flux was related to the flow rate 10 mL/s.

For more specific evaluation, imaging was performed at the cross-sectional area of the membrane. Observations showed that in the absence of a magnetic field, the thickness of the cake layer was about 25 µm. It was reduced to about 4 µm by applying a magnetic field at 10 mL/s (Fig. 10). On the other hand, the structure of the membrane pores in the new membrane and the membrane exposed to the magnetic field shows that this field has not had a destructive effect on the internal structure of the membrane and its pores.

Effect of magnetic field on the physicochemical properties of PJ

Physicochemical properties of PJ were measured before and after the membrane clarification in the presence

Table 2. Effect of magnetic field on the physicochemical properties of PJ

Characteristic	With magnetic field		Without magnetic field	
	before MF	after MF	before MF	after MF
Total anthocyanin content (mg/100 mL)	12.55[b,*]	16.25[a]	14.56[b]	13.39[b]
Total phenolic components (g/100mL juice)	0.63[a]	0.35[a]	0.35[a]	0.30[a]
Acidity (g Citric acid/100g juice)	1.51[b]	1.15[d]	1.71[a]	1.38[c]
Total soluble solid content (˚Brix)	14.0[a]	11.2[c]	13.0[b]	10.5[d]
pH	3.36[a]	3.34[a]	3.26[a]	3.31[a]
Turbidity (NTU)	364.33[b]	103.33[d]	1010.33[a]	223.67[c]
Antioxidant activity	1251.24[b]	1108.72[c]	986.11[d]	1547.91[a]

** Same letter means no significant difference between values in each row (P > 0.05).*

and absence of a magnetic field. Results showed that the Total Anthocyanin Content (TAC) of PJ did not change after membrane clarification in absence of a magnetic field; however, it increased the presence of the magnetic field. The pH differential method can measure monomeric anthocyanins; since probably magnetic field converts polymeric anthocyanins to their monomeric configuration which causes increasing in TAC. Evaluation of total phenolic components showed that it didn't change during the membrane clarification with or without a magnetic field. Antioxidant activity of PJ increased after the membrane clarification in presence of a magnetic field (Table 2); because anthocyanins and phenolic components cause antioxidant activity in the PJ [1]. Due to the fact that after applying the magnetic field, the polyphenolic compounds remain constant, the amount of monomeric anthocyanins has increased, so the antioxidant activity of the pomegranate juice is increased. Antioxidant activity is the most important nutritional property of pomegranate juice, and any increase can have a positive effect on its general acceptance for consumption and human health. Acidity and total soluble solid content of PJ decreased after membrane clarification in the presence and absence of a magnetic field; however, pH was constant during the clarification. Clarification of PJ decreased juice turbidity in both membrane units; however, the magnetic field decreased the intensity of the turbidity reduction. The low reduction of turbidity in the process with the magnetic field confirms the non-destructive effect of the magnetic field on the structure of the membrane, which was previously described in the evaluation of the microstructure of the membrane by SEM.

CONCLUSIONS

Microfiltration is one of the most efficient processes for the clarification of pomegranate juice, but the occurrence of fouling is a deterrent to industrialization. In this study, by focusing on the electric charge of the particles causing membrane fouling, a magnetic field was used to investigate its effects on the efficiency of the process in the membrane clarification of pomegranate juice. It was concluded that the magnetic field can increase the permeate flux during the membrane clarification of PJ. Increasing the magnetic field intensity can increase its efficiency due to decreasing fouling resistance. The best performance can be achieved when the field direction is from feed to permeate and the feed flow rate is to be at its minimum level. Therefore, the best setup for the membrane clarification of pomegranate juice is to combine the microfiltration system with a 500 mT magnetic field and with the direction of feed to permeate and perform the process at a high flow rate. It is necessary to mention that the washing protocol in this work is designed to measure the number of different resistances and study the fouling phenomenon. Therefore, according to the literature, washing was done after reaching a steady state. As a result, the time chosen for washing does not mean the appropriate time for washing the membrane in its industrial application. The nutritional value of PJ is not destroyed during the membrane clarification in presence of the magnetic field. In other words, the application of a magnetic field during the membrane clarification of pomegranate juice has no more destructive effect on the quality parameters of pomegranate juice than when the magnetic field is not applied.

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