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The Effect of Ultrasound on Permeation Flux and Changes in Blocking Mechanisms during Dead-End Microfiltration of Carrot Juice

A. Hemmati, H. Mirsaeedghazi, M. Aboonajmi

Abstract**—**Carrot juice is one of the most nutritious foods that are consumed around the world. Large particles in carrot juice causing turbid appearance make some problems in the concentration process such as off-flavor due to the large particles burnt on the walls of evaporators. Microfiltration (MF) is a pressure driven membrane separation method that can clarify fruit juices without enzymatic treatment. Fouling is the main problem in the membrane process causing reduction of permeate flux. Ultrasound as a cleaning technique was applied at 20 kHz to reduce fouling in membrane clarification of carrot juice using dead-end MF system with polyvinylidene fluoride (PVDF) membrane. Results showed that application of ultrasound waves reduce diphasic characteristic of carrot juice and permeate flux increased. Evaluation of different membrane fouling mechanisms showed that application of ultrasound waves changed creation time of each fouling mechanism. Also, its behavior was changed with varying transmembrane pressure.

Keywords**—**Carrot juice, dead end, microfiltration, ultrasound.

I. Introduction

CARROT juice is widely accepted as an important source of healthy components such as carotenoids, vitamins and phenolics that promote antioxidant activity in humans by scavenging free radicals. The shelf-life of carrot juice is short because its characteristic low acidity leads to microbial spoilage that limits its storage [1], [2]. Production of cloud-stable fruit and vegetable juices is important concept in juice industry and depends upon an adequate softening of the plant tissue. The usual processing methods of mechanical and thermal treatment of the raw material leads to lightly turbid juices with only a small amount of pulp in suspension. Recently, attention has been focused on the production of juices with increased content of soluble or suspended fiber [2].

Over the past years, modifications in the food processing techniques depend on increasing demands. The novel techniques change chemical, physical, and organoleptic properties of food. Ultrasonic treatment is one of the novel techniques that are used in the food industry for numerous processes such as cooking, cutting, crystallization, emulsification/homogenization, extraction, and microbial inactivation [3]. The cloudy stability of carrot juice is a main concern during storage [4]. Large particles in carrot juice causes turbid appearance which makes some problems in concentration process such as off flavor due to the large particles burnt on the walls of evaporators. Therefore, the juice should be clarified before its concentration. MF is a membrane separation method in which pressure is the driving force that can clarify fruit juice without enzymatic treatment [5]. One of the most important limitations during membrane processing is fouling [6].

Many studies have been performed about application of ultrasonic treatment in juice processing and its effect on the membrane filtration. Ultrasound waves increased the cloud stability of guava juice [7]. Delara et al. and Cai et al. evaluated the effect of ultrasound waves on the membrane cleaning. Results showed that ultrasound at low frequencies had more positive effect [8], [9]. Aghdam et al. evaluated the effect of ultrasound waves on the different mechanisms of fouling during membrane clarification of pomegranate juice. They demonstrated that the main mechanism of membrane fouling was cake formation. Also, evaluation of SEM images showed that ultrasound decreased the thickness of cake layer from 6 to 1.5 μm [10].

In all prior works, the ultrasound wave was used in cross flow membrane unit, and the physical property of fruit juice was different from carrot juices.

In this study, best ultrasound power was selected and applied on carrot juice. Then, ultrasonic treated carrot juice was clarified using ultrasound-membrane couple unit. The effect of ultrasound wave and transmembrane pressure on efficiency of clarification process was evaluated.

II. Material and Methods

Fresh carrot was prepared from local market (Tehran, Iran). They were washed, peeled, and manually sliced. The juice was extracted with a domestic juice extractor (Pars Khazar, Iran).

The fresh juice underwent ultrasonic treatment according to the procedure defined in Table I.

The value of diphasic behavior of carrot juice (%) was measured according to (1).

$$\text{Percent of diphasic value} = \frac{\text{Height of the upper phase}}{\text{Total height}} \times 100 \qquad (1)$$

The treated carrot juice was clarified using MF. Flat sheet hydrophile PVDF membrane with pore size of 0.22 μm (Milipore, USA) and effective surface of 20.14×10^{-4} m^2 was

H. Mirsaeedghazi is with Department of Food Technology, College of Abouraihan, University of Tehran, Pakdasht, Iran (corresponding author, phone: +9821-36040614; fax: +9821-36040614; e-mail: mirsaeed@ ut.ac.ir).
A. Hemmati and M. Aboonajmi are with Department of Agrotechnology, College of Abouraihan, University of Tehran, Pakdasht, Iran (e-mail: arashhemmati@ut.ac.ir, aboonajmi@ut.ac.ir).

used in this study.

TABLE I
THE PROTOCOL OF ULTRASOUND APPLIED ON CARROT JUICE

Test No.	Power (W)	Juice volume (ml)	Time (min)
1	1000	100	30
2	1000	200	30
3	1000	300	30
4	1000	400	30
5	800	Best volume	30
6	600	Best volume	30
7	400	Best volume	30
8	Best power	Best volume	20
9	Best power	Best volume	10

The experiments were performed in laboratory-scale. A rotary pump was used to pump the feed on the membrane surface in dead-end mode. Membrane unit was placed in a water filled box, and the ultrasound waves produced by AMMM ultrasound producer (M.P.I, Switzerland) were applied in the set up.

A transmitter coupled with an inverter was used to achieve desirable input pressure in different velocities (Fig. 1).

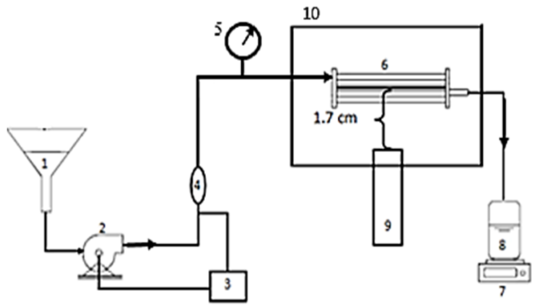


Fig. 1 Coupled ultrasound-membrane unit (1-feed tank; 2-pump; 3-inverter; 4-transmiter; 5-inlet pressure meter; 6-membrane module; 7: balance; 8: permeate tank; 9: ultrasound probe; 10: water bath)

Permeate weight was measured as a function of time to calculate the permeate flux according to (2).

$$Flux = \frac{W_2 - W_1}{(t_2 - t_1) \times A} \quad (2)$$

where W_2 and W_1 are the permeate weights (kg) at t_2 and t_1 (s), respectively, and A is the membrane active surface (m^2).

Hermia's model was used to determine the fouling mechanism according to (3) [11].

$$\frac{d^2t}{dv^2} = k\left(\frac{dt}{dv}\right)^i \quad (3)$$

where v, t, k and i are the permeate volume, the time, the the resistance coefficient, and the blocking index, respectively. When blocking index is 0, 1, 1.5 and 2, cake formation, intermediate blocking, standard blocking and complete blocking were dominant, respectively. On the other hand, Hermia concluded that dominant fouling mechanism in the whole process can be estimated using behavior between permeate volume and time as follows [12]:

- The fouling mechanism is cake formation when the curve of *t*/*v* versus *v* is linear;
- The fouling mechanism is standard blocking when the curve of *t*/*v* versus *t* is linear;
- The fouling mechanism is intermediate blocking when the curve of ln(t) versus *v* is linear.

III. RESULTS AND DISCUSSION

The carrot juice received ultrasonic treatment according to Table I. The results showed that application of ultrasound delayed juice phase separation and achieved more stable juice than the untreated one. Also, the findings showed that the best condition was achieved after application of ultrasound waves with power of 1000 W to 100 ml for 30 min (Fig. 2).

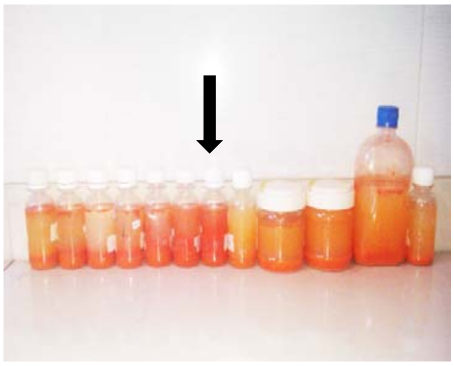


Fig. 2 Effect of ultrasound treatment on stability of carrot juice

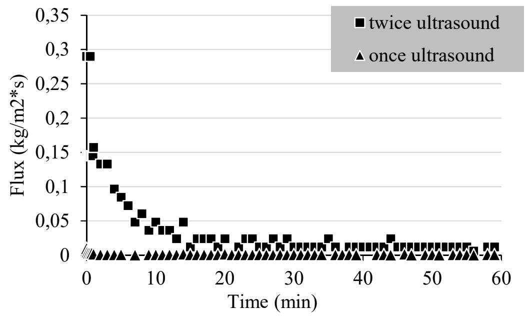


Fig. 3 Effect of ultrasound waves on the permeate flux during dead-end membrane clarification of carrot juice (0.5 bar)

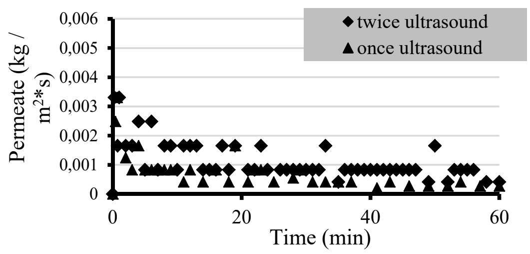
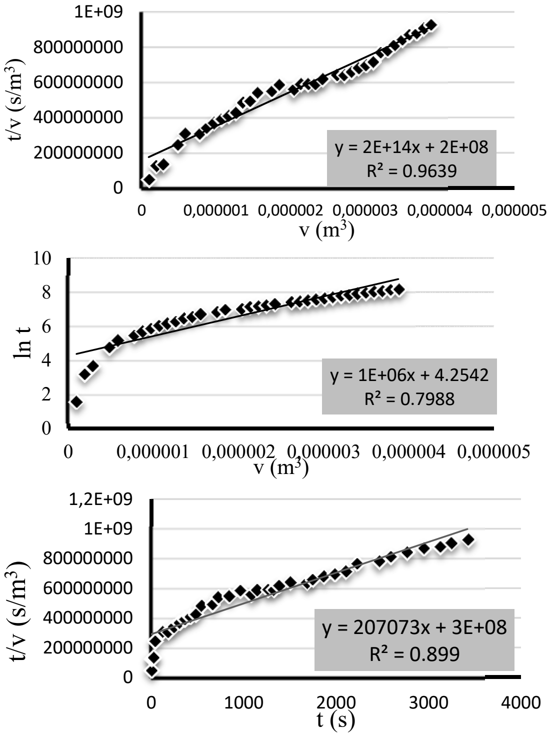
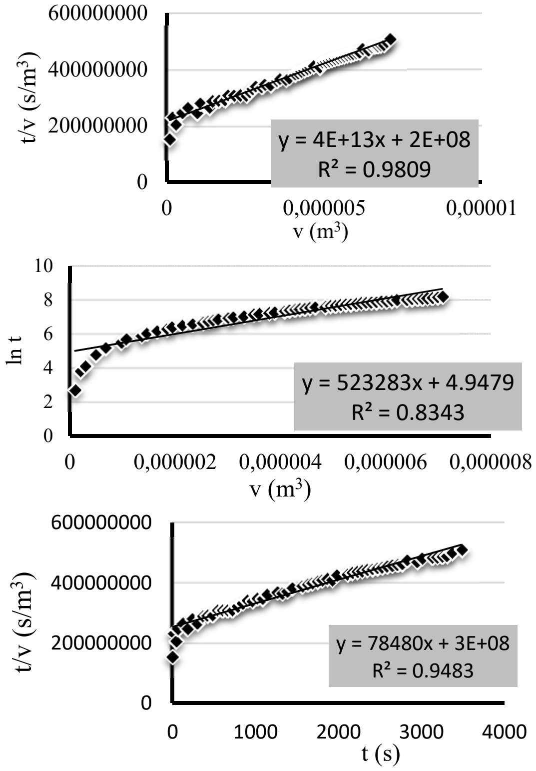


Fig. 4 Effect of ultrasound waves on the permeate flux during dead-end membrane clarification of carrot juice (0.2 bar)



(a)

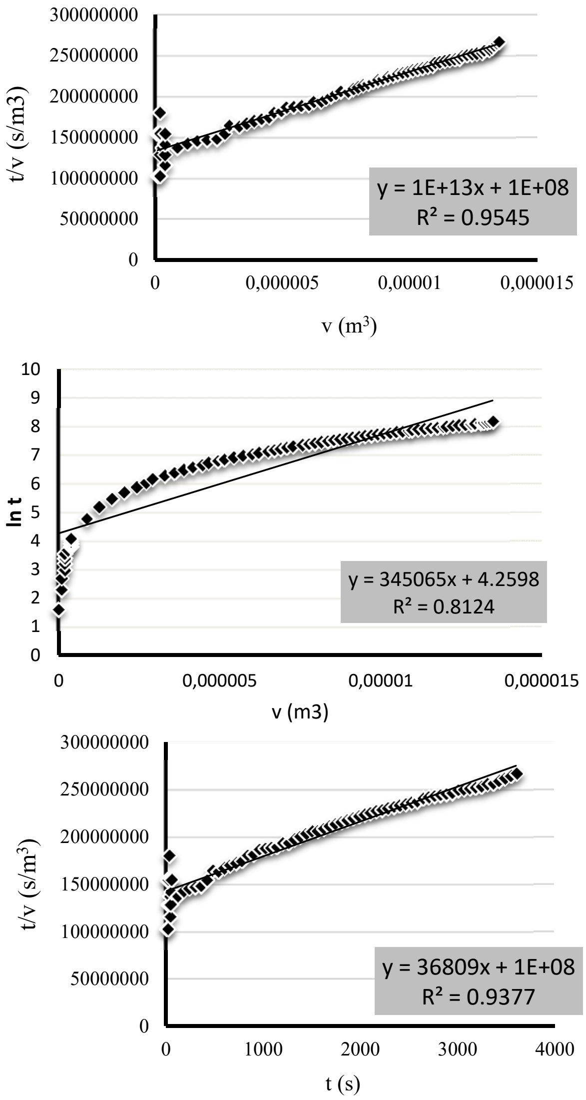


(b)

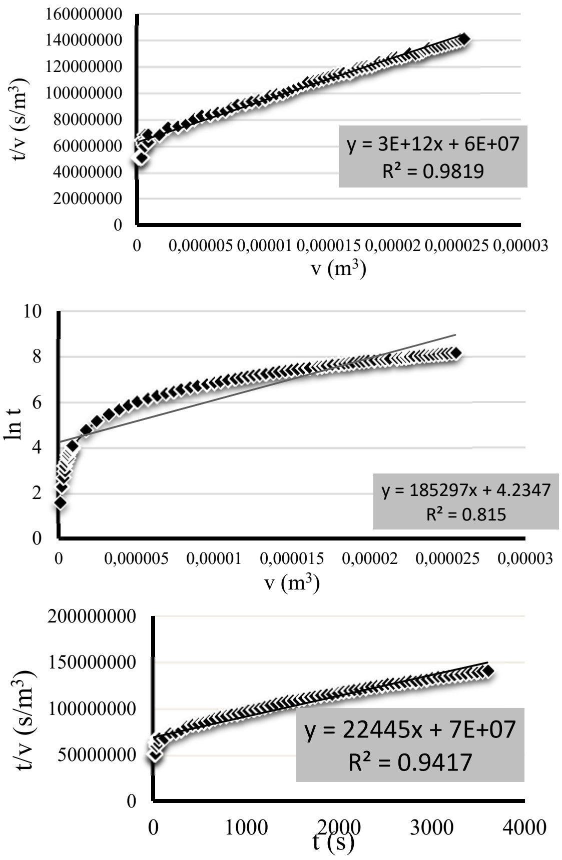
Fig. 5 The relation between permeate volume (v) and time (t) during a: once and b: twice ultrasound dead end membrane in clarification of carrot juice at 0.2 bar

In such condition, diphasic content of carrot juice after 1, 2, and 3 days was 0, 14.28, and 30%, respectively.

The membrane clarification of carrot juice was performed in an ultrasound-membrane coupled unit to evaluate the effect of ultrasound waves on the efficiency of membrane process. In the first experiment, the ultrasonic treated carrot juice was clarified with membrane unit, and in the second one, it was clarified using ultrasound-membrane coupled unit, which was called once ultrasound and twice ultrasound in Fig. 3, respectively. Results showed that ultrasound coupled with membrane unit increased the permeate flux during clarification of carrot juice. The difference between permeate flux of two experiments at the beginning of the process was high, but it became gradually low. Also, improvement of permeate flux at the transmembrane pressure (TMP) of 0.5 bar was better than its value at 0.2 bar (Figs. 3 and 4).



(a)



(b)

Fig. 6 The relation between permeate volume (v) and time (t) during a: once and b: twice ultrasound dead end membrane in clarification of carrot juice at 0.5 bar

The relation between the permeate volume (v) and the process time (t) was studied to evaluate the reason of above finding. Results showed that the curve of t/v versus v was more linear than the other curves in both processes at TMP of 0.2 bar (Fig. 5). Also, these results were similar to the findings at TMP of 0.5 bar (Fig. 6). Since, in all experiments, the cake formation is dominant mechanism during membrane clarification of carrot juice, the improvement of permeate flux after twice ultrasonic treatment can be attributed to reduction of cake layer as the main fouling mechanism during membrane clarification of carrot juice.

The blocking index was evaluated to obtain the reaction time of each fouling mechanism. Results showed that fouling started by cake formation at 0.2 bar with twice ultrasonic treatment and application of ultrasound waves reduced its intensity and other fouling mechanisms happened; however, there is different behavior in once ultrasonic treatment (Fig. 7).

Evaluation of blocking index at 0.5 bar showed that application of twice ultrasonic treatment caused late cake formation compared to once treatment (Fig. 8).

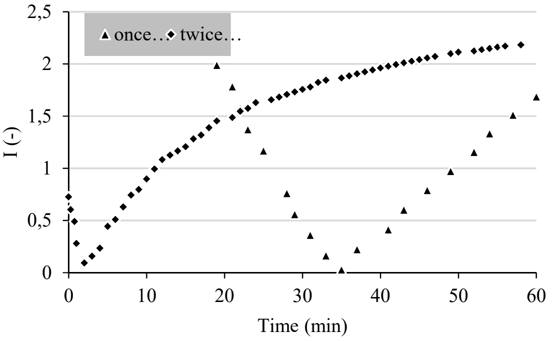


Fig. 7 Changes in the blocking index during membrane processing at TMP of 0.2 bar

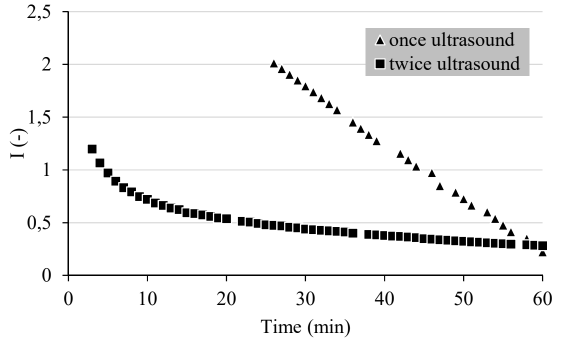


Fig. 8 Changes in the blocking index during membrane processing at TMP of 0.5 bar

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