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Ohmic heating assisted vacuum evaporation of pomegranate juice: Electrical conductivity changes

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ABSTRACT

A novel electrical heating method, named as ohmic heating, was successfully integrated to vacuum evaporation system, and pomegranate juice was concentrated until its total soluble dry matter content reached to 40% by applying three different voltage gradients (7.5, 10, and 12.5 V/cm) at 180 mm Hg absolute pressure in this system. Total evaporation times were determined as 152, 78, and 53 min at the voltage gradients of 7.5, 10, and 12.5 V/cm, respectively. The concentration time of pomegranate juice was shortened about 56% by ohmic heating relative to conventional evaporation. The electrical conductivity values were increased up to reach 25% TSDM for 7.5 V/cm and at 35% TSDM for 10 V/cm, then showed a decreasing pattern. However, it was constant (0.55 ± 0.01 S/m) during evaporation process at 12.5 V/cm. It is recommended that the ohmic heating method could be successfully integrated to vacuum evaporation process to shorten the processing time significantly.

Industrial relevance: Ohmic heating has been utilized as alternative method for the purpose of heating, pasteurization, cooking etc., and relatively better products can be obtained by ohmic heating. Nowadays, energy efficient systems are needed in concentrated juice production. The integration of ohmic heating to the conventional vacuum systems could serve the production high quality juice concentrates with efficient use of energy. In present study, ohmic heating assisted vacuum evaporation of pomegranate juice was conducted, successfully. This method decreased the total process time for juice concentration, which is critically important for industrial scale productions. This novel method can be implemented to the fruit juice production lines by taking into account of design characteristics of ohmic systems such as electrical conductivity changes depending on both temperature and total soluble solids concentration. The effects of main process parameter, named as voltage gradient, on electrical conductivity changes during electrical heating assisted evaporation process has been also reported in the present study.

1. Introduction

Pomegranate is a seasonal fruit that grows widely in Middle East, Anatolia and America. It consists of hundreds of small seeds and a hard red shell covering them. Seeds are the edible parts of pomegranate fruit, and contain rich amount of acid, vitamin, phenolic and mineral contents. It needs immediate process after harvesting due to the limitations of fresh fruit stock in season. Thus, the pomegranate juice is produced to extend the availability of this valuable fruit. On the other hand, the storage of non-concentrated fruit juices should be performed in cold conditions and requires high storage space. Hence, the processing and storage costs raised (Cemeroğlu, 2011). The fruit juices are concentrated to minimize the quality losses during storage, to prevent microbial spoilage and to reduce the cost required for transport, packaging and storage (Alves & Coelhoso, 2006; Gunko, Verbych, Bryk, & Hilal, 2006).

The concentration process is performed to remove the certain amount of water from the liquid food (Toledo, 2007). For this purpose, some concentration methods such as evaporation in atmosphere or in vacuum, freeze concentration and reverse/direct osmosis, etc. could be employed. However, these methods have some disadvantageous such as difficulties in the limitation of final concentration, high installation and operating costs, and long processing time (Cassano, Conidi, Timpone, D'Avella, & Drioli, 2007; Ramaswamy & Marcotte, 2006; Ramteke, Singh, Rekha, & Eipeson, 1993). Vacuum evaporation method was commonly used in food industry since concentration process could be performed in safer temperatures compared to atmospheric evaporation. However, the energy utilization is still high, and requires some enhancements to decrease the total processing time and using the energy more efficiently. For increasing the efficient utilization of the energy,

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multiple effect vacuum evaporator systems and feed/product/condensate flash evaporation methods are used (Bhargava, Khanam, Mohanty, & Ray, 2008; Ho Kon Tiat, Sebastian, & Nadeau, 2008; Ruan, Jiang, Nian, & Yan, 2015). Flash evaporation method also reduces the loss of volatile components (Bouchama, Sébastian, & Nadeau, 2003) where the super-heated water jets enhances the effect of flash evaporation (El-Fiqi, Ali, El-Dessouky, Fath, & El-Hefni, 2007).

In recent studies, it has been reported that novel electrical heating methods also increase the efficiency of the evaporation process and decrease the process time (Icier & Ilicali, 2004; Icier, Sastry, & Illicali, 2006; Mizrahi, 1996; Sastry & Li, 1996). The microwave assisted evaporation method has been investigated to be used as an alternative method to reduce processing time and reduce the quality losses (Assawarachan & Noomhorm, 2011). Similarly, the ohmic heating method, which is a novel electro-heating method, is based on the passage of electrical current through foodstuff. This method provides rapid, uniform and effective heating by conversion of electrical energy to the heat energy inside the food depending on its resistance (İçier, 2003; Jha et al., 2011; Reznick, 1996; Sastry & Salengke, 1998; Shirsat, Lyng, Brunton, & McKenna, 2004). Heating times of fruit juices rapidly takes place in seconds due to their high electrical conductivities (Allali, Marchal, & Vorobiev, 2010; Darvishi, Hosainpour, Nargesi, Khoshtaghaza, & Torang, 2011; Icier, Yildiz, & Baysal, 2006; Sastry & Salengke, 1998). The heat generation occurred within the food during ohmic heating is affected from some factors such as type of food, its composition and power applied (Baysal, İçier, & Baysal, 2011). The electrical conductivity value increases as the temperature increases. On the other hand, it tends to decrease as the water soluble dry matter increases in fruit juices (apple, sourcherry, orange, carrot, strawberry juices) (Castro, Teixeira, Salengke, Sastry, & Vicente, 2003; Darvishi et al., 2011; Icier & Ilicali, 2004, 2005a; Zareifard, Ramaswamy, Trigui, & Marcotte, 2003). It was also reported that electrical conductivity value could change with the voltage gradient applied (Darvishi et al., 2011; Icier & Ilicali, 2004, 2005b). In recent studies, ohmic heating has been used as an energy source in atmospheric evaporation systems (Assiry, 2011; Darvishi, Hosainpour, Nargesi, & Fadavi, 2015; Torkian Boldaji, Borghei, Beheshti, & Hosseini, 2015). Assiry (2011) utilized the ohmic heating method for desalination process under atmospheric conditions. Similarly, the use of ohmic heating to evaporate the tomato juice up to total soluble contents of 30% under atmospheric conditions was also reported (Hosainpour, Darvishi, Nargesi, & Fadavi, 2014; Torkian Boldaji et al., 2015). However, the use of ohmic heating for the vacuum evaporation of fruit juices is a novel application. In addition, there is a lack of information about the electrical conductivity changes of fruit juices during the ohmic heating assisted vacuum evaporation process in open literature.

The objective of present study was to determine the effects of voltage gradient on the rate of the temperature increase, evaporation times and the electrical conductivity during the concentration of pomegranate juice up to total soluble dry matter content (TSDM) of 40% by ohmic heating assisted vacuum evaporation.

2. Material and methods

2.1. Material

Pomegranates (*Punica granatum* cv. Hicaz) were stored in conditioning chamber at 0–5 °C and 90–95% relative humidity. After the cleaning and the separation processes were applied, pomegranate seeds were pressed by pilot scale pressing machine (Bucher, Switzerland). Then, the mash was filtrated by using rough filter under vacuum. The filtered samples were collected in the single batch to make the whole juice a homogeneous set, and then poured into bottles (300 ml). Total soluble dry matter (TSDM) content of pomegranate juice was determined as 17.5 ± 0.1%. The pomegranate juice samples were frozen till the centre temperature in the bottles reach to −18 °C by using air blast type freezer (Electrolux, Sweden) at −29 °C. Frozen juice samples were stored at −18 °C.

Before each replicates of the evaporation process, frozen samples were completely thawed to the temperature of 10 °C at the refrigerator (+4 °C) for 24 h, and then the evaporation process was conducted, immediately.

2.2. Evaporation methods

Ohmic heating assisted vacuum evaporation process (OVE) was conducted in the ohmic heating integrated pilot scale vacuum chamber system (Fig. 1). The system consisted of a vacuum chamber, a power supply, an isolated-variable transformer, a vacuum pump, process vessel, an agitator, a microprocessor board and computer connections. The inside dimensions of the process vessel made from polytetrafluoroethylene (PTFE) were 0.156 m × 0.07 m × 0.075 m. Titanium type electrodes were utilized. The distance between electrodes were 0.154 m. The inside volume of the vacuum chamber was 0.118 m^3. The butterfly type agitator made from PTFE was used to ensure homogeneous mixing in the test cell. The agitation speed was 109 ± 1 rpm. The OVE process was applied at three different voltage gradients (7.5 V/cm, 10 V/cm, and 12.5 V/cm). Vacuum evaporation (VE) was employed in the same vacuum chamber used in OVE process for the case of using the conventional heater (1.1 kW, Şanal, Turkey) as the heating source (Fig. 1).

For both evaporation methods, the pomegranate juice sample (400 ml) was heated from 10 °C to 65 °C under the constant absolute pressure of 180 ± 2 mm Hg, and then held at this temperature until its total soluble dry matter content (TSDM) reached to 40%. During heating period, ohmic heating was applied at any predetermined constant voltage gradient continuously (in full mode). For evaporation period, the evaporation temperature was aimed to maintain constant by controlling the power supply in on/off mode. Conventional heating was applied in full mode at the constant power for heating period. For evaporation period, on/off mode was conducted by using thermostat control to supply the energy required for the continuous evaporation process. The temperatures were measured from the free surface of the juice sample via T-type thermocouples (Cole Palmer, UK), which their tips were custom coated with polytetrafluoroethylene sheet (PTFE). Temperature, current and voltage values were recorded by specifically designed microprocessor.

2.3. The total soluble dry matter content

TSDM content of samples was determined by using digital refractometer (Hanna, Portuguese). TSDM content was measured for each evaporation periods of 10 min by terminating the related experiment. The sample remained in the test cell was not evaporated further. A new juice sample was used for following evaporation trial lasting 10 min longer than previous trial. This steps were followed until desired TSDM content observed.

2.4. pH and titratable acidity content

pH values of pomegranate samples were measured by pH meter (Hanna, Portuguese). Titratable acidity analysis were conducted by titration with 0.1 N NaOH and phenolphthalein used as indicator. Titratable acidity (Eq. (1)) was determined in terms of anhydrous citric acid (Cemeroğlu, 2010).

$$\text{Titratable acidity\%} = \frac{V \times f \times E \times 100}{M} \tag{1}$$

V: Used 0.1 N NaOH amount, ml
f: factor of NaOH