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Direct osmotic concentration of tomato juice in tubular membrane – module configuration. II. The effect of using clarified tomato juice on the process performance

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Abstract

A study was carried out by using a new tubular direct osmosis module, constructed by PCI UK and equipped with a novel AFC99 membrane 400 μm thick, to investigate the effect of clarifying tomato juice on the rate of direct osmotic concentration. Under virtually the same operating conditions five respective clarifications of juice were tried including full, unclarified, tomato juice. The process performance was calculated in terms of permeation flux. In all the experimental runs the osmotic medium was sodium chloride brine (initial concentration approx. 23% NaCl). A remarkable increase of permeation flux (over 100%) was observed shifting from unclarified to the clarified tomato juice. Clarification was carried out by passing the juice through 35 μm mesh and also by using membranes of molecular weight cut-off 200 000, 100 000 and 25 000 Daltons (Da), respectively, in order to obtain the juice ultrafiltrates. It is also worth mentioning that the flux value obtained with 25 000 Daltons (Da) ultrafiltrate appeared to be considerably higher than values reported in experiments carried out by other researchers, where unclarified juice was used, despite the disadvantage of a far thicker membrane being used in the present investigation. This specific finding discloses great potential in using a combined low temperature and pressure ultrafiltration and direct osmosis process to produce tomato concentrates.

Keywords: Concentration; Economics; Osmosis; Tomato juice; Ultrafiltration

1. Introduction

The increase in the performance of a membrane process, expressed as permeation flux through the membrane, has always been a goal of any investigation related with such a process. This was due to both quality and financial reasons. Bolin and Salunkhe [4] tried to concentrate apple and cherry juice by osmosis and found that the original aroma of the juice underwent a noticeable change when concentrated, because of prolonged processing time. The prolonged time was due to poor process performance. This finding made them abandon any thought of proposing the use of this

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novel technology for juice concentration. The lack of observation of either a premium quality product or a financial benefit over the conventional vacuum evaporation process led them to abandon osmosis for this purpose. Among the several conceptions that emerged to improve efficiency of the membrane process was the modification of the processed liquid via clarification. Dale et al. [5] utilized centrifugation to obtain clarified tomato juice serum which was then concentrated by reverse osmosis. The use of the clarified serum instead of full tomato juice in their case appeared very attractive as the membrane fouling phenomenon which is a standard drawback for membrane processes was eliminated, therefore improving the overall process performance. The lower viscosity of the tomato juice serum than the full juice also contributed to better process performance. Köseoglou et al. [7] produced tomato juice concentrates by combining ultrafiltration to clarify the juice, reverse osmosis to concentrate the ultrafiltration permeate (serum), and a final step to mix and homogenize the ultrafiltration retentate and concentrated serum at high pressure. On the same principle of combining ultrafiltration and reverse osmosis to produce premium quality juices at ambient temperature, was also based on a patented process known as "FreshNote". This process emerged as a product of a limited partnership between E.I. DuPont and FMC [1]. Despite the fact several trials have recently been recorded to combine UF and RO in the area of juice concentration, no such attempt has appeared for UF and direct osmosis. However, as a breakthrough occurred with direct osmosis technology [2,3,6], such a combination could possibly improve further the direct osmosis concentration process performance.

Therefore, the target of the present investigation is to ascertain whether or not the clarification of the tomato juice affects the performance of the direct osmosis concentration process. This investigation will also evaluate a low pressure and temperature ultrafiltration and direct osmosis combination, and compare results to the most concentrated juice (tomato juice).

2. Materials and methods

A novel direct osmosis tubular module was constructed by the membrane systems manufacturer Paterson Candy, UK. This system is described in detail elsewhere [9].

The overall arrangement of the direct osmosis (DO) experimental rig is illustrated in Fig. 1.

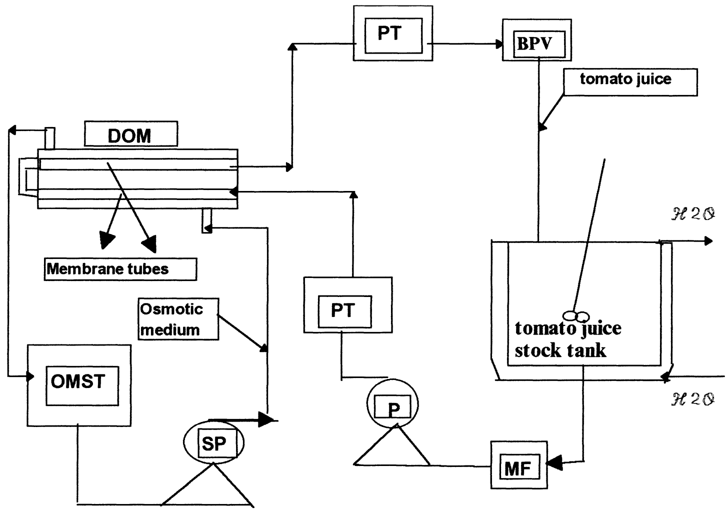
A novel membrane was used as a direct osmosis membrane having the specification of the AFC99 aromatic polyamide thin film composite reverse osmosis membrane but with a thinner backing material. Only one of the three sets of membranes provided by the company was used for all experiments. The overall thickness of this membrane was 400 μm (140 μm membrane active layer+260 μm membrane backing material) and the rejection 99% in sodium chloride. The water permeation coefficient of the membrane, calculated at 40 atm, 25°C by using a solution containing 5000 ppm NaCl in distilled water, was $A=1.125\times10^{-3}$ m^3/m^2 atm h. The active membrane layer was located on the inner surface of the tube. The ultrafiltration membranes used to obtain the ultrafiltrates, were the standard commercial company products with a molecular weight cut-off of 25 000, 100 000 and 200 000 Daltons (Da), respectively. The ultrafiltration runs were carried out at a maximum juice flowrate of 550 l/h and a transmembrane pressure of about 3 bar by using the same direct osmosis module. In order to conduct a UF run the direct osmosis membrane tubes were removed and replaced by a set of UF membranes. After the run was concluded and the permeate was collected by the UF membranes were then disposed of and replaced by the direct osmosis set. The juice ultrafiltrate was collected from the input pipe of the module shroud. The membranes were cleaned by using the P3 Ultrasil 10 alkaline detergent which was supplied by Henkel, UK.

The cleaning regime involved three steps:

1. Initial rinsing for about 20 min with soft water to remove the product residuals.
2. Cleaning for 90 min by using a 1% detergent solution in soft water at 55°C.
3. Final rinse of the system with soft water for at least 20 min.

All cleaning steps were performed under a combination of low pressure (approx. 3 bar) with maximum flow rate.

After the cleaning procedure was concluded, the direct osmosis membranes were preserved by filling the module shroud with a sodium bisulphite solution



MF = Magnetic flowmeter.
P = Positive displacement pump.
SP = Stroke pump.
PT = Pressure transducer.
DOM = Direct osmosis module.
OMST = Osmotic medium stock tank.
BPV = Back pressure valve.

Fig. 1. Direct osmosis (DO) experimental Rig.

of approx. 0.5% (w/w). This preservation process was not applied with UF membranes.

The raw material of the direct osmosis experiments was prepared by mixing commercial double concentrated tomato paste (28–30° Brix) with soft water obtained from the Lab boiler house water purification unit. The mixing was done in a ratio (water:tomato paste) of 5.35:1. This mixture was then left agitated for at least 1 h at 30 rpm in order to be homogenized. The resulted mixture was then clarified either by plain filtration through a 38 μm mesh, or by UF (membranes of 200 000, 100 000, and 25 000 Daltons (Da)) to obtain the raw material used for the experiments. In one respective experiment the unclarified mixture was used to simulate full tomato juice. A total of approx. 11 kg of raw material was used in each experiment.

The tomato paste used for the reconstitution of the juice was supplied by Gerber, UK, in 1 kg tins and it was of Greek origin.

Sodium chloride of technical grade was supplied by UK manufactures. This NaCl was used to prepare the osmotic brine of about 23% (w/w) NaCl used in all experiments as an osmotic medium.

The experimental procedure consisted of the following steps:

1. The raw material prepared for each experiment, weighing approx. 11 kg, was put in the juice stock tank and left agitated for at least 1 h.
2. Preweighed quantities of water and osmotic medium solute at the required ratio were put in the plastic osmotic medium stock tank and the stroke pump was put in operation with the output pipe into the plastic tank. The osmotic medium was in this way recycled and mixed for at least 1 h, to become homogenized.
3. After 1 h had elapsed, the output pipes of the pumps were connected to the module and the tomato juice pump was put in operation. When the first quantity of tomato juice was returned in the stock tank after passing through the module, the back pressure valve was set immediately to the right position to ensure back pressure of about 3 bar and the stroke pump of the osmotic medium was set in operation.
4. The normal run lasted 5 h and in the course of this the osmotic medium was sampled in regular time

intervals, every 15 min for the first 90 min of operation and every 30 min thereafter.

5. The collected samples were then analysed by a refractometer and the refractive index was correlated to concentration.
6. The drop in concentration of the osmotic medium after 5 h run was used to calculate the water that passed through the membrane and consequently the permeation flux by material balance.

For the refractive index measurements, the high presicion refractometer RFM340 was used, which was supplied by Stanley & Bellingham, UK.

3. Results and discussion

A set of five different clarifications of juice, starting from completely unclarified tomato juice (full juice) and followed by juice filtrate through 38 μm mesh, juice ultrafiltrate (200 000 Daltons (Da)), juice ultrafiltrate (100 000 Daltons (Da)) and juice ultrafiltrate (25 000 Daltons (Da)), was tried under virtually the same operating conditions. The experimental conditions were the following: juice flow rate: 510±2% l/h, brine flow rate: 570±1% l/h, tomato juice temperature: 26°C, tomato juice input pressure: 2.95±0.1 bar, brine temperature: 25°C, brine input pressure: 0–2 bar pulsing, initial brine concentration: approx. 23% (w/w) NaCl, type of membrane: AFC99 reverse osmosis membrane (thick 400 μm). Each one of the five experiments lasted 5 h and during this time the osmotic brine was sampled several times. A graphical representation of the calculated direct osmotic flux for each one of the juice clarifications is presented in Fig. 2. From the form of the obtained curve (Fig. 2), it can be observed that as one moves from full tomato juice to the second ultrafiltrate (100 000 Daltons (Da)) the osmotic flux increases. Such an increase is not obvious between ultrafiltrates from UF membranes with molecular weight cut-off 100 000 and 25 000 Daltons (Da). This finding indicates that no further clarification of the juice, after the critical point of MWCO=100 000 Daltons (Da), could be of any substantial benefit to the process performance. The percentage of increase of the direct osmosis flux over the flux obtained with full juice for the several juice clarifications is illustrated in Fig. 3. A comparison of the optimum value achieved in this investigation with tomato juice ultrafiltrate through 25 000 Daltons (Da) membrane to results from previous investigations are summarized in Fig. 4. It becomes apparent from the data of Fig. 4. that even a plain filtration of the tomato juice increases the flux value to a level very close to the value (5–6 l/m^2 h) reported by Herron et al. [6] in the disclosure section of US Patent No: 5 281 430. Also the optimum value of 7.33 kg/m^2 h obtained with raw material ultrafiltrate through 25 000 Daltons (Da) membrane appears to be favourable compared to previous reports [2,3,6,10]. In the course of the present investigation, a membrane was used which was at least 4–5 times thicker than the ones used by Herron et al. [6] and Beaudry and Lampi [2,3]. This was done because the membrane company declined to construct a thinner and more appropriate membrane. Despite this, the use of juice ultrafiltrate instead of full juice improved the performance of the direct osmosis concentration (Fig. 3), counterweighing so, the drawback of using much thicker membranes. These results

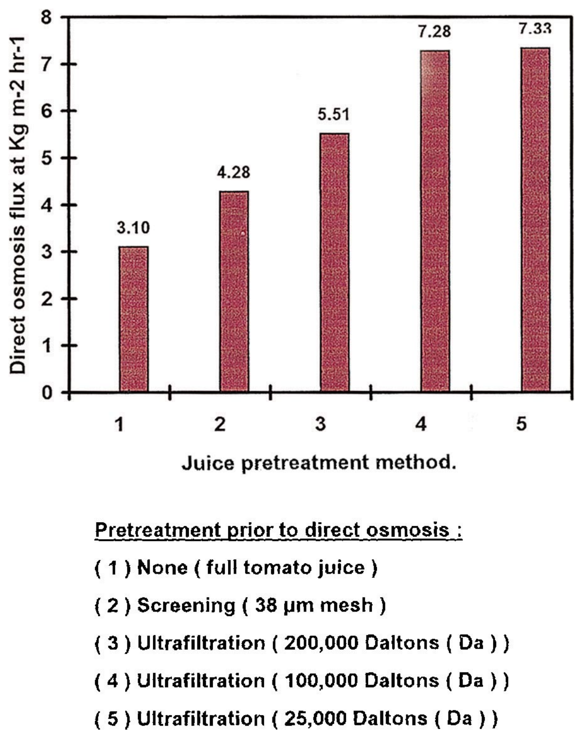


Fig. 2. The direct osmosis flux value measured with different tomato juice clarifications.

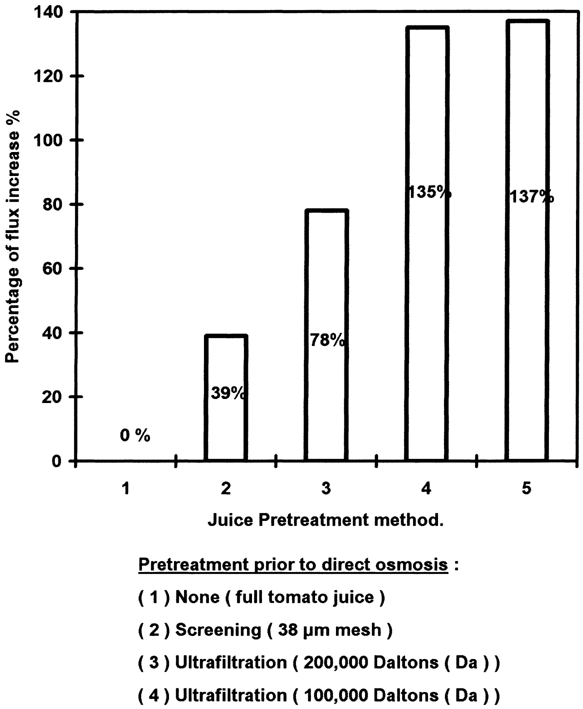


Fig. 3. The percentage of increase of tomato juice direct osmotic flux for different tomato juice clarifications over the flux obtained with full unclarified juice.

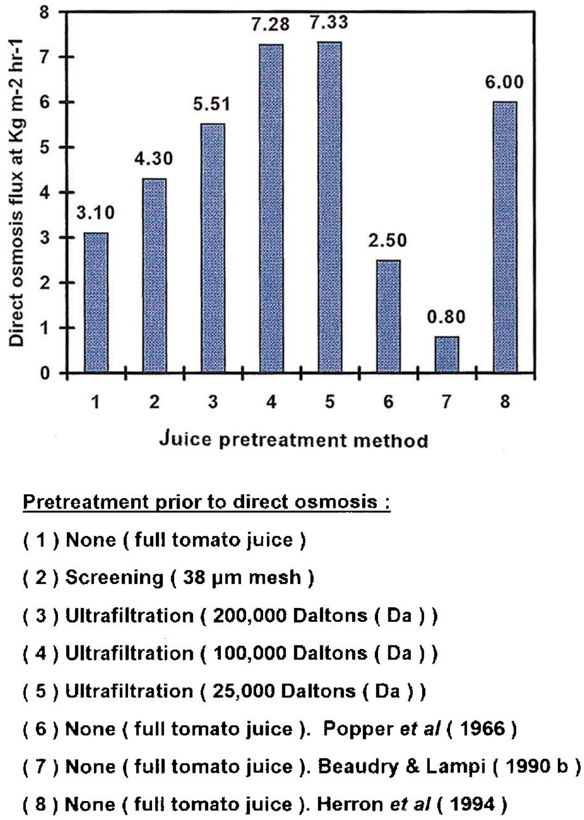


Fig. 4. Comparison of the results obtained in the present study with results reported in previous investigations.

indicate that a combination of ultrafiltration and direct osmosis can overcome the problem of a thick direct osmosis membrane and can provide the necessary magnitude of permeation flux for commercial applications. According to Herron et al. [6] the lowest, commercially accepted, direct osmosis flux value has to be at least 5–6 l/m^2 h measured at the initial juice concentration. This limit was surpassed in this study when ultrafiltrates were used.

The material balances of the two alternative processes, direct osmosis vs. combined ultrafiltration/direct osmosis, are presented in Fig. 5. It must be noted that for the calculation of direct osmosis membrane area average values of flux were used. Additionally, the average value of ultrafiltration flux, which was used for calculating ultrafiltration membrane area, was suggested by Köseoglu et al. [3] and agreed with the measurements performed in this study.

It is apparent from the magnitude of the calculated membrane areas in Fig. 5 that when a combination of ultrafiltration and direct osmosis is used, the required total membrane area is 3308 m^2. In comparison it is almost half of the corresponding membrane area used in direct osmosis (6029 m^2). This suggests that one should expect significant economical benefit by combining the two processes instead of simply applying direct osmosis.

Additionally, fouling is not expected to be a big problem in the case of combining ultrafiltration with direct osmosis. According to Dale et al. [5] the ultrafiltration serum does not have any significant fouling tendency to reverse osmosis membranes and consequently to direct osmosis membranes. Furthermore, Porretta et al. [11] found the fouling not to be a significant problem in the case of tomato juice ultrafiltration through open membranes with MWCO= 100 000 Daltons (Da).

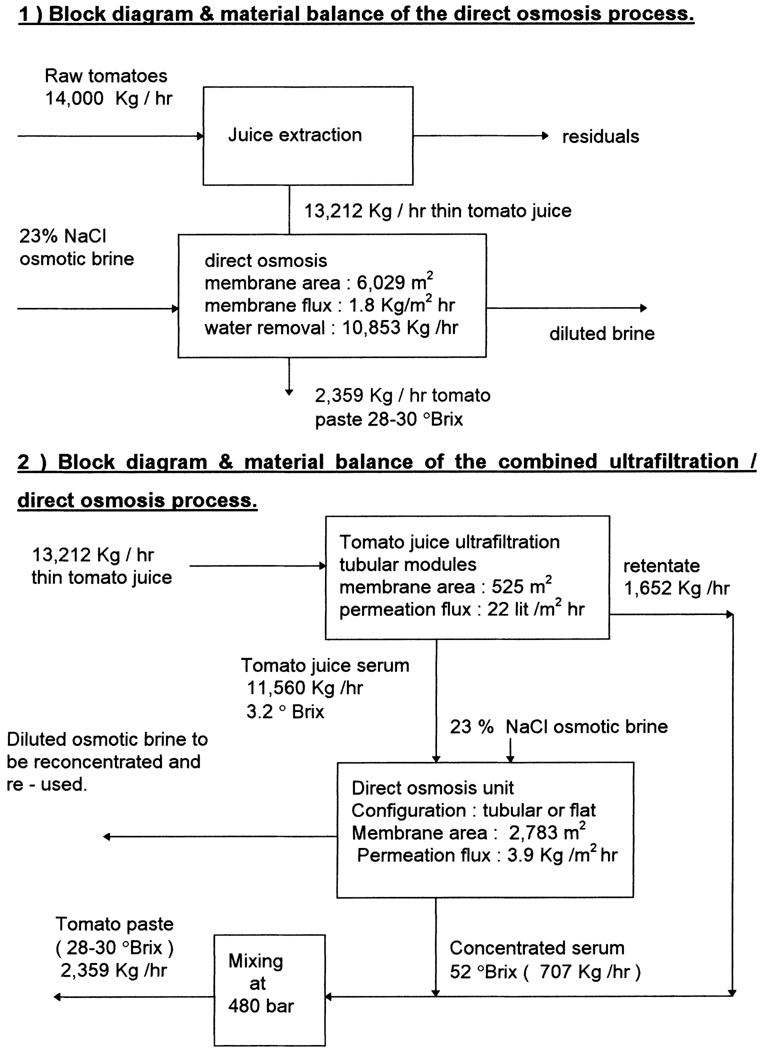


Fig. 5. The flowcharts and the material balances of the two alternative processes to concentrate tomato juice.

4. Conclusions

The use of clarified forms of tomato juice instead of full juice, as raw material in the direct osmosis concentration process, can markedly improve the process performance. In the course of this study, clarification of tomato juice by using plain filtration led to an approx. 39% increase of the direct osmosis flux. Use of tomato juice ultrafiltrates upgraded the flux to a value slightly more than twice the value measured with full tomato juice. However, no substantial increase of permeation was traced when the clarification was conducted with ultrafiltration membranes having a molecular weight cut-off of less than 100 000 Daltons (Da). This molecular weight cut-off seems to be the limit for an effective clarification; no further lowering of the screening capacity of the ultrafiltration membrane could benefit the combined ultrafiltration/direct osmosis operation. It is also worth mentioning that such a combination of the two membrane processes can provide direct osmosis fluxes higher than ones reported in previous direct osmosis investigations. Furthermore greater fluxes were observed despite the fact the membranes in this present study were significantly thicker than ones used in earlier investigations. The adverse effect of membrane thickness on osmotic flux has already been reported [8,9]. This allows the claim that a new combination of this kind has the potential to become a very promising, low temperature and pressure process to produce tomato juice concentrates. With such a combination, it was proved that the required total membrane area is much less than in the case of plain direct osmosis. This implies significant savings of fixed capital, membrane replacement money and power.

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