

Production of concentrated kiwifruit juice by integrated membrane process

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Abstract

The concentration of fruit juices is industrially performed in order to reduce storage, packaging, handling and shipping costs. This paper describes the research efforts to develop and optimise an integrated membrane process, on laboratory scale, for the production of concentrated kiwifruit juice as alternative to the traditional vacuum evaporation. Fresh depectinated kiwifruit juice was previously clarified by ultrafiltration (UF) process. In experimental tests performed according to the total recycle mode the effect of transmembrane pressure, axial flow-rate and temperature on permeate fluxes were studied. Clarified kiwifruit juice was produced in experimental tests carried out according to the batch concentration mode working in optimal operating and fluid dynamic conditions. The osmotic distillation (OD) process was used to concentrate the clarified juice up to a total soluble solids (TSS) content higher than 60 °Brix at 25 °C. The effect of various operating parameters on vapour flux was studied. An average evaporation flux of almost 1 kg/m² h was obtained using a calcium chloride dihydrate at 60 w/w% as brine solution. The effects of UF and OD processes on the total antioxidant activity (TAA) and other analytical parameters of the kiwifruit juice were also studied. A little reduction of the TAA was measured during the membrane treatment; vitamin C content was well preserved in the concentrated juice. On the basis of the results obtained on laboratory scale an integrated membrane process scheme for the clarification and the concentration of kiwifruit juice is proposed.

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Keywords: Kiwifruit; Ultrafiltration; Osmotic distillation; Integrated membrane processes; Total antioxidant activity

1. Introduction

Kiwifruit originates from an indigenous plant of southern China (*Actinidia Chinensis*) introduced in New Zealand at the beginning of the century (Luh & Wang, 1984). The species subsequently spread in England, United States, France and, only towards the end of the seventies, in Italy.

Actinidia plantations occupy a total of some 60,000 hectares worldwide, corresponding to a production of more than 800,000 tons.

Italy is the world's largest producer of kiwifruit with a production of about 330,000 tons/year (about 33% of the world-wide production) and a cultivation land area of about 19,500 hectares mainly in four regions (Latium, Emilia-Romagna, Piedmont and Apulia).

The most widely grown variety (95%) is the *Hayward*, while the remaining 5% are made up of strains such as *Bruno*, *Koryoku* and *Top Star*.

Studies performed on the nutrient density (a calculation frequently used by dietitians and nutritionists to reflect the nutritional value of a food) of different commonly consumed fruits demonstrated that kiwifruit is the most nutrient dense of all fruits with an index of 16 (daily value/100 grams) followed by papaya (14), mango (11) and orange (11) (<http://www.calharvest.com/kinutr2.html>). In particular kiwifruit has the

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Nomenclature

Q	axial flow rate (l/h)
J	mass flux (kg/m ² h) or volume flux (l/m ² h)
T	temperature (°C)
TMP	transmembrane pressure (bar)
VRF	volume reduction factor = initial feed volume/ resulting retentate volume
TSS	total soluble solids (°Brix)
P_w	water vapour pressure (Pa)
a_w	water activity
P_w^*	vapour pressure of pure water (3.22×10^3 Pa)
x	solute mass fraction (w/w%)

Greek symbols

η	dynamic viscosity (Pa s)
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Subscripts

f	feed
w	water or vapour
p	permeate
j	juice
b	brine
1	feed side
2	extract side

highest level of vitamin C (3–5 times more than citrus fruits) and it is a good source of dietary fiber, vitamin E, folic acid and minerals (P, K, Ca, Mg, Mn). It also has an impressive antioxidant capacity, containing a wealth of phytonutrients, including carotenoids, lutein, phenolics, flavonoids and chlorophyll. On the contrary the content in sodium is very low. On the basis of these characteristics kiwifruit offers benefits for specific health conditions and, consequently, it has a great potential for industrial exploitation (Cano Pilar, 1991).

The production of concentrated fruit juices is of interest at industrial level since they can be used as ingredients in many products such as ice creams, fruit syrups, jellies and fruit juices beverages. Furthermore, fruit juices concentrates, because of their low water activity, have a higher stability than single-strength juices. In addition, package, storage and shipping costs are remarkably reduced (Luh, Feinberg, Chung, & Woodroof, 1986). However, it is known that concentration of fruit juices by evaporation determines a loss of most volatile aroma compounds with a consequent remarkable qualitative decline (Maccarone, Campisi, Lupo, Fallico, & Asmundo, 1996). Besides, the heat required to perform the evaporation results in some “cooked” notes recognised as off-flavors. Commercial freeze concentration systems (cryoconcentration) permit to preserve the volatiles during the water removal process but they require a remarkable energy consumption. Another limitation of the process is that the achievable concentration (about 50 °Brix) is lower than the values obtained by evaporation (60–65 °Brix).

Membrane processes are today consolidated systems in various productive sectors, since the separation process is athermal and involves no phase change or chemical agents. The introduction of these technologies in the industrial transformation cycle of the fruit juices represents one of the technological answers to the problem of the production of juices with high quality, natural fresh taste and additive-free. The integration or the substitution of some traditional operations with

membrane separation technologies permits the rationalisation of direct and indirect energy consumption improving at the same time the organoleptic properties of the finished product.

The possibility to realise integrated membrane systems in which all the steps of the productive cycle are based on molecular membrane separations can be considered a valid approach for a sustainable industrial growth within the *process intensification* strategy. The aim of this strategy is to introduce in the productive cycles new technologies characterised by low encumbrance volume, advanced levels of automation capacity, modularity, remote control, reduced energy consumption, etc.

Juice clarification, stabilisation, depectinization and concentration are typical steps where membrane processes as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) have been successfully utilised (Álvarez, Riera, Álvarez, & Coca, 1998; Fukumoto, Delaquis, & Girard, 1998; Gökmen, Borneman, & Nijhuis, 1998; Palmieri, Dalla Rosa, Dall'Aglio, & Carpi, 1990; Todisco, Tallarico, & Drioli, 1998). These traditional operations have been completed with new membrane systems such as the membrane reactors, the catalytic membranes and the osmotic distillation (OD).

OD is a recent membrane process, also known as osmotic evaporation, osmotic concentration by membrane, membrane evaporation, isothermal membrane distillation or gas membrane extraction. It is an attractive alternative process for the concentration of solutions containing thermally sensitive components, like fruit juices and pharmaceuticals, because it can be operated at room temperature and atmospheric pressure with minimal thermal and mechanical damage (Alves & Coelho, 2002; Bailey, Barbe, Hogan, & Sheng, 2000; Courel, Dornier, Herry, Rios, & Reynes, 2000; Gabelman & Hwang, 1999; Hogan, Canning, Peterson, Johnson, & Michaels, 1998; Kunz, Benabiles, & Ben-Aim, 1996; Vaillant et al., 2001).

In the OD process the water is removed from the feed by a hypertonic solution (concentrated brine) flowing downstream a microporous and hydrophobic membrane. The hydrophobic nature of the membrane prevents penetration of the pores by aqueous solutions, creating air gaps within the membrane. The difference in solute concentration, and consequently in water activity between the two sides of the membrane, induces a vapour pressure difference causing a water vapour transfer across the pores from high-vapour pressure phase to the low one (Gostoli, 1999).

The water vapour pressures at the pore mouths are related to the temperature and activities prevailing in the liquids facing the membrane by:

$$P_{w1} = P_w^* a_{w1} \quad (1)$$

$$P_{w2} = P_w^* a_{w2} \quad (2)$$

in which P_w^* represents the vapour pressure of pure water and a_w the water activity in the solutions. The driving force ($\Delta P_w = P_{w1} - P_{w2}$) for water transport is sustained by the activity difference $\Delta a_w = a_{w1} - a_{w2}$.

The aim of this study was to evaluate, on laboratory scale, the potential of UF and OD in the clarification and concentration of kiwifruit juice in order to design an integrated membrane process for the production of a concentrated kiwifruit juice with high nutritional value. The raw juice, produced after an enzymatic treatment, was previously clarified by UF. The permeate coming from the UF process was then submitted to a concentration step by OD. The performances of the membrane modules were evaluated on the basis of productivity and quality of the products (evaluation of the antioxidant activity).

2. Materials and methods

2.1. Preparation of fresh kiwifruit juice

Kiwifruits of cv. *Hayward* were purchased from fresh market located in Rende (Cosenza, Italy). Kiwifruits were manually washed with running water in order to remove foreign material from the skin (pesticides, hairs, particles). Hence they were manually cut-up and then pulped using a multiple shaker-liquidizer (Aristarco S. r.l., Treviso, Italy) in order to facilitate and accelerate the action of pectolytic enzymes added later. After pulping, 2–3 g/kg Na_2SO_3 (Sigma–Aldrich, Milan, Italy) were added in order to avoid a browning of the product. Then a pectolytic enzyme (Pectinex Ultra SP-L – Standard activity: 26,000 PG/ml, Novo Nordisk A/S, Novo Allè, 2880 Bagsvaerd, Denmark) was added in quantity of 10 g/kg and the puree was kept for 4 h at room temperature in plastic tanks with a capacity of 5 l. The puree was filtered with a Nylon cloth and the obtained

kiwifruit juice was stored in a refrigerator cell at -17°C before clarification by UF. This method gave an average juice yield of 75–80 w/w%.

2.2. UF unit and procedures

Ultrafiltration of kiwifruit juice was performed using a laboratory pilot unit (Fig. 1) supplied by Verind SpA (Rodano, Milan, Italy). The equipment consists of a 25 l stainless steel feed tank, a feed pressure pump, a pressure control system, a feed flow meter, a thermometer, two manometers for the measure of the inlet and outlet pressures. A tube and shell heat exchanger, placed after the feed pump, was used to maintain the temperature of the feed juice constant. A data acquisition system, permitting the continuous monitoring of the transmembrane pressure and of the axial feed flow rate, was connected to the UF plant. A digital balance, connected to the system, was used to measure the permeate fluxes. The plant was equipped with a tubular membrane module, supplied by Koch–Glitsch Italia S. r.l. (Milan, Italy), the characteristics of which are reported in Table 1.

UF experiments were performed according two types of operating mode: the total recycle mode and the batch concentration mode. In the former, the experimental trials were devoted to the investigation of the effect of the operating conditions on the flux performance of the

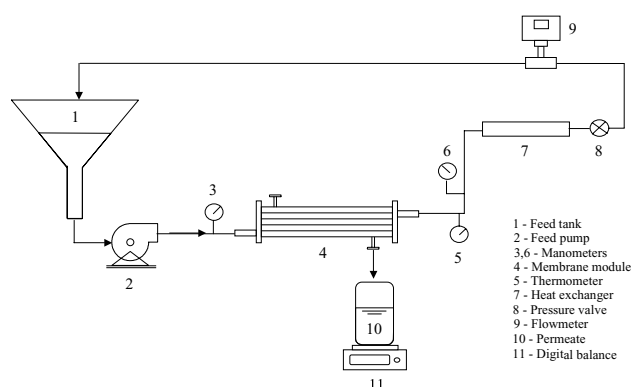


Fig. 1. Scheme of UF pilot laboratory plant.

Table 1
Characteristics of Koch ultrafiltration membrane module

Type	Koch Series-Cor™ HFM 251
Configuration	Tubular
Membrane polymer	Polyvinylidene fluoride
Nominal molecular weight cut-off	15 kDa
Membrane surface area	0.23 m ²
Average pores diameter	59 Å
pH operating range	2–11
Temperature operating range	0–55 °C
Pressure operating range	0.8–5.5 bar

system. In this case the permeate was continuously recycled to the feed tank to ensure a steady state in the volume and composition of the feed. In the batch concentration mode the UF system was operated to concentrate the juice up to a recovery factor of 85%. In these experiments the effect of the UF process on the total antioxidant activity (TAA) and other parameters was analysed.

The membrane module was rinsed with tap water for 30 min after the treatment of the juice; then it was submitted to a cleaning procedure with the alkaline detergent Ultrasil 10 (Henkel Chemicals Ltd., Dussendorf, Germany) at a concentration of 0.2 w/w% and at a temperature of 40 °C for 60 min. A final rinse of the system with tap water for at least 20 min was carried out.

After each cleaning procedure the water flux of the membrane module in fixed conditions (temperature 25 °C; axial feed flow rate 500 l/h) was measured.

2.3. OD unit and procedures

The clarified juice was submitted to an OD treatment using a laboratory plant (Fig. 2) supplied by Hoechst–Celanese Corporation (Wiesbaden, Germany) equipped with a Liqui-Cell® Extra-Flow 2.5 × 8-in. membrane contactor (Hoechst–Celanese Corporation, Wiesbaden, Germany) (Table 2).

The clarified juice was pumped through the shell side of the membrane module; Calcium Chloride Dihydrate at 60 w/w% by Carlo Erba (Milan, Italy), used as stripping solution, was pumped through the fibre lumens (tube side). It was chosen because it is not toxic and it is readily available at low cost. Both solutions were recirculated back to their reservoirs after passing through the contactor. Circulation of both brine and juice was counter-current.

Inlet and outlet pressures for both tube side and shell side streams were registered by pressure gauges in order to control the pressure differentials between the two

Table 2

Data sheet of Liqui-Cell® Extra-Flow 2.5 × 8 in. membrane contactor

Fiber characteristics	
Fiber type	Celgard® microporous Polypropylene Hollow fiber
Cartridge operating limits	
Maximum transmembrane differential pressure	4.2 kg/cm ² (60 psi)
Maximum operating temperature range	40 °C (104 °F)
Cartridge characteristics	
Cartridge dimensions (D × L)	8 × 28 cm (2.5 × 8 in.)
Effective surface area	1.4 m ² (15.2 ft ²)
Effective area/volume	29.3 cm ² /cm ³
Fiber potting material	Polyethylene

sides of the membrane. OD system was generally operated with a slightly higher pressure on the shell side of the module than the lumen side in order to avoid the leakage of the brine strip into the product.

The clarified juice was recirculated in the shell side of the OD membrane module with an average flow rate of 28.7 l/h. The stripping solution was recirculated in the tube side with an average flow rate of 30.3 l/h. The temperature of both, juice and brine, was 25 ± 1 °C whereas the average transmembrane pressure (TMP) was 0.28 bar.

The flow rate of extracted water was measured with a balance (Gibertini Elettronica, Milan, Italy) placed under the juice tank and it was used to calculate the evaporation flux (J_w).

After each trial, the pilot plant was cleaned first by rinsing the tube side and shell side with de-ionised water. Then, a NaOH solution at 2 w/w% was circulated for 1 h at 40 °C. After a short rinsing with de-ionised water a citric acid solution at 2 w/w% was circulated for 1 h at 40 °C. Finally, the circuit was rinsed with de-ionised water.

2.4. Analytical methods

Samples of fresh, clarified and concentrated juice were collected and stored at −20 °C for further analyses.

The stability of antioxidants during juice processing is of interest since they play an important role in reducing the risk of free radical related oxidative damage associated with a number of diseases. The effect of membrane processes on the TAA of the kiwifruit juice was evaluated. The TAA was determined by an improved version of the 2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) free radical decolourisation assay in which the ABTS radical cation is generated by reaction with potassium persulphate before the addition of the antioxidant (Re et al., 1999). The decolourisation of the ABTS is measured as the percentage inhibition of absorbance at 734 nm. The concentration of antioxidant

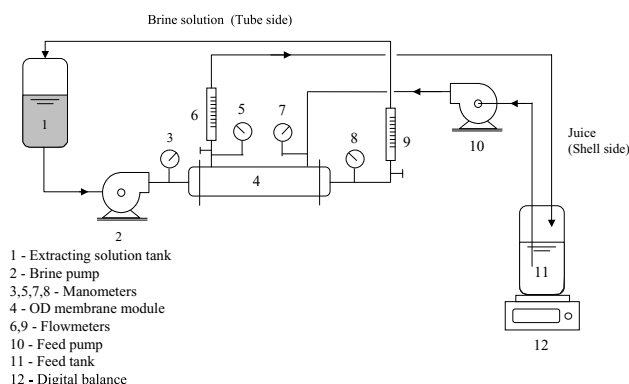


Fig. 2. Scheme of OD laboratory plant.

giving the same percentage inhibition of absorbance of the radical cation at 734 nm as 1 mM 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) was calculated in terms of the trolox equivalent antioxidant capacity (TEAC) at 5 min contact. Concentrated samples were diluted to the same total soluble solids (TSS) concentration of the fresh juice (12.5 °Brix) before the analysis, in order to allow the direct comparison between the different values.

ABTS, potassium persulphate and Trolox were obtained from Sigma–Aldrich (Milan, Italy). Spectrophotometric measurements were performed by a Lambda Bio 20 model spectrophotometer (Perkin–Elmer, Norwalk, USA) at 30 °C.

Ascorbic acid was determined by HPLC-analyses performed using a Waters model 2690 separation module equipped with a Waters model 2487 dual-band UV–Vis detector on a C₁₈ Spherisorb RP-column (3 m, 250 × 2.1 mm i.d.) (Waters) with an isocratic elution with a 0.2 M phosphate buffer pH 3.0 and UV detection (254 nm). The ascorbic acid was quantified by peak area. Working ascorbic acid solutions were prepared starting from a standard ascorbic acid solution prepared dissolving pure ascorbic acid (Fluka Chemika–Biochemika, Milan, Italy) in bidistilled water.

TSS measurements were carried out using hand refractometers (Atago Co., Ltd., Tokyo, Japan) with scale range of 0–32, 28–62 and 58–90 °Brix. Turbidity was determined using a HI 93703 portable turbidity meter (Hanna Instruments Inc., RI, USA). Viscosity was measured using a RFS III viscometer (Rheometric Scientific, USA). pH was measured by an Orion Expandable ion analyzer EA 920 pH meter (Allometrics, Inc. LA, USA). The suspended solid content (SS) was determined in relation to total juice (w/w%) by centrifuging, at 2000 rpm (number of $g = 670.72$) for 20 min, 45 ml of a pre-weighed sample; the weight of settled solids was determined after removing the supernatant.

The water activity of the kiwifruit juice (a_{wj}) was estimated by correlating the data published in the literature for glucose solutions at various solute concentrations and at a temperature of 25 °C (Peng, Chow, & Chan, 2000). The water activity of the brine solution (a_{wb}) was estimated by correlating the data published in the literature for CaCl₂ solutions at various solute concentrations and at a temperature of 25 °C (Courel, 1999).

3. Results and discussion

3.1. Ultrafiltration

UF experiments, carried out according to the total recycle mode, were performed in order to study the effect of TMP, temperature and axial feed flow rate on the permeate fluxes.

Fig. 3 shows permeate flux values at steady state vs. the applied TMP. For small pressures the solvent flux is proportional to the applied pressure. As the pressure is increased flux shows a deviation from a linear flux–pressure behaviour and it becomes independent of pressure. In these conditions a limiting flux is reached at a TMP value of about 0.8 bar and any further pressure increase determines no significant increase of the permeate flux. The existence of a limiting flux can be related to the concentration polarization phenomenon that arises as the feed solution is convected towards the membrane where the separation of suspended and soluble solids from bulk solution takes place. A concentration profile from bulk solution to membrane surface is generated by the rejected material accumulated on the membrane. The formation of a viscous and gelatinous-type layer is responsible for an additional resistance to the permeate flux in addition to that of the membrane.

The TMP limiting value (TMP_{lim}) depends on physical properties of the suspension and feed flow rate. The cross-flow velocity affects the shear stress at the membrane surface and, consequently, the rate of removal of deposited particles responsible of flux decay. Fig. 4 shows the influence of the axial feed flow rate on the permeate flux at a temperature of 20 °C and at a TMP of 0.85 bar.

Fig. 5 shows the influence of the temperature on the permeate fluxes: when the operating temperature is raised the feed viscosity is reduced and diffusion coefficients of macromolecules increase. The effect of these two factors is to enhance mass transfer and to increase the permeation rate.

UF experiments carried out according to the batch concentration mode were performed at a TMP of 0.85 bar, an axial feed flow rate of 800 l/h and a temperature of 25 °C.

The results showed that the permeate flux decreased gradually with the operating times by increasing the volume reduction factor (VRF, defined as the ratio

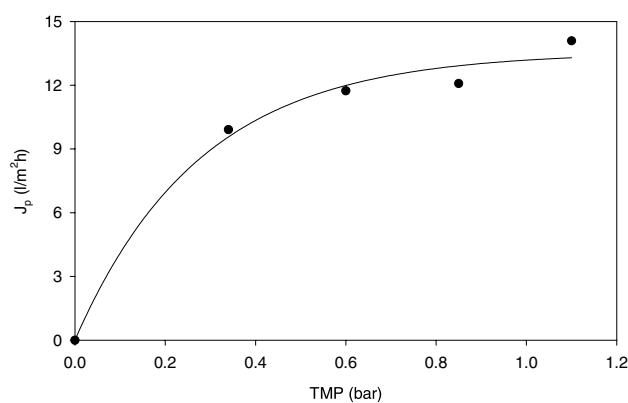


Fig. 3. Effect of TMP on the permeate flux during UF of kiwifruit juice (operating conditions: $Q_f = 500$ l/h; $T = 20$ °C).

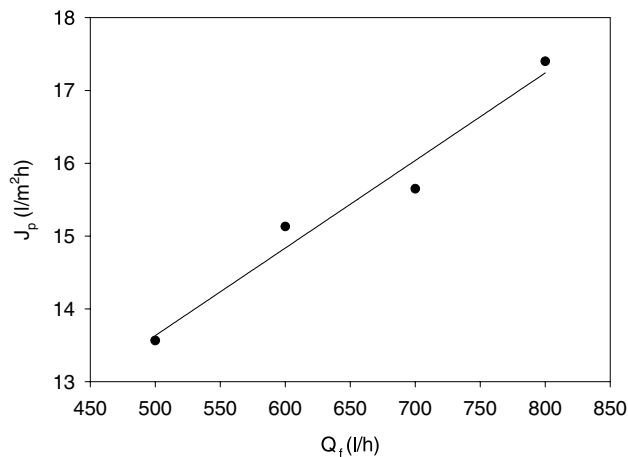


Fig. 4. Effect of axial feed flow rate on the permeate flux during UF of kiwifruit juice (operating conditions: TMP=0.85 bar; $T = 20^\circ\text{C}$).

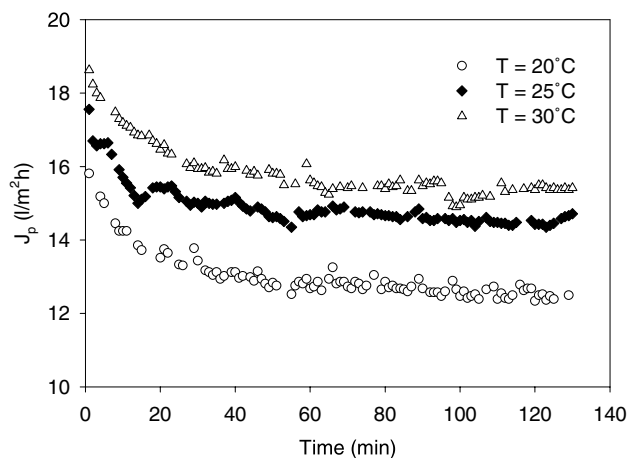


Fig. 5. Effect of temperature on the permeate flux during UF of kiwifruit juice (operating conditions: $Q_f = 500\text{ l/h}$; TMP=0.85 bar).

between the initial feed volume and the volume of the resulting retentate) (Fig. 6) due to concentration polarization and gel formation. The initial permeate flux of $15.65\text{ l/m}^2\text{ h}$ decreased to about $7\text{ l/m}^2\text{ h}$ when the VRF value reached 5.4. The J_p vs. VRF curve (Fig. 7) could be divided in three periods. An initial period in which a rapid decrease of permeate flux occurred; a second period, up to VRF 3, corresponding to a smaller decrease of permeate flux; a third period characterised by a small decrease of permeate flux up to a steady-state. These observations corroborate the results obtained by Constela and Lozano (1997) in the clarification of apple juice.

A good restore of the hydraulic permeability (about 95%) of the membrane was observed after a cleaning treatment with a 0.2w/w% Ultrasil 10 solution.

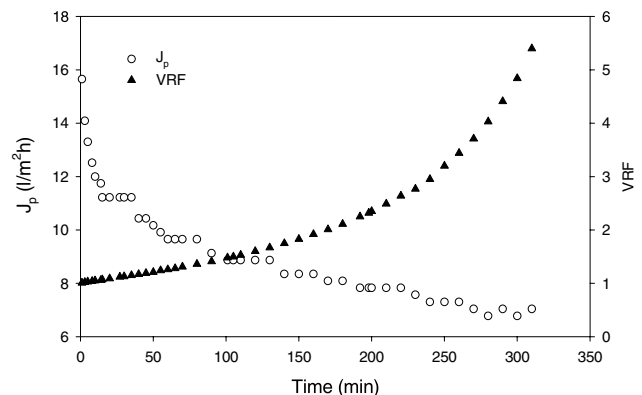


Fig. 6. Ultrafiltration of kiwifruit juice according to a batch concentration mode. Time course of permeate flux and VRF (operating conditions: TMP=0.85 bar; $Q_f = 500\text{ l/h}$; $T = 25^\circ\text{C}$).

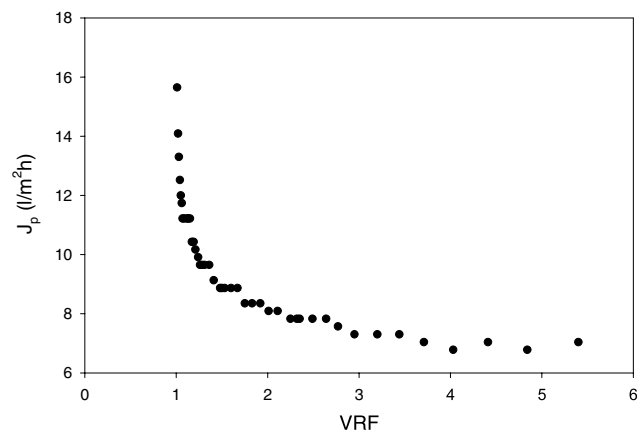


Fig. 7. Ultrafiltration of kiwifruit juice according to a batch concentration mode. Variation of permeate flux as a function of VRF (operating conditions: TMP=0.85 bar; $Q_f = 500\text{ l/h}$; $T = 25^\circ\text{C}$).

3.2. Osmotic distillation

Preliminary OD experiments were performed in order to evaluate the effect of the brine solute content on the evaporation fluxes. They consisted in extracting pure water at 25°C using brines of decreasing $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ mass fraction from 60.0 w/w% ($a_w = 0.280$) to 30.0 w/w% ($a_w = 0.800$) simulating the brine dilution.

The OD flux is significantly affected by the salt content of the brine as a 50% mass fraction reduction leads to a 70% vapour flux decay from 1.16 to $0.35\text{ kg/m}^2\text{ h}$. This result may be mainly explained by the strong dependence of the water activity of the brine on salt content (Fig. 8).

Fig. 9 shows experimental results concerning a generic run in which the clarified kiwifruit juice, with a TSS concentration of 9.4°Brix ($a_w = 0.989$), was concentrated up to 61.4°Brix ($a_w = 0.827$). Throughout the experimental run brine and juice temperature were maintained almost constant at $25 \pm 1^\circ\text{C}$.

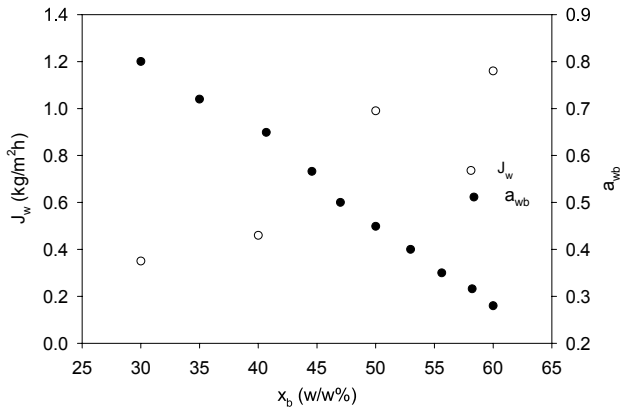
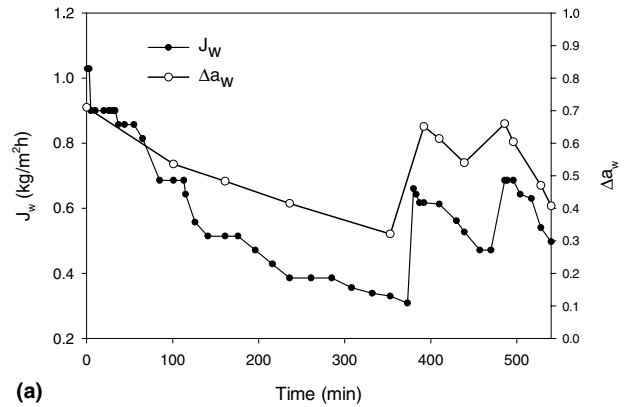


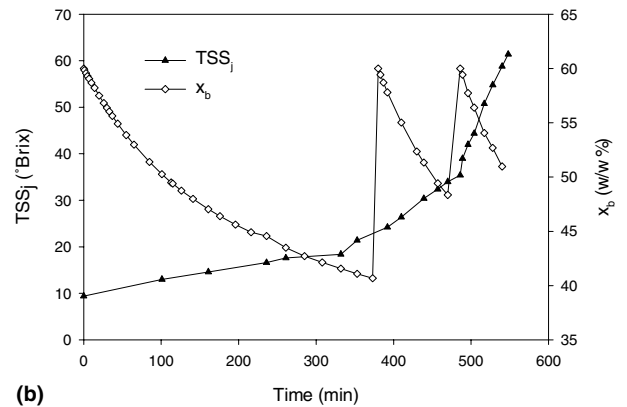
Fig. 8. Evaporation flux and water activity of the brine vs. brine solute content (operating conditions: $T = 25\text{ }^{\circ}\text{C}$; $Q_j = 29.8\text{ l/h}$; $Q_b = 37.8\text{ l/h}$).

As showed in the Fig. 9(a) the driving force for water transport is sustained by the water activity difference between the juice and brine ($\Delta a_w = a_{wj} - a_{wb}$). At first the brine concentration was 60 w/w% giving rise to an evaporation flux of about $1\text{ kg/m}^2\text{ h}$. In the range 0–380 min the decrease of the evaporation flux had a behavior very similar to those observed for the dilution of the stripping solution while the juice viscosity remained almost constant (Figs. 9(b) and (c)). At 380 min the original concentration of the calcium chloride solution was restored: the evaporation flux increased towards a value of $0.66\text{ kg/m}^2\text{ h}$ as a result of the brine concentration increasing. The 34% reduction of the evaporation flux, with respect to the initial value, can be explained assuming the raised viscosity of the juice. In the range 380–480 min the evaporation flux values decreased from 0.66 to $0.47\text{ kg/m}^2\text{ h}$ corresponding, respectively, to brine concentration values of 60.0 and 48.3 w/w%. In the range 480–550 min the evaporation flux decay can be attributed to the dilution of the stripping solution but mainly to the further increasing of the juice viscosity. These observations confirm the data obtained by other Authors (Courel et al., 2000; Vaillant et al., 2001) in the concentration of sucrose solutions and passion fruit juice by osmotic distillation: at low TSS of the feed juice the flux decay is more attributable to the dilution of the stripping solution; at higher TSS concentration values it mainly depends on juice viscosity (viscous polarization) and, consequently, on juice concentration and temperature.

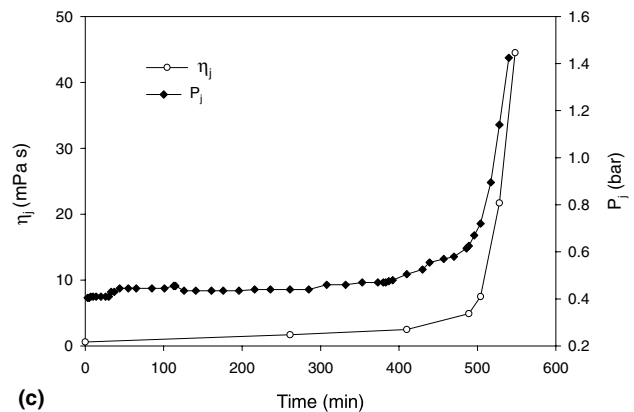
Pressure inside the brine rig (P_b) remained constant because the concentration of calcium chloride solution in the range of variation found in the trial did not affect the solution's viscosity. On the other hand, in the shell side, when concentration reached a value of about 38 °Brix pressure (P_j) began to increase exponentially (Fig. 9(c)). At concentration values of 61 °Brix, pressure increased to almost 1.4 bar, which, when compared with the pressure drop in the brine rig, had still remained safe for the membrane.



(a)



(b)



(c)

Fig. 9. Concentration of clarified kiwifruit juice by osmotic distillation. Time course of: (a) evaporation flux and water activity difference between juice and brine; (b) TSS and brine concentration; (c) kiwifruit juice viscosity and shell side pressure (operating conditions: $T = 25 \pm 2\text{ }^{\circ}\text{C}$; $Q_j = 28.7\text{ l/h}$; $Q_b = 30.3\text{ l/h}$; $\text{TMP} = 0.28\text{ bar}$).

Fig. 10 shows the effect of the water vapour pressure difference between juice and brine solution ($\Delta P_w = P_{wj} - P_{wb}$, calculated as $P_w^* \Delta a_w$) on the evaporation flux.

The juice viscosity increases exponentially with the total soluble solids content as showed in Fig. 11. As was to be expected, the effect of increasing the temperature was a decrease in viscosity. In contrast, the opposite effect was observed when soluble solids content became higher.

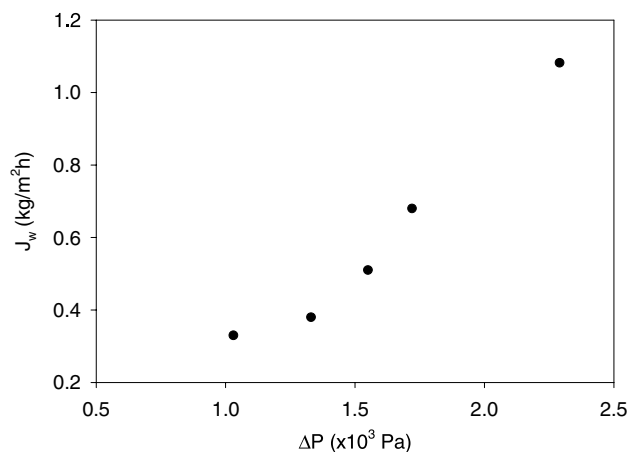


Fig. 10. Effect of water vapour pressure difference between juice and brine on the evaporation flux.

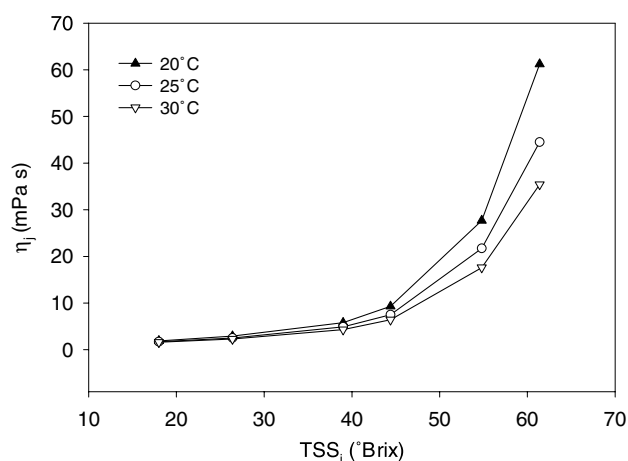


Fig. 11. Kiwifruit juice viscosity vs. TSS at different temperature values.

3.3. Analytical evaluations

As showed in Table 3, suspended solids in fresh kiwifruit juice was completely removed by UF and the resulting clarified juice had lower viscosity and negligible turbidity. Similar results were obtained by Hernandez, Chen, Shaw, Carter, and Barros (1992) during UF of fresh squeezed orange juice using 50 kDa polysulfone

membrane. A 3.2% loss in TSS concentration was found in UF permeate.

In the permeate coming from the UF process a little decrease of the TAA (only 4.3%) was observed with respect to the fresh juice. The UF retentate showed a 2.5% reduction of the TAA. A 8% reduction of the TAA was observed in the concentrated juice with respect the UF permeate.

Leong and Shui (2002) found in kiwifruits of New Zealand an ascorbic acid contribution to the TAA of 38.7%. Our measurements on the fresh juice extracted from the Hayward variety produced in Italy indicated an ascorbic acid contribution to the TAA of 23%. During the clarification/concentration step this contribution keeps constant as evidenced by the measurements performed on samples coming from the UF and OD treatment (Fig. 12). So the low reduction of the TAA observed during the membrane treatment can be attributed to other antioxidant components.

On the basis of the results obtained on laboratory scale it is possible to suggest an integrated membrane process scheme (Fig. 13) for producing clarified kiwifruit juice concentrate with high nutritional value. The proposed process employs partial batch recycle on the feed side of the OD process in order to minimise large feed viscosity changes through the membrane contactors and continuous countercurrent recycle plus evaporative

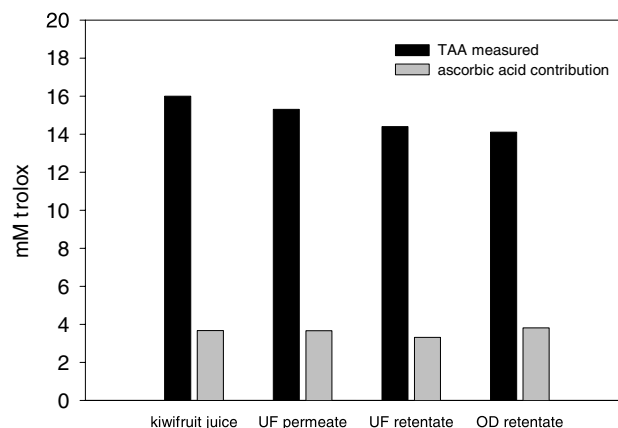


Fig. 12. Contribution of ascorbic acid to the TAA of fresh kiwifruit juice and in samples coming from the integrated membrane process.

Table 3

Analytical measurements on fresh kiwifruit juice and in samples coming from UF and OD treatments

Sample	Total soluble solids (°Brix)	pH	Suspended solids (w/w%)	Turbidity (NTU)	Ascorbic acid ^a (mg/100 g)	TAA ^a (mM trolox)
Fresh juice	12.5	3.58	5.16	299.5	69.6	16.0
UF permeate	12.1	3.60	0	0	69.3	15.3
UF retentate	13.5	3.58	51.5	1336.7	62.8	15.6
OD retentate	65.8	3.40	0	0	69.6	14.1

^a Values referred to 12.5 °Brix.

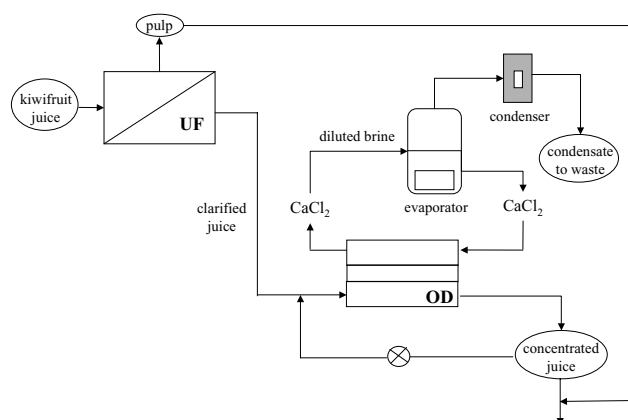


Fig. 13. Integrated membrane process scheme for the production of concentrated kiwifruit juice.

reconcentration of the brine strip. The residual fibrous phase coming from the UF process (retentate) could be submitted to a stabilising treatment (pasteurisation, ohmic heating, high pressures, electric fields at high voltage) (Byrne, 1993; Knorr, 1994; Skudder, 1992) and successively added to the final OD concentrate for the preparation of fiber enriched beverages (nectars).

4. Conclusions

Fresh kiwifruit juice, after enzymatic treatment, was submitted to a clarification/concentration process by a sequence UF–OD on laboratory scale.

The UF process permitted a good level of clarification reducing totally the suspended solids and the turbidity of the fresh juice. Additional advantages are in terms of: possibility to operate in a single step reducing working times; increasing of yield in terms of volumes of clarified juice produced; possibility to avoid the use of gelatines, adsorbents and other filtration coadiuvant.

The clarified juice was submitted to a concentration step by OD in which a concentrated juice with a final concentration of TSS higher than 60 °Brix was produced. Average evaporation fluxes of 1 kg/m² h were obtained.

A little reduction of the total antioxidant activity was measured during the UF–OD treatment where the ascorbic acid values in the samples coming from the membrane process and their contribution to the TAA were constant.

According to the results obtained, an integrated membrane process for the production of concentrated kiwifruit juice of high quality and high nutritional value was proposed.

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