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Ultrafiltration of kiwifruit juice: Operating parameters, juice quality and membrane fouling

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Abstract

Fresh depectinised kiwifruit juice has been clarified by ultrafiltration (UF) process on laboratory scale. In experimental tests performed according to the total recycle mode the effect of transmembrane pressure (TMP), axial flow-rate and temperature on permeation flux has been studied. The results showed that flux increased with temperatures from 20 to 30 °C and with axial feed flow rate from 300 to 700 l/h. The flux-pressure curves showed no increase in permeate fluxes for TMP values higher than 90 kPa (TMP_{lim}).

Clarified kiwifruit juice has been produced in experimental tests carried out according to the batch concentration mode working in optimal operating and fluid dynamic conditions. The quality of clarified juice has been analysed in terms of total antioxidant activity (TAA), content of ascorbic acid, suspended solids, turbidity and viscosity. The UF process permitted a good level of clarification reducing totally the suspended solids and the turbidity of the fresh juice. In the permeate a 16% reduction of ascorbic acid was observed with respect to the fresh juice; however, the reduction of the TAA was lower than 8%.

Cake layer and irreversible fouling resistances gave a minimum contribution to the total resistance (2.23% and 2.75%, respectively) while the contribution of the reversible fouling was more significant (29.4%). A good restore of the hydraulic permeability of the membrane (about 96% of the initial one) was observed after a cleaning treatment performed by using alkaline and acid detergents. Thus, the flux decline during UF could be ascribed to fouling layers formed by a combination of suspended particles and adsorbed macromolecular impurities.

Keywords: Kiwifruit juice; Ultrafiltration; Fouling; Total antioxidant activity; Ascorbic acid

1. Introduction

Kiwifruit originates from an indigenous plant of Southern China (Actinidia Chinensis) which was first developed commercially in New Zealand at the beginning of the 20th century (Luh & Wang, 1984). Nowadays it is commercially cropped in many European countries.

The majority of commercial production is harvested from vines of the cultivar ''Hayward'', tipically characterised by a greenish brown skin covered with hairs and a light green flesh with a white core (Ferguson, 1990).

Kiwifruit is characterised by significant amounts of biologically active compounds, including ascorbic acid (Kvesitadze, Kalandiya, Papunidze, & Vanidze, 2001). In particular it contains more ascorbic acid than the average amounts found in fruit such as grapefruit, oranges, strawberries and lemons and ten times as much as that found in apples and peaches (Beever & Hopkirk, 1990). Besides, it has an impressive antioxidant capacity, containing a wealth of phytonutrients, including carotenoids, lutein, phenolics, flavonoids and clorophyll.

A series of epidemiologic studies demonstrated that fruits and vegetables help to prevent cancer. This is commonly attributed to the presence of antioxidant compounds, which are supposed to decrease cancer risk by protecting DNA against oxidative damage. Real foods,

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including kiwifruit, decrease DNA oxidation in human lymphocytes tested ex vivo. In vitro, kiwifruit juice was shown to suppress the DNA damaging action of H_2O_2 even when it is diluted 10,000 times (Collins & Harrington, 2002; Collins, Horská, Hotten, Riddoch, & Collins, 2001).

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 consumers' interest for healthier and natural products has been growing and contributing to the consumption of lighter and refreshing products such as fruit juices and based fruit drinks (nectars, cocktails and drinks) (Matta, Moretti, & Cabral, 2004). The possibility to process kiwifruit is of great interest to both fruit growers and food industries so that many researchers have put efforts to study the suitability of this fruit to give a commercial differentiation from the fresh market. However, the realisation of a good quality processed kiwifruit is not easy and the possibility to have an industrial valorisation of the fruit is yet away to be found.

At the moment the kiwifruits derivatives on the market are represented mainly by semi-processed products, addressed to the food industry as ingredients or components for ice-creams, yoghurt, cakes and juice blending.

The main goal of the kiwifruit processing is to obtain safe and stable products able to retain as much as possible the peculiarity of fresh fruit, as well as green colour, aroma, nutritional value and structural characteristics (Dalla Rosa, Mastrocola, Maltini, & Sacchetti, 1999).

In order to guarantee the microbiological stability fruit juices are industrially pasteurised at temperatures of about 90 °C. These processes increase the shelf life of product and assure its safety, but affect the sensory properties of the juice which depend on volatile substances that are largely heat sensitive (Braddock & Goodrich, 2003). In addition, most vitamins are also heat sensitive loosing or reducing their activity when submitted to thermal processes. Besides, the heat required to perform the evaporation results in some ''cooked'' notes recognised as off-flavours.

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. 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; Koseoglu, Lawhon, & Lusas, 1990; Palmieri, Dalla Rosa, Dall'Aglio, & Carpi, 1990; Todisco, Tallarico, & Drioli, 1998). In particular, UF represents a valid alternative to the use of traditional fining agents such as gelatine, bentonite and silica sol which cause problems of environmental impact due to their disposal (Eykamp, 1995). Another advantage of the UF over conventional method includes the production with a continuous simplified process (Fukumoto et al., 1998). This process can be used to separate juices into a fibrous concentrated pulp and a clarified fraction free of spoilage microorganisms. Then, the clarified fraction can undergo non-thermal membrane concentration, such as membrane or osmotic distillation, and eventually whole juice reconstitution by combination with pasteurised pulp in order to obtain a product with improved sensorial properties (De Barros, Andrade, Mendes, & Peres, 2003).

The purpose of this work was to evaluate, on laboratory scale, the effect of different operating parameters, such as transmembrane pressure (TMP), cross flow velocity and temperature, on permeate flux in order to identify process conditions that would ensure acceptable flux with adequate juice quality. In this last contest the clarified juice and retentate were analysed for total antioxidant activity (TAA), ascorbic acid content, suspended solids, turbidity and viscosity.

An analysis of membrane, fouling and cake layer resistances, including their contribution to the total resistance, was also performed through the evaluation of the hydraulic permeability of the membrane measured before and after the treatment with juice and cleaning procedures.

2. Materials and methods

2.1. Juice extraction

Hayward kiwifruits, of Chilean origin, were purchased from the local open market (Cosenza, Italy). Unpeeled fruits were manually washed in water and cut in pieces. The kiwifruit pieces were milled 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 sodium sulphite (Sigma-Aldrich, Milan, Italy) was added (2–3 g/kg of pulp) in order to inhibit the enzyme polyphenol oxidase that determines a browning of the pulp. A pectinase from *Aspergillus aculeatus* (Pectinex Ultra SP-L, Novo Nordisk A/S, Novo Allè, Bagsuaerd, Denmark) (10 g/kg of pulp) was also added. The enzyme is able to hydrolyse both high and low esterified pectins and, partially, cellulose, hemicellulose, starch and proteins, thus decreasing the viscosity to a greater extent (Schmitt, 1988). This enables a faster and more extensive maceration of the fruit, thereby liberating juice and releasing flavour components and subsequently pigmentation. The puree was incubated for 4 hours at room temperature (~25 °C) and then filtered with a nylon cloth (Fig. 1). This method gave an average juice yield of 75–80% (w/w). The juice was stored at −17 °C and was defrosted to room temperature before use.

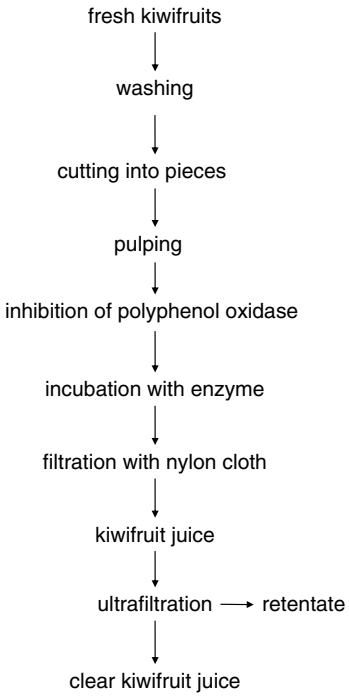

Fig. 1. Process for the extraction of kiwifruit juice.

2.2. UF experimental setup

Ultrafiltration of kiwifruit juice was performed using a laboratory pilot unit (Verind SpA, Milan, Italy) equipped with a tubular membrane module (Koch Series-Cor™ HFM 251, polyvinylidenefluoride, 15 kDa, 0.23 m^2), supplied by Koch-Glitsch Italia S.r.l. (Milan, Italy). The equipment consists of a 25 l stainless steel feed tank, a feed pressure pump, two manometers (0–40 kPa) located at the inlet (P_{in}) and outlet (P_{out}) of the membrane module and a magnetic flow meter for the measure of the axial feed flow rate (Q_f). Transmembrane pressure (TMP) was calculated as $TMP = (P_{in} + P_{out})/2$. 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 TMP 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. A schematic of the UF lab plant is reported in Fig. 2.

UF experiments were performed according to two types of operating mode: the total recycle and the batch concentration mode. In the former the permeate and retentate streams were continuously recycled to the feed tank to ensure a steady state in the volume and the composition of the feed. The experimental trials were devoted to the determination of the optimal operating and fluid-dynamic conditions (TMP, axial feed flow rate and temperature) for the clarification process. In the batch concentration mode (permeate is collected separately and retentate is recycled to the feed tank) the UF system was operated at a TMP of 90 kPa, at an axial feed flow rate of 700 l/h and at a temperature of 25 °C to clarify the juice up to a recovery factor of 75%. In these experiments, the effect of the UF process on the total antioxidant activity (TAA), ascorbic acid content, suspended solids, turbidity and viscosity of the juice was studied.

2.3. Measurement of hydraulic permeability and membrane cleaning

Water flux was measured in fixed conditions of temperature (20 °C) and axial feed flow rate (500 l/h) at different values of TMP. The hydraulic permeability of the membrane was determined by the slope of the straight lines obtained plotting the water flux values versus the applied TMP. The value obtained for new clean membrane is referred to as L_p^0.

The hydraulic permeability measured after the treatment with kiwifruit juice was indicated as L_p^1.

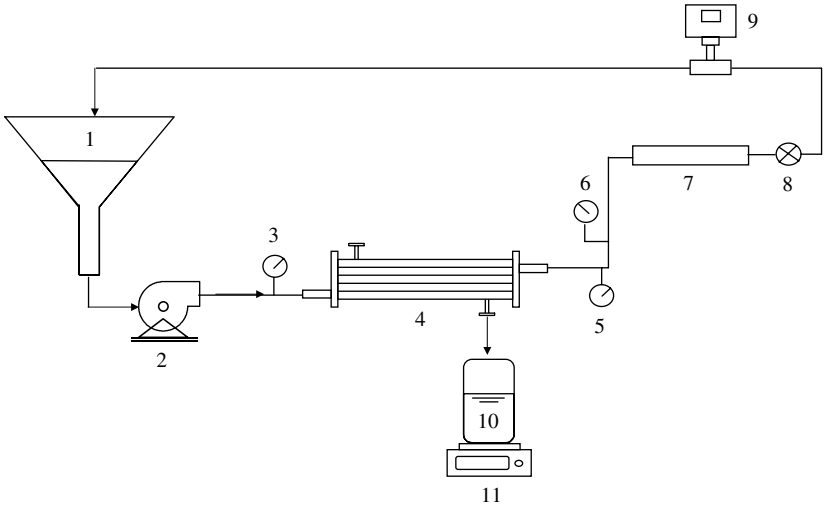

Fig. 2. Scheme of the UF pilot laboratory plant (1 – feed tank; 2 – feed pump; 3, 6 – manometers; 4 – membrane module; 5 – thermometer; 7 – heat exchanger; 8 – pressure valve; 9 – flowmeter; 10 – permeate; 11 – digital balance).

After the experiments with kiwifruit juice the membrane module was cleaned in two steps. The first cleaning step was performed recirculating tap water for 30 min through the module at a high water flow rate (about 900 l/h) and at low TMP (about 40 kPa) in order to remove the reversible polarized layer. The hydraulic permeability measured afterwards was L_p^2.

In the second step the membrane module was submitted to a cleaning procedure using the following solutions:

- NaOH solution (Aldrich, Milan) at 0.05% (w/w) (pH = 12);
- Deteacid (acid detergent, Separem, Biella) at 0.1% (w/w) (pH = 2.4).

Cleaning solutions were recirculated in the UF plant for 60 min at 40 °C, high axial flow rates (about 900 l/h) and low TMP (about 40 kPa). At the end of each cleaning procedure the membrane module was rinsed with tap water for 20 min and the hydraulic permeabilities, indicated as L_p^3 and L_p^4, respectively, were measured.

The membrane fouling, expressed as a percentage drop in the water permeability, was estimated by measuring the water flux before and after the UF treatment and after the cleaning procedures.

2.4. Analyses of resistances

The decline of permeate flux was analysed by a resistance-in-series model (Jiraratananon & Chanachai, 1996; De Bruijn, Venegas, & Borquez, 2002). The permeate flux for UF is usually written in terms of transmembrane pressure difference (ΔP) and total resistance, as reported in the following:

$$J_p = \frac{\Delta P}{\mu R_t}, \tag{1}$$

where J_p is the permeation flux of solution (m/s), ΔP is the transmembrane pressure difference (kPa), R_t is the total resistance (m^{-1}) and μ is the viscosity of solution (Pa s). R_t is composed of four resistances as

$$R_t = R_m + R_c + R_{frev} + R_{firr}, \tag{2}$$

where R_m is the intrinsic membrane resistance, R_c is the cake layer resistance and R_f is the fouling resistance. This last resistance can be considered as the sum of two components: R_{frev}, a reversible adsorbed layer which can be removed by cleaning with detergents, and R_{firr}, an irreversible fouling resistance due to the adsorption of materials which cannot be removed by chemical cleaning. Experimentally the resistances defined in Eq. (2) can be determined from the values of hydraulic permeabilites after the cleaning procedures described earlier.

In particular, the intrinsic membrane resistance R_m was calculated by measuring the hydraulic permeability of new or clean membrane as

$$R_m = \frac{1}{\mu_w L_p^0}, \tag{3}$$

where μ_w is the viscosity of water (Pa s) and $L_p^0 = J_w/\Delta P$ is the hydraulic permeability ($m\,s^{-1}\,kPa$) of the new membrane.

R_t was calculated by using the following equation:

$$R_t = \frac{1}{\mu_w L_p^1} \tag{4}$$

in which $L_p^1 = J_w^1/\Delta P$ is the hydraulic permeability of the membrane after the treatment with the kiwifruit juice.

The methods of cleaning described in the previous section permit the evaluation of R_c and R_{frev}. R_c is removed through cleaning the membrane with water. The hydraulic permeability measured after such cleaning is L_p^2, therefore:

$$R_m + R_{frev} + R_{firr} = \frac{1}{\mu_w L_p^2}. \tag{5}$$

Similarly for R_{frev}, which can be removed by cleaning the membrane with the alkaline and acid detergents and then measuring the hydraulic permeability (L_p^3 and L_p^4), Eq. (5) is then reduced to

$$R_m + R_{firr} = \frac{1}{\mu_w L_p^4}. \tag{6}$$

where $L_p^4 = J_w^4/\Delta P$ is the hydraulic permeability measured after the acid cleaning.

Each resistance was calculated using the experimental data from Eqs. (1)–(6).

2.5. Juice analyses

Samples of fresh, clarified (permeate) and concentrated (retentate) juice coming from the UF experiments performed according to the batch concentration mode were collected and stored at −20 °C for further analyses.

The TAA was determined by an improved version of the 2,2′-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) free radical decolourisation assay (Rice-Evans & Miller, 1994) 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 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 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 UV-160A UV–Visible

Recording spectrophotometer (Shimadzu Scientific Instruments, Inc., Japan) at 30 °C.

The concentration of ascorbic acid was determined by high-performance liquid chromatography (HPLC) using a HPLC D-7000 System Manager (Merck Hitachi, Darmstadt, Germany) equipped with an UV detector. The following conditions were used: an Alltima C_{18} HP5U column, 5 μm, 250 × 4.6 mm (Alltech Associates, Inc., Deerfield, IL) with a mobile phase of H_3PO_4 0.05 M, flux = 0.7 ml/min, $T = 25$ °C, pressure = 85 bar, $\lambda = 205$ nm. The external standard method was applied. A calibration curve with five standard concentrations was constructed and each standard was injected three times. The samples to be detected were also injected three times.

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 by using a HI 93703 portable nephelometer (Hanna Instruments Inc., RI, USA) after appropriate dilution whenever necessary.

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) with automatic temperature compensation. 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-weighted sample; the weight of settled solids was determined after removing the supernatant.

3. Results and discussion

3.1. Total recycle mode

Fig. 3 shows the time course of the permeate flux in experiments in which temperature and flow-rate were maintained at constant values (20 °C and 500 l/h, respectively) while the TMP was first increased from 60 to 100 kPa and then lowered from highest to lowest. In Fig. 4 the permeate flux values, at steady state, are plotted versus the applied TMP: at low pressure, shear forces are sufficient to minimize particle deposition and the solvent flux is proportional to the applied pressure. When the particles start to deposit on the membrane surface the rate of increasing in flux decreases. Further increases in pressure determine an increase of the thickness of the particle layer without a corresponding increase in flux. In these conditions a limiting flux is reached at a TMP value of about 90 kPa. When pressure was decreased, the layer had consolidated itself so that the prevailing cross-flow shear forces could not remove the particles from the membrane surface, resulting in the hysteresis effect shown in Fig. 4.

The effect of temperature on the permeate flux was evaluated in experimental trials in which TMP and axial feed flow rate were fixed at values of 115 kPa and 500 l/h, respectively. Fig. 5 shows the time course of the permeate flux at 20, 25 and 30 °C, in the conditions above mentioned. A 94%

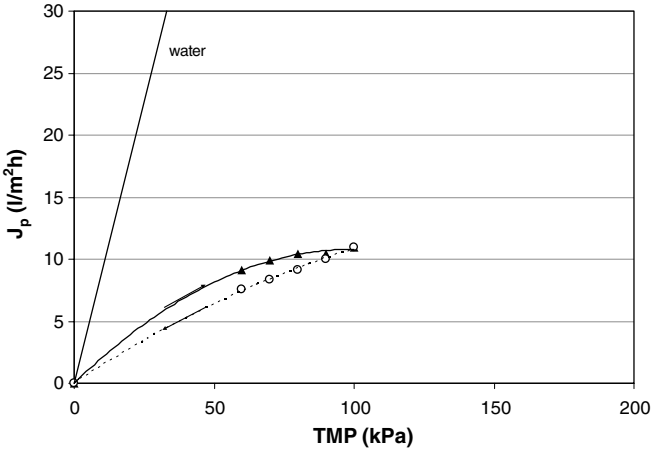

Fig. 4. Effect of the applied TMP on permeate flux (operating conditions: $Q_f = 500$ l/h; $T = 20$ °C). Arrows show direction of changing TMP. Broken line indicates experiments when pressures were lowered from highest to lowest.

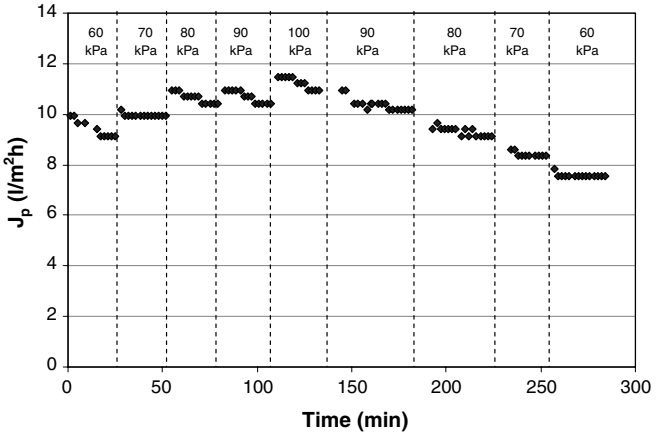

Fig. 3. Time course of permeate flux at different applied TMP (operating conditions: $Q_f = 500$ l/h; $T = 20$ °C).

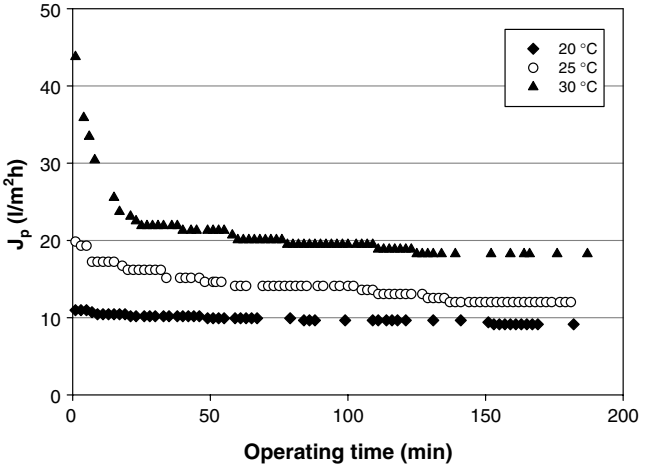

Fig. 5. Time course of permeate flux at different temperatures (operating conditions: TMP = 115 kPa; $Q_f = 500$ l/h).

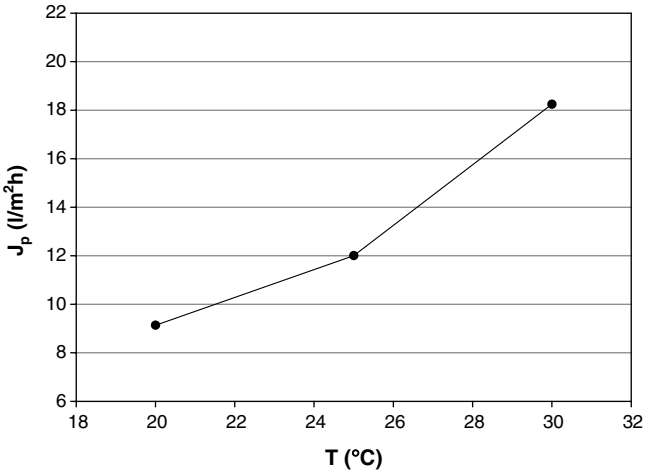

Fig. 6. Effect of temperature on permeate flux (operating conditions: TMP = 115 kPa; Q_f = 500 l/h).

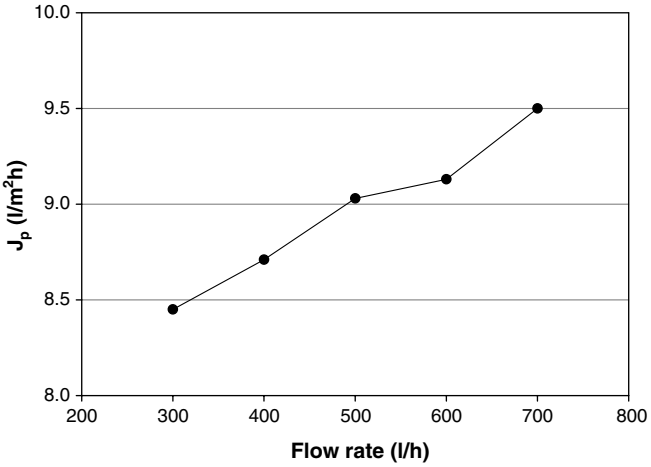

Fig. 7. Effect of axial feed flow rate on the permeate flux (operating conditions: TMP = 115 kPa; T = 20 °C).

increase in the flux, at steady-state, was observed when the temperature was raised from 20 to 30 °C (Fig. 6): this phenomenon can be attributed to a reduction of the feed viscosity and to an increase of the diffusion coefficient of macromolecules. The effect of these two factors is to enhance mass transfer and to increase the permeation 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 decays. The effect of varying feed flow rate on the permeate flux, at a temperature of 20 °C and at a TMP of 115 kPa, is shown in Fig. 7. As expected, an increase in the flow rate led to higher permeate fluxes.

3.2. Batch concentration mode

Although the studies performed in the total recycle configuration showed an increase of the permeate flux by increasing the temperature, elevated temperatures should be avoided in the production of a clear, sterile juice thus minimizing potential heat-induced flavour changes. Besides proteins are stable when the juice is held at temperatures lower than 30 °C. At higher values a haze formation is observed in few minutes (Wilson & Burns, 1983).

Since one of the primary aims of this study was to optimize the conditions of the UF treatment and to produce a juice with the same organoleptic and nutritional properties of the fresh juice, an operating temperature of 25 °C was chosen in the experimental trials performed according to a batch concentration mode. TMP and axial feed flow rate were fixed at 90 kPa and 700 l/h, respectively.

The results showed that the permeate flux decreased gradually with the operating times by increasing the volume reduction factor (VRF, defined as the ratio between the initial feed volume and the volume of the resulting retentate) (Fig. 8) due to concentration polarization and

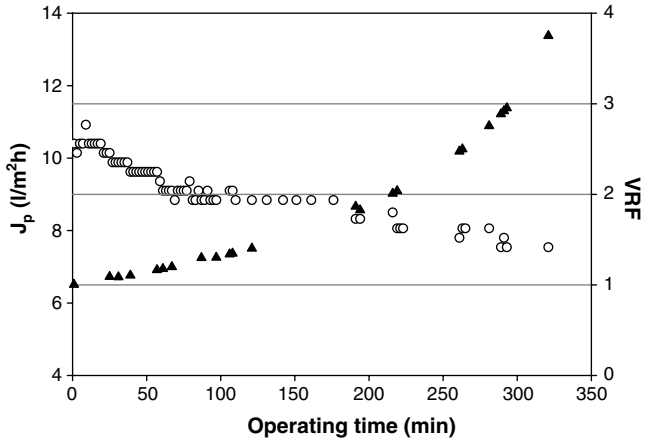

Fig. 8. Ultrafiltration of kiwifruit juice according to a batch concentration mode. Time course of permeate flux and VRF (operating conditions: TMP = 90 kPa; Q_f = 700 l/h; T = 25 °C).

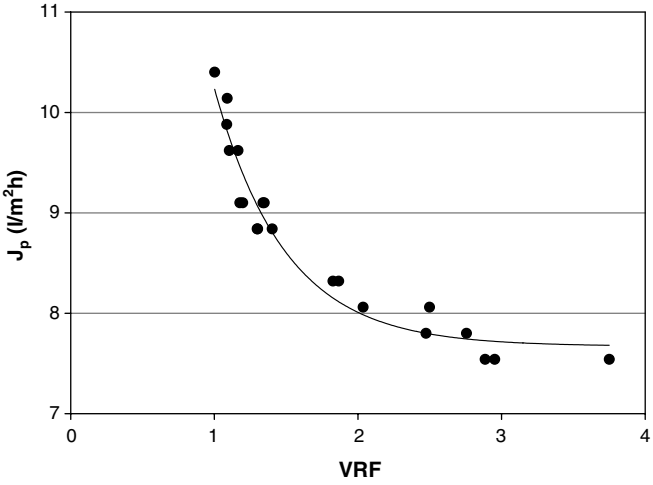

Fig. 9. Ultrafiltration of kiwifruit juice according to a batch concentration mode. Variation of permeate flux as a function of VRF (operating conditions: TMP = 90 kPa; Q_f = 700 l/h; T = 25 °C).

gel formation. The initial permeate flux of 10.4 l m^{-2} h^{-1} decreased to about 7.5 l m^{-2} h^{-1} corresponding to a final VRF value of 3.75. The J_p versus VRF curve (Fig. 9) could be divided in three periods: an initial period in which a rapid decrease of permeate flux occurred; a second period, up to VRF 2, 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.

3.3. Cleaning procedures and analyses of resistances

Table 1 shows the total resistance, membrane resistance, cake layer resistance and fouling resistance for the depectinised kiwifruit juice measured according to the resistance-in-series model. It can be noted that the membrane resistance contributes to 68.3% of the total resistance while the contribution of the combined cake layer and fouling resistances is about of 31.6%. In particular, the reversible component of the fouling resistance is 29.4% of the total resistance while the irreversible component represents only the 2.75% of the total resistance: this indicates that there are still smaller sized particles remaining in the juice after depectinization which cause irreversible fouling during the ultrafiltration. The cake layer resistance gives a minimum contribute (2.23%) to the total resistance.

Fig. 10 shows the pure water permeate flux of the membrane before and after UF and cleaning treatments. In Table 2 hydraulic permeabilities of the membrane measured before and after cleaning procedures are reported. It can be observed that the membrane water permeability dropped by 32% after juice UF. A good restore of the hydraulic permeability of the membrane (about 96% of the initial one) was observed after a cleaning treatment performed by using alkaline and acid detergents. Thus, the flux decline during UF could be ascribed to fouling layers formed by a combination of suspended particles and adsorbed macromolecular impurities.

3.4. Analytical evaluations

As showed in Table 3, suspended solids in fresh kiwifruit juice was completely removed by UF and the resulting clarified juice had a 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 11.1% loss in TSS concentration was found in the UF permeate.

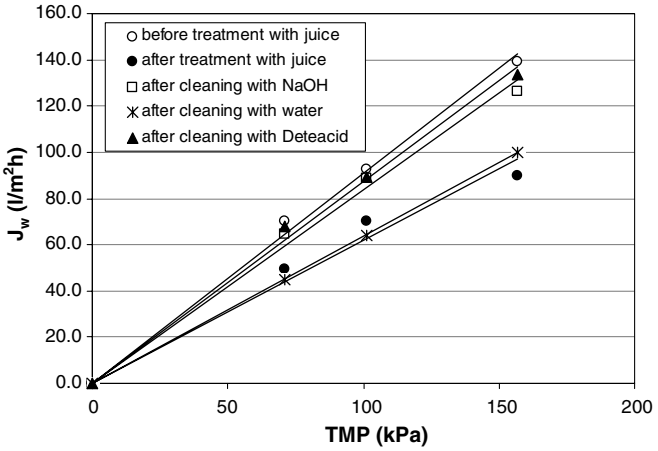

Fig. 10. Pure water permeate flux of membrane before and after UF and cleaning treatments (operating conditions: $Q_f = 500$ l/h; $T = 20$ °C).

Table 2
Hydraulic permeabilities of the membrane before and after cleaning processes

	Hydraulic permeability m s^{-1} kPa (l m^{-2} h^{-1} bar^{-1})
Before treatment with juice (L_p^0)	2.52×10^{-7} (90.8)
After treatment with juice (L_p^1)	1.72×10^{-7} (62.0)
After cleaning with water (L_p^2)	1.76×10^{-7} (63.5)
After cleaning with NaOH (L_p^3)	2.32×10^{-7} (83.6)
After cleaning with Deteacid (L_p^4)	2.42×10^{-7} (87.2)

Table 3
Analytical determinations on samples coming from UF of kiwifruit juice

Parameters	Samples		
	Kiwifruit juice	Permeate	Retentate
pH	3.58	3.60	3.58
TSS (°Brix)	12.6	11.2	12.4
Turbidity (NTU)	299.5	0	1336.7
Viscosity (mPa s)	1.455	1.427	1.451
Suspended solids (%w/w)	17.0	0	59.5
TAA (mM Trolox)	17.6	16.2	13.3
Ascorbic acid (mg/l)	900	750	720
TAA ascorbic acid (mM Trolox)	4.75	3.56	3.80
Ascorbic acid contribution to TAA (%)	27.0	22.0	28.6

In the permeate of the process a 16% reduction of the ascorbic acid was observed with respect to the fresh juice while for the TAA a reduction of about 7.8% was mea-

Table 1
Determination of resistances during ultrafiltration of depectinised kiwifruit juice

	R_t ($\times 10^{12}$) (m^{-1})	R_m ($\times 10^{12}$) (m^{-1})	R_c ($\times 10^{12}$) (m^{-1})	R_{frev} ($\times 10^{12}$) (m^{-1})	R_{firr} ($\times 10^{12}$) (m^{-1})	R_m/R_t (%)	$(R_c + R_{frev} + R_{firr})/R_t$ (%)	R_c/R_t (%)	R_f/R_t (%)
Depectinised kiwifruit juice	5.81	3.97	0.13	1.55	0.16	68.3	31.6	2.23	29.4

Table 4
Mass balance of the UF process

	Feed	Total permeate		Final retentate		Balance
Volume (l)	15.4	11	71.4%	4.4	28.6%	100.0%
Ascorbic acid (g)	13.86	8.25	59.5%	3.16	22.8%	82.3%
TAA (mmol Trolox)	271.04	178.2	65.7%	74.4	27.4%	93.1%
Suspended solids (g)	2618.0	0	0.0%	2618.0	100.0%	100.0%

sured. Considering the TAA value due to the ascorbic acid in the permeate and in the fresh kiwifruit juice it was possible to determine the contribution of the ascorbic acid to the TAA in these solutions. In particular, the contribution of the ascorbic acid to the TAA of the fresh juice and permeate was of 27% and 22%, respectively. In Table 4 the mass balance of the UF process for ascorbic acid, TAA and suspended solids is reported. This balance is referred to an UF run in which starting from 15.4 l of fresh juice 11 l of permeate and 4.4 l of retentate (final VRF = 3.5, recovery factor = 71.4%) were obtained. It can be noted that 60% and 65% of the initial content of ascorbic acid and TAA, respectively, were maintained in the permeate of the UF process. The 17.7% loss of ascorbic acid, as quantified by the mass balance, was probably due to an oxidation of this component caused by continual recycling of the juice around the UF pilot plant loop. Considering the lower contribution of ascorbic acid to the TAA in the permeate, the reduction of the TAA in the permeate stream (about 8%) can be attributed totally to the loss of ascorbic acid.

4. Conclusions

The selection of the best conditions for UF processing of kiwifruit juice was performed on the basis of the experimental results. If maximum permeation flux, minimum fouling and quality of juice are the requirement, the best conditions should be at 25 °C of temperature, 90 kPa of pressure and 700 l/h of flow rate.

Cake layer and irreversible fouling resistances gave a minimum contribution to the total resistance (2.23% and 2.75%, respectively) while the contribution of the reversible fouling was more significant (29.4%). A good restore of the hydraulic permeability of the membrane (about 96% of the initial one) was observed after a cleaning treatment performed by using alkaline and acid detergents. Thus, the flux decline during UF could be ascribed to fouling layers formed by a combination of suspended particles and adsorbed macromolecular impurities.

The UF process permitted a good level of clarification reducing totally the suspended solids and the turbidity of the fresh juice. A 7.8% reduction of the total antioxidant activity was measured in the permeate stream with respect to the fresh juice. This reduction can be attributed to a 16% degradation of the initial content of ascorbic acid.

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