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MEMBRANE FILTRATION OF FRUIT JUICE - AN EMERGING TECHNOLOGY

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ABSTRACT

The traditional or commercial fruit juice method involves heat treatment which is responsible for nutritional loss, vitamin loss, 'cooked flavour' and loss of color and aroma. Overall qualities of the juice deteriorate. Moreover these technologies are labour and time consuming methods. Whereas membrane filtration method {Ultrafiltration (UF), Microfiltration (MF), Nano-filtration (NF) and Reverse osmosis (RO)} is a good alternative for the fruit juice and beverage industry, has a significant impact on the organoleptic and nutritional properties of the juice. The use of membrane process associated to the enzymatic hydrolysis resulted in a clarified and concentration of fruit juices with a high nutritional quality and sensory quality. Microfiltration was efficient in removing the substance that cause haze. Resulting in clear juice free of pulp or suspended particles. The advantage of non-cellulosic membrane, having high retention of low molecular weight organics and good physical and chemical stability, has enabled reverse osmosis to be used commercial scale for the concentration of juice. This article provides an overview of recent developments and the published literature on Microfiltration, Ultrafiltration and Reverse osmosis with regard to fruit juice processing and its integration with other membrane processes. Various components of the fruit juices that impose problems during filtration process along with their quality requirements and regulatory concerns also been included in this review, so as to identify the constraints related to concentration of fruit juices using various separation methods.

Keyword: Fruit juices, Microfiltration, Ultrafiltration, Reverse osmosis, membrane fouling, integrated membrane processes.

INTRODUCTION

India is the largest producer of fruits in the world. Fruit juice is considered as one of the main important nonalcoholic beverage. Fruit juice blends of traditional juices (e.g. orange, grape fruit, apple and grape juices) and non-traditional fruits (e.g. tropical fruits) contribute significantly to the fruit juice market and have received wide consumer acceptance. The traditional or commercial fruit juice method involves heat treatment which is responsible for nutritional loss, vitamin loss, 'cooked flavour'and loss of color and aroma. Overall quality of the juice deteriorate. Moreover these technologies are labour and time consuming. Whereas membrane separation method (Ultrafiltration, Microfiltration, Nano-filtration, Reverse osmosis) is a good alternative for the fruit juice and beverage industry which has a significant impact on the organoleptic and nutritional properties of the juice.

Indian food industry is a 'sun-rise' sector in the world. The present growth rate of Indian food industry is 15%, against the world which is at 3% only (Gupta. R., & Malik. P, 2012). However, India is still struggling to achieve self-sufficiency in food security and safety. Especially, fruit juices and beverages represent an important market in Indian food industry. Growing at a rate of 25%, the fruit drinks category is among the fastest growing segment in the beverages market driven by the positive changes in India's consumer profile. Among the fruits mango, guava, pineapple, litchi, banana and grape are the most widely available in market and sample traded fruit beverages (Radha. T, & Mathew. L, 2007).

Consumption of plant-based products, such as fruits and vegetables, are associated with a healthier life style with lower risk of chronic diseases like cardiovascular disease (CVD) (Thilakarathna & Rupasinghe, 2012). Classical processes, including thermal pasteurization and also concentration simply by vacuum evaporation, significantly change the quality of products like fresh fruit drinks and seed extracts. Temperatures higher than 50°C degrade the sensory properties and nutritional compounds such as vitamins, and induce a loss of aroma compounds, leading to a partial loss of the fresh juice flavor (Cisse, *et al*, 2005; Shaw *et al*., 2001; Vaillant *et al*., 2001).

To overcome the problem due to heat treatment, various juice industries are adopting membrane technology process such as microfiltration (MF), ultra- filtration (UF), Nano filtration (NF) and reverse osmosis (RO). Classification of membrane separation process is given in Table 1.

Table 1 Classification of membrane separation processes [Paul DR (2004)]

Characteristics	Microfiltration	Ultrafiltration	Nanofiltration	Reverse Osmosis
Membrane	Symmetrical-asymmetric	Asymmetrical	Asymmetrical	Asymmetrical-composite
Thickness	S[a]≈10-150µm	S≈150-250µm; T[b]≈1µm	S≈150µm; T≈1µm	S≈150µm; T≈1µm
Pore size	0.1–10µm	0.01–0.1µm	<0.001µm	<0.001µm
Driving force (pressure)	<2 bar	1-10 bar	5-40 bar	10-100 bar
Rejects	Particles, clay, bacteria	Macromolecules, proteins, polysaccharides, viruses	HMWC mono-di and oligosaccharides, polyvalent anions	HMWC[c], LMWC[d], sodium, chloride, glucose, amino acids, proteins.
Membrane material	Ceramic, PP[e], PS(PSO)[f], PVDF[g]	Polymer (e.g. polysulfone, polyacrylonitril), PVDF, PS(PSO), PES[h], ceramic (e.g. Zirconium oxide, aluminium oxide)	Cellulose triacetate, aromatic polyamide, polyamide thin film	Cellulose triacetate, aromatic polyamide, polyamide thin film
Membrane module	Tubular, hollow fibre, spiral wound, plate and frame	Tubular, hollow fibre, spiral wound, plate and frame	Tubular, spiral wound, plate and frame	Tubular, spiral wound, plate and frame

[a] Sub layer, [b] Top layer, [c] High molecular weight compound: 100,000-1million mol/g
[d] Low molecular weight compound: 1,000-100,000mol/g, macromolecules: 1million mol/g
[e] Polypropylene membrane, [f]Polysulfone (either polyethersulphone or polyarylethersulphone)
[g]Polyvinylidenefluoride membrane, [h]Polyethersulphone membrane

The market share of UF systems and membranes accounts for the largest share of the membrane market with 35%, followed by MF systems and membranes with a share of 33%, and NF/RO systems and membranes with a share of 30% (Lipnizki. F, 2010). Other membrane processes such as membrane concentration (MC), electro dialysis (ED) and per evaporation (PV) have a small market share. The major applications in this market are in the dairy industry (milk, whey, brine, etc.) followed by other beverage industries (beer, fruit juices, and wine, etc.). Research has been done on concentration of apple juice, grape juice pomegranate & aloe Vera juice. It's advantages will include a lower running cost and a chance to avoid heat-treatment functions, which causes it to be suitable with regard to heat-sensitive substances such as the protein, enzymes and also anti-oxidant properties of the juice. It is a better alternative method using a different operating pressure, temperature & permeates flux. A Schematic representation of process for concentration of fruit juices using various membrane separations is given in Fig. 1.

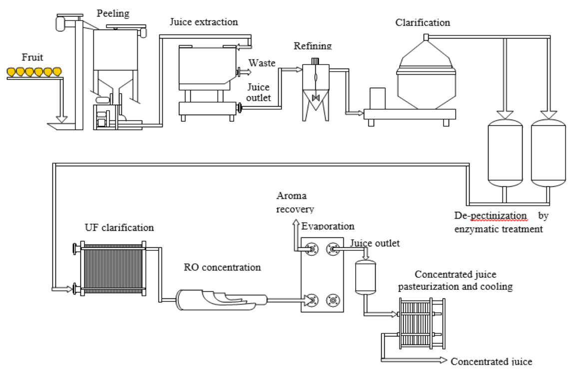

Fig.1 Schematic representation of process for concentration of fruit juices

Over the last two decades, the worldwide market for membrane technology in the food industry increased to a market volume of about 800–850 million (Peinemann. K *et al*, 2011). Within the food markets regarding concentration, purification enzyme membrane reactors (EMRs), microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) in addition to reverse osmosis (RO) usually are key practice. Their own intrinsic components (low working temperature, not any special compounds required, not any phase adjustments involved, easy scale-up in addition to modularity, uncomplicated functioning and potential for automation) make them a valid alternative to traditional strategies of liquid food treatment. Additionally, potential power savings extracted by membrane processes application in the food and drink industry can be estimated since 50%, since reported by Eichhammer (1995).

The advantages of using membrane technology in the beverage industry are related to economy, working conditions, environment and product quality (Koseoglu *et al.*, 1990; Hagg, 1998). Mostly the juice is treated after enzymatic pulping. This pre-treatment of juices before membrane layer filtration is usually an essential step to further improve filtration overall performance. In distinct, mixtures of enzymes, generally known as pectinases, are used to hydrolyse pectin straight into poly-d-galacturonic acidity fragments, reducing the particular viscosity with the juice with relatively low pulp resulting in an escalating in penetrate fluxes in addition to yield recovery (Alvarez *et al* ., 1998).

ENZYMATIC PRETREATMENT

A different factor which affects the filtration efficiency involving juice is usually proteins, muscles, suspended solids, and so forth. Therefore, along with depectinisation, various treatments may be used to improve this performance involving MF and also UF membranes. They contain treatment with proteases for removing proteins, centrifugation (before as well as after depectinisation) and use of fining brokers, such while gelatine and also bentonite. In case of fruit juice for depectinization and to increase the product yield several enzymes have been used for a long time as a pretreatment.

Several studies have reported on depectinization using enzymatic treatment such as pectinases could effectively clarify the fruit juices (Alvarez *et al*, 1998; Chamchong & Noomhorm, 1991; Ceci & Lozano, 1998; Grassin & Fauquembergue, 1996; Isabella *et al*, 1995; Kashyap *et al*, 2001; Vaillant *et al*., 1999; Yusof & Ibrahim, 1994). The pectinase hydrolyses pectin in addition to cause pectin– proteins complexes in order to flocculate. The ensuing juices using this pectinase treatment have a lower amount associated with pectin along with a lower viscosity that can useful to facilitate the filtration processes.

There are several studies on the optimization of enzymatic pretreatment for clarification of fruit juices being reported especially for tropical fruit juices (Lee *et al*, 2006; Rai *et al*, 2004; Sin *et al*, 2006). The enzymatic treatments for hydrolysis of pectic substances are influenced by several factors such as incubation time, incubation temperature and enzyme concentration (Baumann, 1981; Lee *et al*., 2006; Rai *et al*., 2004; Sin *et al*., 2006). Table 2 shows various enzymes used in fruit juice processing as pretreatment of membrane separation.

Table 2 Enzymes used in fruit processing [Lonsdale *et al*, 1965].

Enzymes	Characteristics
Polygalacturonase (PG)	Responsible for the random hydrolysis of alpha-1,4-glycosidic linkages between galacturonic acid residues; Depolymerize low esterified pectin (endo- and exo-enzymes)
Pectin lyase (PL)	Cleaves the pectin, by an elimination reaction releasing oligosaccharides with non-reducing terminal alpha-1,4-linked galacturonic acid residues, without the necessity of pectin methyl esterase action
Pectin methylesterase (PE)	Releases methanol from the pectyl methyl esters, a necessary stage before the polygalacturonase can act fully (the increase in the methanol content of such treated juice is generally less than the natural concentrations and poses no health risk)
Xylanase (hemicellulase)	A mixture of hydrolytic enzymes including xylan endo-1,3-beta-xylosidase and xylan 1,4-beta-xylosidase, which degrade hemicellulose
Arabonases (ARA)	Hydrolyse arabinans
Ferulic acid esterase (FAE)	Cuts ferulic acid and other phenolic linkages between the xylan chains opening the structure to further degradation by xylanases
Cellulase	Breaks down cellulose
Amylases	Breaks down starch

CLARIFICATION OF FRUIT JUICE THROUGH MF AND UF

MF is based on the using symmetric as well as asymmetric filters having pore size in the range 0. 05–10 μm. Basically, the separation principle is a sieving device and transport over the membrane occurs caused by an operating force engaged on the personal components within the feed. Additionally, MF could be the membrane process which nearly has a resemblance to conventional coarse filtration, and it enables to separate juices into a right amount of fibrous concentrated pulp plus a spoilage microorganism free clear clarified fraction.

UF membranes are actually extensively studied throughout the last 25 decades for this clarification of fruit and vegetable juices (Rai. P., & De. S, 2009). They have the ability to retain significant components in the product, such as micro-organisms, lipids, proteins in addition to colloids though small solutes, intended for example vitamin products, salts in addition to sugars, move across the membrane in addition to water (i.e. permeate). As a result, the UF course of action substitutes this fining step in the standard process. An opportunity of microbial contamination within the permeate mode is reduced avoiding almost any thermal cure and, consequently, a loss in volatile smell substances will certainly occur (Tallarico et al., 1998).

Clarifications of several fruits through UF and MF have been studied for decade. Grape (clarified by UF), Blackcurrant, redcurrant, sour cherry, raspberry (clarified by UF), Orange and passionfruit (clarified by MF), Pineapple (clarified by MF), Kiwi (clarified by UF), Camu-camu (clarified by MF), Chokeberry, redcurrant, cherry (clarified by UF), Cactus pear (clarified by UF), Passionfruit (clarified by MF), Pineapple (unclarified and clarified by MF), Orange (clarified by MF), Melon (clarified by MF) (Cassano *et al*, 2004, 2006,2007,2009. Koroknai *et al*, 2006, 2008. Shaw *et al*, 2001, 2002. Vaillant *et al*, 2001, 2005. Cisse *et al*, 2005). Fig 2 shows the line diagram for clarification and concentration of juice.

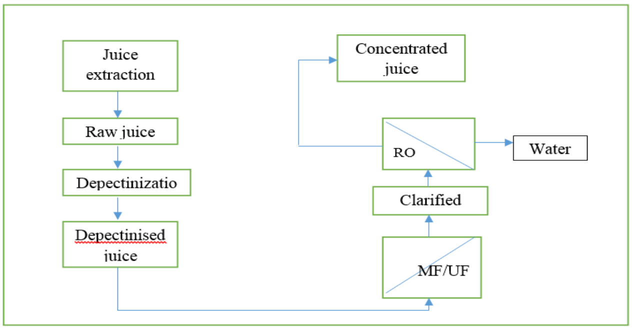

Fig.2 Process of concentration followed by clarification

Galaverna *et al*., 2008 studied integrated membrane process for the production of concentrated blood orange juice. The process was based on the initial clarification of freshly squeezed juice by ultrafiltration (UF); the clarified juice was successively concentrated by two consecutive processes: first reverse osmosis (RO), used as a pre-concentration technique (up to 25–30^{0}Brix), then osmotic distillation (OD), up to a final concentration of about 60^{0}Brix. During the concentration process of the liquid fractions, partial degradation of ascorbic acid (ca. -15%) and anthocyanins (ca. -20%) and a slight decrease of total antioxidant activity (TAA) was observed (-15%), with comparison to thermally treated product reduction of ascorbic acid is -30%, anthocyanins -36% and TAA -26%.

Cassano et al. (2010) evaluated the effect of MF and NF on cactus pear juice quality. After clarification with both the process retention of antioxidant compounds such as polyphenols, vitamin C, sugars and amino acid in a large amount in clear juice. The rennet can be used as jellies, ice creams and baby food.

Cassano et al. (2011) studied the test on clarification and concentration of pomegranate juice (*Punica granatum* D.) by applying membrane separation. The clarified juice contain 162 g TSS for every kg of fruit juice and UF helped by increasing the yield and reduce the microbial toxins. Then juice was moved to osmotic distillation unit for concentration containing micro skin pores polypropylene membrane. The final result was concluded that an integrated membrane process scheme for the production of concentrated pomegranate juice, it is helps to retain the antioxidant activity, nutritional content and flavours.

Chhaya et al. (2012) reported clarification of stevia extract by ultrafiltration method and concentration of the juice by nanofiltration method. To clarify the juice cross flow ultrafiltration was used where there is a significant flux enhancement (200%) was achieved with a cross flow rate and 140% with transmembrane pressure drop. Nanofiltration was applied to concentrate the juice with 1241kPa and 1500rpm of stirrer speed with 1 hr of operation.

Aguiar et al, (2012) conducted the experiment on concentration of apple juice by membrane separation processes at Brazil, to evaluate the final quality of apple juice, clarified and concentrated by microfiltration, reverse osmosis, along with osmotic evaporation. Then finally result was conclude that phenolic content and antioxidant activity increased proportionally with volumetric concentration factor (VCF).

Bagci (2014) evaluated the clarification of the pomegranate juice by ultrafiltration method with enzymatic pretreatment. Different enzyme combination such as gelatin, gelatin with bentonite, polyvinyl polypyrrolidone (PVPP) and PVPP with bentonite was used for the study. The best result was observed by sequential application of PVPP and bentonite to both the fouling behavior of the UF membrane and the juice clarity. Table 3 shows various membrane specification for fruit juice treatment.

Table 3: Specification and parameters used for membrane

Fruit	Specification and parameters used for membrane	Reference
Cashew apple (MF)	0.3 µrn pore size membranes with 0.05 m^2 of permeation area. The membranes were made of polyethersulfone. The operation conditions were 200 kPa of transmembrane pressure and temperature of 30°C.	Campos et al., 2002
Cashew apple (MF)	Clarification was carried out on a tubular microfiltration module presenting a polyethersulfone membrane with a medium pore size of 0.3 µrn , with 0.05 m^2 permeation area. Process conditions were 35^{0}C and 100 kPa	Wolkoff et al., 2004
Kiwi Fruit (UF)	Tubular membrane module, polyvinylidenefluoride, 15 kDa, 0.23 m^2. A data acquisition system, permitting the continuous monitoring of the transmembrane pressure (TMP) and axial feed flow rate, was connected to the UF plant.	Cassano et al., 2007
Stevia Extract (UF + NF)	UF - 30 kDa membrane of polyethersulfone with permeability 4.4 x 10^{-}11 m/Pa s NF - 400 molecular weight cut off membrane consisting of a polyamide skin over a polysulphone support	Sharma et al., 2012
Blood Orange(UF)	Tubular membrane module (PVDF, NMWCO 15 kDa, membrane surface area 0.23 m2, inner diameter of each tube 12.7 mm, average pores diameter 59 Å, pH operating range 2–11, temperature operating range 0 55°C, pressure operating range 0.8–5.5 bar)	Cassano et al., 2007
Black Current (UF + RO)	UF - tubular, hydrophilic, polyethersulfone 100 kDa MWCO membrane from Berghof with 0.41m^2 active area. According to the membrane producer the maximum value of the transmembrane pressure (TMP) is 80 bar, and the temperature maximum can be 60^{0}C. RO – The salt retention of the polyamide flatsheet RO membrane from Trisep was 91%, its active area was 0.18m2. The effect of TMP difference was examined. The operating parameters were 400 L/h recycle flow rate, 308C temperature, and 30-50 bar TMP differences.	Bánvölgyi et al., 2009

Pineapple juice (MF+UF)	MF - 0.3 lm pore diameter MF tubular polyethersulfone membrane with filtration area of 0.05m^2.Trans membrane pressures (TMP) of 1.5 and 3.0 bar, at room temperature (25^{0}C ± 2) were applied UF – 30 – 80 KDa (PVdF) tubular UF membrane, filtration area of 0.05 m^2, 1.5 bar, at the same temperature. Module M20-DSS (plate and frame), with an 8 L feed tank, was equipped for each process with 40 flat sheet polysulfone membranes with MWCO (molecular weight cut-off) of 50 and 100 KDa, respectively. The filtration area was 0.72 m^2, and 6.0 and 7.5 bar TMP were applied. The same plate and frame module was used for MF using a 0.1 and a 0.45 lm pore diameter PS membranes, at 3.5; 4.5 and 5.5 TMP, and 1.5 and 3.0 bar, respectively.	Carvalho et al.,2008
Grape Juice (RO)	Plate and frame module composed of HR98PP thin film composite membranes, 0.68 m^2 and rejection of 95% to a 0.25% NaCl solution at 25 ^{0}C.	Gurak et al., 2010
Black Current(RO)	18 perforated stainless steel tubes. Each tube is lined with a 1.2-m long membrane element 12.5mm in diameter (total area of 0.9m2). The module contained AFC 80 polyamide tubular membrane	Pap et al., 2009
Buckthorn berries (MF+RO) /(RO/NF)	A Millipore multi-tube ceramic membrane was used for microfiltration (MF) on 0.7–3.2 bar transmembrane pressure difference range. The clarified juice was concentrated with a Millipore. Spiral wound reverse osmosis (RO1) module on 9–30 bar transmembrane pressure difference range. The raw juice (without clarification) was concentrated once with a flat sheet Trisep nanofiltration (NF) membrane on 9–32 bar transmembrane pressure. Difference range and in the other case with a flat sheet Filmtec DOW reverse osmosis (RO2) membrane on 22–48 bar transmembrane pressure difference range.	Vincze et al., 2007
Melon Juice (MF+OE)	Ceramic multichannel membrane, total effective filtration area of 0.24 m^2 and an average pore diameter of 0.2 Am.	Vaillant et al., 2005
Camu Camu (RO+OE)	RO - plate and frame reverse osmosis system, composed of HR98PP thin film composite membranes (DSS, Silkeborg, Denmark), with 98% nominal rejection to a 0.25% NaCl solution and permeation area of 0.288 m^2	Souza et al., 2013
Apple Juice (RO+OE)	RO - plate and frame reverse osmosis system, composed of HR98PP. Thin film composite membranes (DSS, Silkeborg, Denmark), with nominal rejection to NaCl of 98%. The permeation area was 0.36 m^2 and the transmembrane pressure was 6 MPa	Aguiar et al., 2012

* UF- Ultrafiltration; MF- Microfiltration; RO- Reverse osmosis; PV- Pervaporation; EMR- Enzyme membrane reactor; OD- Osmotic distillation; MD- Membrane distillation; OE- Osmotic evaporation.

CONCENTRATION THROUGH REVERSE OSMOSIS

The process of fruit juice concentration using RO becomes practical only with the development of suitable membranes. Fig.3 shows a schematic representation of an RO system. RO membranes do not have distinct pores that traverse the membrane and lie at one extreme of commercially available membranes. The polymer materials of RO membranes forms the layered, web-like framework, and water must comply with a tortuous pathway throughout the membrane to achieve the permeate side. RO membranes can reject the contaminants, monovalent ions, whilst other membranes, including nanofiltration (NF), ultrafiltration (UF), along with microfiltration (MF), are made to remove components of improving size.

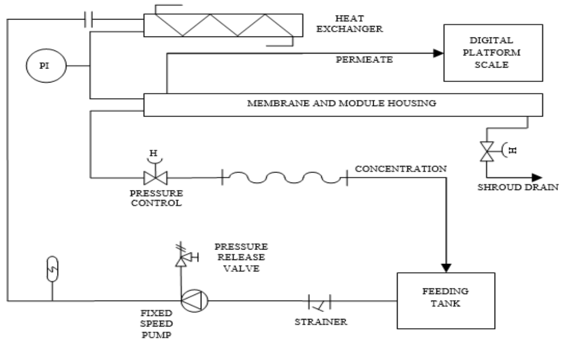

Fig.3 Integrated membrane process for the clarification and concentration of fruit juices involving ultrafiltration (UF), pervaporation (PV), osmotic distillation (OD) and reverse osmosis (RO)

Membranes can be used in either dead-end or cross-flow filtration. RO membranes are typically operated in cross-flow mode and are most commonly available as spiral wound modules, where the membrane sheets are wound around an inner tube that collects the permeate (Baker, 2004). Most membranes allow filtration through pore flow, where the fluid is forced through the membrane by a positive hydrostatic pressure. The fluid flow depends upon the membrane porosity, the fraction of membrane volume that is the void space which can contain liquid, and tortuosity, ratio of the distance a molecule must travel through the membrane to the thickness of the membrane. The general relationship that describes transport due to pore flow and diffusion can be expressed as follows (Bird *et al.*, 2002):

$$N_{Ax} = \frac{\rho_A \kappa}{\mu}\frac{dp}{dx} - D_{AB}\frac{d\rho_A}{dx} \qquad (1)$$

Where, N_{Ax} is the mass flux of A in the x-direction (perpendicular to the membrane surface), ρ_A is the mass density of A, κ is the permeability, μ is the viscosity, dp/dx is the pressure gradient in the x-direction, and D_{AB} is the binary diffusion coefficient for the diffusion of A in B (the membrane).

For MF and UF membranes, the diffusion term is negligible compared to the convection term. Solvent transport through NF membranes occurs through a combination of convective flow and diffusion, while recent studies show that solute transport through NF membranes is primarily controlled by diffusion (Bowen and Welfoot., 2002). Transport through RO membranes, however, is controlled by diffusion, and no open channels exist for pore flow; the RO transport mechanism has been termed solution-diffusion (Paul, 2004).

Mass transport through RO membranes can be described as follows:

$$N_A = L(\Delta p - \Delta\Pi) \qquad (2)$$

Where, N_A is solvent flux through the membrane, L is the permeability coefficient, Δp is the transmembrane pressure difference, and ΔΠ is the osmotic pressure difference between the influent and the permeate. The osmotic pressure (p) depends on the solution concentration and the solution temperature. The relationship for a thermodynamically ideal solution, is described as follows:

$$\Pi = CRT \qquad (3)$$

Where, C is the ion concentration (molar units), R is the ideal gas constant, and T is the operating temperature.

The permeability coefficient, L, depends on characteristics of the membrane and is described by Wijmans and Baker, 1995:

$$L = \frac{DSV}{RTl} \qquad (4)$$

Where, D is the solvent diffusivity, S is the solvent solubility, V is the solvent partial molar volume, R is the ideal gas constant, T is the operating temperature, and l is the membrane thickness. This definition of L is based on the solution-diffusion model of liquid transport across a RO membrane (Bird *et al.*, 2002).

The osmotic pressures of the juice concentrate ranges from 10 to 200 bar (Matta *et al.*, 2004). The osmotic pressure (p) in the concentrate is related to the recovery (R_w) by Perry and Green, 1997.

$$\Pi_{concentrae} = \frac{1}{1-R_w} \qquad (5)$$

Recovery is an important indicator of RO performance. The recovery of a membrane or an overall RO system is given by:

$$R_w = \frac{Q_P}{Q_F} \qquad (6)$$

Where, Q_P is the permeate volumetric flow rate and Q_F is the feed volumetric flow rate (Rahardianto *et al.*, 2007). Reverse osmosis restoration varies from 35% to 85%, depending on pretreatment, feed composition, pretreatment, optimum energy design configuration and concentrate disposal options. Slight adjustments in restoration can considerably affect the entire cost of RO technique, as well for the reason that extent regarding typical restricting factors, such as osmotic pressure, fouling propensity, and mineral scaling (Wilf and Klinko, 2001).

RO membrane performance is measured by solute flux through the membrane, and also by solute rejection. The rejection rate for RO is often measured using the help of NaCl and it reaches 99.7% or more. Solute flux is a function of salt concentration, and its transport occurs from a region of higher solute concentration to a region of lower solute concentration. Solute flux is described by Baker, 2004.

$$N_S = B(C_{feed} - C_{permeate}) \qquad (7)$$

Where, N_s is the solute flux across the membrane, B is a constant (similar to L in the solvent flux equation) that depends on membrane characteristics, C_{feed} is the ion concentration inthe feed solution, and $C_{permeate}$ in the ion concentration in the permeate. B is described by:

$$B = \frac{D_s K_s}{l} \qquad (8)$$

Where, D_s is the solute diffusivity through the membrane, K_s is the solute partition coefficient between the solution and membrane phases, and l is the membrane thickness.

A number of research have analyzed the effects of temperature, cross-flow velocity, trans-membrane pressure, and concentration on the RO concentration of various juices and the optimal conditions found in each of the studies were dependent on the juice processed, the type of equipment used, and the procedure adopted (Table 4).

Table 4 Optimal operating parameters reported during RO concentration of various fruit juices

Juice	Membrane	Optimal paramaters			Findings	Reference
		TMP	CFV	T (°C)		
Grape juice	HR98PP thin film composite membrane	40-60 bar	-	20-40	Juice was concentrated up to 28.5 °Brix, with an increase in total titrable acidity, anthocyanin and phenolic compound contents, colour density and colour index proportional to the volumetric concentration factor.	Cadotte J, 1981
Apple juice	MSCB2521 R99 and MSCE 4040 R99 spiral wound membrane	1.5-7.0 MPa	200-600 L/h (lab scale); 4200 L/h (pilot-plant scale)	20-30	At 7.0 MPatransmembrane pressure, 4200 L/h feed flow & 25 °C temperature, concentration higher than 22 °Brix was reached with high permeate flux (higher than 25 L/h-m^2) and high aroma retention (higher than 80% for most of the compounds).	Bhattacharyya and Williams, 1992
Blackcurrant juice	AFC-80 polyamide tubular membrane	60 bar	30 L/h	25	Juice was concentrated up to 28.68 °Brix with improved filterability and high end concentration of the retentate, on application of PSE (Panzym Super E) enzyme.	Schuster et al., 2002
Pineapple juice	HR98PP polyamide composite membrane	60 bar	-	20	Juice was concentrated to a soluble solids content of 31 °Brix corresponding to a Volumetric Concentration Factor (VCF) of 2.9 and the concentration of soluble solids, total solids, and total acidity increased proportionally to VCF.	Sudak, 1990
Watermelon juice	Thin polyamide composite membrane	60 bar	650 l/h	30	Juice was concentrated from 8 to 30 ºBrix, with concentration of acidity, colour and total solids increased in relation to the single strengh juice. Lycopene content and antioxidant activity also increased but not proportional to the Volumetric Concentration Factor (VCF).	(Loeb and Souri,1963)
Acelora juice	FILMTEC BW30-2514 compound film membrane	20-40 bar	23 l/min	23±1	RO permeated fluxes showed a typical decrease along the time, as well as with the concentration factor (Fc) at different pressures. Juice physicochemical characteristics and the lack of turbidity were also maintained and the vitamin C concentration was equivalent to the Fc juice concentration.	Wilf and Klin, 2001
Orange juice	HR98PP polysulphone/polyethylene composite layer membrane	20-60 bar	650 l/h	25	Concentration factors of 2.3, 3.8 and 5.8 were obtained at three transmembrane pressures of 20, 40 and 60 bar, with the final soluble solids contents of 16, 28 and 36 °Brix, respectively. The vitamin C content increased from 29.3 mg ascorbic acid/100 g (single strength juice) to 53.9, 82.7 and 101.1 mg/100 g, in the concentrated juices obtained at 20, 40 and 60 bar, respectively.	Buonomenn, 2013
Grape juice	HR98PP thin film composite membrane	20-60 bar	-	20-50	Juice was concentrated up to 30 °Brix, with no change the quality parameters of the concentrated juice when compared to the single strength one. A temperature of 30ºC and 60 bar transmembrane pressure was found adequate.	Lamminen et al., 2004

INTEGRATION OF RO WITH OTHER MEMBRANE PROCESSES

Concentrating fruit juices by integrating the method of RO with other membrane processes, particularly for industrial production of high quality concentrated juices, is being widely used. There are many fruit juices that have high solids and pectin content, which creates a very viscous stream when it is directly, concentrated using RO, thus, resulting in a lower permeates flux. Also, it is difficult to reach concentrations larger than 25–30°Brix in a single-stage RO system due to high osmotic pressure limitation. Flux increases considerably when the process of RO is combined with other processes like MF, UF, pervaporation (PV) and enzyme membrane reactor (EMR) (Jiao *et al.*, 2004). The different steps of the integrated membrane process applied for the concentration of fruit juices are optimized in terms of various technical parameters like temperature, transmembrane pressure, feed flow rate, membrane fouling and cleaning procedures. Therefore, the benefits including high quality product and lower energy consumption could be achieved with integrated membrane processes.

CONCLUSION

The potential advantages of membrane filtration and RO over conventional clarification and concentration techniques for fruit juices are undeniable, including improved product quality, easily scaled up and lower energy consumption. However, these techniques are generally limited by problems related to fouling and by the relatively short lifespan of the membranes. But, many researchers have now found various methods and techniques to overcome this problem, like back flushing, membrane surface modification, use of enzymes and other membrane processes like UF and MF. Although today fruit juice clarification and concentration by membranes may be more expensive than evaporation, but with the enlargement of the world's fruit juice market and the demands of good product quality, commercial applications of RO in concentrating fruit juices, especially integration of other membrane processes with RO, will expand in the near future. However, in order to gain a foothold in the juice industry, studies on developments of new membranes which are both highly selective and permeable, or robust and stable in long-term application for juice concentration and improvements of process engineering including module design and process design and optimization need to be carried out in detail. The use of membranes is constantly bringing great changes in the juice industry, and now future developments will determine whether such membrane-based processes can provide the required product quality, purity, yield and throughput while remaining economically viable for the fruit juice industry.

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