



**CHARACTERISATION AND FLUX DECLINE
MECHANISM OF WATERMELON
JUICE BY USING MICROFILTRATION**



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BONAFIDE CERTIFICATE

A PROJECT REPORT

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ABSTRACT

Membrane filtration is an attractive process, which have been widely used in food and biotechnology industries, especially in clarifying the fruit juices. Flux decline mechanism during microfiltration of watermelon juice was studied in detail. Identification of the flux decline mechanism was carried out by conducting experiments in an unstirred batch cell. The operating pressure was 0.2 kg/cm² and the operating temperature was 27 ± 3°C. Complete pore blocking was identified as the main reason for flux decline for clarification of watermelon juice. This result in clear permeate juice retaining almost the total amount of soluble solids in feed. The clarity of the juice increased to 96.8% and the colour has decreased to 99.93%. The other characteristics like pH, density, total soluble sugars, total suspended solids etc., of juice has also decreased in the range of 5-15%. The antioxidant property was determined using 2,4-DNPH method, before and after microfiltration and showed that 16 mg/ml. These results were also compared with Rai *et al.*,(2010) literature values.

Keywords : Microfiltration, Complete Pore Blocking, Permeate, Antioxidant, Flux

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LIST OF ABBREVIATIONS

AIS	Alcohol in Soluble Solids
CA	Cellulose Acetate
CP	Concentration Polarization
CPB	Complete Pore Blocking
CMC	Carboxy Methyl Cellulose
HMWC	High Molecular Weight Compound
IPB	Intermediate Pore Blocking
ID	Internal Diameter
kPa	Kilo Pascal
LMWC	Low Molecular Weight Compound
MFP	Micro Filtered Permeate
MFR	Micro Filtered Retentate
NTU	Nephelometric Turbidity Units
PA	Polyamides
PAN	Polyacrylonitrile
PES	Polyethersulfone
PP	Polypropylene
ppm	Parts Per Million
PVDF	Polyvinylidene Fluoride
RO	Reverse Osmosis
SDS	Sodium Dodecyl Sulphate
SPB	Standard Pore Blocking
SS	Suspended Solids
TMP	Trans Membrane Pressure
TSS	Total Suspended Solids
UV Spectrophotometer	Ultra Violet Spectrophotometer
VRR	Volumetric Reduction Ratio

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Filtration is defined as the separation of two or more components from a fluid stream. In conventional usage, it usually refers to the separation of solid, immiscible, particles from liquid or gaseous streams. Membrane filtration extends this application further to include the separation of dissolved solutes in liquid streams and for separation of gas mixtures. The primary goal of the membrane is to act as a selective barrier. It should permit passage of certain components and retain certain other components of mixture. The four developed industrial membrane separation processes are Microfiltration (MF), Ultrafiltration (UF), Reverse Osmosis (RO) and Dialysis. The range of application of the three pressure driven membrane water separation processes are Reverse Osmosis, Ultrafiltration and Microfiltration. UF and MF are basically similar in that the mode of separation is molecular sieving through increasingly fine pores. MF membranes filter colloidal particles and bacteria from 0.1 to 10 μm in diameter. UF membranes can be used to filter dissolved macromolecules, such as proteins, from solutions. The mechanism of separation by RO membranes is quite different. In RO membranes, the membrane pores are so small, from 3 to 5 \AA in diameter, that they are within the range of thermal motion of the polymer chains that form the membrane. Each process has its own advantages. Here, MF has its advantage in food industry, waste water treatment, concentration of product etc., especially MF is used to clarify fruit juices.

Clarifying fruit juice using membrane filtration has been common place since the late 1970's. The process has many advantages over conventional plate and frame filtration processes including: no filter aid requirements and reduced enzyme dosages. Nevertheless, juice clarification via membrane filtration is not without its problems. During processing membranes tend to foul, greatly reducing system productivity. To reduce fouling problems, the juice is typically pre-treated using pectinases, gelatin, heat or some combination of all three.

Membrane processes are potentially attractive for processing tropical fruit juices due to the preservation of their nutritional and sensory characteristics. The product juice has

extremely low haze value, devoid of microorganisms and of high quality. Since these processes are carried out at room temperature, pasteurization and sterilization at higher temperature are not required. UF and MF are generally used for clarification and reverse osmosis is used for concentration of fruit juice.

Clarification of cashew apple juice using enzymatic hydrolysis followed by MF is reported (Campos *et al.*, 2002). Application of MF for clarification of enzymatically treated juice from McIntosh and red delicious apples was studied (Yu and Lencki, 2004). The influence of pectin layer on the fouling behaviour of the membrane was analysed and found that clarification of pineapple juice using MF was investigated (Cameiro *et al.*, 2002).

Watermelon (*Citrullus lanatus*, family Cucurbitaceae) is the fruit of a vine-like (climber and trailer) herb originally from southern Africa. In India, it is available during the summer time from April to May. Therefore, processing the watermelon juice is necessary to make it available all year round and to minimize post-harvest losses.

The resulting clarified juice was remarkably similar to the initial juice, except for insoluble solids and carotenoids, which were concentrated in the retentate. This integrated membrane process permitted production of two valuable products: a clarified concentrate of melon juice that had not undergone any thermal treatment and a retentate that was enriched in Lycopene. Although works on many fruit juices have been reported, there is no report available on clarification and Flux decline mechanism of watermelon juice by microfiltration using Pall Life Sciences's Casatte™ membrane.

The permeate flux and product quality are two important aspects for selecting a membrane clarification procedure. The main problem during clarification of juice by UF and MF is decline in permeate flux with time. A high permeate flux is necessary for filtration to be practical and economic, and product quality should at least meet those obtained by other clarification methods.

1.2 OBJECTIVE

- To evaluate the physio-chemical properties of the water melon juice.
- To evaluate the antioxidant property of the juice before and after microfiltration.
- To evaluate different models for flux decline of watermelon juice.

CHAPTER 2
REVIEW OF LITERATURE

2.1 MICROFILTRATION

Membrane filtration has potential applications in downstream processing. It can be classified into certain types based on the pore size of the membrane like Microfiltration (MF), Ultrafiltration (UF), Reverse osmosis (RO) and Dialysis. The degree of selectivity depends not only on the type of membrane being used (pore size and reactivity), but also on the other conditions of the process, including temperature, pressure, velocity, flow schematic, and other conditions. Among the many applications are product concentration, product sterilization (i.e. Removal of bacteria and virus particles), solute fractionation, solute removal from solutions (e.g. Desalination, Demineralization), purification, and clarification. A membrane may be made from organic polymers or inorganic material such as glass, metals and ceramics, or even liquids. Examples of polymeric (or organic) membranes include those made from cellulose, cellulose acetate (CA), polysulfone (PS), polyethersulfone (PES), polyamides (PA), polyvinylidene fluoride (PVDF), polyacrylonitrile (PAN). Inorganic membranes can be made from ceramics, glass, pyrolyzed carbon and stainless steel.

Here, MF can efficiently separate cell matter from fluids (Liquid & gas). A typical MF membrane pore size range is 0.1 to 10 micrometres (μm). MF is fundamentally different from reverse osmosis and nanofiltration because those systems use pressure as a means of forcing water to go from low pressure to high pressure. Microfiltration can use a pressurized system but it does not need to include pressure. Most MF membranes capture particles by surface filtration, i.e. on the surface of the membrane. In some cases depth filtration is also used. MF is most commonly used for clarification, sterilization and slurry concentration. Most MF membranes are symmetric.

	Reverse osmosis	Nanofiltration	Ultrafiltration	Microfiltration
Membrane	Asymmetrical	Asymmetrical	Asymmetrical	Symmetrical, Asymmetrical
Thickness	150 μm	150 μm	150-250 μm	10-150 μm
Thin film	1 μm	1 μm	1 μm	
Pore size	<0.002 μm	<0.002 μm	0.2-0.02 μm	4-0.02 μm
Rejection of	HMWC, LMWC Sodium chloride Glucose Amino acids	HMWC Mono-,di-, and oligosaccharides Polyvalent neg. Ions,	Macromolecules, Proteins, Polysaccharides, Virus	Particles, clay Bacteria
Membrane material(s)	CA Thin film	CA Thin film	Ceramic PSO, PVDF, CA Thin film	Ceramic, PP, PVDF
Membrane module	Tubular, Spiral wound Plate and frame	Tubular Spiral wound Plate and frame	Tubular Hollow fibre Spiral wound Plate and frame	Tubular Hollow fibre
Operating pressure	15-150 bar	5-35 bar	1-10 bar	<2 bar

Table 2.1 Comparing different membrane process

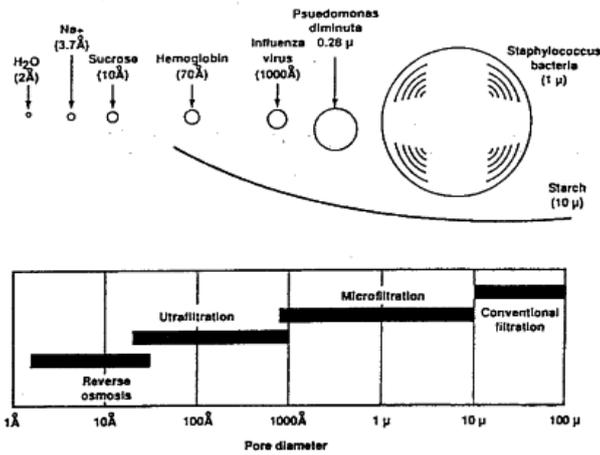


Figure 2.1 Separation of compounds based on the pore size of the membrane for the pressure driven process (Cheryan, 1986)

The various applications of microfiltration in biotechnology include:

1. Cell harvesting from bioreactors
2. Virus removal for pharmaceutical products
3. Clarification of fruit juice and beverages
4. Water purification
5. Air filtration
6. Sterilization of products

The most widely used process design are (i) Cross Flow Microfiltration and (ii) Dead End Microfiltration

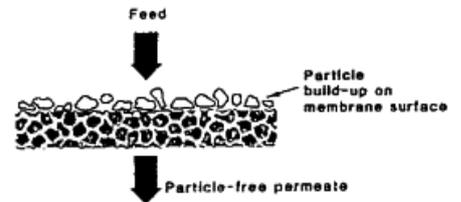


Figure 2.2 Dead End Filtration

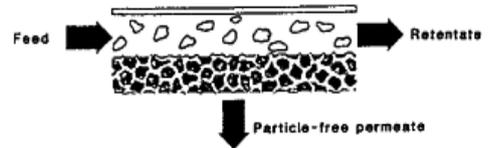


Figure 2.3 Cross Flow Filtration

2.1.1 Dead End Microfiltration

In dead-end or in-line filtration, the entire fluid flow is forced through the membrane under pressure. As particles accumulate on the membrane surface or in its interior, the pressure required to maintain the required flow increases, until at some point the membrane must be replaced. It is used for air filtration, virus removal and sterilization processes. To overcome the above problem an alternative process design known as cross-flow filtration is begun to be used.

2.1.2 Cross Flow Microfiltration

In cross-flow systems, the feed solution is circulated across the surface of the filter, producing two streams: a clean particle-free permeate and a concentrated retentate containing the particles. The equipment required for cross-flow filtration is more complex, but the membrane lifetime is longer than with in-line filtration. Streams containing less than 0.1% solids are almost always treated with in-line filters; streams containing 0.5% solids are almost always treated with cross-flow filters. Between these two limits, both in-line and cross-flow systems can be used, depending on the particular characteristics of the application.

One major problem that arises with microfiltration processes is fouling of the membrane. Fouling occurs when components adsorb to the membrane surface or within the pores forming a filter cake, preventing normal separation to occur. The effects of fouling are detrimental as selectivity and efficiency are lost, and it is timely to clean the system to restore proper functioning. Unfortunately, all systems will eventually show a decline in performance due to a gradual build up of foulants, but certain design features can be adopted to reduce this tendency. Using a Cross flow method of MF in one way to reduce fouling. This design uses a pump as the driving force to pass the feed stream tangentially to the membrane (as opposed to perpendicularly). The concentration of the retained species in the loop increases as permeate is removed from the system (Akhtar *et al.*, 1995; Short, 1988; Tanny *et al.*, 1982).

The permeate flux in microfiltration is given by

$$J_v = \frac{\Delta P}{\mu(R_M + R_C)} \quad (2.1)$$

Where,

R_M = membrane resistance (m^{-1})

R_C = cake resistance (m^{-1})

μ = permeate viscosity ($kg/m \cdot s$)

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2.2 FACTORS AFFECTING MEMBRANE FILTRATION

Despite the improvements in efficiency when using membrane as compared to traditional filtration, membrane fouling remains a problem. Low membrane fluxes are a direct result of two phenomena: concentration polarization (Cp) and fouling (Van den Berg and Smolders, 1990). The build up of colloidal particles at the surface of the membrane (concentration polarization) creates flow resistance, resulting in reduced flux. During watermelon juice filtration, the fouling colloids can potentially gel at the concentrations obtained on the surface of the membrane. Gel layer formation is the key step underlying one of the principle flux resistance models developed for protein ultrafiltration (Belfort *et al.*, 1994). This particular mechanism is probably the most applicable to untreated apple juice containing pectin and protein, which both have gel-forming potential.

2.2.1 Mechanisms of Membrane fouling

The other mode of flux resistance, fouling, is more irreversible and involves the adsorption of colloids onto membrane and pore surfaces (Fane and Fell, 1987). The resulting pore restrictions and plugging creates an additional flow resistance which further reduces flow through the membrane. Pectin has inherent aggregation tendencies (Fishman *et al.*, 1991) which likely play a role in fouling layer formation and structure. In fact, it is difficult to analyse for pectin molecular weight distributions because of these tendencies (Fischer and Bennett, 1991). Proteins have also been extensively studied because of their membrane fouling ability (Belfort *et al.*, 1994). The inherent fouling tendencies of various fruit juice compounds were studied by Wucherpfennig *et al.*, (1987). His group found that starch, dextran, arabinogalactan and laminarin did not foul ultrafiltration membranes. Since MF pore sizes are larger than UF, these same solutions should not foul MF membranes. The troublesome solutions included carboxymethylcellulose (CMC), pustulan, xylan, orange pectin and galectomanan. Once again, their results proved that, in the case of membrane fouling potential, the amount of substance in solution is not near as important as its chemical structure. However, no work has yet been done in the literature on the specific foulant formation mechanisms of these compounds, not to mention the types of interactions occurring in the juice fouling layer.

In order to maximize flux, membrane processing parameters should be chosen that minimize the flow resistances created by concentration polarization and fouling phenomena.

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The cake resistance is given by:

$$R_c = r \frac{V_s}{A_m} \quad (2.2)$$

Where,

r = Specific cake resistance (m/kg)

V_s = Volume of cake (m^3)

A_m = Area of membrane (m^2)

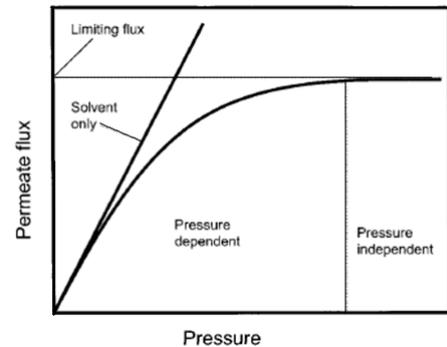


Figure 2.4: Relation between pressure and permeate flux using microfiltration

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Although concentration polarization and fouling cannot be avoided during filtration, the structure of the particles and resulting foulant porosities can possibly be controlled. Of course, conditions that maximize flux do not necessarily produce a final product with desirable properties. Conditions must be found that will produce the highest flux but still produce a product of acceptable quality.

2.2.2 Mechanism of Concentration Polarization

Concentration polarization is a reversible process, the flux can be regained after filtration by washing the membrane with water. The main reason for concentration polarization is solid particles in the feed which clogged on the surface of the membrane. These particles are larger in size compared to pore size of the membrane. These particles get accumulated above the pores and does not enter into the membrane. So, it forms a gel layer on the surface of the membrane.

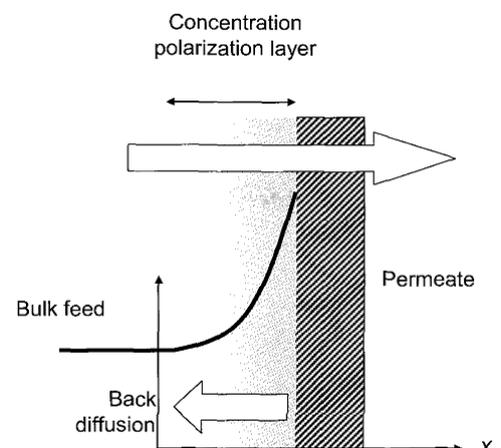


Figure 2.5 Effect of Concentration Polarization during microfiltration

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2.3 TYPES OF MEMBRANE

The two principal types of microfiltration membrane filter in use depth filters and screen filters. Screen filters have small pores in their top surface that collect particles larger than the pore diameter on the surface of the membrane. Depth filters have relatively large pores on the top surface so particles pass to the interior of the membrane. The particles are then captured at constrictions in the membrane pores or by adsorption onto the pore walls. Screen filter membranes rapidly become plugged by the accumulation of retained particles at the top surface. Depth filters have a much larger surface area available for collection of the particles, providing a larger holding capacity before fouling.

Depth membrane filters are usually preferred for in-line filtration. As particles are trapped within the membrane, the permeability falls, and the pressure required to maintain a useful filtrate flow increases until, at some point, the membrane must be replaced. The useful life of the membrane is proportional to the particle loading of the feed solution. A typical application of in-line depth microfiltration membranes is final polishing of ultrapure water just prior to use. Screen membrane filters are preferred for the cross-flow microfiltration systems because screen filters collect the retained particles on the surface of the membrane, the recirculating fluid helps to keep the filter clean.

2.4 MF Membrane Modules

There are several membrane configurations available on the market.

2.4.1 The spiral wound element

This is the workhorse in the membrane world. The spiral wound element design was originally made exclusively for water desalination, but the very compact design and the low price made it attractive to other industries. After a lot of trial and failure, redesigned elements emerged which can be used for a variety of industrial applications in the dairy industry, the pulp and paper industry, for high purity water, and at high temperature and extreme pH, but the number of membrane companies who really can and will develop and supply spiral wound elements for extreme applications is in many cases limited to one.

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2.4.5 Ceramic systems

Ceramic systems are very, very expensive. Theoretically, ceramic systems can be very effective for MF. In reality the market is diminutive.

2.4.6 Hollow Fine Fibres

It was pioneered by DuPont for sea water desalination. They demand extremely good prefiltration. DuPont has ceased production.

2.5 Factors affecting the MF system

There are several factors that can affect the performance of the system.

- Operating pressure
- Operating temperature
- Flow across the Membrane surface

2.6 Factors affecting transmission of juice in MF

Watermelon juice is separated against their size gradient, so that the bigger molecules get collected in the retentate. The following factors affect the transmission process

1. Membrane Properties

- Pore size
- Surface properties
- Mechanical strength
- Fouling
- Chemical properties

2. System Hydrodynamics

- Transmembrane pressure
- Flow rate
- Concentration polarization

3. Solution Environment

- Temperature
- pH

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2.4.2 Tubular membranes

Tubular membranes have been around for a long time. The design is simple and easy to understand. Universities love tubular membranes because it is so simple to calculate the Reynolds number and to theorize about mass transfer coefficients. Tubular membranes have one big advantage. They can tolerate suspended solids, and most notoriously fibers, to a very high extent.

All tubular membranes suffer from several disadvantages:

- They require a lot of space.
- Change of membranes may be quite difficult and time consuming.
- The tubular systems with large ID (1 inch) use a lot of energy.
- Large internal volume makes flushing costly in terms of usage of chemicals and water.
- It is costly and difficult for the manufacturer to change the tubular design.

The advantages of the tubular systems sometimes outweigh the disadvantages, and the tubular membrane design has a place in the market, although quite small.

2.4.3 Plate-and-frame (flat sheet) systems

There are several new plate-and-frame systems available in market. Flat sheet systems offer a very robust and compact design, but for a price. Modern flat sheet systems are built to tolerate very high pressure, in excess of 100 bar. There is a small market for this extreme pressure range in treatment of landfill leachate and for desalination of sea water onboard ships.

2.4.4 Fibre systems

Fibre systems are (with one exception) similar to tubular systems. Only the ID of the fiber is small, typically <2 mm. The biggest difference from large diameter tubular membranes is that fiber systems are always unsupported. They came early on the market but are quite expensive. The fiber systems are mechanically weak. They have been used to a limited extent for UF of whole milk and are now used also for oil emulsions.

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- feed concentration
- ionic strength

2.7 CLARIFICATION OF FRUIT JUICES BY USING MICROFILTRATION

2.7.1 Watermelon

Watermelon (*Citrullus lanatus*, family Cucurbitaceae) is a vine-like (scrambler and trailer) flowering plant originally from southern Africa. Its fruit, which is also called watermelon, is a special kind referred to by botanists as a pepo, a berry which has a thick rind (Exocarp) and fleshy centre (mesocarp and endocarp). Pisos are derived from an inferior ovary, and are characteristic of the Cucurbitaceae. The watermelon fruit, loosely considered a type of melon – although not in the genus *Cucumis* – has a smooth exterior rind (Green, Yellow and sometimes White) and a juicy, sweet interior flesh (usually deep red to pink, but sometimes orange, yellow and even green if not ripe). It is also commonly used to make a variety of salads, most notably fruit salad. A watermelon contains about 6% sugar and 92% water by weight. As with many other fruits, it is a source of vitamin C.

2.7.2 Nutrition content

A watermelon contains about 6% sugar and 92% water by weight. As with many other fruits, it is a source of vitamin C.

The amino-acid citrulline was first extracted from watermelon and analyzed. Watermelons contain a significant amount of citrulline and after consumption of several kg, an elevated concentration is measured in the blood plasma; this could be mistaken for citrullinaemia or other urea cycle disorders.

Watermelon rinds, usually a light green or white colour, are also edible and contain many hidden nutrients, but most people avoid eating them due to their unappealing flavour. They are sometimes used as a vegetable. Watermelon juice can be made into wine.

Watermelon is mildly diuretic and contains large amounts of beta carotene. Watermelon with red flesh is a significant source of lycopene.

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2.8 Permeate Flux Decline during microfiltration of watermelon juice

Rai *et al.*, (2010) studied about flux decline during microfiltration of watermelon juice. Identification of the flux decline mechanism was carried out by conducting experiments in an unstirred batch cell. Using the identified mechanism, flux decline was predicted during stirred microfiltration in a continuous mode. The operating pressure range was from 137 to 276 kPa and that of Reynolds number was 1.40×10^5 to 1.87×10^5 . Cake formation was identified as the main reason for flux decline. Prediction of flux decline during stirred continuous microfiltration using this mechanism was found adequate.

2.9 Fouling in microfiltration of wine

Mathias Ulbricht *et al.*, (2009) has determined fouling in microfiltration of wine, due to the influence of the membrane polymer on adsorption of polyphenols and polysaccharides. They found that, data from MF clarification of a white wine are presented which show that membranes made from polypropylene (PP) yield significantly higher fluxes and through-put than membranes made from polyarylsulfone, both having the same cut-off pore size (0.2 μm). The aim of this study was then to pursue the hypothesis that different membranes (based on PP or Polyethersulfone, (PES)) exhibit different levels of adsorption of typical foulants in wine such as polyphenols and polysaccharides, to link the level of adsorption to polymer characteristics and to correlate membrane fluxes with these findings. It was found that polyphenols and polysaccharides are only marginally adsorbed by PP but strongly adsorbed by PES membranes. In consequence, the low adsorption tendency of wine ingredients to PP membranes results in higher fluxes and longer service life of the respective filtration modules in wine clarification.

2.10 Clarification of tomato juice by cross-flow microfiltration

Behnaz Razi *et al.*, (2010) had clarified and optimized parameters for tomato juice using cross flow microfiltration. They maintained, the influence of transmembrane pressure (1 - 3 bar), cross-flow velocity which corresponds with Reynolds number (300, 1500 and 2500) and temperature (30, 40 and 50 °C) on permeate flux and properties of clarified juice such as colour, turbidity, density, viscosity, pH and total soluble solid have been studied. The results revealed that the investigated parameters had an increasing effect on the permeate flux and colour and the greatest effect on the permeate flux and colour was supplied by cross-flow velocity. The other permeate properties did not significantly change with variations of the

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2.13 Optimisation and clarification of pulpy fruit juices using crossflow microfiltration

Dornier *et al.*, (2001) has clarified six different pulpy fruit juices using cross flow microfiltration. Microfiltration, using a mineral tubular membrane with nominal pore diameter of 0.2 μm , was applied to six tropical fruit juices (mango, pineapple, naranjilla, Castillas blackberry, passion fruit, tangerine) after partial enzymatic liquefaction. For passion fruit juice, it was found that, when estimating the total costs of producing clarified juice to volumetric reduction ratio (VRR) specifications, a VRR exists at which these costs are minimal. Nevertheless, for juices with a high pulp content, these optimal economic costs are reached at relatively low VRR, inducing a low processing yield and costs that are too high for the expected selling price. For the process to be more efficient, it was found that the retentate must have a commercial value close to that of the original raw juice. The kinetics of liquefying and concentrating the suspended solid (SS) during enzymatic treatment and microfiltration were monitored for all juices tested. It was shown that, by controlling the VRR, increasing the SS content was possible until it reached the same concentration level found in the raw juice. Under these conditions, the retentate is very similar to the initial juice and can be reintroduced into the pulpy juice processing line. This strategy was carried out on the pulpy juices, following a fully continuous processing with constant feeding and removal of retentate so as to keep the SS content constant in the emerging retentate. During these trials, the permeate flux fluctuated around an average value without showing signs of decreasing. Estimated production costs were also much more competitive.

2.14 Determining optimum conditions for sugarcane juice using microfiltration

Farmani *et al.*, (2008) has optimized certain conditions for sugarcane juice. The conditions for the refinement of clarified sugarcane juice, including temperature (50, 60 and 70°C) and pressure (0, 0.5, 1 and 1.5 bar) by micro-filtration membrane technology were investigated. The raw sugarcane juice was initially pre-filtrated with lime and then the juice obtained (clarified juice) processed using a ceramic micro-filter membrane (0.2 micrometer). The characteristics investigated included brix, polarity (sucrose percent), turbidity, color and purity. The results showed that the effects of different process conditions with micro-filtration on reduction of turbidity and color were significant at probably <0.01 and probably <0.05 , respectively. For other characteristics, no significant difference was observed. Finally,

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operating parameters. Eventually, the statistical analysis indicated that the interactional effect of cross-flow velocity and TMP on the permeate flux was significant.

2.11 Physio-chemical changes during microfiltration of jackfruit Juice

Chauchan *et al.*, (2010) had studied about the physio chemical changes of jackfruit juice after microfiltration. During microfiltration, the permeate flux (Kg/h/m^2) of the Jackfruit juice was decreased gradually where as permeate collection (cumulative weight in Kg) per minute shows almost linear trend ($y=0.2435x+3364$, $R^2=0.9887$) and uniform trend for its gradual increase. The trends in slight increase of total soluble solids ($^{\circ}\text{Bx}$), pH, acidity, total sugars during enzymatic liquefaction of jackfruit pulp and corresponding decrease in color (L, a, b values), viscosity and alcohol in soluble solids (AIS) of MFP were observed as compared to FP. Aroma volatiles of FP contains 40 components of which thirty six were identified. Jackfruit juice contains only 27 components, while MFP and MFR showed the presence of 12 and 17 components respectively. The heat treatment during the processing like inactivation of enzyme indicates the loss of major components, which were present in FP. Some of significant flavour components like Ethyl, 3-methyl butanoate; Decanal; 2 phenylethyl, 3-methylbutyrate; Methyl oleate were found to be retained in MFR.

2.12 Pre-concentration of longan juice extract with microfiltration

Montatip Yunchalad *et al.*, (2007) has pre-concentrated the longan juice extract with microfiltration and reverse osmosis. It was found that yields of the pre-concentrated longan juice were $71.63 \pm 1.31\%$ and $37.69 \pm 2.72\%$ obtained from MF and RO process, respectively, under optimal operation parameters. Total yield of pre-concentrated longan juice was only $21.67 \pm 0.95\%$ of the dried longan. Following this, pre-concentrated longan juice in a hermetically sealed container (90 ml) was sterilized at 240 °F for 20 min providing 4.8 min of sterilizing value (F_0) for product safety. Chemical and microbial qualities and nutrient compositions of the product were then investigated. Results showed that the product had $25.87 \pm 1.63\%$ TSS, pH 5.16 ± 0.09 and $0.42 \pm 0.03\%$ acid as anhydrous citric acid. Furthermore, the microfiltration membrane could still retain protein, sucrose, glucose, fructose, some vitamins and minerals in longan juice pre-concentrate compared to the dried longan.

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a temperature of 70°C and transmembrane pressure of 1.5 bar were determined as the optimum conditions for ceramic micro-filtration. Membrane processing at 70°C and 1.5 bars reduced the turbidity, viscosity and colour of clarified juice 56.25%, 16.67% and 6.49%, respectively, and increased 0.87 units of purity.

2.15 Evaluation of permeate flux in microfiltration of Tamarind juice

Luiz Antonio viotto *et al.*, (2006) has studied the effects of transmembrane pressure and crossflow velocity in permeates fluxes during the tamarind juice clarification, using or not using enzymatic treatment. It is microfiltrated by a membrane unit containing three polypropylene tubes of 750 mm long, pore size 0.2 mm and 0.038 m^2 of permeation area. The experiments were conducted by varying the transmembrane pressure (0.5–1.1 bar), crossflow velocity (4 – 6 m/s) and enzyme content (0 – 100 ppm). The temperature of the product was maintained at 35° C. It is observed that the better final flux results (60% higher than the lowest flux) occurred in the experiments with high pressures, in spite the flux curve had more accentuated decline. When high velocity and high pressure are used, the enzyme broke the pectin particles, increasing the pore obstruction and decreasing the flux.

2.16 Clarification of lemon juice

Cecilia Pagliero *et al.*, (2006) has clarified the lemon juice using microfiltration. All the experiments were carried out in a crossflow test cell with an effective membrane area of $6.9 \times 10^3 \text{ m}^2$. The mean pore radius size obtained was 0.2 microns. The experimental conditions were as follows: feed temperature of 20 °C, feed flow rate between 0.2 to 1 m/s, transmembrane pressure 0.2 and 1 bar. The results shows that an increase in pressure does not alter the permeate characteristics. Permeate flux increase with the increased of both, pressure and feed flow rate. The optimal performance was achieved with 0.6 bar transmembrane pressure and 1 m/s feed flow rate.

2.17 Clarification of pineapple juice using tangential microfiltration

Lucia Carneiro *et al.*, (2002) has cold sterilized and clarified the pineapple juice by using microfiltration associated with enzymatic treatment. A tubular polyethersulfone 0.3 μm pore size membrane with effective filtration area of 0.05 m^2 was used in the pilot system. Ten experiments were carried out under the same operational conditions, 25°C and 100 kPa, in order to evaluate the cold sterilisation and clarification of pineapple juice by microfiltration.

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The permeate of the process was collected in sterile bottles inside a laminar flow station and kept under refrigeration (8°C) for a period of 28 days. The samples were submitted to microbiological evaluations in intervals of seven days. The microbiological analysis of the microfiltered pineapple juice showed that it was in agreement with the requirements by the Brazilian Legislation for juices and drinks.

In the present work, Microfiltration was applied for the clarification of watermelon juice using hydrophilic polyethersulfone membrane and the effect of transmembrane pressure (TMP) on the permeate flux was investigated to ensure acceptable flux with adequate juice quality.

The clarified juice was also analysed for total suspended solid, total soluble sugars, pH, colour, density, ascorbic acid, clarity and turbidity. And also it is studied in detail about the different models for identification of the permeate flux decline mechanism during microfiltration of watermelon juice.

CHAPTER 3 MATERIALS AND METHODS

3.1 BATCH CELL MODULE

This module was used during the course of experiments conducted to characterize the given membrane and also to check the transmission of insoluble materials through the membrane. It requires minimum of 500 ml feed and is useful only at the laboratory level.

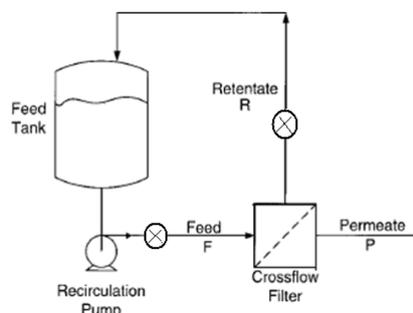


Figure 3.1 Schematic diagram of the Batch Cell Apparatus

3.2 Apparatus and Materials

- Microfiltration Tangential Flow filtration, Batch cell Module (Pall Life Science, USA).
- Effective membrane area: 0.098 m².
- Maximum surface temperature 35 ± 2°C

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3.2.1 Peristaltic pump

- Materflux 7250 (USA)
- 6-600 RPM
- 0.1 Horse Power

3.2.2 pH meter

1. Ecotestr pH 1 (Oakton, USA)

- Resolution: 0.01 pH
- Accuracy: ±0.01 pH
- Automatic temperature compensation

2. Elico LI120 (Elico, India)

- Resolution: 0.01 pH
- Accuracy: ±0.01 pH
- Automatic temperature compensation

3.2.3 Weighing balance

- Shimadzu EL300 (Japan)
- Accuracy: ±0.01 g

3.2.4 Refractometer

- Vaiseshika Electron Devices (India)
- Accuracy: ± 0.01 °Bx

3.2.5 UV-Vis Spectrophotometer

Elico SL159 (Elico, India)

- Range 190 to 1100 nm
- Range ±2.5 Abs
- Repeatability ± 0.003 Abs. at 1.0 Abs

3.2.6 Membrane

- Centramate cassette – hydrophilic polyethersulfone (Pall Life Science, USA)
- Pore size : 0.2 µm

3.3 Juice preparation

Fully matured and ripe watermelon, procured from the local market, was used as raw material. Watermelon was washed properly with water, cut, and deseeded manually. The fruit pulp was cut into cubes of 1 inch size and juice was extracted by means of hand-operated juice extractor. After extraction, the juice was filtered by a fine muslin cloth (size of pore-150 µm).

3.4 Reagents Required

Table 3.1 Chemicals used

Chemicals	Distributors
Potassium di hydrogen phosphate (extra pure)	Himedia, Mumbai
Di potassium hydrogen phosphate	Himedia, Mumbai
Sodium Dodecyl Sulphate	Himedia, Mumbai
Sodium Hydroxide	Himedia, Mumbai
Oxalic acid	Himedia, Mumbai
Ascorbic acid	Himedia, Mumbai
Sulphuric acid	Himedia, Mumbai
2,4-Dinitrophenyl Hydrazine	Himedia, Mumbai
Bromine water	Himedia, Mumbai

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3.5 PROTOCOL

3.5.1 Phosphate Buffer

Phosphate buffer of 7.2 pH is prepared by using monobasic potassium phosphate and dibasic potassium phosphate.

- 27.2 g of 0.2 M Monobasic Potassium Phosphate(A) was made up to 1000 ml with distilled water
- 34.84 g of 0.2 M Dibasic Potassium Phosphate(B) was made up to 1000 ml with distilled water
- 28 ml from A and 72 ml from B is added and then made up to 200 ml with distilled water to get pH of 7.2.

3.5.2 Microfiltration

To predict the flux data and obtain values for permeability, the following steps were followed (Narsaiah and Agarwal, 2007)

- The feed tank was filled to its capacity with RO water.
- The transmembrane pressure was set by peristaltic pump and monitored using pressure gauge (kg/cm²).
- The flow rate of permeate was measured by timing the collection of X ml of permeate at X pressure, using stop watch.
- After one set of data the pressure/ flow rate is changed and the similar procedure is followed.
- Similarly for buffer (phosphate buffer of 7.2 pH) and juice, the above procedure was followed.
- Permeate and Retentate samples were collected after microfiltration at each pressure flow rate.
- Permeability was measured before and after microfiltration using the buffer to know the extent of fouling.
- A curve was plotted with transmembrane pressure (kg/cm²) on X axis and Flux (m/s) on Y axis.
- The slope obtained gave permeability of the membrane for the juice.

- The permeate and retentate of water juice were analyzed in the UV-Vis spectrophotometer to find the colour intensity.
- Rejection data was then calculated from the concentrations of permeate and retentate streams.

3.5.3 Membrane Washing

To use the membrane for subsequent runs, the membrane was cleaned with SDS (Sodium Dodecyl Sulphate) and 0.5 N sodium hydroxide solution. To free the membrane from SDS and sodium hydroxide, it was flushed with water at gradually increasing pressures.

After washing the membrane was stored into 0.1 N sodium hydroxide solution to prevent any microbial growth on the membrane surface and for the reuse of the membrane.

- Fouling(%) = 100* [(Initial buffer permeability – Final buffer permeability)/ Initial Buffer permeability]

3.5.4 Estimation of Ascorbic acid by 2,4-DNPH method

To predict the presence of Ascorbic acid in Feed, Permeate and Retentate (Joseph H. Roe,1961)

- Pipette out 0.2, 0.4, 0.6, 0.8 and 1 ml (concentration varying from 20 to 100 µg) of the working standard solution into a series of test tubes.
- Make up the given unknown sample to 100 ml and from that pipette out 0.6 ml of the sample into a test tube
- To all the test tubes, add 1 ml of 2, 4-DNPH, mix the contents and incubate at 37°C for 3 hours.
- Add 7 ml 80% H₂SO₄ to all the test tubes to dissolve the orange red osazone crystals formed.
- Note the absorbance spectrophotometrically at 540 nm.
- Draw the graph by plotting the concentration of vitamin C along X axis and the optical density reading at Y axis.
- Determine the concentration of unknown sample from the standard curve on the graph and calculate the vitamin C content in the given sample

CHAPTER 4 RESULTS AND DISCUSSION

4.1 ANALYSIS OF COMPONENTS IN JUICE

Before determining whether some relation existed between watermelon juice composition and flux resistance, analytical techniques for the key fouling compounds had to be chosen and optimized. A large number of compounds make up watermelon juice. Those compounds exist in soluble and suspended forms. Also of importance is suspended cell wall debris which will be present in various amounts, but due to its multi-component nature, is difficult to isolate and characterise.

Compositional analysis of commercial watermelon juice was chosen as a starting point for this investigation. Values obtained for pH, density, absorbance, turbidity etc., and compared to literature values for Rai *et al.*, (2010). Watermelon juice assay values will depend on many variables including watermelon growing location, storage conditions, time of storage and extraction technique as well as assay method; these values must therefore be scrutinized with these limitations in mind. Nevertheless, the results obtained were within those previously observed in the literature.

Soluble solids, accounting for 9.8% of the juice, includes sugars and the major non-sugar soluble solids although sugars typically account for the majority of the Abbe refractometer reading. Once again, this value was of little use because it contained both fouling and non-fouling components. By difference, the suspended solids amounted to roughly 0.5% of the total juice. Since centrifugation removes suspended materials and can clarify watermelon juice, membrane filtration must also be removing these compounds. Therefore, suspended solids gives a better indication of what is accumulating on the membrane surface even though soluble compounds are also known to play a role in juice fouling behaviour (Wucherpfennig *et al.*,1987).

Table 4.1 Comparison of watermelon juice properties and literature values

Properties	Results		Rai <i>et al.</i> , (2010)	
	Feed	Permeate	Feed	Retentate
pH	5.8	5.7	5.10	5.03
Density (g/ml)	1.023	0.996	1.03	1.02
Colour A _{420nm}	2.542	0.18	3.27	0.102
Clarity %T _{660nm}	3.2	100	1.6	98.6
Turbidity (NTU)	67	55	-	-
Total suspended solids (g/ml)	0.2	1.1	-	-
Total soluble solids(°Bx)	9.2	8.3	7.4	6.8
Ascorbic acid (mg/ml)	16	-	62.5	61.2

4.2 FLUX ANALYSIS

There are different type of mathematical models are available which relates the flux to the time and/or volume permeated. Most of them are based on the assumption that the build up of the fouling layer is a first order reaction. Some of the models are shown in table 4.2 and discussed in detail. In general, almost any fouling data (flux vs. time) will adequately fit almost any of these models reasonably well. Also many models predict the flux will be zero at infinite time, which may not actually occur in practice. Most of the exponential models are useful in that the parameters like fouling index, initial flux or zero time flux etc., can be correlated with operating parameters.

Table 4.2 Mathematical models of the fouling process

S.No	Model	Reference
1.	$J_t = J_1 t^{-b}$	Sheppard and Thomas (1970) Kuo and Cheryan (1983)
2.	$J_t = J_0 e^{-bt}$	Sheppard and Thomas (1970)
3.	$J = J_0 V^{-b}$	Merrin and Cheryan (1980)
4.	$J = e^{\alpha V^{-b}}$	Matthews <i>et al.</i> , (1978)
5.	$J_t = A + B e^{-bt}$	Mehta (1971)
6.	$J_0 - J_f = (J_0 - J_f)(1 - e^{-t/\tau})$	Probstein <i>et al.</i> , (1981)
7.	$\frac{J_0}{J_e} = 1 + \frac{\alpha a}{AU} 1 - \exp \left[\frac{J_0/J_e - 1 - J_0 AU t}{(1 + \frac{\alpha a}{AU})} \right]$	Gutman (1977)
8.	$\frac{d^2 t}{dV^2} = -\alpha J^{3-n}$	Hermia (1982)

From above these models H ermia (1982) model is taken for further studies, which lead to study in detail about Standard Pore Blocking model, Complete Pore Blocking model, Intermediate Pore Blocking model and Cake filtration model which is used to identify how the flux is declined for watermelon juice.

The mode of flux decline during filtration can be identified by an analysis of the characteristic curve (H ermia 1982)

$$\frac{d^2 t}{dV^2} = \beta \left(\frac{dt}{dV} \right)^n \quad (1)$$

where V is the cumulative volume of filtrate, t the time of operation, and β is a constant.

The permeate flux is presented as,

$$J = \frac{1}{A} \frac{dV}{dt} \quad (2)$$

From Eq. (2), the expression of dt/dV is given as,

$$\frac{dt}{dV} = \frac{1}{AJ} \quad (3)$$

Taking derivative of Eq. (3) with respect to t leads to the expression of $d^2 t/dV^2$

$$\frac{d^2 t}{dV^2} = -\frac{1}{AJ^3} \frac{dJ}{dt} \quad (4)$$

Substituting the derivatives from Eqs. (3) and (4) in Eq. (1) leads to the governing equation of flux decline with time,

$$\frac{dJ}{dt} = -\alpha J^{3-n} \quad (5)$$

where α is a constant.

For different modes of flux decline, the exponent n assumes different values (Bowen *et al.*, 1995). The value of n is 2 for complete pore blocking; it is 1.5, 1.0, and 0.0 for standard pore blocking, intermediate pore blocking, and cake filtration controlling, respectively. (Bowen *et al.*, 1995).

Table 4.3 Initial Flux values using phosphate buffer of 7.2 pH, pressure at 0.2 kg/cm²

TMP (kg/cm ²)	Time (s)	Permeate (ml)	Flux (ml/m ² s)	Average Flux (ml/m ² s)
0.2	30	90	32.25	30.33
	60	90	32.25	
	90	90	32.25	
	120	85	30.46	
	150	85	30.46	
	180	85	30.46	
	210	85	30.46	
	240	85	30.46	
	270	85	30.46	
	300	85	30.46	
	330	80	28.67	
	360	80	28.67	
	390	80	28.67	
	420	80	28.67	

Table 4.4 Initial Flux values using phosphate buffer of 7.2 pH, pressure at 0.4 kg/cm²

TMP (kg/cm ²)	Time (s)	Permeate (ml)	Flux (ml/m ² s)	Average Flux (ml/m ² s)
0.4	30	150	53.76	52.22
	60	150	53.76	
	90	145	51.97	
	120	145	51.97	
	150	145	51.97	
	180	145	51.97	
	210	145	51.97	
	240	145	51.97	
	270	145	51.97	
	300	145	51.97	
	330	145	51.97	
	360	145	51.97	
	390	145	51.97	
	420	145	51.97	

Table 4.5 Flux data for Watermelon juice

TMP (kg/cm ²)	Time (s)	Permeate (ml)	Retentate (ml)	Flux (ml/m ² s)	Pressure (kg/cm ²)	Average Flux (ml/m ² s)
0.2	30	23	135	8.24	0.3	6.477
	60	23	156	8.24	0.35	
	90	21	166	7.52	0.5	
	120	19	150	6.81	0.6	
	150	18	150	6.45	0.75	
	180	18	144	6.45	0.9	
	210	17	134	6.09	1.0	
	240	17	130	6.09	1.15	
	270	19	125	6.81	1.2	
	300	16	125	5.73	1.35	
	330	16	125	5.73	1.35	
	360	14	125	5.01	1.35	
	390	14	120	5.01	1.35	
	420	12	125	4.30	1.35	
	450	12	125	4.30	1.35	
	480	11	128	3.94	1.35	
	510	11	130	3.94	1.35	
	540	11	128	3.94	1.35	
	570	12	125	4.30	1.35	
	600	11	127	3.94	1.35	

4.2.1 STANDARD PORE BLOCKING MODEL (SPB)

In case of standard pore blocking, the pore volume decreases proportionally to filtrate volume and the decrease is due to particle deposition inside the pore walls, which may lead to a continuous blocking of pores. Putting the value of n as 1.5 and integrating Eq. (5), the time variation of the permeate flux is expressed as (Bowen *et al.* 1995),

$$\frac{1}{\sqrt{J}} = \frac{1}{\sqrt{J_0}} + k_1 t \tag{6}$$

Where J₀ is the initial flux, t is the operating time, and k₁ is rate of decrease in cross section area of the pore due to adsorption on the pore wall.

Thus, a linear variation of 1/J^{0.5} versus time indicates standard pore blocking is the governing mechanism. This is plotted in Fig. 4.2. It is observed from this figure that the plot is not linear at all and the linear fittings (as shown by straight line) yield a correlation coefficient, r², in the range of 0.881 for the pressure. Therefore, the flux decline is not caused by standard pore blocking.

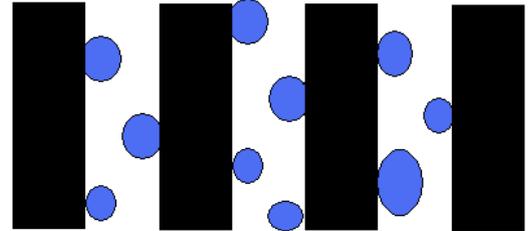


Figure 4.1 Standard Pore Blocking Model

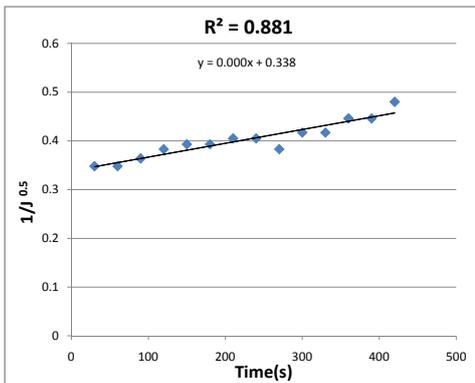


Figure 4.2 Linear variation of 1/J^{0.5} on time for SPB model

4.2.2 COMPLETE PORE BLOCKING MODEL (CPB)

In complete pore blocking, each particle arriving to the surface of the membrane blocks some pores without any superposition. Substituting the value of n as 2.0 and integrating Eq. (5), the time variation of the permeate flux is then given as (Bowen *et al.* 1995),

$$\ln\left(\frac{1}{J}\right) = \ln\left(\frac{1}{J_0}\right) + k_3 t \tag{7}$$

Where J₀ is the initial flux, t is the operating time, and k₃ is the rate of blocking of the pore by this mechanism.

Therefore, a linear plot of ln(1/J) versus t indicates that intermediate pore blocking is the cause of flux decline. This is shown in Fig.4.4. It is observed from this figure that the linear fittings lead to a good correlation coefficient, r², in the range of 0.9012 for the pressure. Therefore, the flux decline caused by complete pore blocking.

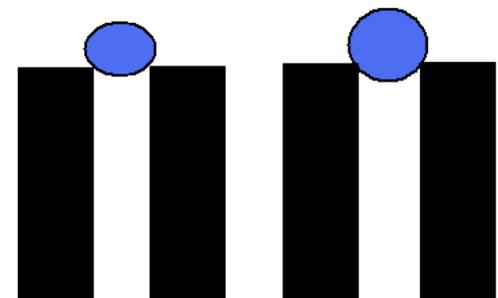


Figure 4.3 Complete Pore Blocking Model

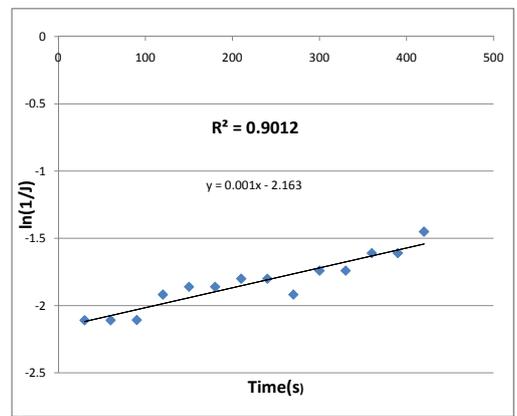


Figure 4.4 Linear plot of ln(1/J) versus time for CPB model

4.2.3 INTERMEDIATE PORE BLOCKING MODEL (IPB)

In this case, each particle arriving at the membrane surface sits on another particle (previously arrived), which is already blocking the pore, or it may directly block some other portion of the membrane area. Putting the value of n as 1.0 and integrating Eq. (5), the time variation of the permeate flux is then given as (Bowen *et al.* 1995),

$$\frac{1}{J} = \frac{1}{J_0} + k_2 t \quad (8)$$

Where J_0 is the initial flux, t is the operating time, and k_2 is the rate of blocking of the pore by this mechanism.

Therefore, a linear plot of $1/J$ versus t indicates prevalence of intermediate pore blocking. This is shown in Fig. 4.6. It is observed from this figure that the plot is not linear and the linear fittings (as shown by straight lines) result in a correlation coefficient, r^2 , in the range of 0.8373 for the pressure. Therefore, the flux decline is not due to intermediate pore blocking.

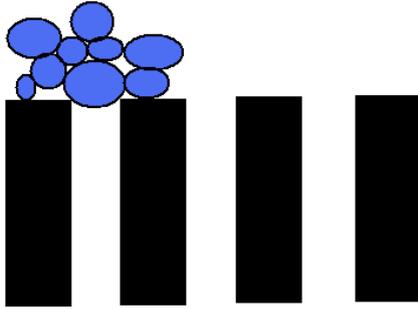


Figure 4.5 Intermediate Pore Blocking Model

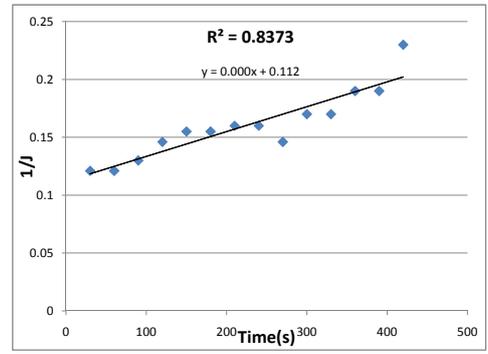


Figure 4.6 Linear plot of $1/J$ on time for IPB model

4.2.4 CAKE FILTRATION

In cake filtration, it is assumed that all the membrane pores are already blocked and the particles arriving deposit on the other particle and a cake layer is being built over the membrane surface, which grows in time and therefore causes further flux decline (Bowen *et al.* 1995). Substituting the value of n as 0.0 and integrating Eq. (5), the time variation of the permeate flux is then given as (Bowen *et al.* 1995),

$$\frac{1}{J^2} = \frac{1}{J_0^2} + k_4 t \quad (9)$$

Where J_0 is the initial flux, t is the operating time, and k_4 is the rate of build up of cake resistance.

Therefore, a linear plot of $1/J^2$ versus t confirms that the growth of the cake layer is the cause of flux decline. This is shown in Fig.4.8. It is observed from this figure that the linear fittings (as shown by straight lines) yield a correlation coefficient, r^2 , in the range 0.8414 for the pressure. Therefore, the permeate flux for watermelon juice declines due to

build up of cake type of layer, constituted by suspended materials, tissues, and cell debris over the membrane surface (Omoni and Aluko 2005).

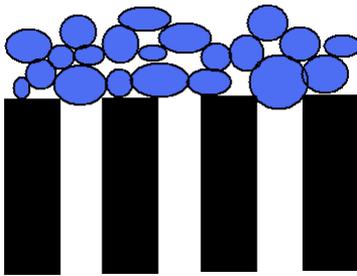


Figure 4.7 Cake filtration model

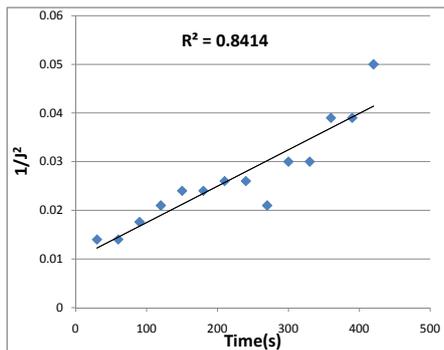


Figure 4.8 Linear plot of $1/J^2$ on time for cake filtration model

Table 4.6 Final Flux values using phosphate buffer of 7.2 pH, pressure at 0.2 kg/cm²

TMP (kg/cm ²)	Time (s)	Permeate (ml)	Flux (ml/m ² s)	Average Flux (ml/m ² s)
0.2	30	27	9.67	11.21
	60	27	9.67	
	90	35	12.54	
	120	33	11.82	
	150	33	11.82	
	180	34	12.18	
	210	34	12.18	
	240	32	11.76	
	270	31	11.11	
	300	30	10.75	
	330	30	10.75	
	360	30	10.75	
	390	30	10.75	
420	30	10.75		

Table 4.7 Final Flux values using phosphate buffer of 7.2 pH, pressure at 0.4 kg/cm²

TMP (kg/cm ²)	Time (s)	Permeate (ml)	Flux (ml/m ² s)	Average Flux (ml/m ² s)
0.4	30	54	19.35	52.22
	60	54	19.35	
	90	66	23.65	
	120	68	24.37	
	150	75	26.88	
	180	75	26.88	
	210	73	26.16	
	240	73	26.16	
	270	72	25.80	
	300	72	25.80	
	330	72	25.80	
	360	72	25.80	
	390	71	25.44	
	420	71	25.44	

CHAPTER 5 CONCLUSION

Flux decline mechanism during microfiltration of watermelon juice was conducted using unstirred membrane cells in continuous mode. Flux decline suits into four models namely Standard Pore Blocking (SPB), Complete Pore Blocking (CPB), Intermediate Pore Blocking (IPB) and Cake filtration. Among these four models, experiment results were substituted and found to be Complete Pore Blocking was the main reason for flux decline. Before that, this experiment was conducted using Pall life science's Centramate™ tangential flow filtration cassette.

Microfiltration results in clear permeate juice retaining almost the total amount of soluble solids, Ascorbic acid in feed, permeate and retentate. It has been found that, the physio-chemical properties of the juice has changed in permeate after microfiltration. The clarity of the juice increased to 96.8% and the colour has decreased to 99.93%. the other characteristics of juice has also decreased in the range of 5-15%.

- The clarified permeate juice presents pH, density and TSS values comparable with those of untreated fresh lemon juice.
- The results shows that an increase in pressure does not alter the permeate characteristics.
- Permeate flux increase with the increased of both, pressure and feed flow rate.

4.3 THE PHYSICO-CHEMICAL PROPERTIES OF PERMEATE

The feed property and permeate quality are shown in Table 4.7. It is evident from the table that almost all the sugar (as Total Soluble Sugars, TSS) present in the feed can be recovered in the permeate after filtration. This indicates that sugar and acid permeate through the pores of microfiltration membrane freely. The slight decrease in TSS compared to feed is observed. This is due to retention of some high molecular weight soluble solids by the membrane (Scott *et al.* 1960). There is a remarkable improvement in clarity of watermelon juice after filtration due to removal of suspended colloidal particles present in the juice during microfiltration. Removing all the suspended solids and high molecular weight soluble solids during microfiltration, the viscosity of filtered juice has been reduced and they are close to water viscosity. Hence, during microfiltration, all the nutritional quality (except lycopene) of the watermelon juice is recovered in the permeate and a much clearer (clarity 98%) juice is obtained. Thus, lycopene, a valuable anti-oxidant, can be a byproduct of this process and can be used in the pharmaceutical industry. Some part of it can be mixed with clarified juice after sterilization.

Table 4.8 Comparison of feed values and permeate values

Properties	Results	
	Feed	Permeate
pH	5.8	5.7
Density (g/ml)	1.023	0.996
Colour A _{420nm}	2.542	0.18
Clarity %T _{660nm}	3.2	100
Turbidity (NTU)	67	55
Total suspended solids (g/ml)	0.2	1.1
Total soluble sugars (°Bx)	9.2	8.3
Ascorbic acid (mg/ml)	16	-

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