Detailed Study of Mosambi Juice Clarification by Hybrid (Packed Column and Membrane) Process

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ABSTRACT: *Citrus fruit juice especially mosambi demands were raised during non-seasoning time owing to a rich source of vitamin C. Membrane separation was the unique method to store the clarified juice at different operation conditions. Membrane performance such as, flux declined and cake layer formation was enhanced with continuous operation. Such demerit was improved by pretreatment method before clarification of juice. Several pretreatment such as, centrifugation, fining agent (gelatin and bentonite), and centrifugation followed with the fining agent were commonly employed. Individually packed columns supported with glass beads and molecular sieves were used for the pretreatment of mosambi juice. During packed column study pretreated juice physicochemical properties depended on the packing support, feed flow rate, packing factor and operating time. The packing factor value was enhanced from 446 to7625 by replacing the support material glass beads support from molecular sieves. Series column operation had a better ability to maximize removal of the high molecular weight compounds (pectin, cellulose and hemicellulose) from raw juice compared to single column treatment. After series column pretreatment, average particle size was reduced from 40 to 1 µm. Column pretreated juice was clarified from dead end membrane filtration unit. Polyamide membrane had average pore size 2.5 µm was used for clarification of juice at 69 kPa transmembrane pressure drops. 95% clarity enhanced and 97% alcohol insoluble solids were removed for pretreated juice after membrane process.*

KEYWORDS*: Pretreatment; Packed column; Packing factor; Membrane; Alcohol insoluble solids*.

INTRODUCTION

Citrus fruit especially, mosambi was seasonally available around each part of the country in India. Mosambi fruit juice flavor was also good and had a several health benefits [1]. During the pandemic phase, its demand rise rapidly due to natural contents. It was a good source of natural elements to enhance the immune system of human beings. The main natural antioxidant element in mosambi juice ascorbic acid (Vitamin C) helps to neutralize the harmful free radicals [2]. Ascorbic acid is supportive of repairing the body tissues and also protects from several diseases such as cancer, stroke, and eye. Mosambi juice was a rich source of pectin and

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carbohydrates (cellulose and hemicellulose). During seasonal time fruit juice is consumed directly and during the non-seasoning period clarified juice could be taken directly as an immunity booster. It was also the main ingredient of the food industry for making several products such as jam, marmalade, and sweets. Other uses were in the beverages industry for making soft drinks [5].

Clarification was an important step for mosambi juice processing. Several methods, such as screening, decantation, centrifugation, heating, chemical fining, enzymes, evaporation, and membrane separation were applied in industries for fruit juice processing [6-8]. Membrane operation was mostly employed for clarification of juice and clarified juice was concentrated by evaporation process. The evaporation process had several disadvantages such as; high capital investment, energy requirement, and huge size of the instrument [9]. The main disadvantages were the degradation of aroma contents and burn of vitamin C. Membrane separation was the unique process for clarification of fruit juice with surplus advantages such as no chemical addition, less energy requirement, less space occupied, and no degradation of natural contents. Polymer membrane was commonly employed for fruit juice clarification. During clarification, suspended materials retentate on the membrane surface, and clarified juice with a natural fresh taste was collected on the permeate stream [2]. Permeate flux decline and permeability factor change with operating time were the main drawbacks of the membrane separation process.

Flux decline was due to the pectin molecule of juice starting to accumulate on the membrane surface. Pectin had a long chain of polysaccharide compounds and its presence extracted juice became coagulate and turned into cloudiness [10,11]. Extracted mosambi juice viscosity raised with storage time due to the presence of polyphenol and protein compounds [12]. Separation of polyphenol and pectin compounds from raw mosambi juice was upgrading of physicochemical properties such as reduction of viscosity and alcohol insoluble content resulting in enhancement of the browning index and clarity value of clarify juice [13]. This juice could be stored at different operating conditions for extended duration.

Pretreatment is essential ladders before the clarification of mosambi juice by a membrane separation process. Several pretreatments such as centrifugation, fining agents, a combination of finning agent-centrifugation, and enzymetic treatment were commonly employed [14-15]. Under these pretreatment methods, pretreated juice qualities were enhanced with the change of operating parameters such as variation of rpm in centrifugation and concentration in a fining agent. Depectinized of mosambi juice with centrifugation improved the color, clarity, and alcohol-insoluble solids of extracted juice but it takes too much time and is not cost-effective. With a fining agent, the single agent was not enough to improve the qualities of pretreated juice. Common fining agents were gelatin, bentonite, and a combination of gelatin with bentonite [16]. The physicochemical properties of pretreated juice were not improved too greatly with a fining agent and the waiting period was also long for settling down the suspended solids. Enzymatic pretreatment had the maximum ability to hydration and subsequent degradation of pectin and starch molecules from extracted mosambi juice [17]. Pectin substance derived from polysaccharides present in plant walls had a molecular weight of 30-300 kDa. Pectin lyase enzyme was derived from plant and micro-organisms that could break down the structure of polysaccharides in fruit pulp resulting in reducing the viscosity and enhancing the yield of fruit juice. Pectin lyase was produced from bacteria, fungi, and yeast. Industrial use of pectin lyase was a clarification of juice and paper making. Immobilized enzyme was commonly used as compared to free enzyme with extra advantages such as, protecting the activity, preserve extend the time, and reuse [18-22]. Degradation of the pectin molecule reduced the viscosity of pretreated juice with the resultant enhancement of membrane performance.

Preparation of suitable enzyme characterization, activity, and appropriate dose was also an enormous task for the use of enzymes. Selective enzyme preserving and preparation cost was also another parameter to limited use of enzyme. Different pretreatment methods such as fining agent, centrifugation, and fining agent-centrifugation combination were not continuous mode operation. Another pretreatment method, such as, a packed column with certain advantages such as continuous mode operation, less waiting period, and extreme ability to remove impurities from raw juice [17]. Industrial waste such as Pb (II) and Cr (VI) impurities was removed by a packed column supported with granular activated carbon and neem (azadirachta Indica) sawdust. Packed column pretreatment supported with glass beads was used for clarification of juice [23-24].

The current investigation was employed to examine the detailed study for pretreatment of mosambi juice by packed column. Pretreated juice was further clarified by dead-end membrane filtration cells. During column pretreatment, three studies were done such as column support with glass beads, column support with molecular sieves, and other combinations of two columns arranged in series. In series column operation one column support with glass beads and the other column support with molecular sieves were arranged in sequence. Pretreatment of juice was done at different flow rates with variations in operating time. Detailed physicochemical properties of pretreated mosambi juice were studied for individual column juice samples. Under column operation, series column operation had the highest capability to remove maximum suspended materials from extracted juice. Individual column pretreated juice was clarified by dead-end membrane filtration unit support with polyamide membrane under microfiltration range. Comparative studies were done of the physicochemical properties of raw, pretreated, concentrated, and clarified mosambi juice.

EXPERIMENTAL SECTION

Materials

Seasonal mosambi (citrus limetta) fruits and screw-type extractor were purchased from the local market of Guwahati, India. The physicochemical properties of raw juice are shown in Table 1.

The packed column (height 0.32 m) was assembled under the supervision of departmental technicians at IIT Guwahati, India. Supported materials, namely glass beads (diameter 0.0035 m) and molecular sieves (length-width 0.013×0.0015 m) were procured from Loba Chemie Ltd., Mumbai, India. Physicochemical properties such as alcohol insoluble solids analysis purposes, chemical mainly methanol (purity>99%, lab reagent grade) was purchased from Merck Ltd., Mumbai, India.

An organic thin sheet polyamide membrane with an average pore size 2.5 µm was procured from Permionics Membrane Pvt. Ltd., Gujarat, India. The stainless steel membrane filtration batch unit (diameter 0.062 m, volume 1 m^3) was made up under the supervision of the workshop supervisor at IIT Guwahati, India.

Systematic scheme of pretreatment of mosambi juice

Good quality fresh mosambi fruits (quantity 4 kg) were washed with deionized water and scrubbed with dry cotton cloth. After that, it was cut in two halves and peeled (manually) properly. The halves were passed to screw-type extractor, extracted juice was collected in a beaker (capacity 0.0025 m^3) and the waste solids were discarded. Extracted raw juice was passed through low-density polyethylene mesh (1×10^{-4} m). Heavy pulp parts of juice were retained on surface of the mesh and rejected; fine juice was collected separately in another beaker (capacity 0.002 m^3). Raw juice was pretreated with the individual support of a packed column unit. After pretreatment, the juice was clarified with the help of a membrane filtration unit. A detailed of systematic scheme for the pretreatment and clarification of mosambi juice is shown in Fig. 1.

A systematic scheme for pretreatment of mosambi juice by packed columns supported with individual packing support such as glass beads and molecular sieves at different operating conditions is shown in Table 2. Under the packed column pretreatment method, two packing materials such as glass beads (mode I) and molecular sieves (mode II) were used separately and the pretreated juice was clarified by membrane operation. In packed bed column pretreatment, a new scheme (mode III) was proposed such as packed column series operation. During this operation two packed columns of the same dimensions were taken, the first column was supported with glass beads, and the other column was packed by molecular sieves respectively. The operating time for the altered process in packed bed treatment was 60 min and a room temperature 28±2ºC was maintained with the help of a water bath. Extracted juice was passed through a peristaltic pump in packed columns at different volumetric flow rates.

Experimental setup of packed bed column and membrane filtration cell

Pretreatment of raw mosambi juice through a packed column was performed by a laboratory scale pilot plant fabricated at IIT Guwahati (India). The packed column fabricated from perspex, consisted of the specifications as internal diameter (*d*) 0.03 m, length (*L*) 0.32 m, and volume 227×10^{-6} m^3. Two tapered neoprene rubber corks with the same dimensions (0.0002 m length, upper surface diameter 0.031 m, and lower surface diameter 0.029 m) were placed at the top and bottom of the column. Two different packing support materials such as, glass beads (diameter 0.0035 m, void fraction 0.26) and molecular sieves (length and width 0.013×0.0015 m,

Table 1: Physiochemical properties of raw mosambi juice

Browning index (A_{420})	Clarity ($\%T_{660}$)	Total soluble solids (ºBrix)	pH	Density (g/cm^3)	Viscosity (m.Pas)	Alcohol insoluble solids (wt %)
2.251	0.6	9.3	4.5	1.10	3.30	0.30

Table 2: Operating conditions for pretreatment of mosambi juice by packed column

S. No.	Pretreatment operation	Feed flow rate×10^7 (m^3/s)
1	Packed column supported with glass beads	0.139, 0.278, 0.556, 0.833, 1.111 & 1.389
2	Packed column supported with molecular sieves	0.139, 0.278, 0.556, 0.833, 1.111 & 1.389
3	One glass bead and other molecular sieve supported column, attached in series in packed operation	0.139

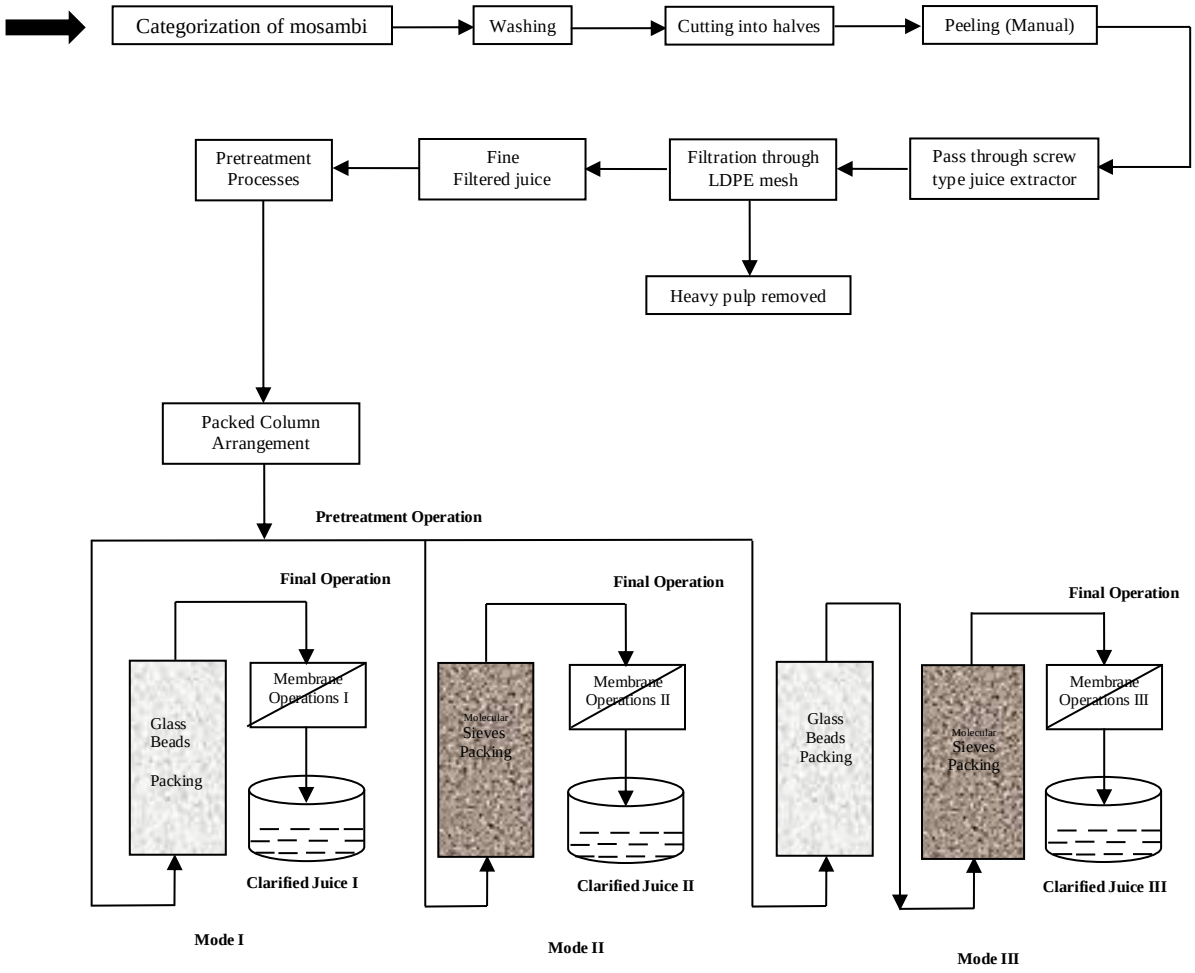

Fig. 1: Flowchart for extraction, pretreatment, and clarification of mosambi juice

void fraction 0.57, BET surface area 574 m^2/g, and total pore volume 0.374 mL/g) were used for the pretreatment of raw mosambi juice. 0.0063 m diameter of two rubber corks was fitted at both (top and bottom) ends of the column. The upper end tube was used for pretreated juice collection and the lower end tube was attached with a peristaltic pump to raw juice circulation in the packed column as shown in Fig. 2. Empty space of the column was filled with packing supports material. The packed column was tightened at clamp support and fixed with a biuret support stand. Raw juice (feed) beaker was kept in the water bath at a temperature of 28±2ºC

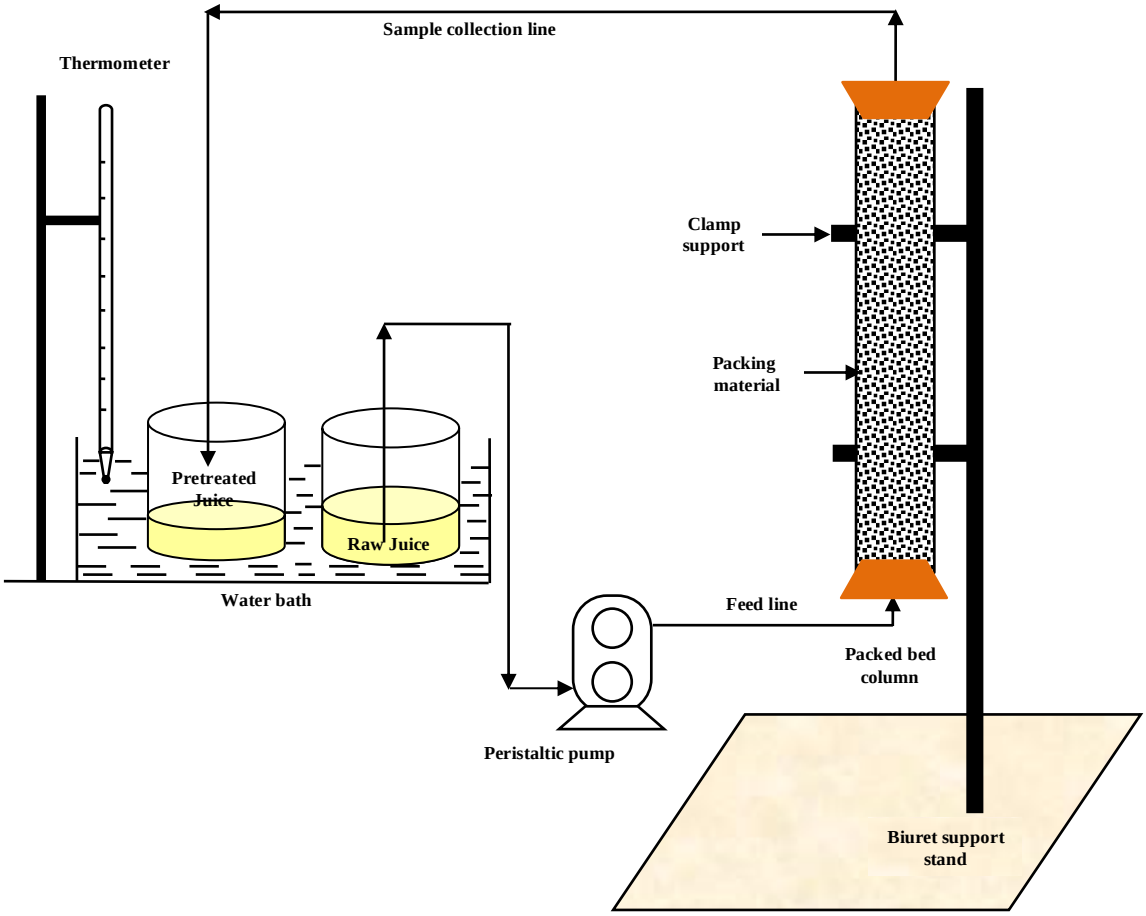

Fig. 2: Schematic flow diagram of pretreatment of mosambi juice by packed column

to prevent the degradation of raw mosambi juice quality. Peristaltic pump was started in the forward direction and the flow rate was adjusted by controllable variable parameters. Pretreated juice samples were collected at different time intervals at particular volumetric flow rates. Glass bead packing support had been limited to pretreatment due to low packing factor value and charge independence. Molecular sieves strongly adsorbed the suspended material on its surface due to the high packing factor value compared with glass beads. For the removal of maximum suspended materials in raw juice, a series column operation was applied during pretreatment.

After pretreatment, pretreated juice was clarified by membrane filtration batch unit as shown in Fig. 3. The experimental set was fabricated from stainless steel metal at cylindrical shape with a capacity of 1 m^3 and outer diameter of 0.065 m in the workshop of IIT Guwahati (India). Pretreated juice collected by individual support of packing material in the packed column was clarified by the membrane filtration cell. Low-feed transmembrane pressure drops at 69 kPa in the membrane unit were maintained by a pressure regulator to a nitrogen gas cylinder. In the membrane filtration unit, a polyamide membrane with an average pore size of 2.5 µm was fixed in the bottom of the cell. In the dead-end membrane filtration unit, the feed (pretreated juice) was forced perpendicular to the membrane cell. Feed molecules were moved from high to low-concentration areas. By applying external pressure, molecules moved from low to high concentration areas. Due to pressure difference on both sides permeate comes out through membrane pores. During filtration, large suspended or colloidal molecules in the feed solution were attached to the membrane surface and pore's structure due to charge attraction resultant in membrane fouling. Credit of solute molecule on membrane surface cause reduction of permeate rate due to van der Waals force, hydrogen bonding,

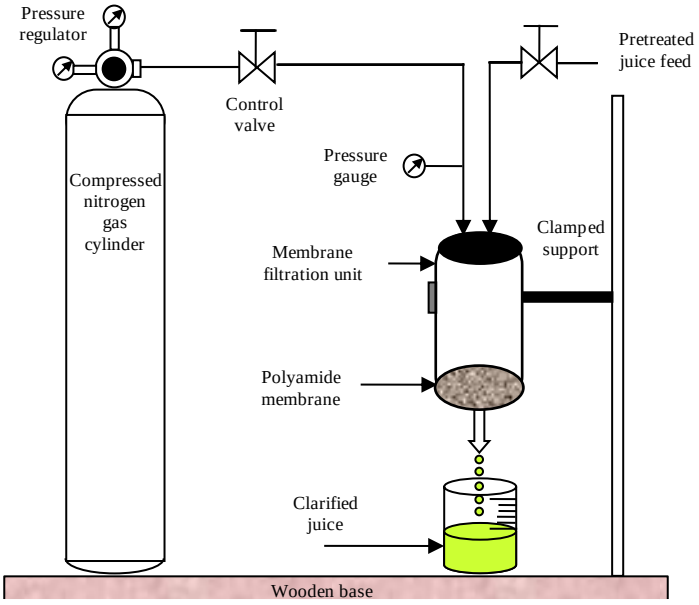

Fig. 3: Membrane filtration batch cell set up

and electrostatic attraction. So the pretreatment of raw mosambi juice helped delay fouling. In the membrane unit, clarify juice (permeate) and concentrate juice (retentate) were collected separately for physicochemical properties analysis. After clarification of pretreated juice, the membrane setup was dismantled and washed properly with deionized water at two cycles for reuse of polyamide membrane. Membrane performance was estimated by regaining hydraulic permeability after each experiment cycle.

Sample analysis

Different physiochemical properties, such as browning index, clarity, Total Soluble Solid (TSS), pH, density, and Alcohol Insoluble Content (AIS) (wt %) were measured separately of raw, pretreated juice (after pretreatment), clarified, and concentrate juice (left in membrane filtration cell). All the properties were measured three times. During citrus juice pretreatment and clarification, loss of nutrients and formation of undesirable compounds like hydroxymethylfurfural (HMF) were measured in terms of browning index. It was determined by absorbance value at 420 nm, using a UV spectrophotometer (Perkin-Elmer Precisel, Lamda-35, Waltham, Massachusetts, United States). Clarity was measured as percentage transmittance at 660 nm by using a UV spectrophotometer [1]. The total soluble solid reported by ºBrix was determined by using an ABBE -3L Benchtop Refractometer (Thermospectonic, USA) (Joslyn 1971). The pH values of all samples were determined by using a digital pH meter (VSI. Electronics Pvt. Ltd., Punjab, India). The viscosity of the sample was determined by using a HAAKE rheostress (Thermo Scientific, Germany) at a constant water bath at a temperature of 28±1ºC. Relative viscosity (η_r) is defined as the ratio between the viscosity of solution after time *t* min of pretreatment and $\eta(0)$ is the viscosity of raw juice i.e., $\eta(t)/\eta(0)$ [25]. Densities of all samples were measured by accurately weighing 25 mL of sample into a pycnometer bottle with a capacity of 25 mL. Pectin content was measured in terms of alcohol-insoluble solids. The pectin content in juice was evaluated in terms of alcohol insoluble solids (AIS) content. 20 gm of juice sample mixed with 300 mL of methanol solution and simmering of 0.5 hr. After simmering, the solution was again rewashed with methanol solution and filtered. The mixture was dried at 100ºC for 2 hr., after drying the alcohol insoluble solids content in juice was expressed in terms of wt (%) [2-4].

Theoretical consideration

Mosambi juice pretreatment was done through packed column with individual support of different packing materials such as glass beads and molecular sieves.

Pressure drops through the packed column was estimated by using the Kozeny-Carman Eq. (1).

$$\Delta P = \frac{150 V_o \mu (1-\varepsilon)^2 L}{\phi_s D_p \varepsilon^3} \quad (1)$$

Where V_o was the feed velocity, μ was the viscosity of mosambi juice, ε was the porosity of packing materials (glass beads 0.26 and molecular sieves 0.57). L was the length of column, ϕ_s was the sphericity of packing materials (glass beads 1 and molecular sieves 0.87) and D_p was the particle diameter of packing materials (glass beads 0.0035 m and molecular sieves 0.0015 m). Flow profiles (laminar or turbulent) were determined by using the dimensionless Reynolds number (*Re*) from Eq. (2) [26].

$$Qd < \frac{U_n C_o \square e}{\square\square^1} \quad (2)$$

Where ρ_f was the density of juice. Value of m dependent on sphericity to porosity ratio. Pretreated juice quality was dependent on packing factor value and was derived by using the Eq. (3). Packing factors value was varied with variation of volumetric flow rate.

$$f = \frac{90(1-\varepsilon)^2}{\varepsilon^3 Re} \quad (3)$$

Higher packing factors value means suspended materials or higher molecular weight compounds (pectin) were trapped inside the column and physichochemical properties of pretreated juice was improved after pretreatment. Lower packing factors value means suspended materials were passed through the column and pretreated juice quality was not improved [24].

In batch filtration cells, mathematical membrane flux was estimated by using Eq. (4). It is defined as the ratio of permeate flow to cross-sectional area from Darcy's law.

$$J_s = \frac{dV}{A_{cross} dt} \quad (4)$$

dV (m^3) is the volume of permeate collected at a particular time interval dt (sec), A_{cross} membrane cross-sectional area (m^2) and J_s is steady-state permeate flux ($m^3/m^2.s$). Membrane performance estimate in terms of hydraulic permeability by using the following relation such as Eq. (5)

$$J_s = L_p \Delta P \quad (5)$$

ΔP is transmembrane pressure drops of membrane filtration cell with deionized water feed as a solution through the membrane. L_p is membrane hydraulic permeability specifies the porosity of the membrane. Hydraulic permeability affects the overall performance of a membrane at a particular application. Factors such as impurities in the solution, solute size, and degree of saturation affect the membrane's hydraulic permeability. After each membrane experiment, the membrane was cleaned with deionized water for reuse purposes, and estimates the hydraulic permeability at 28±2 ^{0}C [1].

RESULTS AND DISCUSSIONS

Variation of relative viscosity and clarity at different feed flow rates in packed column support with glass beads

Deviation of relative viscosity and clarity of pretreated juice with operating time at altered feed flow rate or pressure drops during packed column occupied with glass beads (0.0035 m) were shown in Figs. 4(a) and 4(b), respectively.

It was observed from Fig. 4(a) that the relative viscosity of pretreated juice reduced gradually within an operating time of up to 45 min. Below 45 min, variation in relative viscosity was observed and no change in relative viscosity was detected after 45 min almost a steady state was achieved. At an operating time 45 min, with increased feed flow rate from 0.139×10^{-7} to 1.39×10^{-7} m^3/s (corresponding packing factor values of glass beads decrease from 446 to 45 and pressure drops raise from 0.173×10^7 to 1.73×10^7 $kg/m.s^2$, shown in Table 3), relative viscosity increase from 0.65 to 0.90 and clarity decrease from 5.2 to 1.9% of pretreated juice due to enriched of higher molecular weight compounds such as pectin and phenol were passed in pretreated juice [27].

At a low flow rate 0.139×10^{-7} m^3/s, the relative viscosity of clarified juice was decreased by up to 35% and clarity was found to increase from 0.6 to 5.2% due to suspended materials of raw juice trapped in the column leading to the improvement of pretreated juice characteristics shown in Fig. 4(b).

Variation of relative viscosity and clarity at different feed flow rates in packed column support with molecular sieves

In this column studies, packing materials glass beads were replaced by molecular sieves (0.013×0.0015 m). Suspended solids and charge molecule of raw mosambi juice were adsorbed on the molecular sieves surface, resulting pretreated juice viscosity decrease and clarity

Table 3: Variations of variable parameters during packed column pretreatment with glass beads and molecular sieve support

Flow rate ×10^{-7} (m^3/s)	Velocity×10^7 (m/s)	Glass Beads			Molecular Sieves		
		ΔP×10^7(Kg/m.s^2)	Reynolds No.	Packing factor (*f*)	ΔP×10^7 (Kg/m.s^2)	Reynolds No.	Packing factor (*f*)
0.139	4.60	0.173	5.85	446	0.043	0.012	7625
0.278	9.21	0.346	11.71	223	0.086	0.024	3813
0.556	18.43	0.692	23.42	112	0.171	0.047	1906
0.833	27.64	1.038	35.14	74	0.257	0.071	1271
1.111	36.86	1.384	46.85	56	0.342	0.094	953
1.389	46.07	1.730	58.57	45	0.428	0.118	763

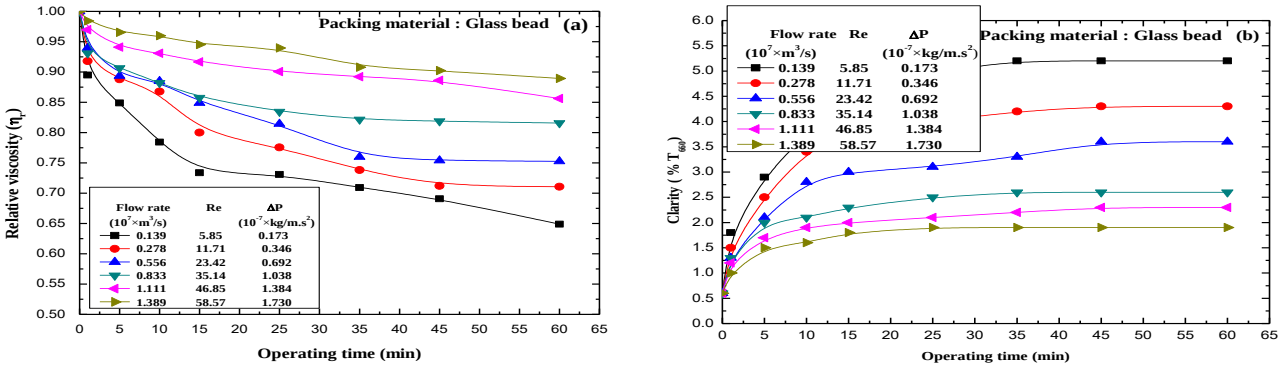

Fig. 4: Variation of relative viscosity (a) and clarity (b) with operating time at different flow rates

increase. Packing factor values for molecular sieves vary from 7625 to 765 at a volumetric flow rate that deviates from 0.138×10^{-7} to 1.38×10^{-7} m^3/s, shown in Table 3. Variations of relative viscosity and clarity with operating time at different feed flow rates were shown in Figs. 5(a) and 5(b). Initially, relative viscosity declined sharply within 15 min, after that decline was gradual and continued up to 45 min, as shown in Fig. 5(a).

At a low volumetric flow rate 0.138×10^{-7} m^3/s the relative viscosity was decreased up to 47% and clarity was increased from 0.6 to 12.3% of pretreated juice within the operating time 45 min. With the increase of the feed flow rate from 0.138×10^{-7} to 1.38×10^{-7} m^3/s at corresponding pressure drops from 0.043×10^7 to 0.428×10^7 kg/m.s^2, more suspended materials from the raw juice were passed through the passive of molecular sieves resulting impact on physicochemical properties of pretreated juice [17]. For example, at a feed flow rate of 1.38×10^{-7} m^3/s, relative viscosity decreased up to 35.2% and clarity was increased from 0.6 to 2% in the pretreated sample, shown in Fig. 5(b). Throughout column studies, pretreated juice qualities were immensely dependent on adsorption, packing factor value, and feed flow rate. With molecular sieves, adsorption of more pectin and protein molecules in the juice was bound with molecular sieves particles resulting in more clear juice obtained after pretreatment [27-28].

Extreme enhancements of physicochemical properties were observed at a low volumetric flow rate 0.139×10^{-7} m^3/s. It was observed maximum reduction of relative viscosity of pretreated juice was 25.13 and 35.2% with glass beads and molecular sieves respectively at a low volumetric flow rate 0.139×10^{-7} m^3/s. Clarity was improved from 0.6 to 12.3% with molecular sieves and 0.6 to 5.2% with glass beads.

Variation of viscosity and clarity with operating time in series column operation

For enhancement of physicochemical properties of pretreated juice during packed bed operation, two packed columns were arranged in sequence at continuous operation and operated at a low volumetric flow rate 0.138×10^{-7} m^3/s. For better pretreatment, raw mosambi juice first passed through a glass beads-filled column, and after that juice passed to another column supported with molecular sieves for better control of flow rate. Raw juice had different sizes (up to 90 µm) of pulp molecule, in packed columns random packing was implemented with glass beads and molecular sieves. The particle diameter and passage with glass beads packing was higher as compared to molecular sieves packing so glass beads packed column first prefer. Other

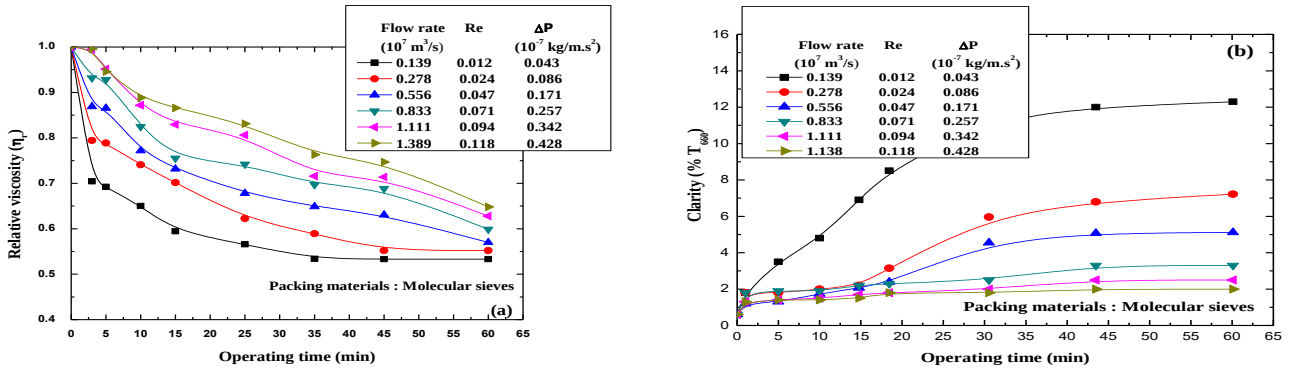

Fig. 5: Variation of relative viscosity (a) and clarity (b) with operating time at different feed flow rates

the reason was the low packing factor value of 446 of glass beads packed column. Due to the low packing factor large pulp molecules were retained in the column and small pulp molecules were passed through passage in this column. These small molecules were trapped in the molecular sieves' support column. Small pulp molecules of pectin and cellulose were adsorbed in a molecular sieve support column due to a high packing factor value 7625. Variation of clarity and viscosity with operating time at a low volumetric flow rate of 0.138×10^{-7} m^3/s was shown in Fig. 6. During series column arrangement, higher molecular weight compounds were stuck in the first column and lower molecular weight compounds were passed. These lower molecular weight compounds are mostly trapped in the second column resulting enhancement of pretreated juice qualities. At combined operation, the clarity of treated juice was increased from 0.7 to 16.33% and reduced viscosity was 54% at an optimum operating time within 45 min, The resultant pretreated juice qualities (clarity and viscosity) had improved compared to the single-column pretreatment method.

During combined packed bed pretreatment, Particle Size Distribution (PSD) of raw and pretreated juice was measured by a laser particle size analyzer (Malvern Instruments, Mastersizer 2000). The average particle size of fresh mosambi juice was 40 µm. After pretreatment through combined packed column operation, average particle size of pretreated mosambi juice was 1 µm it's came in the microfiltration range, as shown in Fig. 7.

It indicated that maximum larger size particles in raw mosambi juice were retained in series operation. So the combined series packed column pretreatment method was beneficial for next operation such as clarification and storage of juice by membrane filtration.

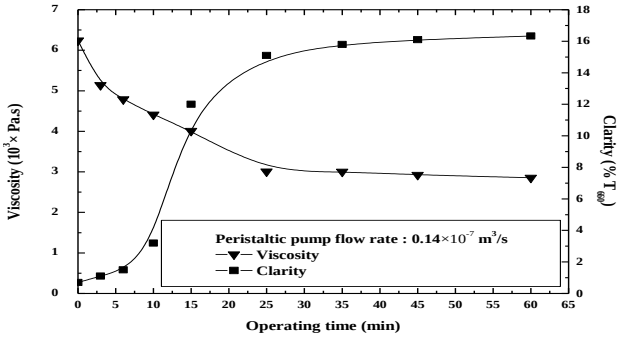

Fig. 6: Variation of viscosity and clarity in series column arrangement.

Transient flux decline

Deviations of membrane permeate flux with operating time at 69 kPa, for packed column pretreated juice were shown in Fig. 8.

In membrane operation, 0.5 m^3 pretreated juice had been taken for individual operation. Clarification of single column support with glass beads pretreated juice permeate flux value declined from 1.58×10^{-5} to 1.27×10^{-6} m^3/m^2.s within 1600 s. With molecular sieves supported column pretreated juice the permeate flux declined from 1.60×10^{-5} to 2.25×10^{-6} m^3/m^2.s within 1600 s. Combined column supported pretreated juice permeate flux value was declined from 1.57×10^{-5} to 3.65×10^{-6} m^3/m^2.s within 1600 s. Permeate flux declined of glass beads and molecular sieve support column pretreated juice were 90.18% and 85.93%. With series column packed pretreated juice flux declined was 76.85%. Extreme permeate flux declined up to 90.18% was due to low packing factor value 446 of glass beads support column pretreated juice. A low packing factor value of the column means a high molecular weight compound passed through the column during pretreatment. In clarification pectin compounds retained on the membrane

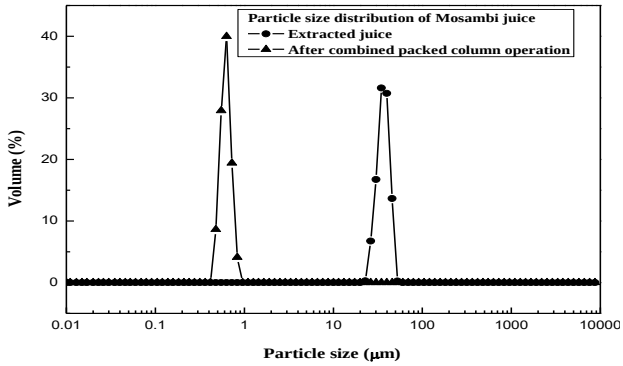

Fig. 7: Particle size distribution of fresh and pretreated juice

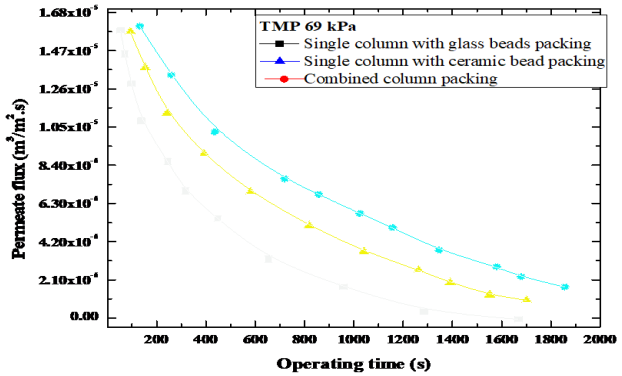

Fig. 8: Transient flux decline with operating time at 69 kPa

surface resultant high permeate flux declined 90.18%. A low permeate flux drop up to 76.85% was observed with series column arrangement due to a higher packing factor up to 7625. A high packing factor means carbohydrate compounds were retained in the column and pretreated juice had low pectin compounds. Due to low pectin compounds in pretreated juice rate of permeate flux decline was observed to lower during membrane filtration. Initial permeate flux declined within 400 s due to the gel layer formation of the membrane surface. Afterwards 400 s, the gel layer was turned to a cake layer resultant rate of permeation was decline fast with operating time [16]. After each run of the experiment, membrane was cleaned with deionized water and estimates the hydraulic permeability for reuse purpose. Membrane hydraulic permeability was decreased from 2.47×10^{-11} to 1.58×10^{-11} m/Pa.s. Decreased of membrane hydraulic permeabity was due to retentate of solute particle on membrane pores and some active pores tuned into dead ones [1].

Quality analysis raw, pretreated and clarified juice

Raw, Pretreated and clarified juice physicochemical properties was shown in Table 4. Initial raw juice had total soluble solids 9.3°Brix, density 1.10 g/cm^3, alcohol insoluble solids 0.30 wt% clarity 0.6 and viscosity 3.31 m.Pas. After pretreatment the total soluble solids mainly sucrose content in juice was decreased from 9.3 to 9.1 °Brix with glass beads, 8.8 °Brix with molecular sieves and 8.6 °Brix after membrane clarification. Clarified juice density was reduced from 1.10 to 1.04 g/cm^3. No significant difference was observed in pH of raw, pretreated and clarified juice. Clarity of glass beads support pretreated juice was improved from 0.6 to 5.2% with molecular sieves 0.6 to 12.30%. Maximum clarity enhancement 16.33% was observed with combined column pretreatment operation. After clarification clarity was enhanced from 0.6 to 95% due to removal of high molecular weight compound in juice. Viscosity reduced after column pretreatment support with glass beads was 3.31 to 2.47 m.Pas, with molecular sieves 3.31 to 2.14 m.Pas, 42.32% with combined column and 73.4% after clarification of pretreted juice. Viscosity reduction indicates removal of pectin and carbohydrates compound from juice. The alcohol insoluble solid in terms of pectin content was reduced 0.30 to 1.65 wt % with molecular sieve supported column, 48.52% with series combine packed column operation and 97% (from 0.30 to 0.009 wt%) after membrane clarification. Different support column pretreated juice qualities were same after membrane clarification. Low permeate flux declined with operating time was observed in series column operation due to maximum removal pectin molecule under pretreatment.

CONCLUSIONS

Individual detail studies of pretreatment of mosambi juice by packed column support with glass beads and molecular sieves were done separately. During packed column pretreatment, physicochemical properties of juice was depend of volumetric flow rate and packing factor. With variation of volumetric flow rate 0.139×10^{-7} to 1.38×10^{-7} m^3/s clarity of glass beads support column pretreated juice was decreased 5.5 to 1.5 and packing value was reduced from 446 to 45. Viscosity reduction 30% was observed at 0.138×10^{-7} m^3/s and 5% at 1.38×10^{-7} m^3/s with glass beads support column. With molecular sieve support column 50% viscosity reduction of juice was observed at 0.138×10^{-7} m^3/s with packing factor 7625. With enhancement of flow rate from 0.139×10^{-7} to 1.38×10^{-7} m^3/s, packing factor reduced from 7625 to 763 and resultant clarity reduced from 12.3 to 1.0. Maximum improvement of juice properties was at low flow rate

Table 4: Variations in physicochemical properties of raw pretreated and clarify juice

S. No.	Operations		Total soluble solids (°Brix)	Density (g/cm^3)	Alcohol insoluble solids (wt%)	Clarity (% T_{660})	Viscosity (m.Pas)
1	Raw juice		9.3	1.10	0.300	0.60	3.310
2	Column pretreatment	Glass beads	9.1	1.09	0.180	5.20	2.478
		Molecular sieves	8.8	1.04	0.165	12.30	2.146
		Combined operation	8.8	1.04	0.154	16.33	1.909
3	Clarified juice		8.6	1.04	0.009	95.00	0.881

0.138×10^{-7} m^3/s. The physicochemical properties of pretreated juice were improved with molecular beads supported column. In column pretreatment, improvement of physicochemical properties was done with combined column operation. Clarity was improved from 0.6 to 16.33%, and viscosity reduced from 3.31 to 1.90 m.Pas. Due to the retention of high molecular weight compound in combined column operation average particle diameter of mosambi juice was reduced from 40 µm to 1 µm. During membrane clarification, a maximum permeate flux decline 90.18% was observed with glass beads supporting column pretreated juice, and the lowest permeate flux dropped 76.85 % was detected with combined column pretreated juice. Clarity was improved from 16.33 to 95% and alcohol insoluble was reduced from 0.154 to 0.009 wt% due to pectin molecules retained on the membrane surface and permeate was almost free with pectin compounds.

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