FINAL REPORT
ON

APPLICATION OF PROCESS INTENSIFICATION IN FOOD PROCESSING INDUSTRIES

UGC APPROVAL LETTER: F.NO: 43-150/2014(SR)
DATE: 05.08.2015

Jadavpur University

UGC MAJOR PROJECT

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Annexure – IX
UNIVERSITY GRANTS COMMISSION
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PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF SENDING THE FINAL REPORT OF THE WORK DONE ON THE PROJECT

1. **TITLE OF THE PROJECT**: Application of Process Intensification in food processing industries.

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4. **UGC APPROVAL LETTER NO. AND DATE**: F.NO: 43-150/2014(SR) Date: 05.08.2015.

5. **DATE OF IMPLEMENTATION**: 01.07.2015

6. **TENURE OF THE PROJECT**: 3 years.

7. **TOTAL GRANT ALLOCATED**: Rupees 15,72,312.

8. **TOTAL GRANT RECEIVED**: Rupees 11,42,081.

9. **FINAL EXPENDITURE**: Rupees 12,12,236.

10. TITLE OF THE PROJECT

Application of Process Intensification in food processing industries.

11. OBJECTIVES OF THE PROJECT

A crucial segment of the total processed fruit industry is represented by Juice and juice products. Most of the fruits grow in a particular season and a specific climatic zone. Also they have a limited life span and are perishable in nature. So it is impossible to make the fresh fruits available throughout a large area in a limited period of time. It is easier to make it available over the entire year in the form of juice products. Concentration means reduction of water content of a solution. Concentration of raw juice has many benefits including increased shelf life, easy transportation and packing, reduction in volume and weight of product, increase in stability and overall reduction in cost. Large amount of solutions are concentrated in different process industries such as food processing industries, organic and inorganic chemical industries, oil industries, petrochemical industries etc. for optimal utilization of storage volume.

Concentration is mainly done industrially by Thermal evaporation under vacuum using various types of evaporators [Cyklis et al., 2017]. Thin film and wiped film evaporator is commonly used for fruit juice [Sangrame et al., 2000] as the products are heat sensitive. The liquid flows vertically down the evaporator wall by gravity. It forms a thin film on the wall aided by mechanical wipers that covers the evaporating surface. Heat is supplied to other side of surface. Non uniform distribution of the heat and formation of local hotspots are major disadvantages of the equipment. The low values of heat transfer coefficient, decrease in the magnitude at high feed rate results in large size of evaporators and also high operating cost.

An alternate to using thermal energy for concentration of the solution could be stripping of water from the solution using gas/air. Air stripping involves transfer of the water from the

solution in the form of vapor from the liquid into the unsaturated air stream. The operating cost is expected to also be lower as the process that relied completely on thermal energy in evaporators for reduction in water content of the solution is partly replaced by mass transfer. Some of the conventional equipment for directly contacting air-liquid mass transfer are packed bed, spray column, staged column, etc. The major concern with air stripping process is that removal of water by mass transfer in these equipments would be low as gas-liquid mass transfer coefficients are small. Therefore, the volume of conventional mass transfer equipment for this method such as fixed bed would be large.

In this study, a novel technique of air stripping in a Rotating Contactor was considered to overcome the shortcoming of the conventional gas-liquid contactors. The traditional gravitational force in film evaporators is replaced with the Centrifugal force in a doughnut shaped packing element. Due to high centrifugal acceleration rapid regeneration takes place in the interface of gas and liquid. As a result, the mass transfer rate increases drastically with consequent improvement in efficiency.

The heart of a rotating contactor is the rotor that gives the contactor specific mass transfer characteristics. Various types of rotor viz. waveform discs, packed bed, spiral discs, helical discs, multistage spraying have been reported in the literature [Wang et al., 2008]. Among them rotating zigzag bed has shown to be more effective for providing high mass transfer rates for absorption and distillation process. However, there are no available results on the feasibility of using rotating contactors for concentration of fruit juice.

The major objective of this study have therefore been to explore the possibility of replacing traditional wiped film evaporators for the concentration of fruit juice by air (unsaturated) stripping performed in rotating contactors. To this end the following has been done

(a) Comparison of the evaporation rate of pure water achieved in Rotating Zigzag bed with rotating packed bed for determining the more suitable rotating equipment for carrying fruit juice concentration.

(b) Study the concentration of a wide variety of fruit juice in the rotating contactor with higher evaporation rate as determined by experiments carried out in part (a).

(c) Study the intensification achievable for concentration of fruit juice by comparing with conventional wiped film evaporator.

The fruit juices used were Tomato, Orange, Grape, Pomegranate, Black currant, watermelon, and sugarcane. The effect of operating parameters such as rotational speed, flow rate, temperature on the concentration has been studied by continuously circulating a given volume of solution through the equipment.

12. WHETHER OBJECTIVES WERE ACHIEVED

As noted earlier, the major objective was whether replacing traditional wiped film evaporators for the concentration of fruit juice by air (unsaturated) stripping performed in rotating contactors would be beneficial. The results indicated that objectives were achieved. The summary of the results based on which this conclusion was drawn is given below:

(a) At a given time, the concentration of all the fruit juice was higher in rotating zig-zag bed as compared to wiped film evaporator suggesting that the evaporation rate is higher.

(b) The volume of the rotating zig-zag bed is also lower than wiped film evaporator. Therefore, evaporation rate per unit contactor volume was noted to be much higher in rotating zig-zag bed than conventional evaporator. This implies that the equipment volume can be lowered.

(c) The energy requirement was also lower in the former.

The details of the experimental studies are stated briefly.

Experimental Method

❖ **Preparation of the juices:**

The fruits bought from the supermarket were properly washed with double distilled water. The juice was extracted using the juicer. The extracted juice was filtered through a fine muslin cloth to ensure that no solid particles were presented in the solution to block the liquid distributor openings. Fresh juice was extracted for each and every experiment.

❖ **Experimental set up:**

❖ **Schematic diagram of the experimental set up:**

A schematic diagram for the Rotating Zigzag bed is provided in Figure 1.The rotor consisted of a pair of 0.002 m thick stainless steel circular disk of 0.360 m diameter fastened coaxially. The axial distance between the two discs is 0.02m. The whole frame-up of the rotor was housed inside a casing of diameter 0.4 m and axial distance 0.105 m. Two internal structure of the rotor was studied for the experiments.

(a) **Rotating zig-zag bed**:

In this rotor, a series of concentric circular sheets (baffles) was welded onto the two circular discs. The distance between the concentric baffles was 0.03 m. The baffles prevent the liquid from flowing radially outward clearance between the two discs and the baffles provide zig-zag flow channel for liquid and gas phase.

(b) **Rotating packed bed**:

This rotor consisted of a pair of 0.002 m thick circular discs of diameter 0.360 m. The space between the two discs was packed with a stack of stainless steel wire mesh (20 meshes per linear inch). The axial distance between the two discs was 0.02 m.

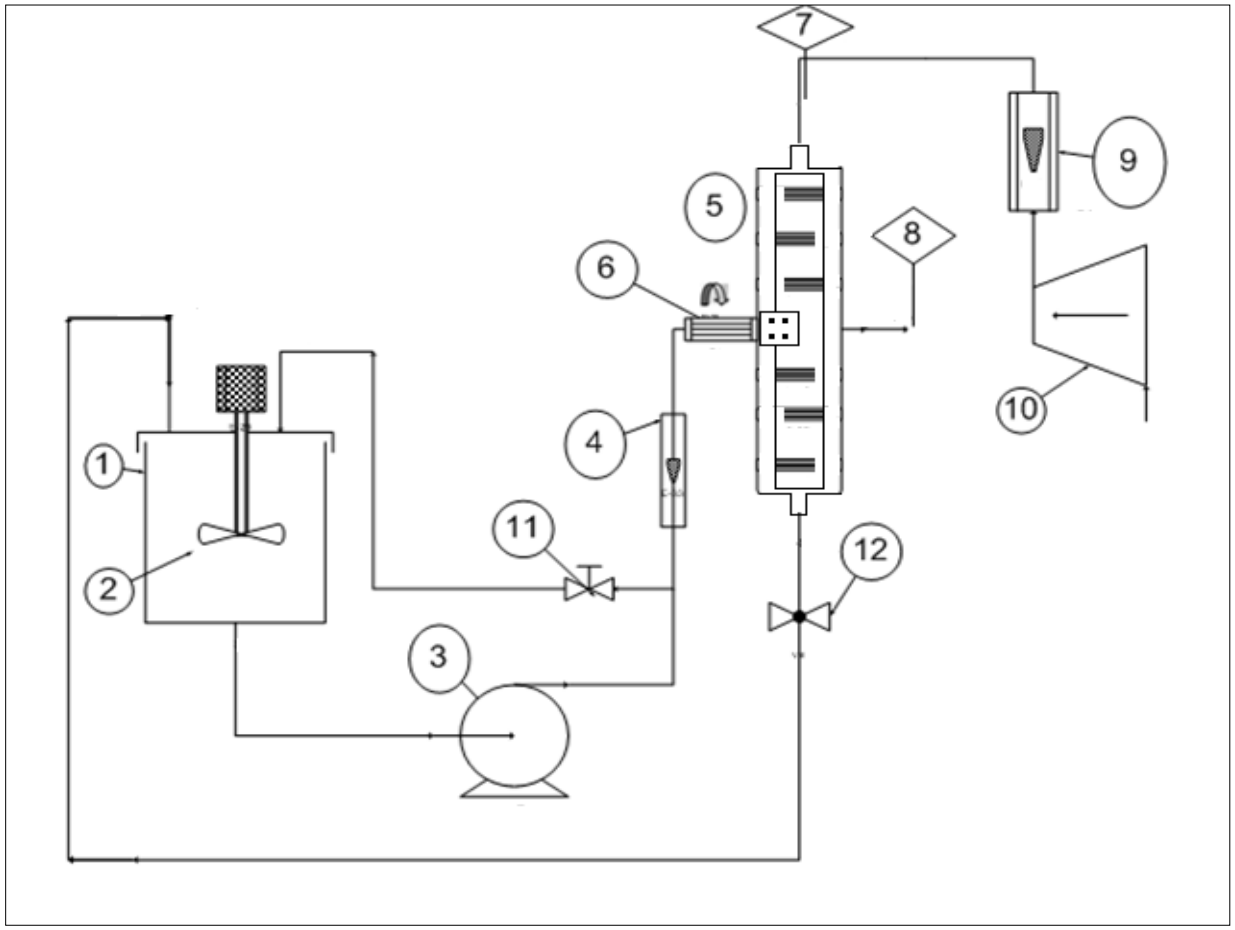

Fig 1: Experimental set up (1 Solution tank, 2 Tank stirrer, 3 Feed pump, 4 Liquid Rotameter, 5 RZB, 6 Rotor, 7 Air inlet, 8 Air outlet, 9 Air Rotameter, 10 Air compressor, 11 Bypass valve, 12 Liquid outlet valve).

A double jacketed feed tank with a temperature regulator and a stirrer for constant mixing was used for preheating the juice solution. The warm feed was pumped into the rotating zigzag bed contactor by a centrifugal pump. A stationary distributor of diameter 0.035 m and length 0.02 m

consisting of 11 numbers of 1 mm diameter holes on its surface was used to distribute the fruit juices uniformly inside the zigzag bed. Clean air was also introduced into the contactor through a compressor wherein it comes in contact with the solution/water in counter-currently. The temperature of the liquid and air entering and leaving the contactor were measured using thermocouples connected to a digital display unit. Two hygrometers (Zeal, Germany) were provided to measure the inlet and outlet wet bulb and dry bulb temperature of the entering and exiting air. The rotational speed of the rotor is controlled by a digital tachometer, DT-2234B (Lutron, Taiwan). The concentration of the fruit juice solutions were measured using a digital Refractometer (Atago, Japan).Figure 2 represents the experimental set up for the rotating contactors.

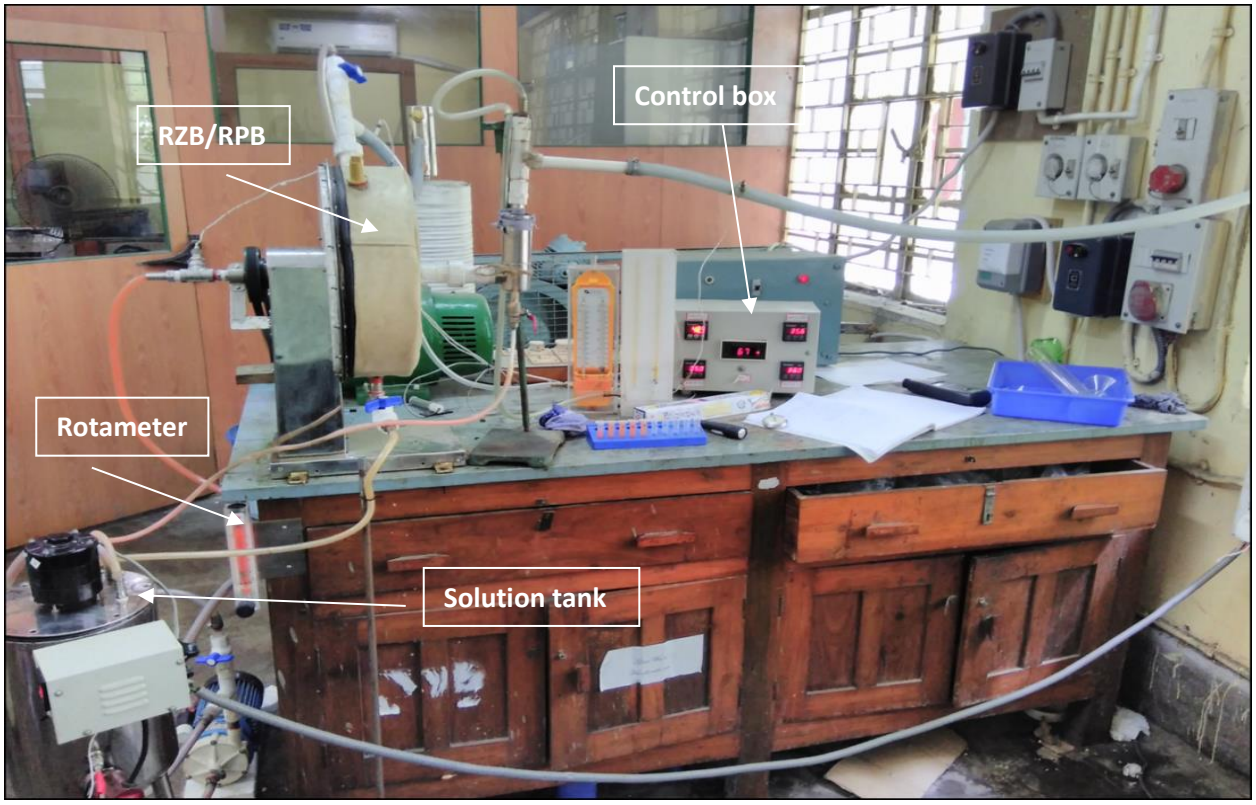

Fig 2: The experimental set up of the Rotating Contactors (RZB/RPB)

The conventional apparatus consists of a wiped film evaporator of shell diameter 0.24 m and length 0.7 m with inner tube diameter 0.18 m. A wiper with 4 blades was stationed inside to spread the solution uniformly on the inner surface of the tube. In the experiments with wiped film evaporator, the inlet solution temperature was kept the same as in rotating equipment while the vacuum was utilized to continuously draw out evaporated moisture. The vacuum was maintained at around 250 mm Hg. Figure 3 represents the set up for wiped film evaporator.

Fig3: The set up for Wiped film evaporator

Chemical analysis was carried out to determine pH, Total acidity, Total Phenol Content, Total Flavonoid Content, L- Ascorbic Acid content, Lycopene content and Antioxidant activity by DPPH and FRAP assay.

Results:

- **Experiment with Air and Water:** Preliminary experiments were carried out to determine the evaporation rate that could be obtained in different rotor designs. These experiments were carried out by contacting warm water with air. The evaporation rate was calculated from the following relation

$$\text{Evaporation rate} = (Y_o - Y_i)\acute{G}$$

Y_o and Y_i are the outlet and inlet humidity (kg moisture/kg dry air) of air and $\acute{G}$ is the dry air flow rate (kg/min).

The effect of the operational parameters on evaporation rate in rotating packed bed and rotating zig-zag bed is provided below in a graphical form. The effect of air flow rate, water flow rate, rotational speed and temperature is given in Figure4, 5, 6 and 7 respectively.

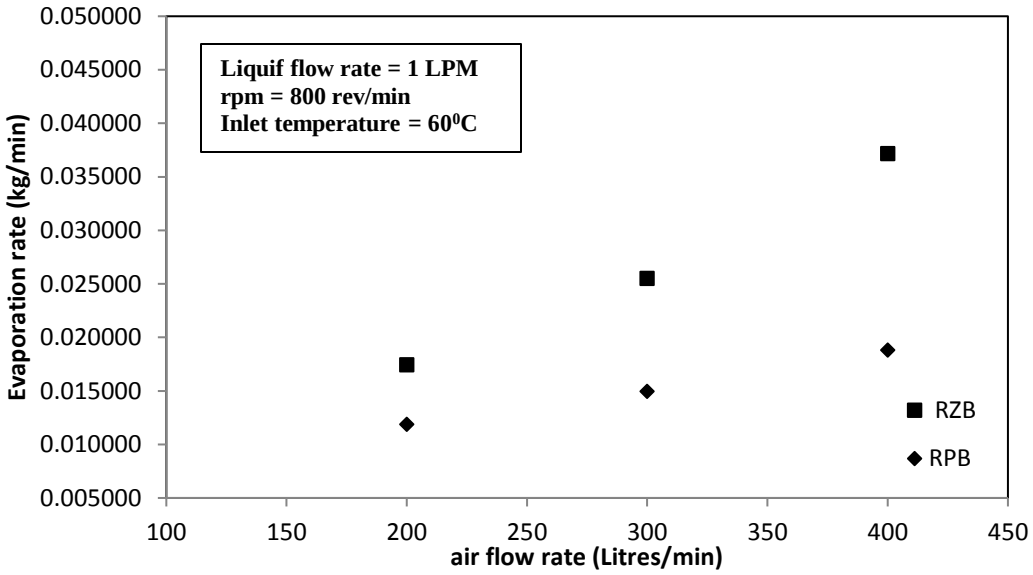

Fig 4: Effect of air flow rate on the Evaporation rate of water.

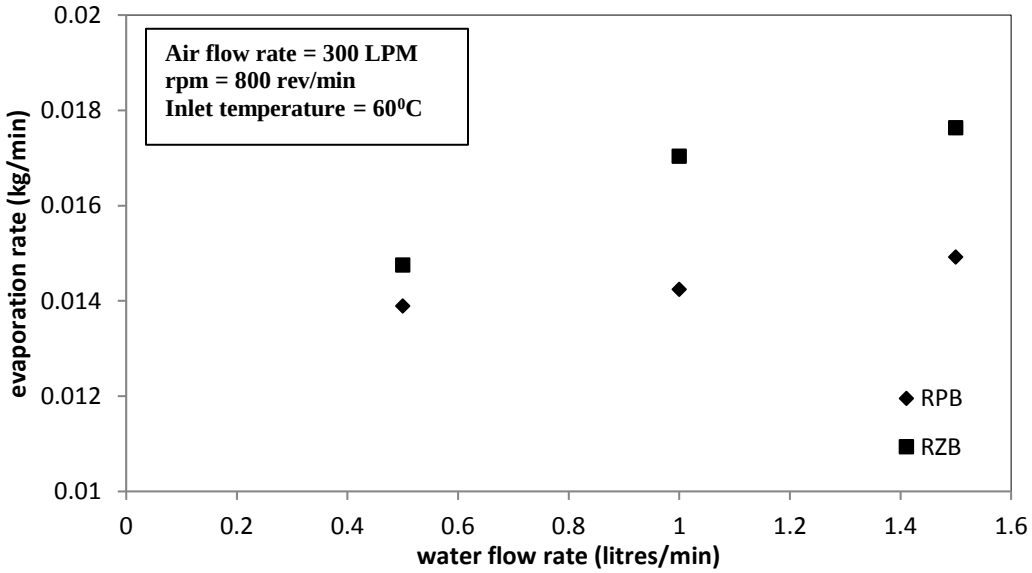

Fig 5: Effect of water flow rate on the evaporation rate of water.

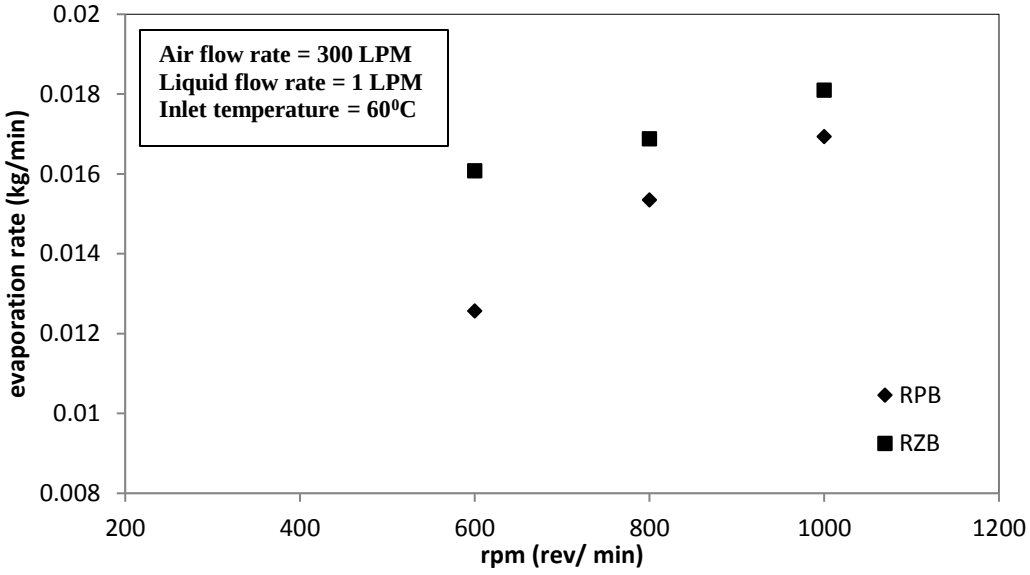

Fig 6: Effect of Rotational speed on the evaporation rate of water.

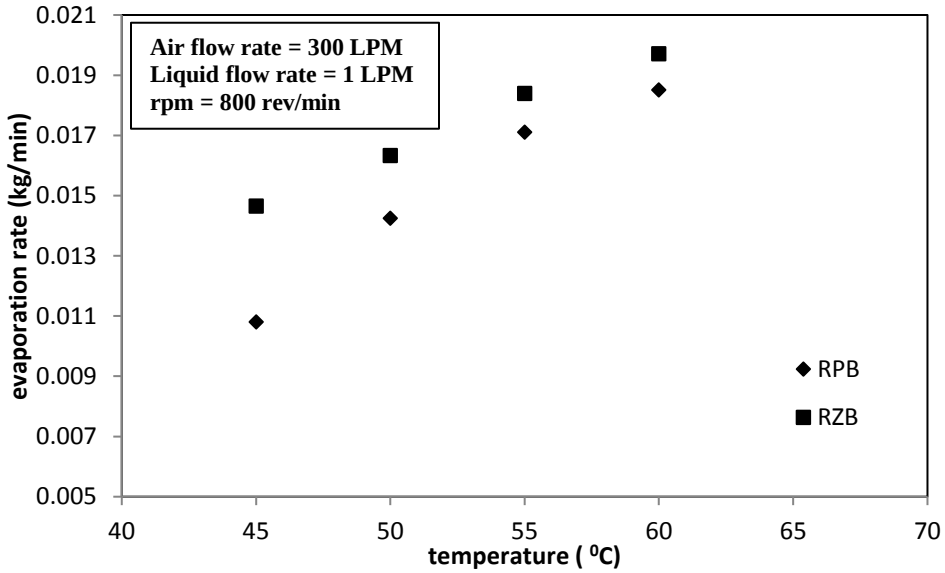

Fig 7: Effect of Temperature on the Evaporation rate of water.

It is noted that the evaporation rate increases with increase in value of air flow rate, liquid flow rate and rotational speed. In all the cases, evaporation rate is higher in rotating zig-zag bed compared to rotating packed bed.

❖ **Experiment performed with various fruit juices:**

Seven fruit juices were used in the experiment. The fruits are Tomato, Orange, Green grapes, Black current, watermelon, pomegranate and sugarcane. Experiments were carried out by changing the operating parameters like air flow rate, liquid flow rate, temperature and rotational speed. A fixed volume of juice was preheated in a reservoir, and then fed to the zig-zag bed contactor (or RPB). It comes in contact with the air inside the rotor in a countercurrent manner and air stripping takes place.

➢ **Tomato juice:**

Tomato is a berry type of fruit of family Solanaceae. It is considered as a functional food that not only provides basic nutrition but also helps to prevent chronic diseases and has various health benefits. It also provides an important phytochemical lycopene that also is a natural colorant as well as antioxidant. But tomato is not available throughout the year factors like seasonality of consumption, fungal disease and limited shelf life. The effects of the operational parameters on concentration in rotating zig-zag bed are provided below.

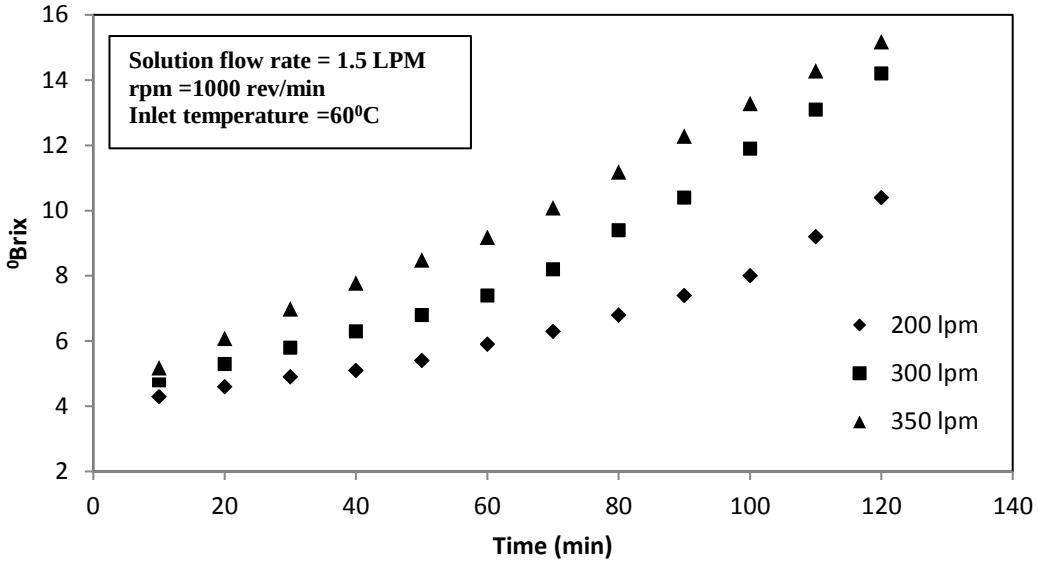

Fig8: Effect of air flow rate on the concentration of tomato juice in ^{0}Brix.

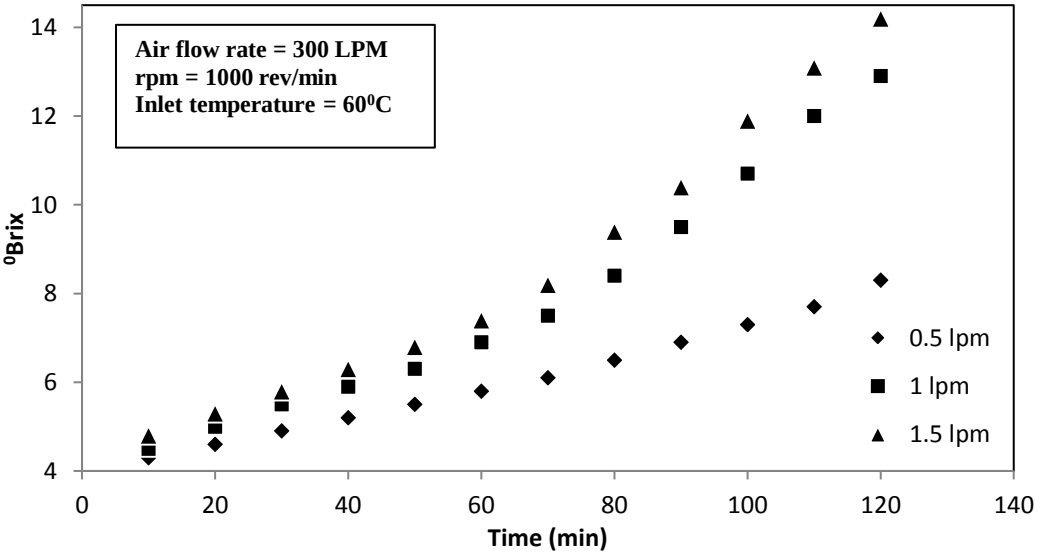

Fig 9: Effect of solution flow rate on the concentration of tomato juice in ^{0}Brix.

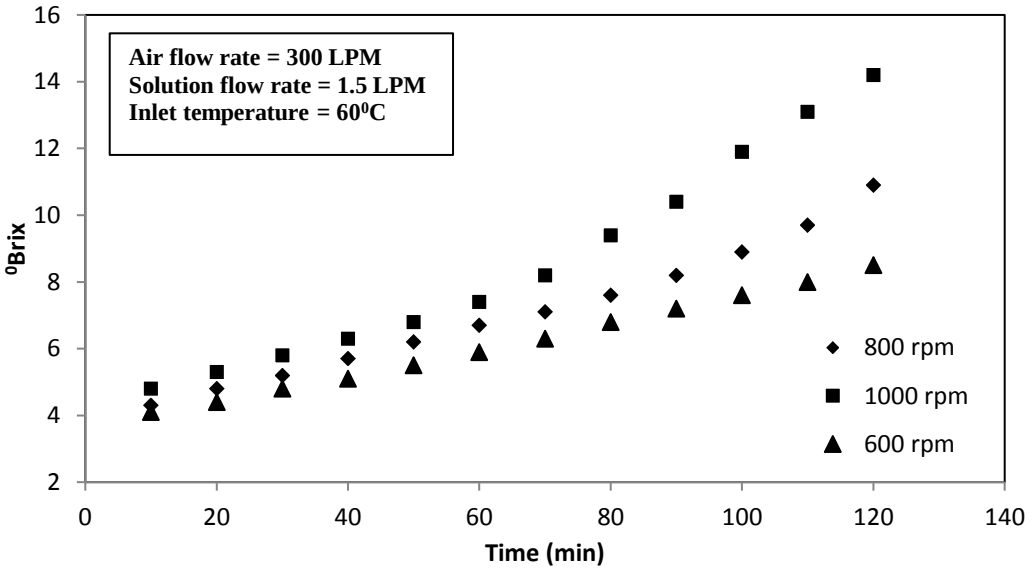

Fig 10: Effect of rotational speed on the concentration of tomato juice in ^{0}Brix.

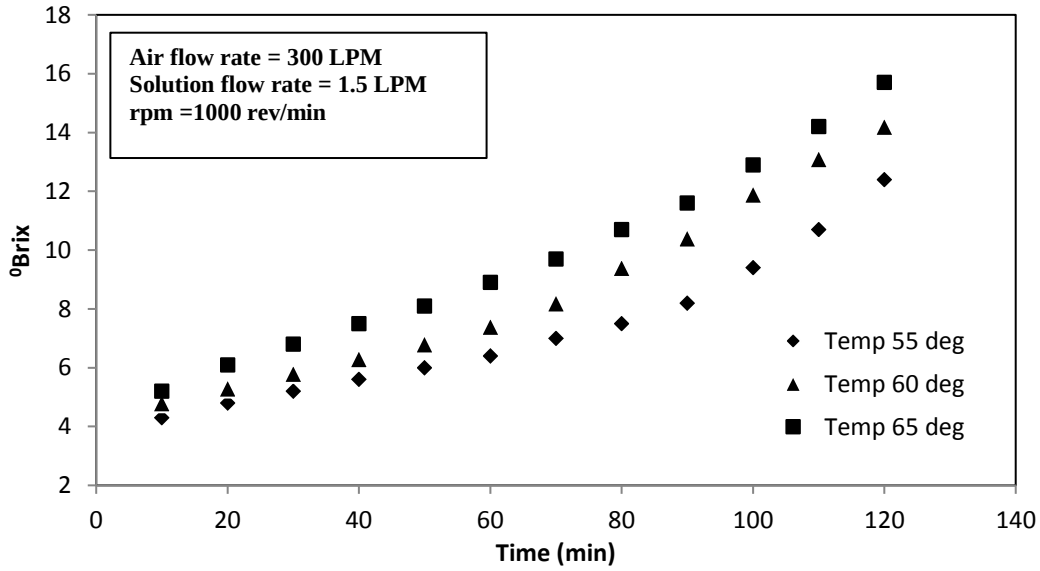

Fig 11: Effect of temperature on the concentration of tomato juice in ^{0}Brix.

A comparative experimental study was performed among Rotating Zigzag bed, Rotating packed bed, and the Wiped film evaporator. The result is shown in a graphical form. It was observed that

the Tomato juice is concentrated from 4 ^{0}Brix to 14^{0}Brix in Rotating zigzag bed which is higher compared to Rotating packed bed where the concentration is from 4 ^{0}Brix to 10 ^{0}Brix and in wiped film evaporator from 4 ^{0}Brix to 7.5 ^{0}Brix.

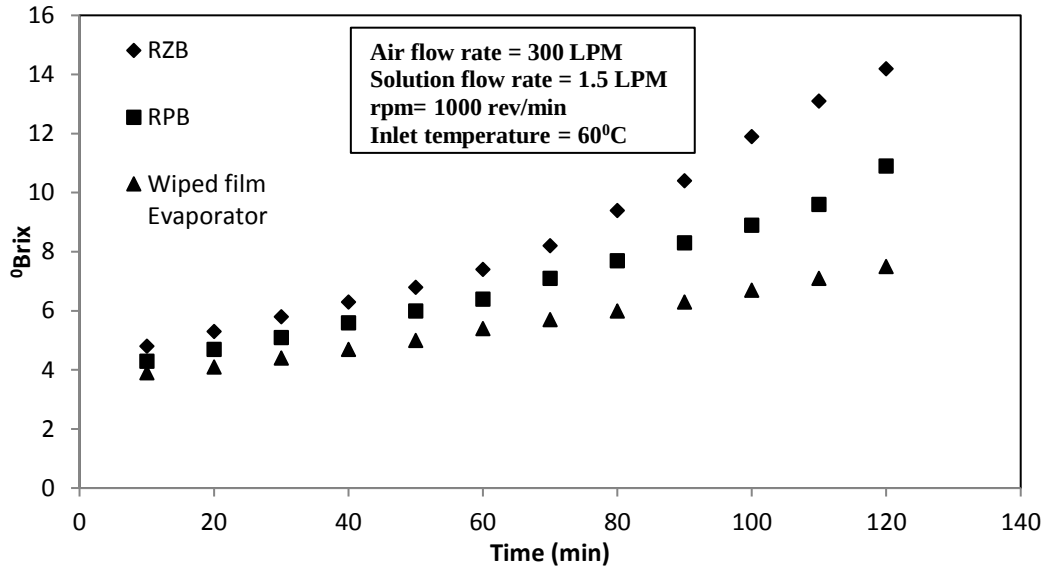

Fig 12: Comparative study on the concentration of tomato juice in RPB, RZB and Wiped film evaporator.

Petrotos et al., 1998has investigated the concentration of tomato juice using Direct Osmosis in a Tubular membrane. The initial juice concentration was 4.3 ^{0}Brix which was increased to 11.7 ^{0}Brix in 300 minutes of operation. Bottino et al., 2002 studied the concentration of juice in an integrated membrane system using Microfiltration followed by Reverse osmosis. The last step was recombination of the concentrates obtained in Microfiltration and Reverse osmosis. The concentration in final stage is 14 ^{0}Brix with flux 20 L/m^{2}h. However, it must be noted that capital cost of membrane process is high as membranes has to be frequently changed due to fouling.

- **Orange juice:**

Orange or *Citrus sinesis* is a fruit of Citrus species in the family Rutaceae. The fruit is widely known for its flavor and sweet and sour taste. It is not only used for juice but also for sweet essential oil used in aromatherapy as well as medicines. The fruit is a rich source of Vitamin C, A, Thiamin, folate, flavonoids and minerals. But seasonal availability is the reason of limited accessibility of the fruit countrywide. The graphical representation of the effect of operating parameters on concentration is given below.

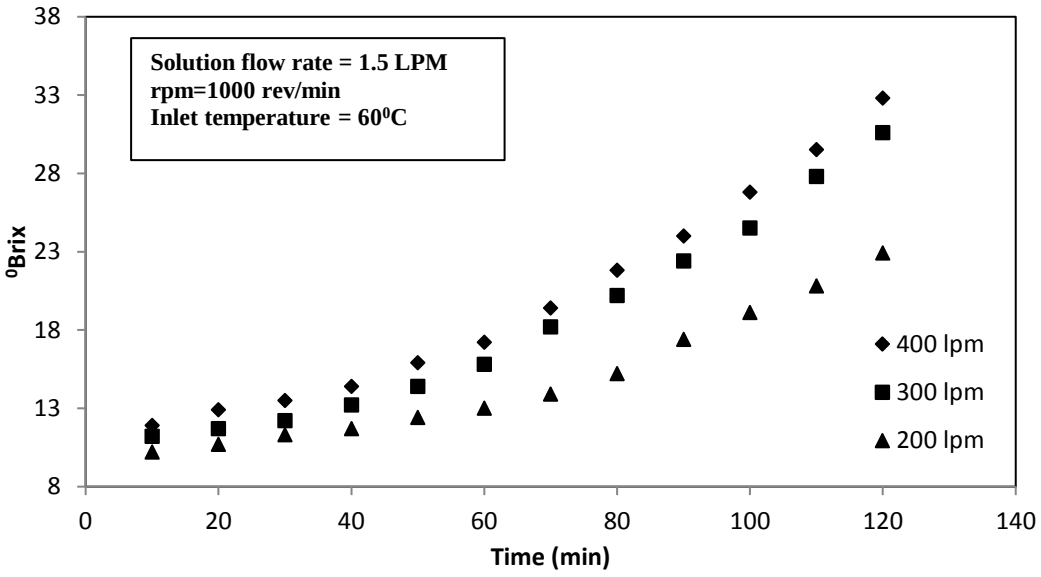

Fig 13: Effect of Air flow rate on the concentration of Orange juice in ^{0}Brix.

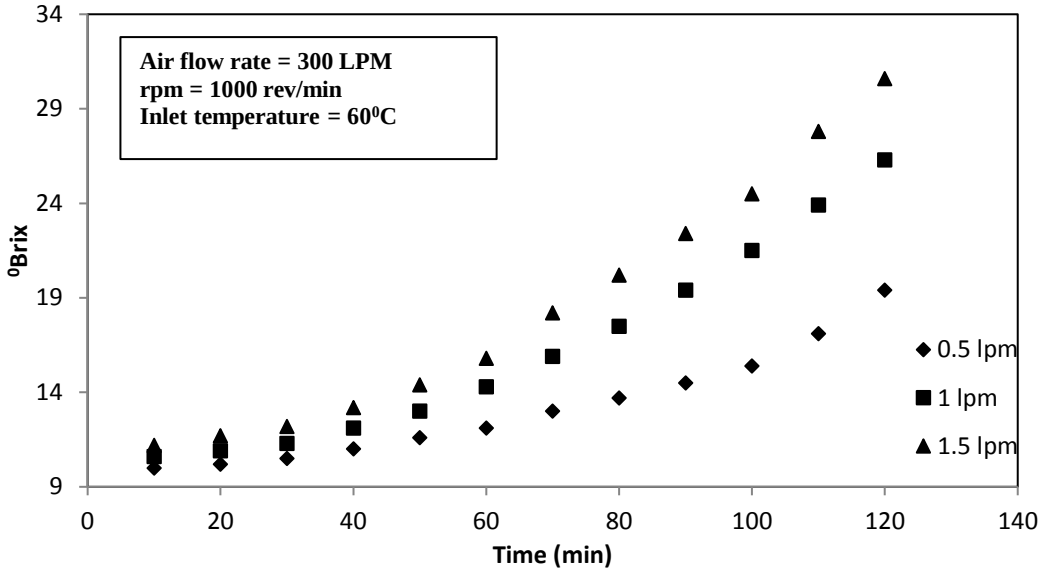

Fig 14: Effect of Solution flow rate on the concentration of Orange juice in ^{0}Brix.

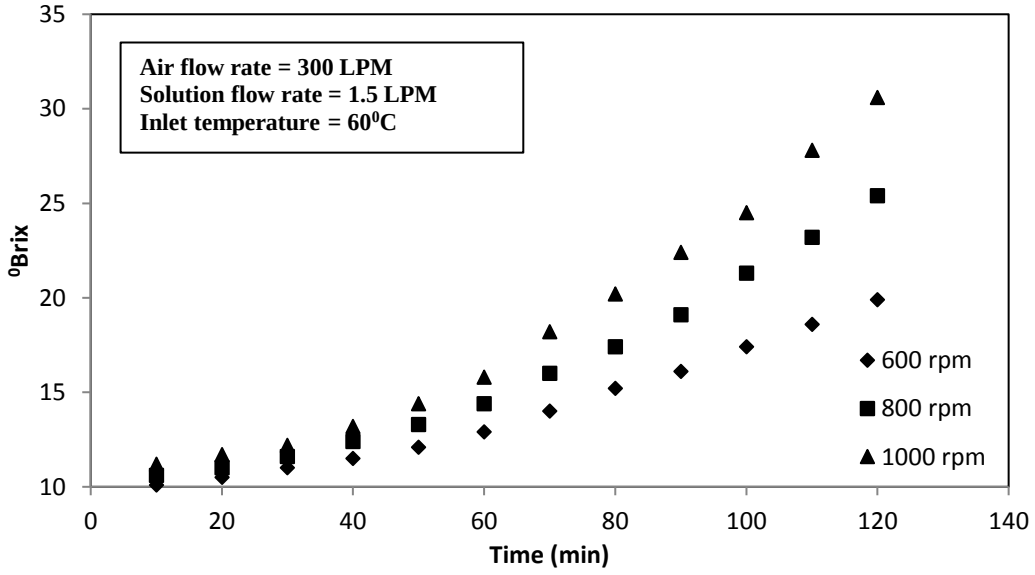

Fig 15: Effect of rotational speed on the concentration of orange juice in ^{0}Brix.

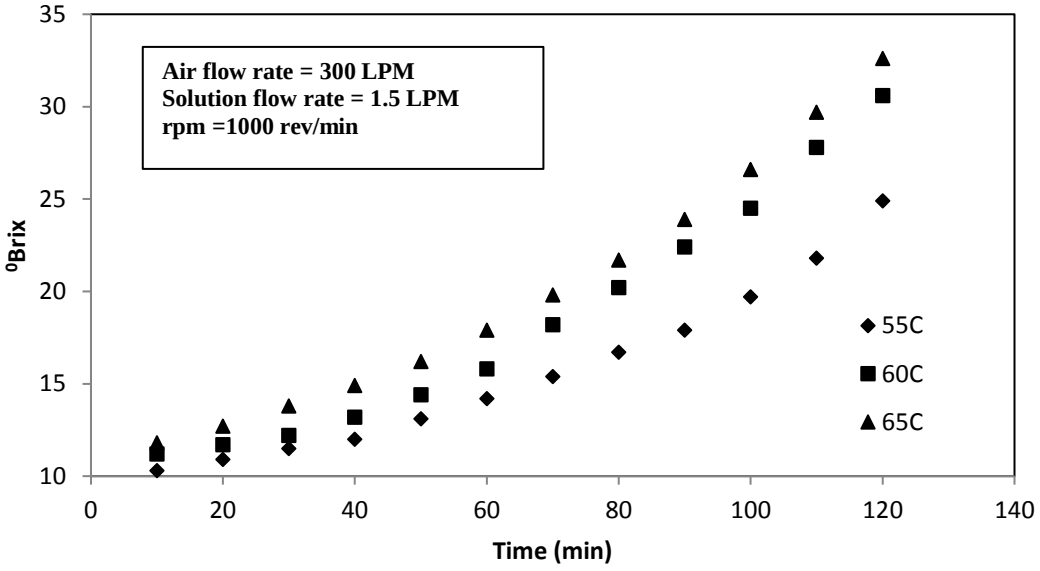

Fig 16: Effect of temperature on the concentration of orange juice in ^{0}Brix.

A comparative study was performed using the RZB, RPB and Wiped film evaporator is shown below in figure 23.

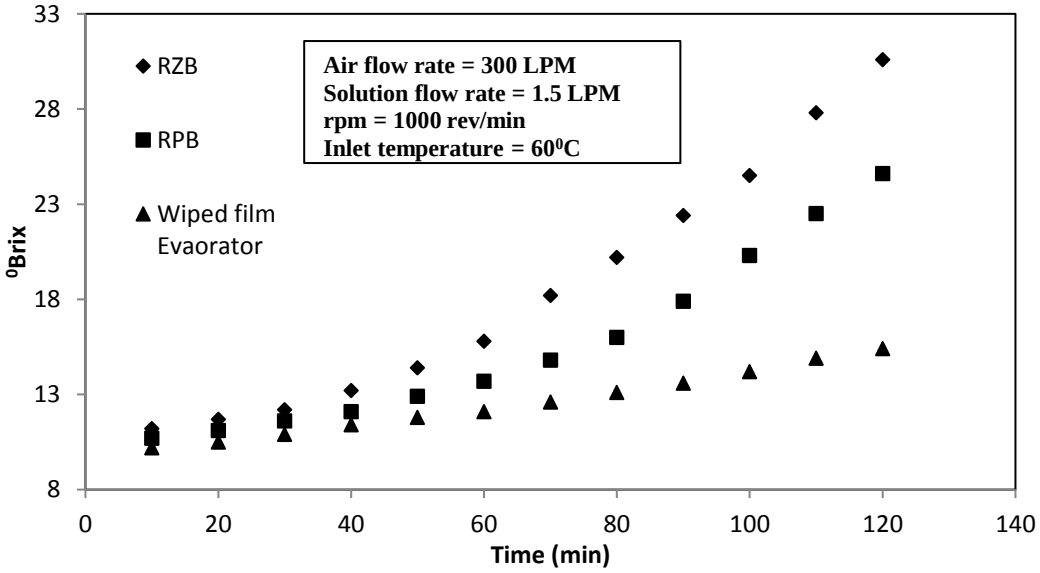

Fig 17: Comparative study on the concentration of Orange juice in RZB, RPB and Wiped film evaporator.

In the graph it is observed that the orange juice is concentrated from 11 ^{0}Brix to 30 ^{0}Brix in case of RZB. This is much higher in comparison to RPB (11 ^{0}Brix to 24 ^{0}Brix), and Wiped film evaporator (11 ^{0}Brix to 15 ^{0}Brix). Echavarria et al., 2012 studied the concentration of various fruit juices using the Ultra filtration along with Reverse Osmosis. In case of the fruit Mandarin (similar to orange) the concentration achieved is from 10.5 °Brix to 22.5 °Brix after 3 hours of operation. Sanchez et al., 2010 reported that freeze concentration or cryo-concentration of the fruit juice resulted in concentration change from 10 ^{0}Brix to 28.8^{0}Brix after 25 hours of operation.

- **Green grapes juice:**

Green grapes or *Vitis vinifera* is a berry type of fruit in the family Viticeae. It is used in wine making along with making raisins, table grapes and alcohol free grape juice. It has a wide range of health benefits which lower the risk of diabetes and ischemic heart diseases, anti-inflammatory in nature and even prevents cancer. It is rich in polyphenols that are potent antioxidants and also vitamin C, dietary fibers and minerals. But regional productivity is the main reason for unavailability of the fruit.

The graphical representation of the effect of operating parameters (air flow rate, liquid flow rate, rotational speed and temperature) on concentration in rotating zig-zag bed is given below.

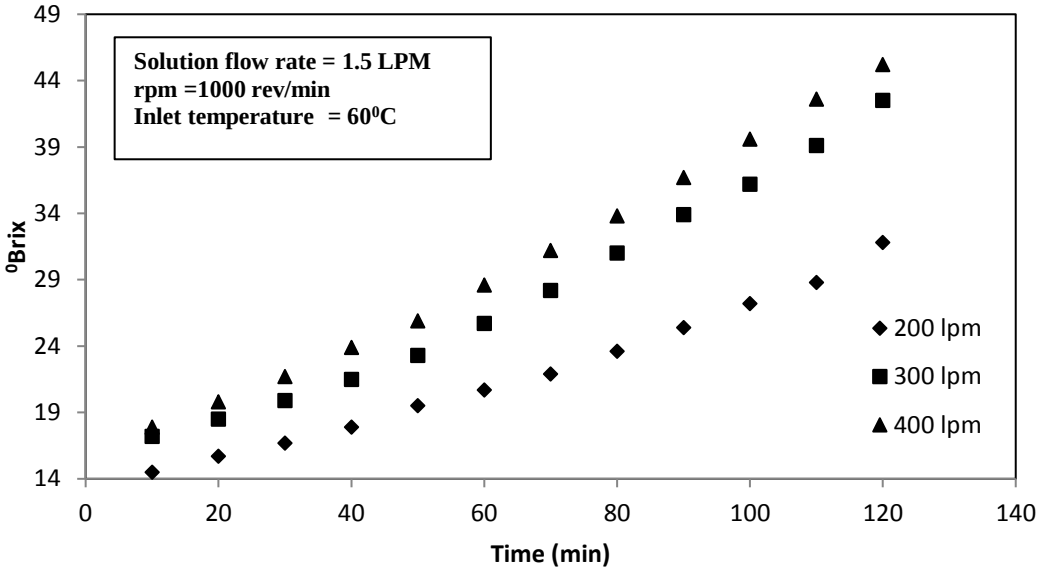

Fig 18: Effect of air flow rate on the concentration of grapes juice in ^{0}Brix.

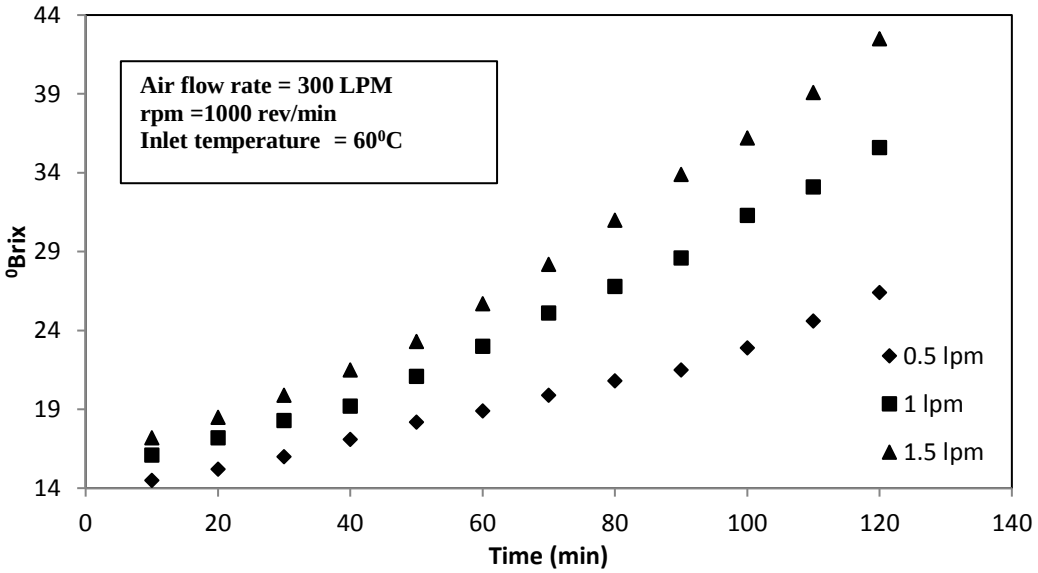

Fig 19: Effect of solution flow rate on the concentration of grapes juice in ^{0}Brix.

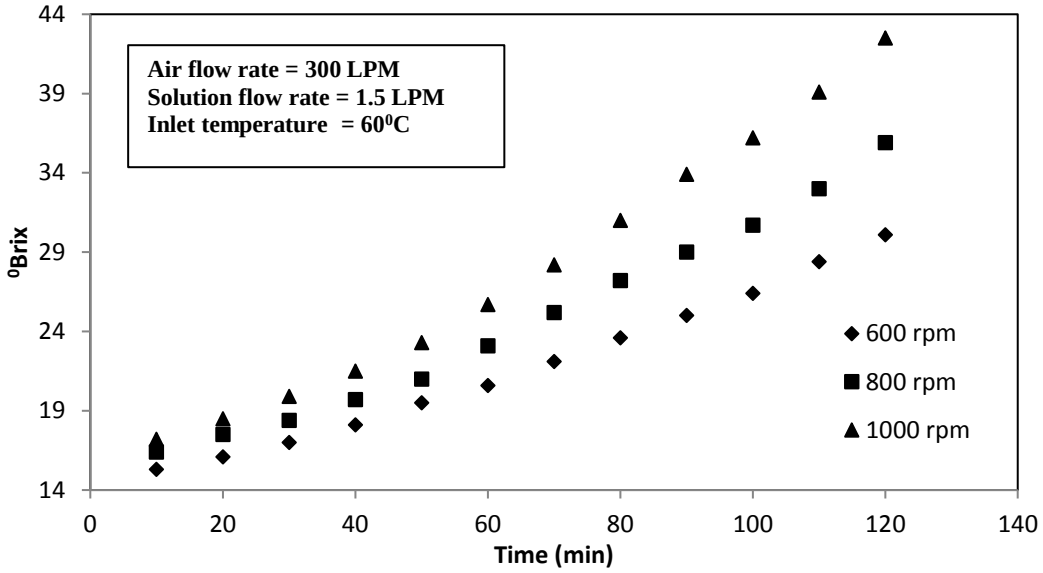

Fig 20: Effect of rotational speed on the concentration of grapes juice in ^{0}Brix.

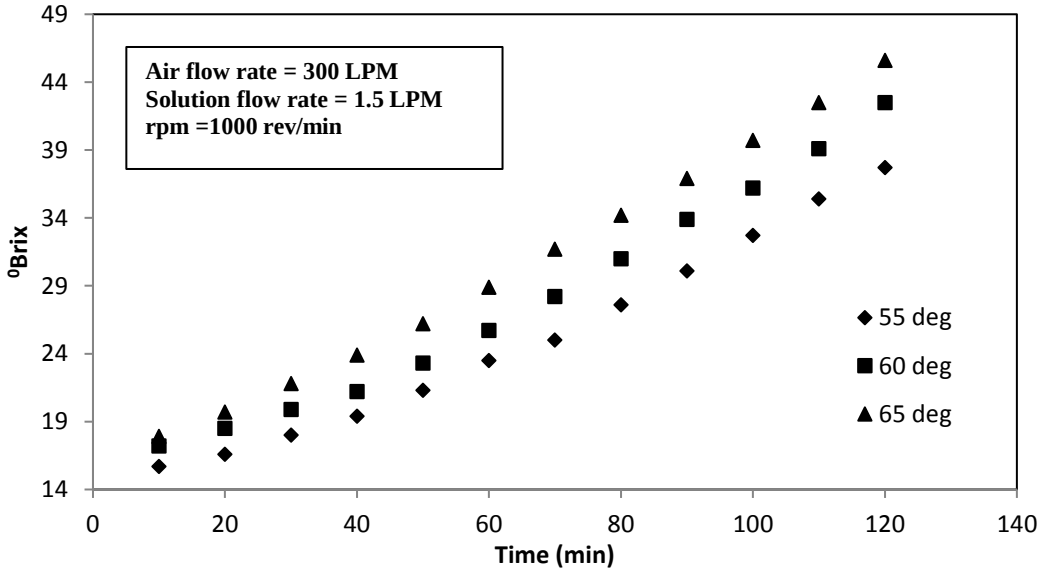

Fig 21: Effect of temperature on the concentration of grapes juice in ^{0}Brix.

The results of comparative study between RZB, RPB and Wiped film evaporator are given below in figure 22.

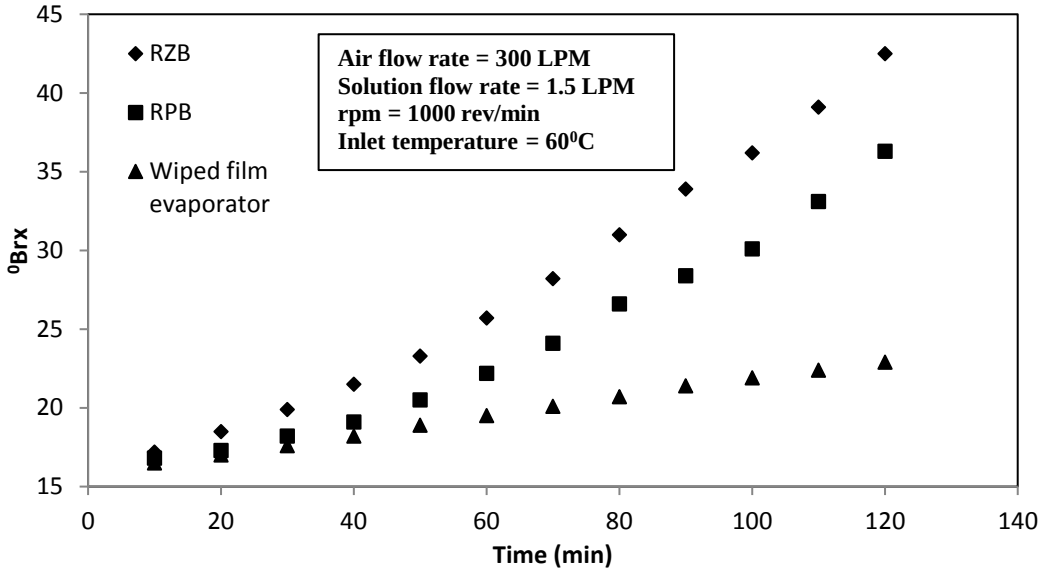

Fig 22: Comparative study on the concentration of Grapes juice in RZB, RPB and Wiped film Evaporator.

It is observed that the juice is concentrated from 17 ^{0}Brix to 42 ^{0}Brix in RZB. The concentration reaches a value of 35 ^{0}Brix in RPB, and 22 ^{0}Brix in case of Evaporator.

- **Watermelon juice:**

Citrullus lanatus or Watermelon is a widely known fruit belonging to the species Cucurbitaceae. 90% of the fruit is water but it is rich source of vitamins, minerals and antioxidants. It is considered that watermelon comprises of lycopene more than any fruits or vegetables. It is also known to prevent diseases like Asthma, Hypertension, obesity, inflammation and diabetes.

The effects of the operational parameters are given below in graphical form.

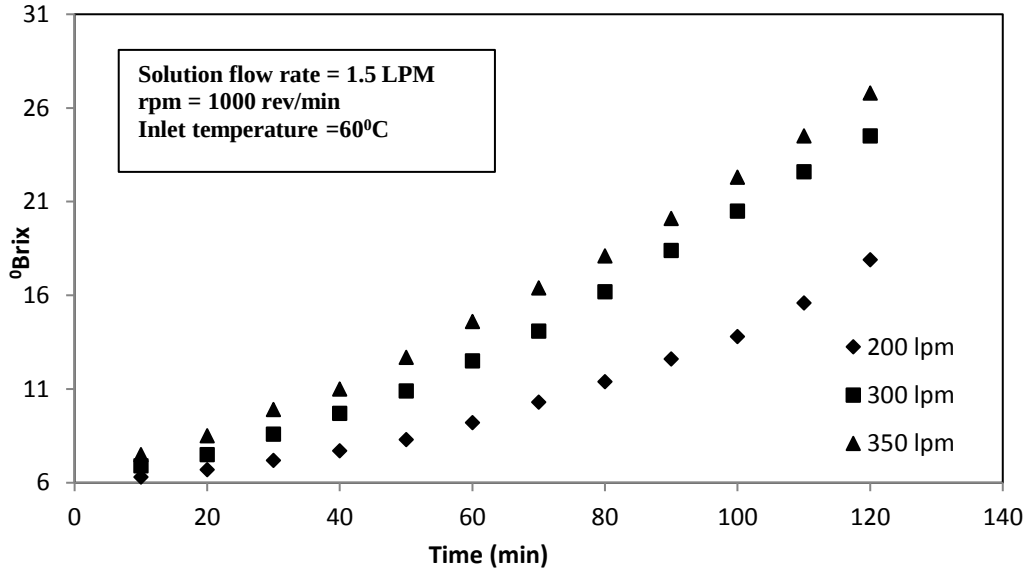

Fig 23: Effect of air flow rate on the concentration of watermelon juice in ^{0}Brix.

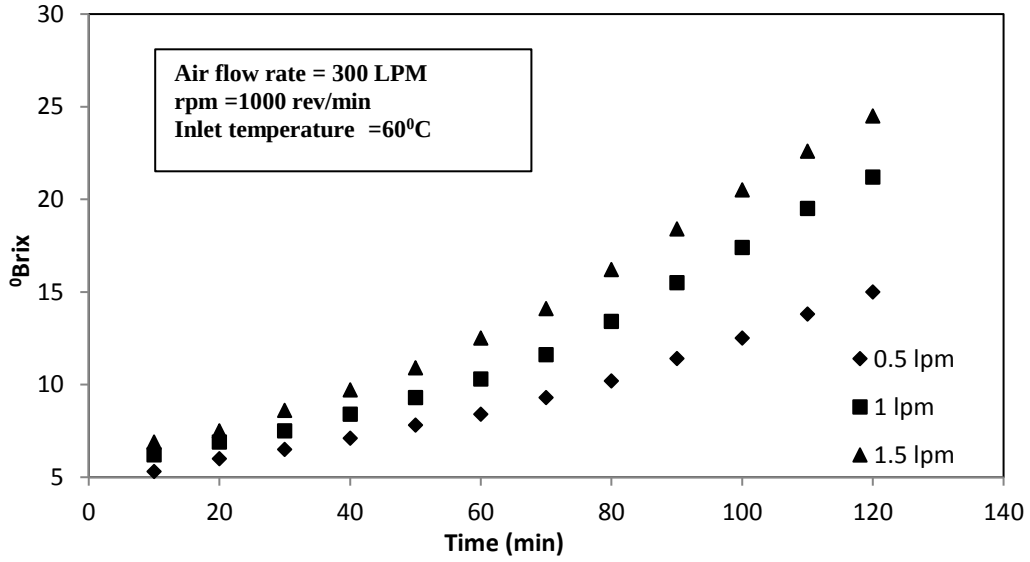

Fig 24: Effect of solution flow rate on the concentration of watermelon juice in ^{0}Brix.

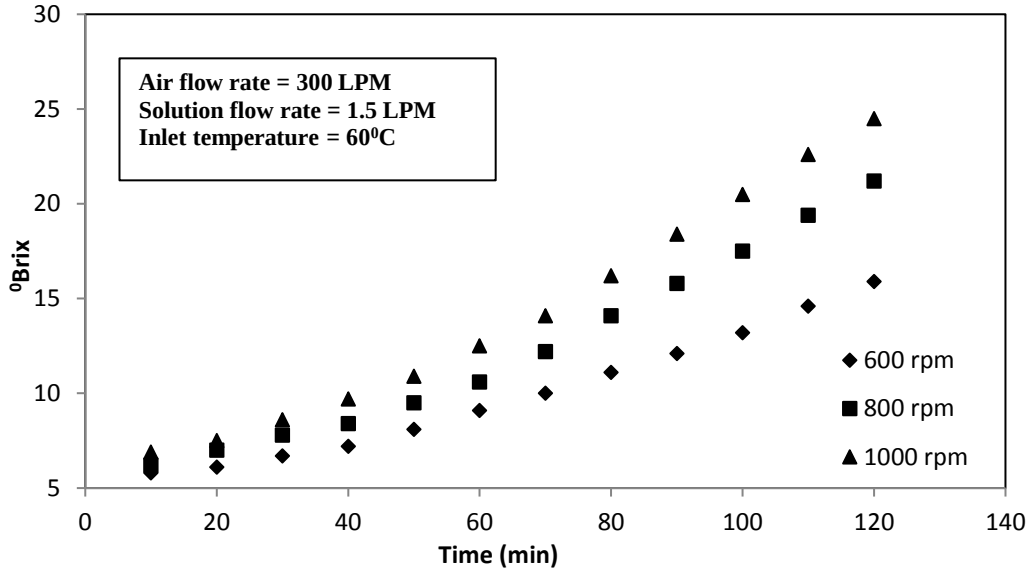

Fig 25: Effect of rotational speed on the concentration of watermelon juice in ^{0}Brix.

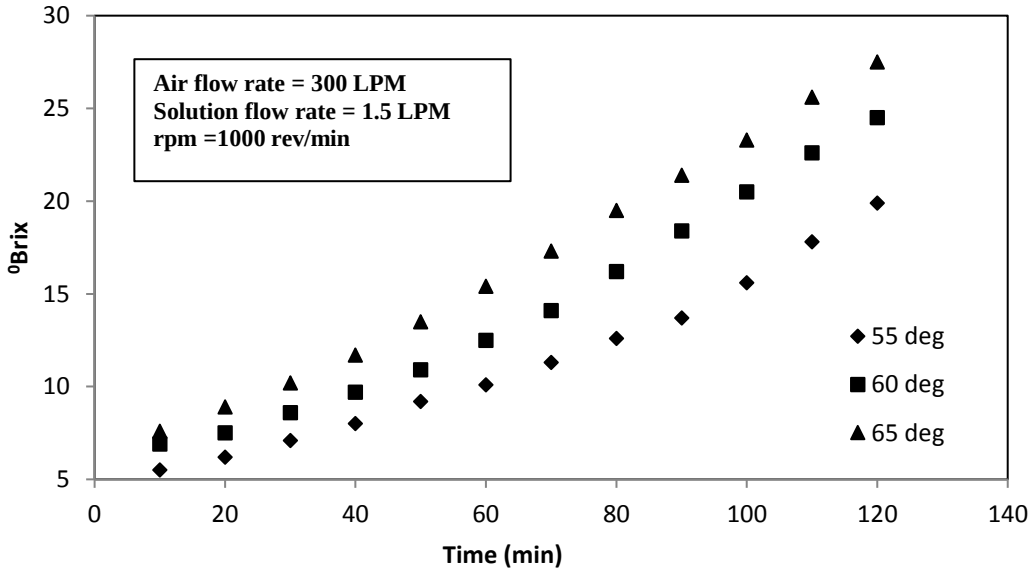

Fig 26: Effect of temperature on the concentration of watermelon juice in ^{0}Brix.

A comparative study using RZB, RPB and Conventional wiped film evaporator is provided graphically.

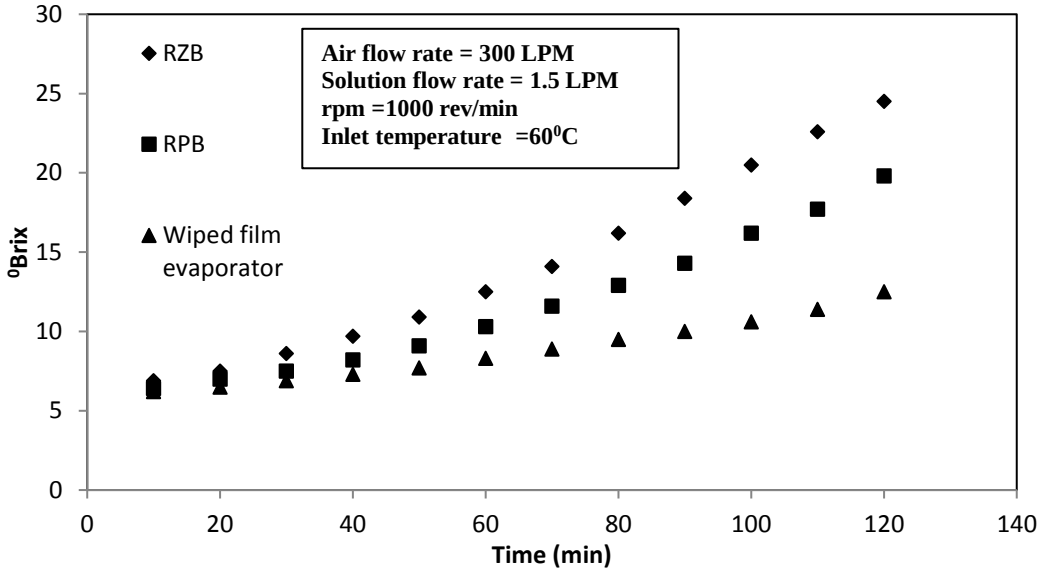

Fig 27: Comparative study on the concentration of watermelon juice in RZB, RPB and Wiped film evaporator.

It is observed from the study that the juice is concentrated from 6.5 ^{0}Brix to 24.5 ^{0}Brix in RZB, whereas from 6.5 ^{0}Brix to 19 ^{0}Brix in RPB, and 6.5 ^{0}Brix to 12 ^{0}Brix in Wiped film evaporator.

- **Pomegranate juice:**

The fruit of Pomegranate or *Punica granatum* has a cluster of juicy gemlike arils on the inside. It is used in making wines and also in making smoothies, juice blends and garnishes. It is a rich source of Vitamin C, K and folate. It also has high content of dietary fibers and minerals. The most dominant phytochemicals in pomegranate are polyphenols and the red color is due to presence of Anthocyanins.

It is very beneficial to health as it prevents cancer and heart diseases. It also helps to reduce inflammation, arthritis, diarrhoea and even prevents Alzheimer's.

The graphical representations of the operational parameters are provided below.

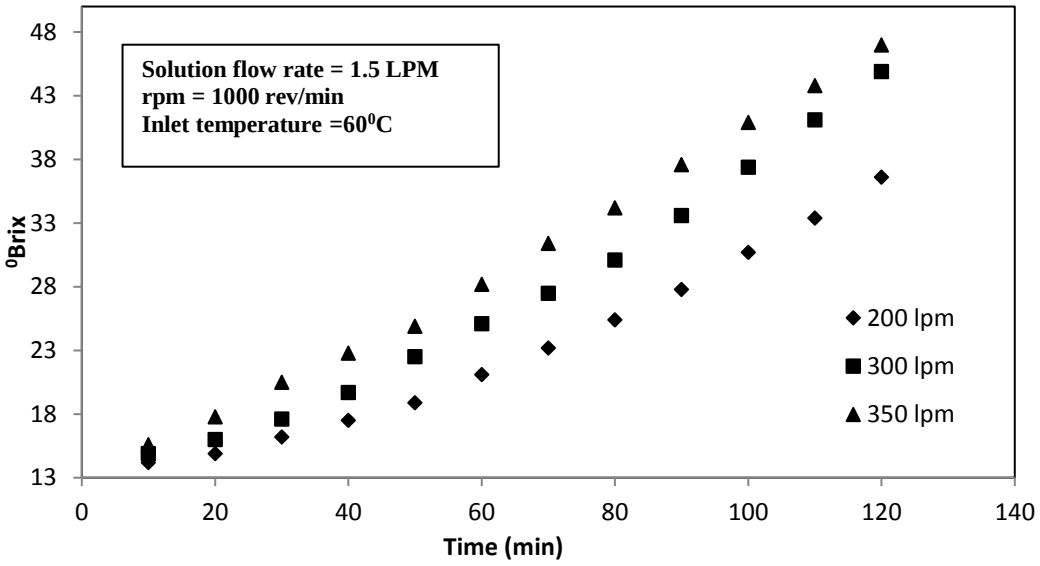

Fig 28: Effect of air flow rate on the concentration of pomegranate juice in ^{0}Brix.

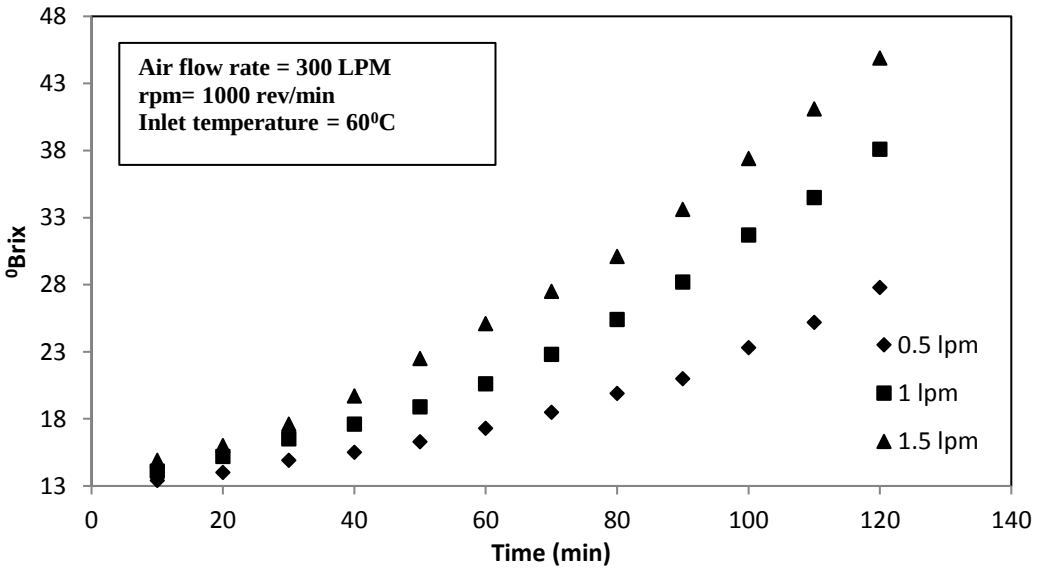

Fig 29: Effect of solution flow rate on the concentration of pomegranate juice in ^{0}Brix.

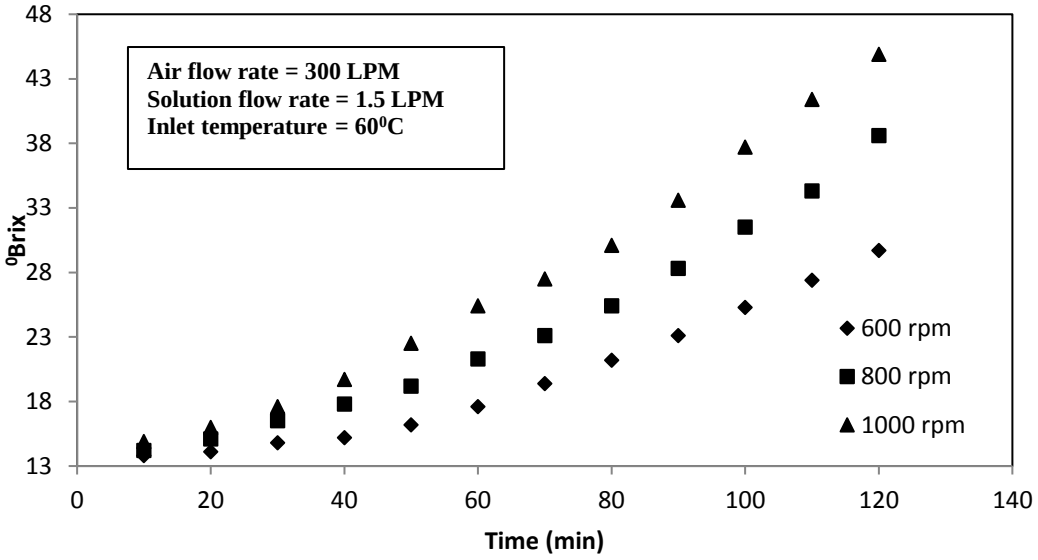

Fig 30: Effect of rotational speed on the concentration of pomegranate juice in ^{0}Brix.

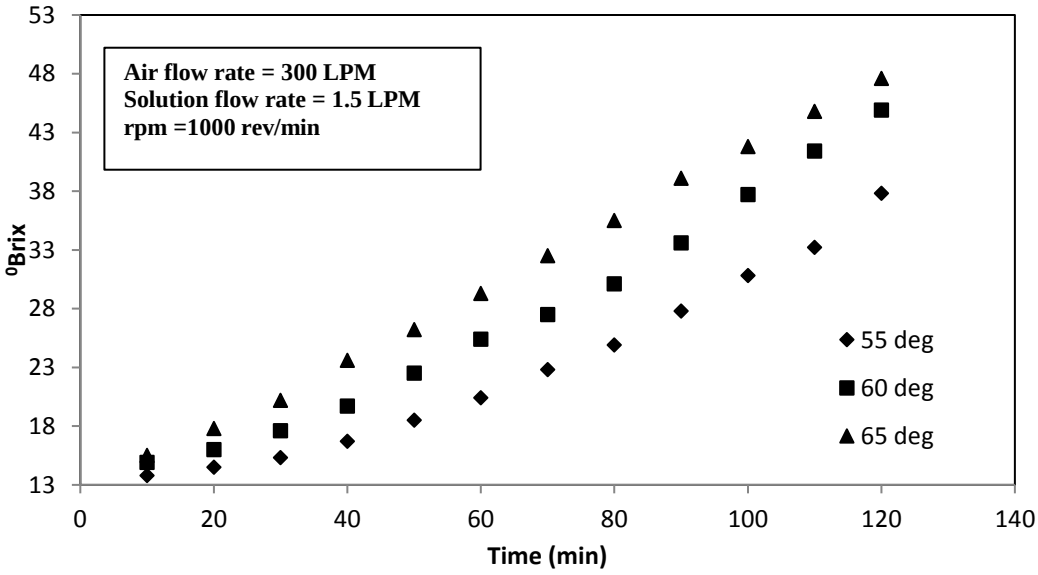

Fig 31: Effect of temperature on the concentration of pomegranate juice in ^{0}Brix.

A comparative study showing the concentration of the pomegranate juice is provided in graphical form below.

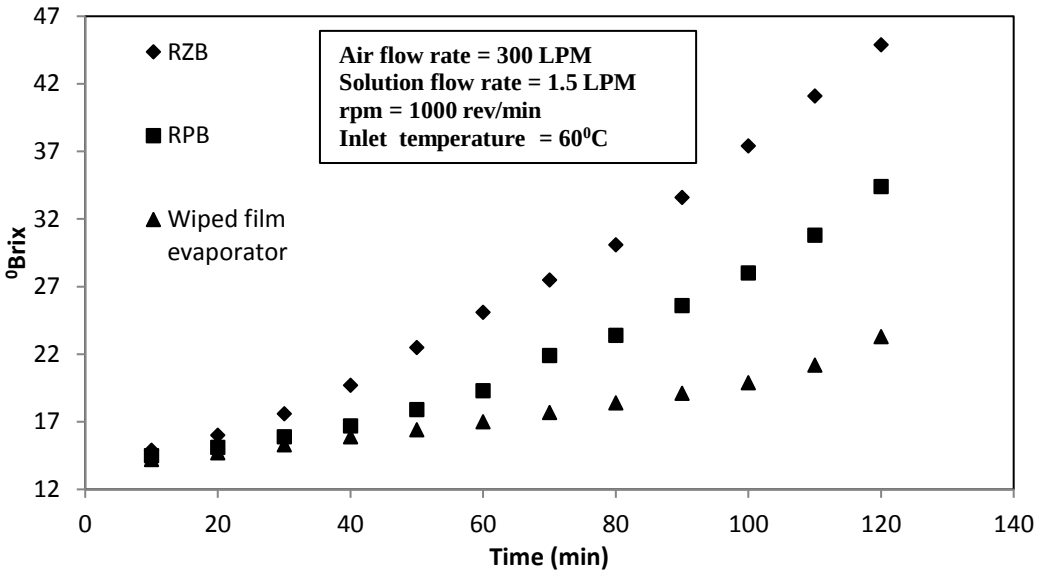

Fig 32: Comparative study of concentration of pomegranate juice in RZB, RPB and Evaporator.

It is observed in the above figure that the concentration obtained in RZB is higher than that in RPB, and conventional wiped film evaporator. The concentration achieved is from 14 ^{0}Brix to 45 ^{0}Brix in RZB, from 14 ^{0}Brix to 35 ^{0}Brix in RPB and 14 ^{0}Brix to 23 ^{0}Brix in evaporator.

- **Black Currant juice:**

Black currant or *Ribes nigrum* are rich in nutrients and antioxidants. It helps to reduce blood sugar level, carotenoids present in it helps to improve eye sight and it even cures cancer. It is also used in wine making. The effects of the parameters are provided below.

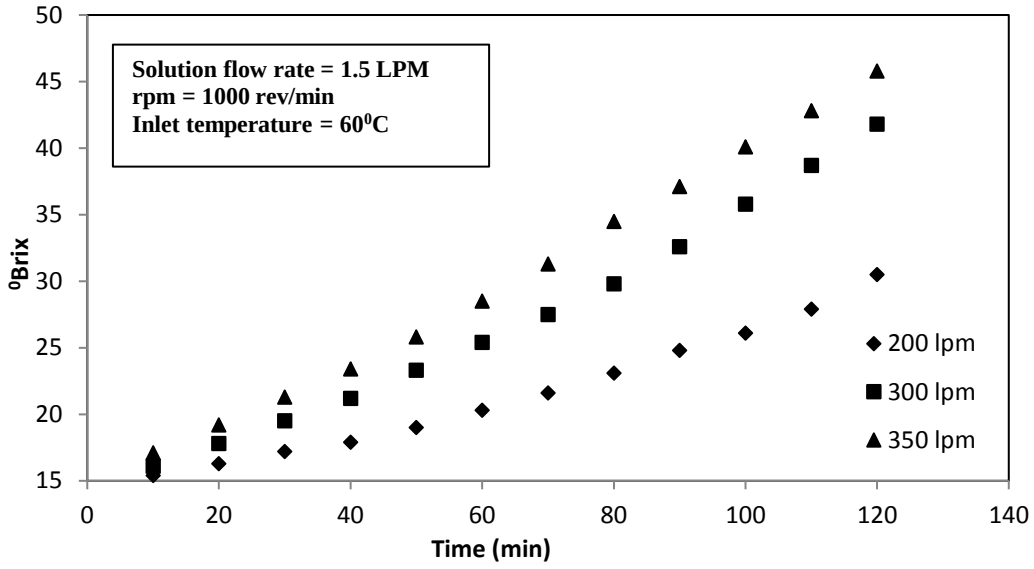

Fig 33: Effect of air flow rate on the concentration of blackcurrant juice.

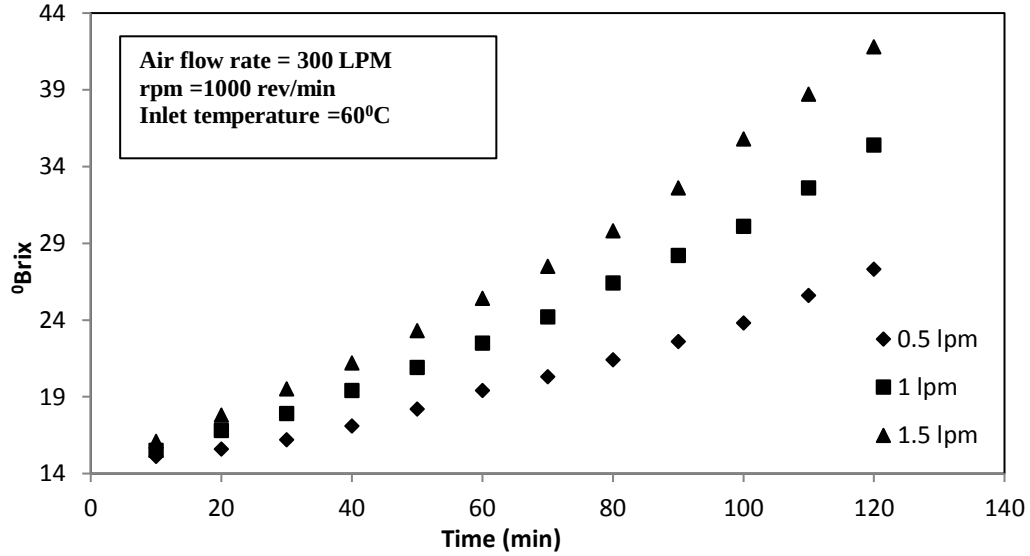

Fig 34: Effect of solution flow rate on the concentration of blackcurrant juice.

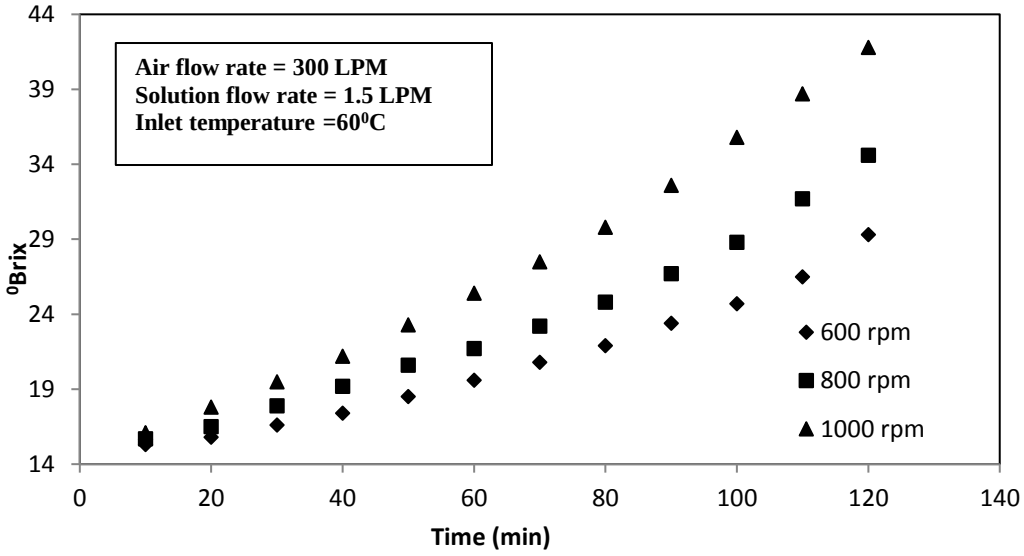

Fig 35: Effect of rotational speed on the concentration of blackcurrant juice.

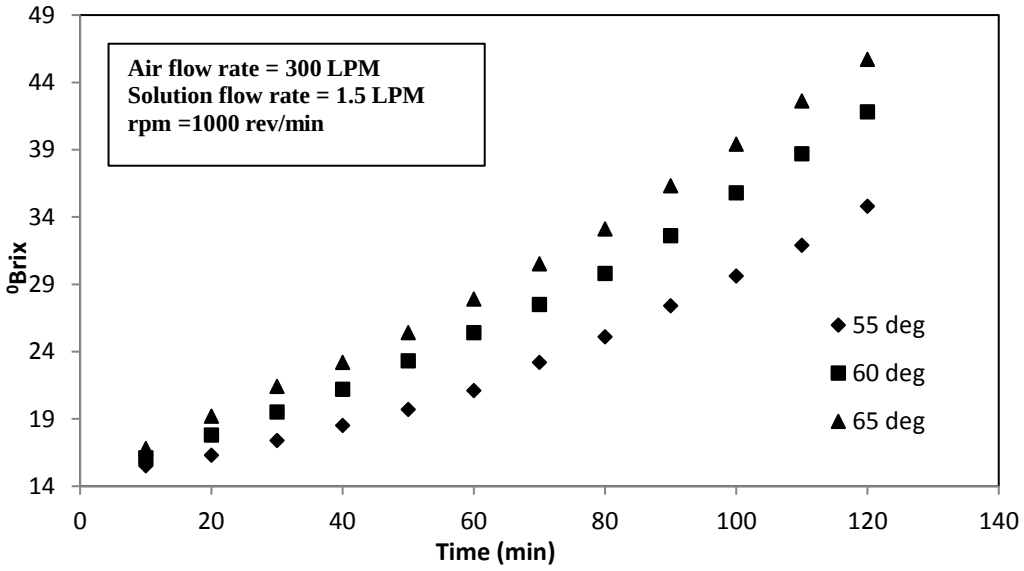

Fig 36: Effect of temperature on the concentration of blackcurrant juice.

A comparative study showing the concentration of the blackcurrant juice is provided in graphical form below.

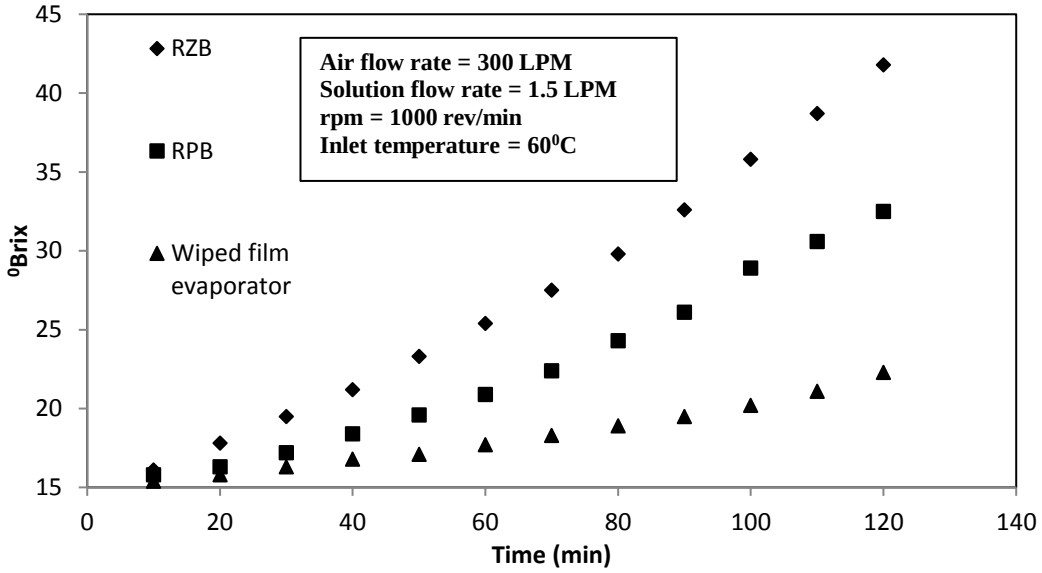

Fig 37: Comparative study of concentration of blackcurrant juice in RZB, RPB and Wiped film evaporator.

It is observed that the juice is concentrated from 16 ^{0}Brix to 42 ^{0}Brix in case of RZB, from 16 ^{0}Brix to 32.5 ^{0}Brix in RPB and from 16 ^{0}Brix to 22.5 ^{0}Brixin wiped film evaporator. Thus from the graphical representation it is clear that the concentration achieved is more in RZB compared to other equipment.

- **Sugarcane juice:**

Sugarcanes or *Saccharum officinarum* are tall perennial grasses of family Poaceae. Sucrose was extracted generally for production of sugar and also for ethanol production. Other products derived from sugarcane are falerum, molasses, rum and bagasses. It is rich in antioxidants which help us in fighting infections and also boosts energy. Due to presence of a large number of

dietary minerals like iron, magnesium and calcium it act as diuretic and strengthens the action of liver. The effects of the operational parameters are provided below.

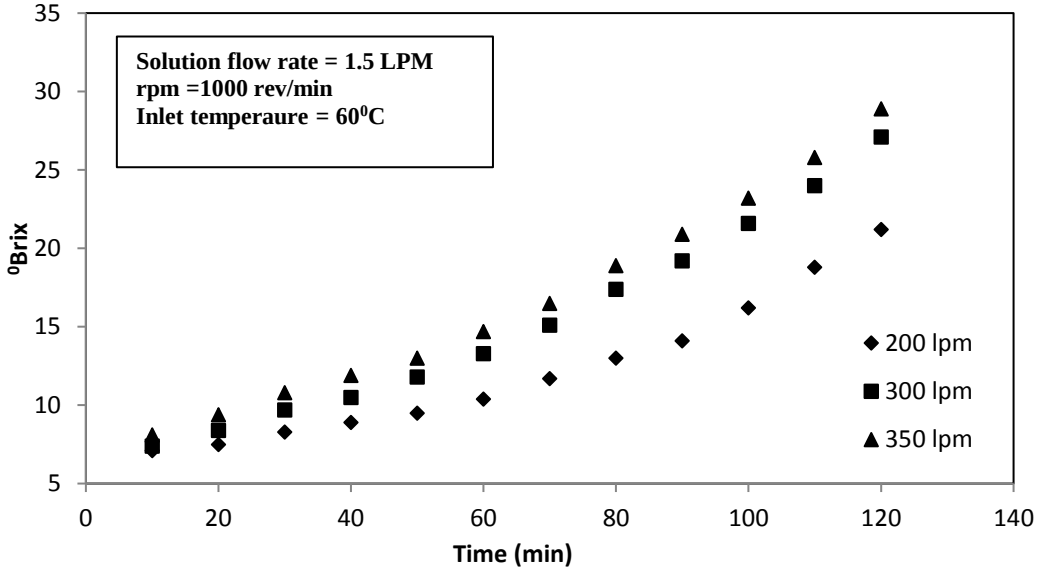

Fig 38: Effect of air flow rate on the concentration of Sugarcane juice.

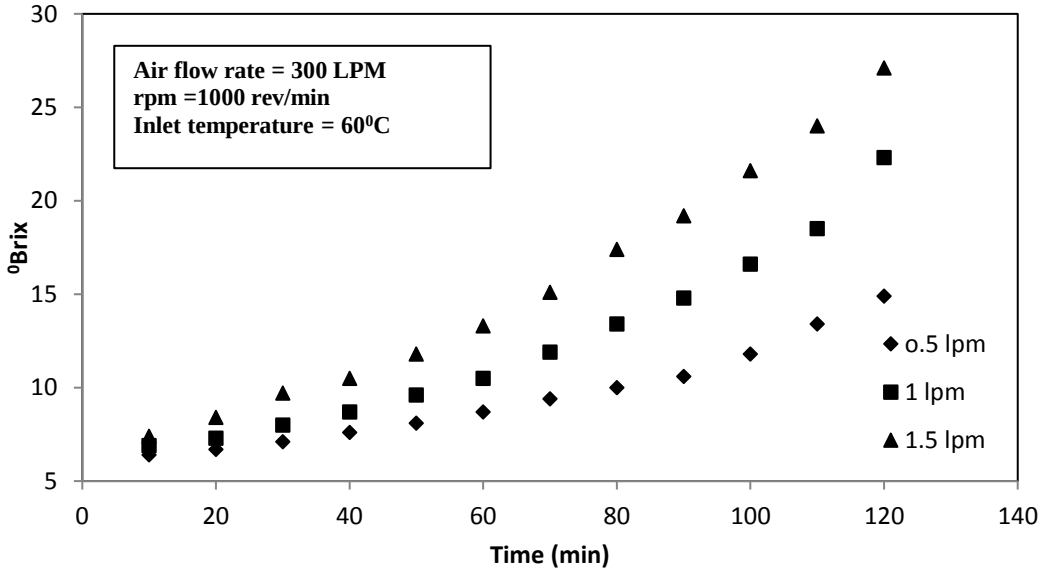

Fig 39: Effect of solution flow rate on concentration of sugarcane juice.

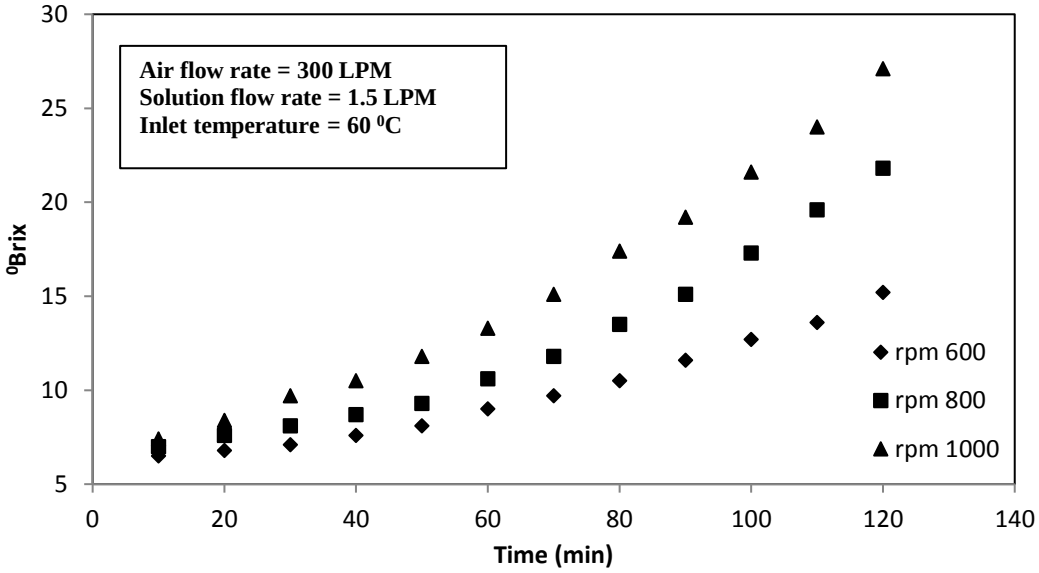

Fig 40: Effect of rotational speed on concentration of sugarcane juice.

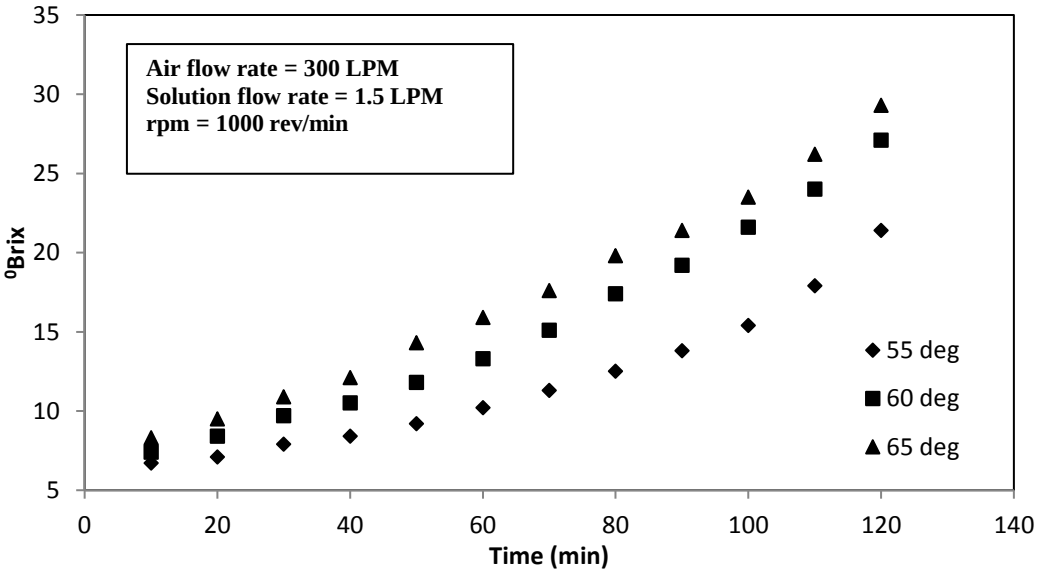

Fig 41: Effect of temperature on concentration of sugarcane juice.

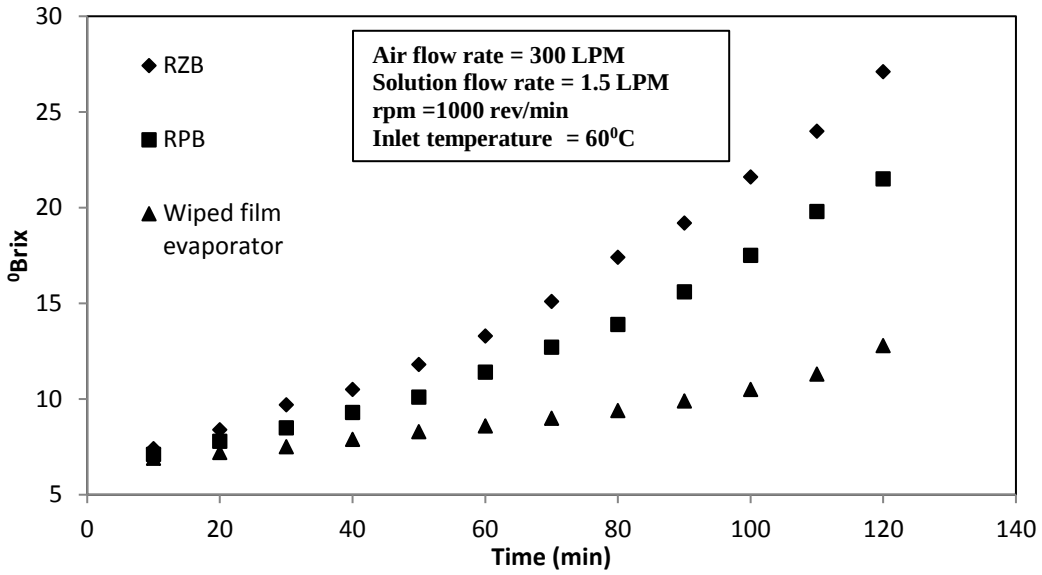

Fig 42: Comparative study on concentration of sugarcane juice in RZB, RPB and Wiped film evaporator.

It is observed that the juice is concentrated from 7 ^{0}Brix to 27 ^{0}Brix in RZB to 21 ^{0}Brix in RPB, and to 12 ^{0}Brixin wiped film evaporator.

13. ACHIEVEMENTS FROM THE PROJECT

- Air stripping in rotating contactor is more energy efficient and time saving technique in comparison to traditional equipment.
- The contactor volume requirement is also lower
- Air stripping in Rotating Zigzag bed could be used as an alternative to conventional evaporators for concentration of juices.

14. SUMMARY OF THE FINDINGS

The objective of the study was to concentrate fruit juice by stripping using a gas (air in this case) to reduce moisture content of fruit juice. The concentration (measured in ^{0}Brix) achieved in a given time in the rotational equipment was compared to conventional wiped film evaporator. The summary of each of these experimental study are given below

- **Comparison with rotating packed bed**:

  The evaporation rate of water in RZB is higher than in RPB.

- **Evaporation of Orange juice**:

  Orange juice could be concentrated within 2 hours from 11 ^{0}Brix to 30 ^{0}Brix in RZB, 11 ^{0}Brix to 24 ^{0}Brix in RPB, and 11 ^{0}Brix to 15 ^{0}Brix in conventional Wiped film evaporator.

- **Evaporation of Tomato juice**:

  Tomato juice was concentrated from 4 ^{0}Brix to 14^{0}Brix in Rotating zigzag bed, 4 ^{0}Brix to 10 ^{0}Brix in Rotating packed bed, and from 4 ^{0}Brix to 7.5 ^{0}Brix after 2 hours of operation.

- **Evaporation of Grapes juice**:

  Grapes juice could be concentrated from 17 ^{0}Brix to 42 ^{0}Brix in case of RZB, upto 35 ^{0}Brix in RPB and 22 ^{0}Brix in wiped film Evaporator.

- **Evaporation of Watermelon juice**:

  The juice could be concentrated from 6.5 ^{0}Brix to 24.5 ^{0}Brix in case of RZB, upto 19 ^{0}Brix up in RPB, and up to 12 ^{0}Brix in Wiped film evaporator.

- **Evaporation of Pomegranate juice**:

  Pomegranate juice could be concentrated from 14 ^{0}Brix to 45 ^{0}Brix in RZB, from 14 ^{0}Brix to 35 ^{0}Brix in RPB and 14 ^{0}Brix to 23 ^{0}Brix in evaporator.

- **Results with evaporation of Blackcurrant juice**:

  Black Currant juice could be concentrated from 16 ^{0}Brix to 42 ^{0}Brix in RZB, and from 16 ^{0}Brix to 32.5 ^{0}Brix in RPB, and from 16 ^{0}Brix to 22.5 ^{0}Brix using wiped film evaporator.

- **Results with evaporation of sugarcane juice**:

  Sugarcane juice could be concentrated from 7 ^{0}Brix to 27 ^{0}Brix in RZB, from 7 ^{0}Brix to 21 ^{0}Brix in RPB, and from 7 ^{0}Brix to 12 ^{0}Brix in wiped film evaporation.

- **Chemical analysis of fruit juice:**

  (a) The pH of the concentrate is nearly same as the feed.

  (b) There is a slight increase in the overall titrable acidity and phenolic content of the concentrate.

  (c) In watermelon and tomato, the Lycopene content increases to a great extent.

  (d) There is a minor reduction in the Ascorbic acid content of the product.

  (e) No significant change in the color of the juice and concentrate was noted.

- **Comparison with wiped film evaporator**:

  Mass Transfer aspect

  (a) Concentration of fruit juice is much slower in wiped film evaporator in comparison to rotating contactor.

  (b) Faster concentration can be achieved is smaller sized rotating equipment

  Energy requirement

  The following equipment of the contactors require electric energy to operate in rotating contactor and evaporator

Rotating contactor: Rotating zigzag bed (450 W), solution tank (where feed was being pre-heated), centrifugal pump (for pumping solution into contactor), and compressor (for pressurizing air to flow through contactor)

Wiped Film Evaporator: motor for rotating wiped blades (180 W), vacuum pump, water pump (for circulating water through the jacket of evaporator), water bath (for generating the hot water for circulation through jacket of evaporator), solution tank (where feed was being pre-heated).

The evaporation rate of water in rotating zig-zag bed at air flow rate of 400 L/min (0.008 kg/s), inlet water temperature of 50 ^{o}C and water flow rate of 1 L/min was determined to be 0.037 kg/min (0.6 g/s). The heat required to be supplied in evaporator (removal is solely dependent on thermal energy) to obtain the same vaporization rate = 0.6 (g/s)x(2240 J/g) = 1344 W. In rotating contactor, concentration of solution is being done by air-stripping. Thus the energy consideration is that of the rotating contactor and energy required to flow air through the contactor. The specific work (work done per unit weight) of a compressor can be calculated from $W = \frac{k}{k-1} RT \left\{ \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right\}$

In rotating contactor $p_2 = 1.2\ atm, p_1 = 1\ atm, T = 303K, k = 1.4$

The total theoretical work done = (mass flow rate of air/s) x specific work = 0.008x17340 = 140 W.

Also required additionally (in comparison to evaporator) in rotating contactor is the energy required to rotate the rotor. The total energy requiring if air stripping is used is

then 0.45 kW + 0.14/0.7 = 0.65 kW (0.7 = efficiency of compressor assumed). Thus the energy requirement is halved using air stripping.

Volume requirement

The volume of only the rotor within which mass transfer takes place in rotating equipment is 0.002 m^3.

The area of heat transfer surface area required for obtaining an vaporization rate of 0.6 g/s is given by $Q = hA\Delta t$

h = heat transfer coefficient, A = surface area for heat transfer, Δt = temperature difference.

Considering tubular form: Δt = 5 ^oC, h = 3.27 KW/m^2K (Hong Chen., 1992), the surface area required for heat transfer A= 0.0.0825 m^2. The volume of the tube on the surface of which evaporation is occurring having diameter 0.18 m will be 0.0037 m^3.

Thus the volume of the rotating contactor will be nearly half of that of evaporator.

15. CONTRIBUTION TO THE SOCIETY

The objective of the project was to explore the possibility of replacing thermal energy conventionally used for concentration of solution (i.e. reduce the water content in the solution) by using unsaturated air. The result indicated that the energy requirement and volume of contactor will be lowered. The benefits of the society will be

- The cost of concentration will be reduced resulting in lower cost of product.

- The results suggest that the equipment size can be drastically decreased. This implies that the space requirement for carrying out the process can be reduced. The small sized equipment can be more easily transported to hilly terrain helping in development of industry in these regions.

16. WHETHER ANY PH.D. ENROLLED/PRODUCED OUT OF THE PROJECT

Yes one PH.D. candidate is enrolled in the project.

Name of The candidate: Moumita Sharma

Ph.D. Registration no: D7/E/1005/16 of 16-17.

17. NO. OF PUBLICATIONS OUT OF THE PROJECT

- Received Best Paper award in Oral presentation in the Category Transport Phenomena with paper titled “Effective Concentration of sucrose solution by Air Stripping” at National Conference CHEMCON, 2017 held at Haldia Institute of Technology, West Bengal.
- Manuscript to be communicated.

(PRINCIPAL INVESTIGATOR) **(REGISTRAR/PRINCIPAL)**
(Seal)

(CO-INVESTIGATOR)

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