

## Ultrafiltration of Tunisian Cactus Juice for Industrial Use

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### Abstract

This paper aims to contribute to the optimization of a membrane based process for the clarification, concentration and preservation of Cactus cladodes juice for an industrial use. The performance of the membrane-based process was evaluated on the basis of the quality of products and its effect when used in water treatment. First, a study of the different parameter was conducted when processing the ultrafiltration, water activity and bio-flocculant activity were measured to validate our work Yield obtained when treating water in cactus juice ultrafiltered with a 300 kDa membrane module are between 40 and 47%, and between 90 and 96% for those treated with 0.1  $\mu\text{m}$  membrane.

**Keywords:** Concentration; Water treatment; Membrane; Bio-flocculant

### Introduction

Cactus plant (*Opuntia ficus indica*; *Opuntiaspp.*, *Cactaceae*) is associated with the semi-arid zones of the world and it grows well in areas like Africa, Australia, the Mediterranean region, Mexico. The major components of the cladodes are water (91%), carbohydrate vary from 64 to 71%, protein (8.3-13.25%) [1], lipid (2.4-7.2%) [2]. The lower water activity of the concentrated juice relative to the natural juice is a clear protection against the growth of microorganisms and can extend the self-life of the juice. In addition, package, storage and costs are remarkably reduced [3]. The basic properties of membrane operations make them ideal in the production of fruit juices with high quality, natural fresh taste and additive-free. They are generally no thermal and do not involve phase changes or chemical additives; besides, they are simple in concept and operation and characterized by low energy consumption [4].

Juice clarification, stabilization and concentration are typical steps where membrane processes as ultrafiltration has been successfully utilized [5]. The extracted juice from cladodes has shown important results in water treatment. As a bio flocculant, the juice has shown a rapid reaction when added in water. The flocculation process was accelerated, only by using whitewash with or other additives to activate the electronic charges. Many experience were held in this field, the cladodes juice, while added in water, can eliminate; Copper, Zinc and Chrome [6,7].

### Nomenclature

Aw: Water Activity

Aw<sub>0</sub>: Initial water Activity

Aw<sub>1</sub>: Water Activity after treatment

Jw: Evaporation flux ( $\text{kg}\cdot\text{min}^{-1}\cdot\text{m}^{-2}$ )

Q<sub>f</sub>: Permeate flow rate ( $\text{L}\cdot\text{h}^{-1}$ )

TMP: Transmembrane pressure (bar)

S: Membrane surface ( $\text{m}^2$ )

Pa: Inlet pressure (Bar)

Pb: Outlet pressure (Bar)

Patm: Atmospheric pressure (Bar)

R: Juice yield (%)

N<sub>0</sub>: Initial absorbance

N<sub>f</sub>: Absorbance after treatment Initial

MCF: Mass concentration factor

V<sub>0</sub>: Initial volume (ml)

V<sub>r</sub>: Retentat volume (ml)

### Materials and Methods

#### Juice extraction

Cactus cladodes were cultivated from 2 regions in Tunisia: The *Opuntia ficus indica* were collected from La Marsa (North of Tunisia), their length vary from 34 to 46 cm, from 21 to 29 cm width and its thickness varies from 2 to 4 cm. The *O. ficus inermis* from Rafraf (North of Tunisia) are 30 to 42 cm length, 15 to 21 cm width and 2 to 2.5 cm thickness. The cladodes were peeled manually, with a knife, and grinded. The juice was purified before the ultrafiltration step. Then it was stored at 4°C until use.

#### Characteristics of the ultrafiltration unit

Cactus cladode juice was clarified by using a pilot unit; model UFA/1000/S brand Pignat (France). The equipment consists of a feed tank, a feed pressure pump, two manometers located at the inlet and outlet of the membrane module. For better results and comparison of the water elimination and water activity to be optimized later, two membrane modules were used, one of 0.1  $\mu\text{m}$  and the other of 300 kDa. The experiences consist on concentrating the juice using the ultrafiltration method. 3 liters of cladode juice was used for every essay. The ultrafiltration was used on moderated rotor frequency of 30 Hz, and a trans-membrane pressure not exceeding 3 bars. Experiments using a 300 kDa module were held for 8 h, a 0.7 liters were obtained from 3 L. Those with a 0.1  $\mu\text{m}$  module were held for about 3 h. Other researchers like Cassano et al. held the experiment for 4 hours. The temperature of juice coming out of the feed tank was 28°C.

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$$\text{Evaporation flux: } J_w = \frac{m}{t * S} \text{ (kg.min}^{-1}.m^{-2}) \quad (1)$$

$$\text{Permeate flow rate: } Q_f = \frac{m}{t} \text{ (L.h}^{-1}) \quad (2)$$

$$\text{Transmembrane pressure: } TMP = \frac{p_a + p_b}{2} - P_{atm} \quad (3)$$

With S: membrane surface (m<sup>2</sup>), Pa: Inlet pressure (Bar), Pb: outlet pressure (Bar)

Patm: atmospheric pressure (Bar)

Also the Mass concentration factor has been calculated. It is given by:

$$MCF = \frac{V_0}{V_r} \quad (4)$$

With V<sub>0</sub>: Initial volume (ml)

V<sub>r</sub>: Retentat volume (ml)

### Bio-flocculant activity

The ultrafiltered juice was used to treat water. A spectrophotometer was used to measure the absorbance and the yield was calculated. All is conducted from the Jar Test method. First the pH of waste water was adjusted. For every 100 ml, 0.3 g of quicklime were added. The mix was agitated 2 min at high speed, than left to settle. For each experiment, we have used 30 ml and added different quantities of cactus juice. Optimized results were represented. Yield is based on the absorbance values. Initial value of absorbance is 1.7. Juice yield values are based on the absorbance which is given by the following equation.

$$R = \frac{N_0 - N_f}{N_0} \times 100 \quad (5)$$

With: N<sub>0</sub>: Initial absorbance, N<sub>f</sub>: Absorbance after treatment

## Results and Discussion

### Study of ultrafiltration process

Table 1 shows experimental results concerning the ultrafiltration process of cactus cladode juice.

### Mass concentration factor

Table 2 below gives MCF of ultrafiltration. When using a 1000 kDa membrane, the juice of the *indica* specie was concentrated for 53.33% from 0.932 to 0.923 and for 24% when using a 300 kDa membrane module. Also, for the *inermis* specie, the water activity was reduced from 0.920 to 0.912 when using 1000 kDa membrane and a concentration factor of 2.09. For the 300 kDa module, the MCF is 1.3 and water activity was reduced to 0.915. The juice was pumped through the shell and the tube side of the membrane module. The rotor frequency was 30 Hz. The juice was recycled back to the tank. Its temperature at the beginning was ambient temperature, but due to the pump heat and circulation in the tube, the juice temperature reached 29 ± 2°C.

The Transmembrane pressure was fixed. Inlet membrane pressure was 2.2 bar and outlet pressure was 1.1 bar  $TMP = \frac{2.2+1.1}{2} - 1.013 = 0.65$  bar. The same parameters were used for both membrane modules. Figures 1 and 2 give us an idea about the volume of permeate and flux as function of time for two different membrane modules. Also Figure 3, represents the flux evaporation as function of time. In the range 0-2 hours, the decrease of the evaporation flux can be remarkable by the increase of the permeate from 0 to 0.16 l for the 300 kDa module and from 0 to 0.89 L for the 0.1 µm module for the *inermis* variety. The same for the *indica* cladode juice, in the range 0-2 hours the permeate increased from 0 to 0.18 L for the 300 kDa module and from 0 to 0.92 L for the 0.1 µm module. In the range of 2 to 5.5 hours for the 300 kDa module, the decrease of the flow rate is due to concentration of the juice, and as a

result the evaporation flux had also decreased from 2,84 to 1,036 for the *inermis* variety and from 3,36 to 1,24 for the *indica* variety.

But for the 0.1 µm module, in the range of 2 to 3.5 hours, the evaporation flux had decreased from 6.95 to 3.97 for the *inermis* variety and from 7.18 to 4.10 for the *indica* variety. The concentration of the juice is not important in the first 3 hours, so the juice viscosity remained almost constant for the 300 kDa membrane module, but it is remarkable that after 3 hours, about the half of the juice water was extracted by the 0.1 µm membrane module, as a result, the viscosity has changed [4]. In the range of 4 to 9 hours for the 300 kDa module, the flux decay is more attributable to the exponential increasing of the juice viscosity. These observations confirm date reported in literature [3] concerning the concentration of passion fruit. These results can be attributed to a stronger shear stress along the condensation side of the membrane [4].

### Effect of concentrated juice on synthetic water treatment

The experiments of coagulation and flocculation using cactus juice on synthetic water containing different concentrations of phosphate, different pH and volumes of juice are given in Table 3. From this Table 3 it is clean that using a 0.1 µm membrane module gave a better yield. They are over 90% which is considered a good result, about all phosphate was coagulated. But for a membrane of 300 kDa, the yields didn't give the same results. Maximum of 47% was obtained. Mostly is it up to the concentration of juice used for water treatments and the phosphor concentration may also have affected the coagulation process. In All cases, objectives were successfully achieved and we can conclude that using cactus juice is an interesting way to water treatment.

## Conclusion

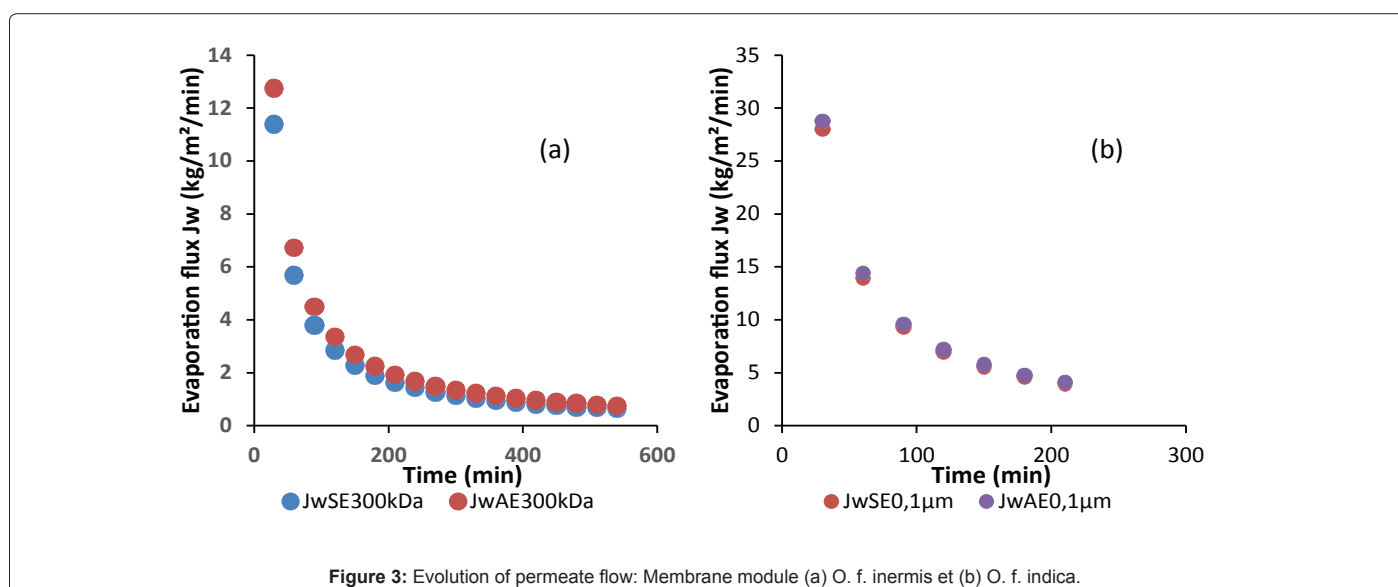
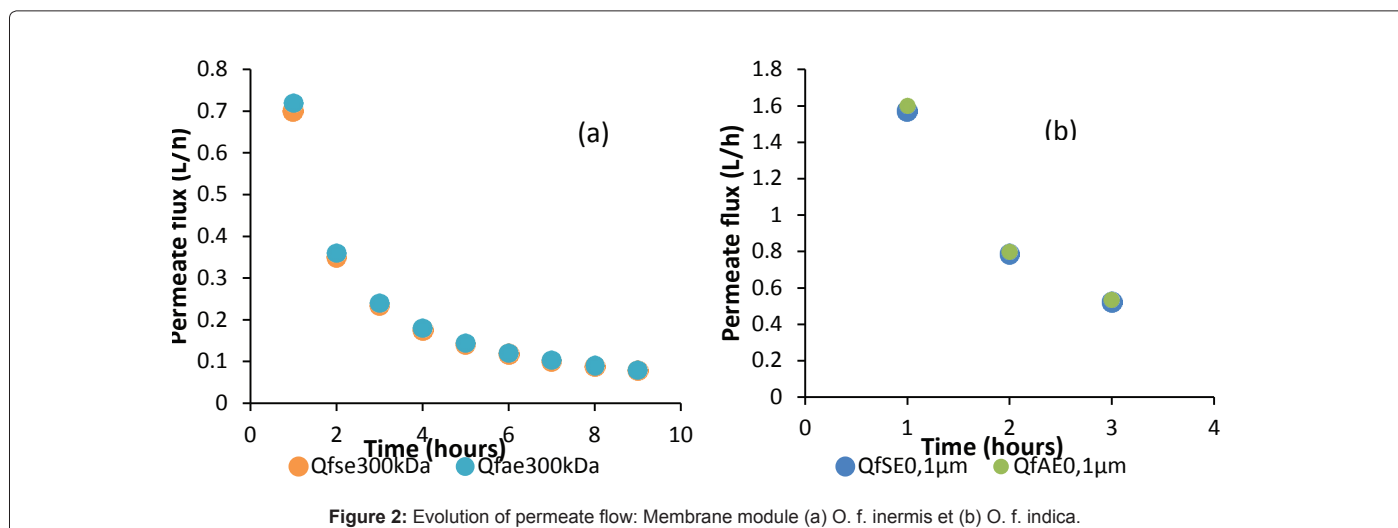
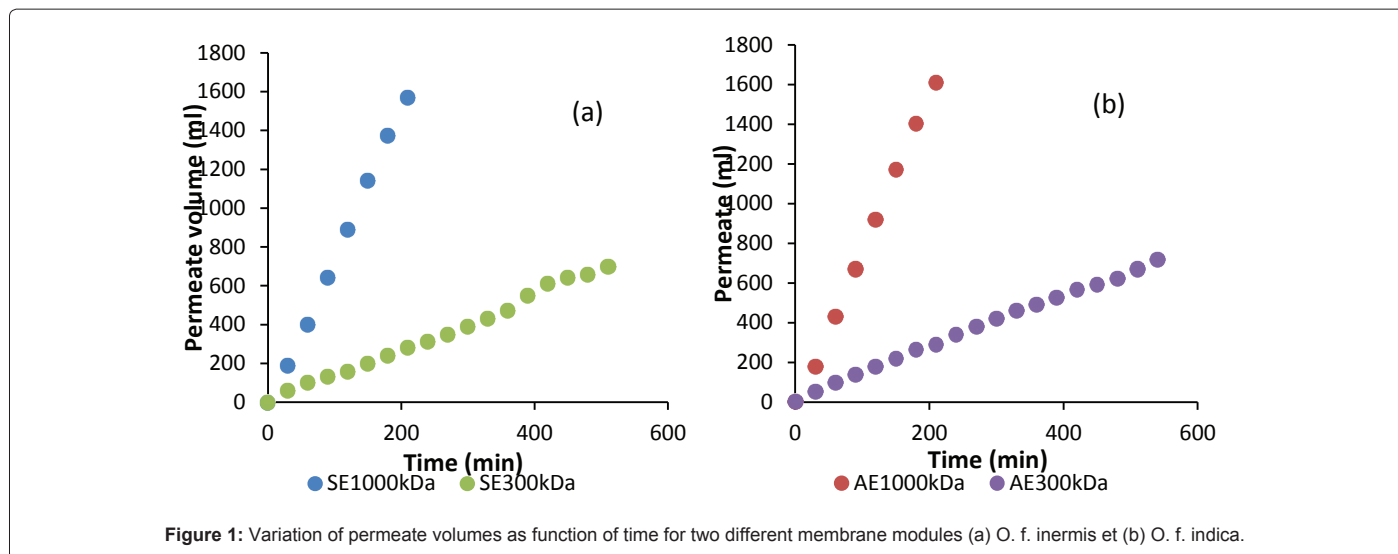
The concentration process represents a valid approach to process the juice at low temperatures, in a no thermal process for an industrial uses like water treatment. The results, after a reduction of water content are not sufficient to have an idea about the stability of the juice. The water activity was note reduced enough even after 53% concentration. The experiences must be optimized to reduce water activity. In this case other proceeds can be used after ultrafiltration like osmotic distillation. The coagulation effect is still present, but the yield and the quantity to use for water treatments should be verified. The concentration of juice with a 0.1 µm membrane module has shown better results when used for the coagulation-flocculation.

Cactus Species	Membrane module (kDa)	A <sub>w0</sub>	Retentate (L)	A <sub>w1</sub>	Permeate (L)
<i>Indica</i>	1000	0.932	1.4	0.923	1.6
	300		2.28	0.924	0.72
<i>Inermis</i>	1000	0.920	1.43	0.917	1.57
	300		2.3	0.915	0,7

Table 1: Water activity values before and after juice concentration.

	Module (kDa)	MCF
<i>O. ficus indica</i>	1000	2.16
	300	1.13
<i>O. inermis</i>	1000	2.09
	300	1.3

Table 2: Mass concentration factor.



Membrane diameter	Liquid type	Volume (ml)	pH	Phosphate concentration (mg/l)	Cactus specie	Yield
300 kDa	Retentate	2	9.5	5	<i>Indica</i>	47%
					<i>Inermis</i>	44%
	Permeate				<i>Indica</i>	45%
					<i>Inermis</i>	40%
0.1 µm	Retentate	4	9.5	15	<i>Indica</i>	94%
					<i>Inermis</i>	96%
	Permeate				<i>Indica</i>	91%
					<i>Inermis</i>	90%

**Table 3:** Optimized results of the coagulation flocculation with concentrated juice.

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