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# Evaluation of Energy Requirement – Direct Contact Membrane Distillation for Orange Juice Concentration

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**Abstract.** This paper presents a study of energy requirements of membrane distillation (MD) for lab-made flat module designs of length 11.5 cm, breadth 10 cm and hydraulic diameter 2.28 mm is supported with stainless steel holding device. Module has effective membrane area $0.0115m^2$. The concentration of Orange was carried out by direct contact membrane distillation using PTFE and PVDF membrane having pore size 0.2 μm and porosity 70%. Cross flow module has been developed with the help of viton gasket, polyester mesh and adhesive. In DCMD, the effect of the operating temperatures and streams flow rates on the flux, the evaporation efficiency and the energy consumption, was studied. The best result in terms of energy consumption and evaporation efficiency were obtained at feed flow rate and temperature of 84 Kg/h and 50 oC, respectively.

**Keywords:** Transmembrane flux, PTFE, Evaporation efficiency, Orange juice.

## 1. Introduction

Orange juice is probably the best known and most widespread fruit juice all over the world, particularly appreciated for its fresh flavour and considered of high beneficial value for its high content in vitamin C and natural antioxidants, such as flavonoids and phenylpropanoids. The oranges have all the nutrients, which can keep heart healthy. An orange contains sugar 10-12%, Ascorbic Acid (Vitamin C mg/100 ml) 25-30, Vitamins 'B' complex (microgram/100 kg) 550, Fat 0.3%, Fibre 0.6%, Protein 0.9%, Sodium (mg/100 gm) 2.2, Potassium (mg/100 gm) 155, Iron (mg/100 gm) 0.2-0.3 and Phosphorus (mg/100 gm) 16-17. Membrane Distillation, a separation process based on evaporation through pores of a hydrophobic membrane. The driving force for membrane processes may have quite a difference character; very often, it is concentration gradient or an electrical potential gradient. Membrane Distillation is a thermally driven process. Although thermally driven process have been known for many years, the membrane distillation process is still considered a new, promising membrane operation. This process has been studied since the 1960's. Development in membrane manufacturing in the 1980's allow us to obtained commercial membrane with desired properties. Improvement to module design and better understanding of phenomenon occurring in a layer adjacent to a membrane also contributed to the renewed interest in Membrane Distillation. In comparison to other separation operations Membrane Distillation has very important advantages; practically a complete rejection of dissolved, non – volatile species, lower operating pressure than pressure driven processes, reduce vapour space compare to conventional distillation, low operating temperature of a feed enables the utilization of waste heat as a preferable energy source. The possibility of utilizing of alternative energy source such as solar, wave or geothermal energy is particularly attractive.

## 2. Evaporation Efficiency

The heat transfer inside the membrane was divided into two possible mechanisms, conduction across the membrane material together with the heat flowing through the membrane. With the assumption of nonlinear temperature distribution and non-isenthalpic flow, the heat transfer equation inside the membrane is given by:

$$Q_m'' = Qv'' + Qc'' \tag{1}$$

$$= J \, \Delta \, H_v + (k_m/\delta)\,(T_1 - T_2) \tag{2}$$

Where, $\Delta H_v$ is the vapor enthalpy at temperature T and $k_m$ is the thermal conductivity coefficient that can be determined based on membrane material data:

$$Q_c'' = (k_m/\delta)\,(T_1 - T_2) = h_m\,(T_1 - T_2) \tag{3}$$

In Eq.2, only the latent heat of evaporation is the heat used effectively; however, the heat transferred by conduction across the membrane is considered as heat lost:

$$Q_{lost} = (k_m/\delta)\,(T_1 - T_2), \tag{4}$$

So the evaporation efficiency, EE, is defined as the ratio between the heat which contributes to evaporation and the total heat exchanged by the feed. The heat that contributes to evaporation is calculated multiplying the mass flux through the membrane by the heat of evaporation Hv. The total heat exchanged by the feed is the difference between the sensible heat of the incoming feed stream (Q1-in) and the sensible heat of the outgoing feed stream (Q1-out). This total heat exchanged by the feed consists of the two contributions indicated in Eq.2 and of the heat that is lost to the environment by conduction through the membrane module (Q.lost). This last contribution can be limited or eliminated if the thermal conductivity of the module material is low and if the module is well designed and thoroughly insulated. We have evaluated the heat lost to the environment from the difference of sensible heat change between the feed and the cooling stream. For all experiments, this difference. (Q1-in −Q1-out) / (.Q2-out−Q2-in) is within the experimental error showing that $.Q.^1$ lost/ and $.Q.^2$ lost are negligible.

So we can express the evaporation efficiency, evaluated as indicated before, in the form

$$\text{EE} = \frac{J\,\Delta H_v}{\text{J}\,\Delta\,\text{Hv} + (\text{km}/\delta)\,(\text{T}_1 - \text{T}_2)} \tag{5}$$

$$\text{EE} = \frac{\textit{part of heat which contribute to evaporation}}{\textit{total heat input in the module}}$$

EE is always less than 1. Part of heat which contributes to evaporation can be calculated by multiplying the measured flux J by the heat of evaporation ΔH vap and the membrane area A.

The total heat input in the module can be calculated from a measurement of the calorific value of the incoming and the outgoing feed stream.

The heat lost per mass flux unit can be expressed, taking into account Eqs.4 and $J = C\,(P_1 - P_2)$

$$\frac{Q_{Lost}}{J} = \frac{k_m}{C}\,\frac{T_1 - T_2}{P_1 - P_2} \tag{6}$$

that for very dilute solutions and for low values of $(T_1 - T_2)$ may be approximated by:

$$\frac{Q_{Lost}}{J} = \frac{k_m}{C}\,\frac{1}{\left(\frac{dP}{dT}\right)_{T_m}} \tag{7}$$

Where T m is the average temperature in the membrane, and where $(dp/dT)_{Tm}$ can be evaluated from the Clausius-Clapeyron equation,

$$\left(\frac{dP}{dT}\right)_{T_m} = \left(\frac{P\Delta H_v}{RT^2}\right)_{Tm} \tag{8}$$

using the Antoine equation to calculate p.

## 3. Evaluation of Energy Requirements

The equation used for obtained the heating and cooling energy is reported below:

$$Q_h = V_f\, Cp_f\, (T_{f,in} - T_{f,out})$$

$$Q_c = V_p\, Cp_p\, (T_{p,in} - Tp_{,out})$$

With $Q_h$ and $Q_c$ the heating and cooling energy (W), $V_f$ the feed flow rate (Kg/h), $V_p$ the permeate flow rate (Kg/h), $Cp_f$ feed specific heat (J/KgK), $Cp_p$ permeate specific heat (J/Kg K), $T_{f,in,}$ $T_{p,in}$ the feed and permeate temperature at the module inlet (K), and $T_{f,out,}$ $Tp_{,out}$ the feed and permeate temperature at the module outlet (K). Table shows comparison; in terms of permeate flux, energy consumption and evaporation efficiency among the different test carried out, it can be noticed that the best result in terms of energy consumption and evaporation efficiency were obtained at feed flow rate and temperature of 84 Kg/h and 50 $^oC$, respectively. The evaporation efficiency is independent on the stream flow rate and increase with temperature: at high operating temperatures the heat effectively used for the evaporation is higher, result is in agreement reported.

Table 1: Energy Consumption

| $V_f$ (L/h) | $V_p$ (L/h) | $T_{f,in}$ (K) | $T_{p,in}$ (K) | Energy consumption (W) | EE (%) | $J_w Kg/m^2h$ |
|---|---|---|---|---|---|---|
| 48 | 30 | 323 | 303 | 287.60 | 30.71 | 11.6 |
| 60 | 30 | 323 | 303 | 274.2 | 34.18 | 14.3 |
| 72 | 30 | 323 | 303 | 254.45 | 32.57 | 16.5 |
| 84 | 30 | 323 | 303 | 227.7 | 32.03 | 20.2 |

Table 2: Evaporation Efficiency

| $Q_m = Q_v + Q_c$ | | Evaporation Efficiency. |
|---|---|---|
| $Q_v = J\, \Delta H_v$ | $Q_c = (k_m/\delta)\,(T_1 - T_2)$ | |
| 1848.24 | 4169.87 | 30.71 |
| 4263.60 | 8208.96 | 34.18 |
| 5984.6 | 12388.89 | 32.57 |
| 6342.6 | 13456.87 | 32.03 |
| 6832.98 | 16578.88 | 29.18 |

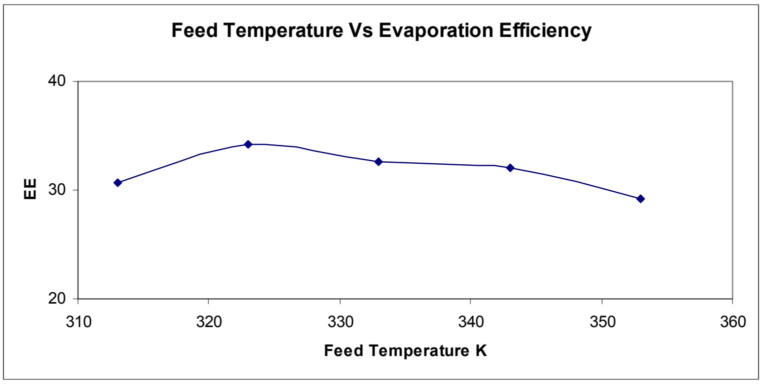


Fig. 1: Effect of feed temperature on Evaporation Efficiency.

## 4. Conclusion

Evaporation efficiency values are low, and they can be lower when the work temperatures are lower. Therefore, if we are interested in working at low temperatures, probably only the availability of cheap energy could make this process economically attractive. The latent heat of evaporation is the heat used effectively and is obtained from the permeate flux. The increase in heat of cooling water is sum of the latent heat of evaporation and the conduction heat lost through the membrane from the feed to cooling water.

In terms of permeate flux, energy consumption and evaporation efficiency among the different test carried out, it can be noticed that the best result in terms of energy consumption and evaporation efficiency were obtained at feed flow rate and temperature of 84 Kg/h and 50 oC, respectively. The evaporation efficiency is independent on the stream flow rate and increase with temperature: at high operating temperatures the heat effectively used for the evaporation is higher.

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