APPLICATIONS OF REVERSE OSMOSIS IN FOOD PROCESSING

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Abstract

Reverse osmosis is only recently used in the food industry and is gaining interest. This article treats the various effects of the physical properties of food towards the permeation flux of water, the apparatus used together with methods of improving their performance. Lastly, a study of the concentration of whey and milk is included.

Introduction

Reverse osmosis separates a solute from a solution by forcing the solvent (in this case, water) to flow through a membrane by applying a hydraulic pressure greater than the osmotic pressure of the solution. In the food industry, dewatering is done for preservation. An added advantage of dewatering is that a smaller amount of material is involved in processing (heating, canning, packaging, etc).

Advantages of reverse osmosis

Traditionally, dewatering is done by vacuum evaporation. The advantages of reverse osmosis over evaporation are:

a) retention of flavour and aroma as no volatile substances are lost due to vaporization

b) preservation of the functional properties (for example, the whipping property of egg white)

c) low energy consumption as no phase change is required and

d) gentle treatment of the product as it involves no elevated temperature (at ambient temperature)

The pressure used in the operation depends on the osmotic pressure of the solution as it is necessary to have a hydrostatic pressure greater than the osmotic pressure of the material being concentrated. The osmotic pressure and the pressure used in reverse osmosis for some products are listed below.

Table 1 : Osmotic pressure of various juices and syrups

Product	Concentration (% Brix)	Osmotic Pressure (psi)	Pressure Required (psi)
Sugar beet juice	20	500	1500
Tomato juice	33	1000	
Citrus juice	10	215	800
Citrus juice	34	1000	
Citrus juice	45	1500	2500
Sucrose	44	1000	
Corn syrup	37	1000	

From the table above, as the concentration of the product increases so does the osmotic pressure and hence, the pressure required for reverse osmosis.

The diffusivity of water and the solutes in the liquid phase of the product also affect the operation. As water is removed through the membrane the rejected solute tends to accumulate at the solution-membrane interface.This concentration polarization is counteracted by diffusive flow in the opposite direction. The diffusion coefficient, the rate of diffusional transport, for solutes and water in most liquid foods are in the order of 10^{-7} and 10^{-5} cm^2/s, tending to be lower at high solute concentration and high viscosity. A decrease in the diffusion coefficient will cause a severe concentration polarization and consequently, a low flux for water.

Table 2 : Solute-water diffusion coefficients for some liquid foods at 25°C

Solute	Solute concentration	Diffusion coefficients (cm^2/s)
Ovalbumin	0.8%	7.62×10^{-7}
Orange juice solids	42° Brix	0.03×10^{-5}
	18° Brix	0.05×10^{-5}
	0° Brix	0.13×10^{-5}
Sucrose	65%	0.083×10^{-5}
	42%	0.19×10^{-5}
	18%	0.35×10^{-5}
	0%	0.52×10^{-5}

Most food show a significant increase in viscosity as its solid content increases. Figure 1 shows the relationship of viscosity with respect to soluble solids in tomato puree. An increase in viscosity increases the phenomenon of concentration polarization.

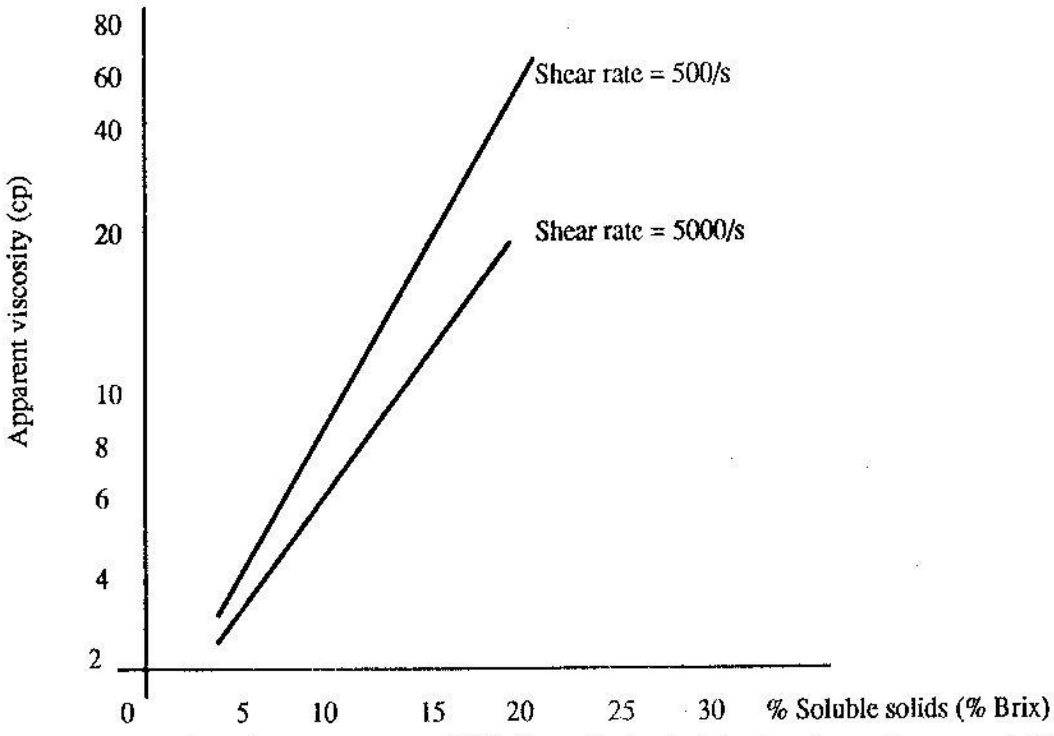

Figure 1 : Viscous properties of tomato puree at 25°C. Data obtained with tube viscometer, commercial canned tomato juice concentrated from reverse osmosis.

Apparatus for reverse osmosis

The effects of increase concentration polarization and increase osmotic pressure with concentration limit the practical degree of concentration that can be obtained.

High osmotic pressure, high viscosity and liability and susceptibility to microbiological attack necessitate the use of a special apparatus. The apparatus need to

a) be able to withstand great pressure up to and exceeding 1000 psi

b) have a large membrane area to counteract the effect of low flux

c) have means to minimize concentration polarization without excessive pressure drop and

d) be easily dismantled for cleaning and inspection.

Different usage also constitutes different uniqueness to the apparatus. All in all, a compromise is made between requirements, simplicity and cost.

Round tube configuration has been widely used especially if the product contains suspended matter and is not viscous so that turbulent flow can be achieved. The disadvantage with this configuration is the difficulty in getting access to its interior for inspection and cleaning. At present, cleaning is done in place.

The spiral-wound module is good for laminar flow. The spacer between the membranes increases mixing in the liquid foods but suspended particles tend to clog the spacer. It is also difficult to clean. An in-line germicidal ultraviolet lamp has been added to the module to minimize the growth of micro-organisms in the product being concentrated.

Hollow fiber unit is used for concentrating viscous foods.

Plate-and-frame module has the advantage of being easily dismantled for cleaning and also, able to operate at pressure up to 1500 psi.

The performance of the apparatus can be improved by:

a) using thinner channels in laminar flow which will result in higher permeation rates as polarization is reduced

b) removing less water per pass through the apparatus as the stagnant layer near the membrane is thinner. A portion of the concentrate is then recycled

c) increasing the velocity as this will prevent sedimentation

d) having two-stage system so as to reduce the pressure necessary to achieve high solute concentration.

Case study : concentration of whey and skim milk

The application of reverse osmosis in the dairy industry is in the concentration of whey and skim milk. Gel polarization occurs when the solubility of protein at the membrane surface is exceeded. The various factors that affect the permeation rate are:

a) concentration ratio of filtrate to retentate. As the concentration ratio increases, the permeation flux decreases due to gel polarization. This effect is much more pronounced in skim milk than in whey as skim milk contains casein which deposited giving rise to gel polarization

b) operating pressure. The permeate flux decreases with increasing pressure due to the compact action of the gel layer. Again the effect is less pronounced in whey as it has lower protein content plus its diffusion coefficient is higher than that of skim milk

c) flow velocity. Low velocity results in complete gel-polarization. Maximum permeate flux is reached by combining higher flow velocity with higher pressure

d) mass transfer coefficient. Low values of mass transfer coefficient result in marked gel polarization as more solutes concentrate at the membrane surface

e) erosive action of fluidized bed system. Permeate flux depends strongly on the bed porosity. Maximum permeate flux is obtained with bed porosity of 0.65 - 0.85 at a narrow range of diffusion coefficient of 8.5×10^{-6} m/s. Fluidized bed has the effect of restricting gel polarization by having an erosive action on the gel layer. This effect is more noticeable in the concentration of whey

f) operating temperature. The permeate flux increases with increasing temperature. However, at high temperature Ca-phosphate in whey will precipitate and thus causes strong fouling of the membrane. To prevent this pre-treatment of either

i) removal of Ca by ion-exchange

ii) decreasing the pH to about 6.0 so as to increase its solubility high enough to prevent serious fouling or

iii) pre-heat so as to cause precipitation of Ca-phosphate and then operate reverse osmosis at a low temperature

The recommended process conditions for whey and skim milk operation using reverse osmosis is given in Table 3, taking into consideration of all the above factors.

Table 3 : Recommended process conditions for reverse osmosis of sweet whey and skim milk.

Process parameter	Whey		Skim milk
	High velocity system	Fluidized bed system	High velocity system
Temperature	10°C	10°C	
	30°C with pre-treatment	-	30°C
Pressure	3-5 MPa	4 MPa	3 - 4 MPa
Flow velocity	2 m/s	0.1 m/s	3 m/s
Concentration ratio	1 - 4	1 - 4	1 - 3
Type of plant	Tubular Plate-and-frame (single pass)	Tubular (vertical framing)	Tubular (internal recirculation)

The use of reverse osmosis in dealing with heat-sensitive or volatile solutes is of an important advantage. However, usage of reverse osmosis is limited in that the final concentration of the product is lower than that required due to the high osmotic pressure and viscosity of the concentrated food liquids.

References

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