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High Quality Cranberry Juice Concentrate Production Using Reverse Osmosis

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Contents

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Contribution No. 408 from Engineering Research Service, Research Branch, Agriculture Canada, Ottawa, Ontario, K1A 0C6.

1.0 Introduction

Cranberry juice has a very distinct and subtle flavor and aroma which is easily damaged by heating during processing. Because of the temperature sensitivity of the juice quality it seems reasonable that reverse osmosis should offer a means of concentration without quality loss due to heating. A study has been undertaken to compare cranberry juice concentrate using reverse osmosis and vacuum concentration and at the same time consider the possible application and limitations of reverse osmosis to the concentration of cranberry juice.

2.0 Review of Literature

The principles of reverse osmosis (RO) have been well outlined in the literature. A useful text summarizing much of the information is that edited by Lacey (1972). This text deals with many aspects of RO processing and covers costs, membrane performance and food applications.

The application of reverse osmosis to various aspects of food processing has been studied by several organizations in recent years. Early work by Morgan (1965) suggested the feasibility of applying RO in the food field. Potential uses suggested at that time included concentration of juices, syrups, whey and egg white as well as some separations (e.g. salt from whey) and for water recovery. Merson et al. (1968) studied the concentration of apple and orange juice up to a concentration of 42^{o} Brix. In their work they considered permeation rates, pressure, concentration and aroma retention.

Willits (1967) applied RO to the concentration of maple sap. Commercial uses of this process is considered feasible by one reverse osmosis company (Osmonics Inc. 1973).

Many papers have been published on the use of RO for the processing of whey and other milk products. In whey recovery RO is now a commercial procedure (Horton et al., 1972). Horton also shows the use of staged ultra-filtration/reverse osmosis in the commercial application of membrane processing.

3.0 Materials, Equipment and Methods

3.1 Reverse Osmosis Apparatus

The RO apparatus used in this study was an Osmo 3319 (Fig. 1) from Osmonics Inc.[a] For these studies the standard pressure vessel was replaced with a lined steel vessel capable of withstanding pressures well in excess of 1000 psi.

The apparatus uses a 33 square ft. spiral wound membrane. For these studies a high rejection membrane was used. The rejection of NaCl by this membrane is about 90-95%, with a cut off for organics at a molecular weight of about 200.

The package Osmo unit has a built in ¾ hp centrifugal pump capable of delivering about 170 psi. As this pressure is far too low for dealing with products with high osmotic pressure, such as fruit juice concentrates, a high pressure pump was used to deliver pressures up to 1000 psi. The pump used was a Mantin-Gaulin three piston high pressure pump.

The arrangement of pump and interconnections for recycling are shown in Figure 2.

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[a] Osmonics Inc., Represented in Canada by Commercial Filters, 1179 Caledonia Road, Toronto 19, Ontario.

3.2 Rising Film Evaporator

A rising film evaporator (Fig. 3) was used to prepare product for comparison with the reverse osmosis material. This evaporator is an all glass, vacuum type which is steam heated.

During operation a vacuum is maintained and the product reaches a temperature of about 160°F (71°C).

Product is recycled through the RFE to achieve the desired degree of concentration.

3.3 Cranberry Juice

The cranberry juice used as feedstock for both the RO and RFE systems was prepared in the laboratory just prior to use. The juice was prepared from frozen cranberries. The procedure was: Grind frozen berries, add 0.83 l H_2O/Kg berries, add 7.0 g Spark-L enzyme per Kg of berries, stand overnight at room temperature or 3 hrs. at 100°F (38°C) to allow enzyme action to release juice, press to extract juice and filter. Juice prepared in this manner had between 4.5 and 5.0% soluble solids.

3.4 Concentration Procedures

During operation of the RO equipment juice was recycled through the system (Fig. 2) until the desired level of concentration was achieved. Once this level was obtained fresh feed juice was added and concentrate removed at rates necessary to balance the permeate flow and maintain a mass balance.

With the RFE, juice was concentrated in stages with the produce being recycled until the desired level of concentration was achieved.

3.5 Summary of Tests

Several preliminary tests were run in the laboratory in Ottawa to check equipment and see if the process appeared applicable.

Run 1	20	lb berries - initial 4.5% concentrated to	6.0%
3	35	" " " " " "	6.3%
4	50	" " " 5.5% " "	7.1%
12	78.5	" " " 5.8% " "	11.1%
13	44	" " + conc. from run 12 " "	21.0%
K1	45 l	juice @ 4.5% conc. to	10.0%
K2	18 l	10% con. + 43.75 l 4.3% conc. to	22.2%
K3	14½ l	5.8% + 75.5 l 5% conc. to	23.0%

3.6 Taste Panel Evaluation

Taste panel trials were conducted to compare the RO prepared material with that from the RFE. Trials were conducted using cranberry cocktail (0.644% acid and 15% sugar) prepared from the two concentrates, K2 and K3 and the concentrate from the RFE. These trials were in the form of ranked preference test (Larmond, 1970).

4.0 Results and Discussion

4.1 Apparatus Performance

Preliminary tests conducted in Ottawa indicated that RO could be a useful procedure. The tests on the small volumes of material are not particularly useful from a numerical point of view as at least 15 minutes are required for the system to come to an operating equilibrium. Each stage or pass in tests 1 and 2 took much less than 15 minutes. The preliminary tests did, however, point out that the high rejection membrane was capable of providing concentration without a loss of sugar or much color in the permeate (waste) stream. A single pass through the system at the low concentration levels could remove from 3 to 10% of the water in the feed stream. Runs 12 and 13 showed that the equipment could be readily operated at a concentration level of 10 to 12% soluble solids and that if low permeation rates could be tolerated that concentrates of 30% soluble solids can be made.

Loss of sugars in the permeate stream was negligible (i.e. no sugars could be detected in the permeate with a hand held refractometer). Some color is detectable in the permeate, particularly after a longer period of operation, however the loss of coloring materials was considered negligible as well.

Trials undertaken at the Kentville Research Station were twofold in nature, producing samples for quality evaluation and evaluating equipment performance.

The results of the three runs conducted at Kentville are presented below. For Runs K2 and K3 initial, final and average permeation rates are given.

Run K1

Feed			Permeate			Concentrate		
Vol	Soluble Solids	Acid	Vol	Soluble Solids	Acid	Vol	Soluble Solids	Acid
45L	4.8%	1.39%	26	0%	0.12%	18L	10%	-

Pressure 800 psi

Duration ½ hour

Permeation rate 52 L/hr = 4.72×10^{-4} ml/cm^2 sec
= 10 gal/ft^2 day

Run K2

Initial start-up of apparatus was done using the 18L of 10% concentrate from Run K1 with subsequent feed material being juice at 4.5% soluble solids and 1.38% acid.

Feed			Permeate			Concentrate	
Vol	Soluble Solids	Acid	Vol	Soluble Solids	Acid	Soluble Solids	Acid
18L	10%						
43.75L	4.5%	1.38%	54.3L	nil	0.24%	22.2%	6.52%

Pressure 750 psi

Duration 1 hr 56 min

Permeation rate

(1) Average over test 2.63×10^{-4} ml/cm^2 sec = 5.6 gal/ft^2 day.

(2) Initial rate (concentration from 10% to about 15% sol. solids) = 34.6L/hr = 3.14×10^{-4} ml/cm^2 sec = 6.65 gal/ft^2 day.

(3) Final rate 22.5L/hr 2.04 ml/cm^2 sec = 4.32 gal/ft^2 day $\times 10^{-4}$.

Run K3

This run was conducted using juice averaging 5.0% soluble solids and 1.45% acid. This juice was prepared for pressing by holding at 100°F for 3 hours with added Spark-L enzyme. Start-up was using 5.8% juice residual from Run K2.

Feed			Permeate			Concentrate	
Vol	Soluble Solids	Acid	Vol	Soluble Solids	Acid	Soluble Solids	Acid
14.25L	5.8%						
75.5L	5.0%	1.45%	75.25	nil	0.3%	23%	5.86%

Pressure 700 psi

Duration 2 hr 58 min

Permeation Rate

(1) Average 2.31×10^{-4} ml/cm^2 sec = 4.9 gal/ft^2 day.

(2) Initial 5 to 10% solids 3.74×10^{-4} ml/cm^2 sec = 7.9 gal/ft^2 day.

(3) Intermediate 10% to 20% solids 2.19×10^{-4} ml/cm^2 sec = 4.65 gal/ft^2 day.

(4) Final 20% to 23% solids 9.33×10^{-5} ml/cm^2 sec = 1.98 gal/ft^2 day.

The three runs K1 to K3 point up one problem for the use of RO with cranberry juice, which is the loss of acid in the permeate stream. Cranberry juice is high in low molecular weight acids and the loss of acids was seen to increase with the three runs. There are two possible reasons for the increasing loss of acids, but with the limited number of tests it is not possible to say if it is due to concentration or just due to the membrane reaching an operating equilibrium. A parallel increase in the colour of the permeate was observed, however, the colour loss was at a very low level.

The loss of acid into the permeate represents a distinct loss of product as cranberry products, such as cranberry cocktail, are made up to specific acid levels.

An important criteria is the loss of soluble solids in the permeate stream, and in this respect membrane performance was good. The level of soluble solids in the permeate was below the level detectable with a refractometer.

The permeation rate, or rate at which water can be removed from the product, is of primary consideration to the industry. The results of runs K2 and K3 show that reasonable permeation rates can be attained when operating at a concentration level of around 20% soluble solids. Permeation rate is directly related to the applied pressure and the osmotic pressure of the material being concentrated. This relationship was given by Lonsdale (as quoted by Merson, 1968) as:

$$J = K\ (\Delta P - \Delta\pi)$$

where: J = permeate flow/unit area of membrane

K = coefficient

ΔP = hydrostatic pressure

$\Delta\pi$ = osmotic pressure of feed - osmotic pressure of permeate liquid

Merson (1968) gives the osmotic pressure of orange juice at various concentrations as: 10.5° Brix, 210 psi; 21.5°, 430 psi; 31.5°, 850 psi; 42.0°, 1370 psi. It is apparent that high operating pressures are required to produce good permeate rates at higher concentration levels. The relatively low final permeate rate in run K3 is a result of the lower operating pressure (700 psi vs 750 for K2) and the higher permeation rates should be readily achieved through an increase in pressure. Higher pressure operation, however, introduces the problem of membrane compaction and consequently it is necessary to balance throughput against membrane life.

Power consumption during concentration is another primary consideration. In theory the energy costs for an RO system should be lower than for an evaporation system, as the water is removed in the liquid phase and the high latent heat of vaporization is not required. In this small laboratory RO system, estimation of exact power consumption is difficult. Energy consumed by the built in pump was easily measured, however because of the extreme overcapacity of the Manton-Gaulin high pressure pump it is difficult to determine the energy actually used. The capacity of the pump is about 1550 lb/hr at 1000 psi whereas the system actually required about 400 lb/hr, with the remainder being recirculated through the pump (see fig. 2).

The energy inputs to the two pumps were measured during operation. The built in pump of the RO system drew between 11 and 12 amps at 110 volts. The high pressure pump was a 550V 30 system and drew between 1.5 and 2.0 amps on each phase during operation. The greatest power consumption is 1320 watts for the RO pump and 3300 watts for the Manton-Gaulin pump for a total of 4620 watts.

From the 1550 lb/hr capacity of the pump approximately 1150 lb/hr (almost 75%) is recirculated back into the pump. As an approximation it is assumed that 1/3 of the input energy to the Manton-Gaulin pump would actually be required to operate the system with a correctly sized pump. Thus, at maximum for this system 2 amps at 550V would actually be used, for a total estimated energy input of 2420 watts.

The energy consumption per Kg of water removed from the product will depend upon the final concentration of the product. Energy consumption per Kg of water removed is summarized in Table I for the various rates of water removal in the tests.

Table I

Energy utilized in reverse osmosis system at various levels of product concentration

Test No.	Rate	Concentration	Energy Consumption watts hr/Kg H_2O removed
K1	Average 521/hr	5 to 10%	46.5 watt hr/Kg
K2	Average - 29.2		83.0
	Initial - 34.6)	10 to 15% range	70.0
	Intermed 38.6)		62.6
	Final - 22.5	15 to 20%	107.5
K3	Average - 25.4	5 to 23%	95.3
	Initial - 41.2	5 to 15%	58.7
	Intermed 24.2	15 to 20%	100.0
	Final - 10.4	20 to 23%	232.5

The energy consumption is dependent on concentration due to the pressure required or the permeation rate at a fixed pressure. The quantities of material available restricted the duration of operation so that the energy consumption figures should be considered as a first approximation.

For an evaporative process the theoritical requirement to vaporize 1 Kg of water would be about 2200 Btu or about 645 watt hr per Kg of H_2O. This figure does not include any regeneration or other steps to improve efficiency. With a double effect evaporator 2 Kg of H_2O could be evaporated using about 1.2 Kg of steam (390 watt hr/Kg of H_2O evaporated).

4.2 Taste Panel Evaluation of Concentrates

Taste panel evaluation indicated that no significant differences were detected in the three samples of cranberry cocktail. However, cocktails prepared from the concentrate K2 rated first in four tests out of five, indicating a tendency to preference of this material. The greater loss of acid in sample K3 may account for the lower rating of this material. All samples were judged to be of good cranberry flavor.

Although concentrates K2 and K3 produced acceptable end products, the loss of acid involved represents a serious loss in yield. Losses of 0.3% in the permeate represent a yield loss of 17.3%.

5.0 Conclusions

From the limited number of trials conducted it appears possible to produce acceptable cranberry juice concentrate using reverse osmosis.

The problem of acid loss, with the resultant yield decrease needs further study. While acid loss could be reduced by using higher rejection membranes, the permeate flows would also be decreased and energy consumption increased.

Energy consumption in the system appeared reasonable in terms of water removal, however, considerably greater time in steady state operation would be required to assess true energy costs.

One of the major costs in reverse osmosis is the replacement of membranes. From a limited study such as this it is not possible to assess the membrane durability and replacement frequency.

6.0 Recommendations

From the experience of operating the small Osmo system in conjunction with the larger Manton-Gaulin high pressure pump, it is recommended that a suitable cooling system be installed to operate in the pump by-pass system. This feature would be useful from two points of view: to prevent temperature buildup due to excessive pumping power and provide a zone for accurate temperature control of feed material. Control of feed temperature will improve testing capabilities as membrane performance is influenced by temperature (Monge, 1973). Excessive temperatures (above 100°F or 38°C) of the feed material can cause damage to the Osmo membranes.

7.0 References

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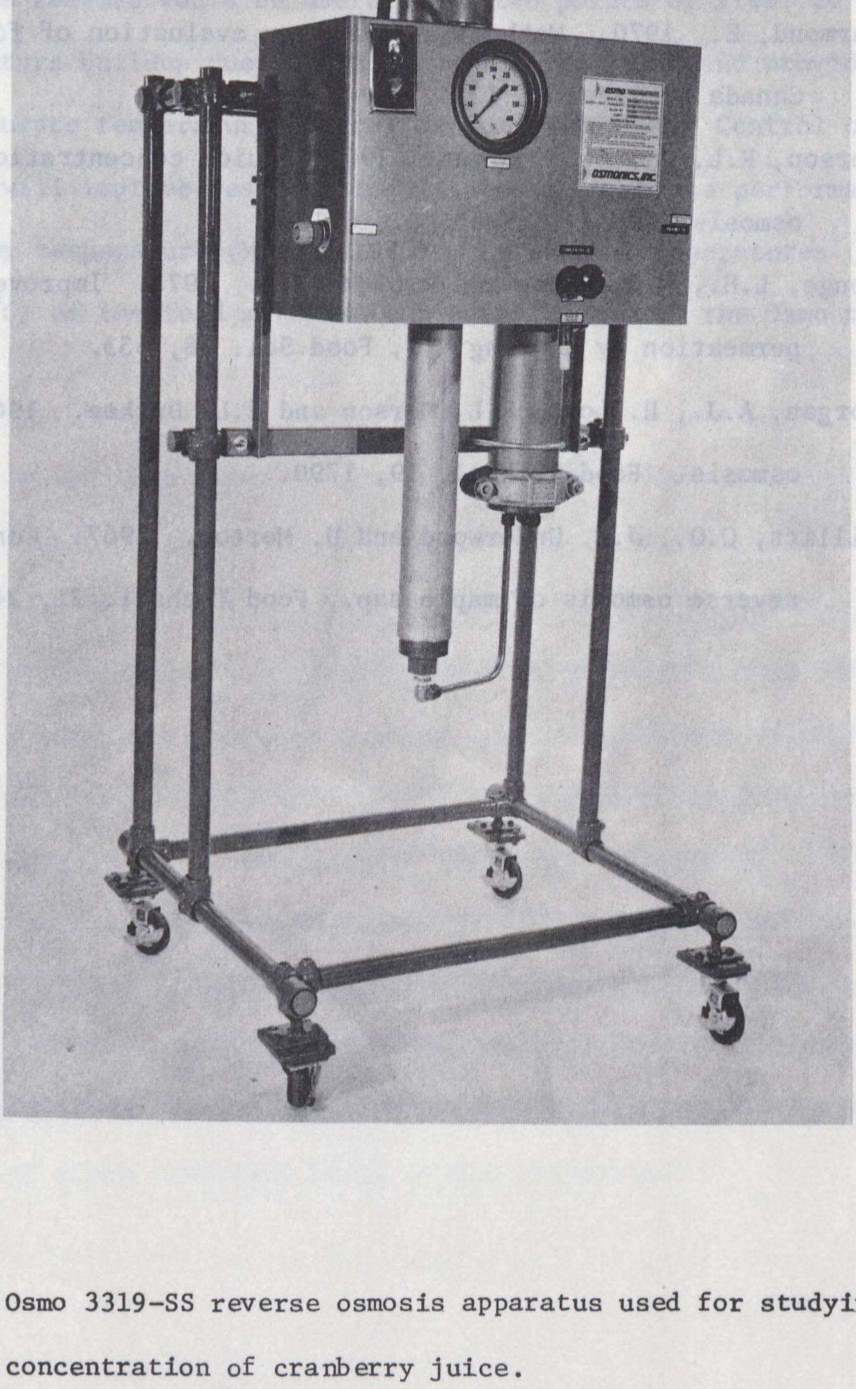

Figure 1. Osmo 3319-SS reverse osmosis apparatus used for studying concentration of cranberry juice.

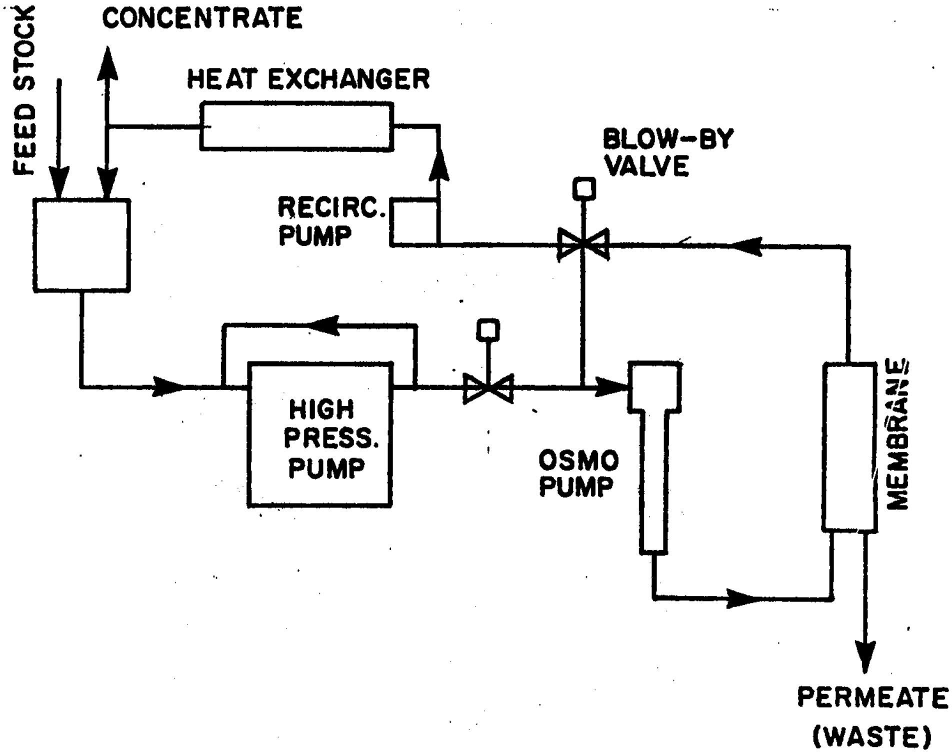

Figure 2. Product flow in reverse osmosis test system used to study cranberry juice concentrate.

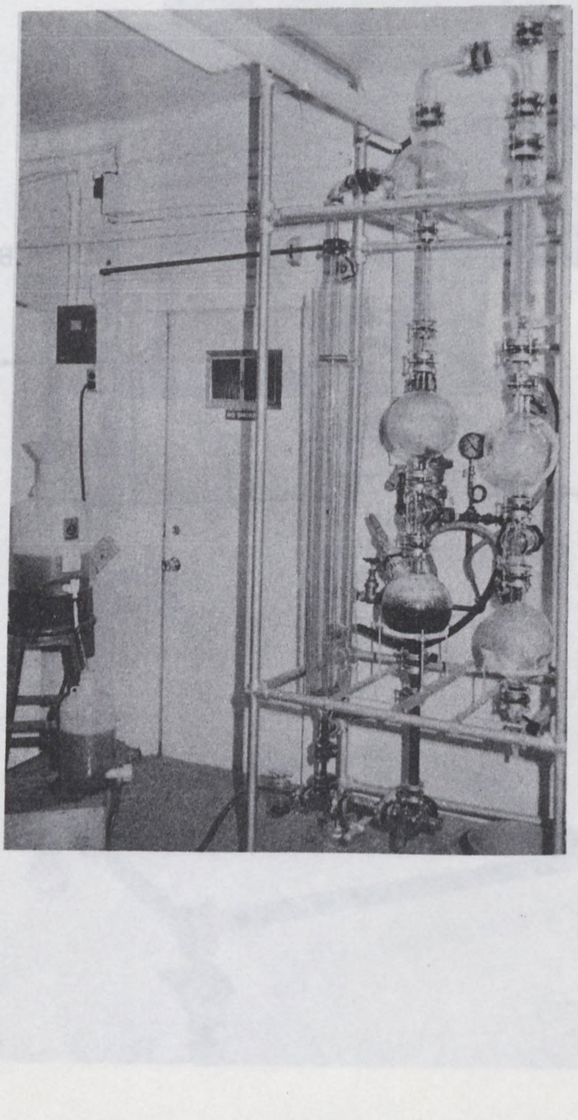

Figure 3 Pilot-plant rising film evaporator installed at the Kentville Research Station.