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The energy consumption during the birch tree sap concentration process using the reverse osmosis system

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Abstract. Birch tree sap was concentrated by mens of the reversed osmosis technique. The energy consumption in a small-scale pilot apparatus was estimated. The threshold value for the water removal above which the specific energy consumption significantly increased was identified. Below the threshold value the reversed osmosis had low energy demand and could be an attractive method for the production of birch tree sap-based beverages.
Key words: specific energy consumption, birch tree sap, reversed osmosis, soft-drink, natural products.

INTRODUCTION

The use of saps of different tree species as food products has had a long history in human culture across the globe. For centuries the palm sap has been processed in the Far East in order to make wine or sugar. A similar procedure has also been popular in Africa and India. Native Americans from the territory of today's Canada tapped maple trees [8]. In the East and North Europe the tradition of birch tree sap collection from the *Betula pendula* and *B. pubescens* is still living and strong [10].

The birch tree sap flow in a trunk serves to transport the nutrients important for the plant physiology in early spring. Its major components, apart from water, are: reducing sugars (together around 8-10 g/dm^3) [2,6] malic acid (0.5 g/dm^3) [6] amino acids: glutamine, citrulline and glutamic acid (up to 0.5 g/dm^3) [1] and various inorganic cations and anions [4,3]. The root pressure has been identified as the driving force of sap movement rate and the highest flow has been observed before the burst of buds burst and development of leaves [8].

Usually, the industrial processing of birch sap is not carried out in the same way as of maple sap. The sugars concentration in maple sap is around fivefold higher [11] than in its birch counterpart. Due to the low content of solutes in birch sap the production of birch syrup requires large quantities of the raw material, greater workload and high consumption of energy for the processing and transport. As a result, the market value of birch syrup is much higher than that of maple syrup.

A potential method of birch syrup production involves the use of reverse osmosis (RO) technology. In the first stage the raw product is concentrated by RO to around 10^{o} Brix and later on the remaining water is removed by boiling under reduced pressure [7]. In this application the benefits of the RO are not full exploited. Due to the high raw material consumption and high sensitivity of the product to thermal treatment the alternative methodology is worth considering. In our recently published work [13] the prospective use of the reverse osmosis technology for the production of birch sap-based beverages was shortly discussed. For an obvious reason, the production costs of such drinks recalculated for the unitary volume will be much lower in comparison to the birch syrup manufacturing. Moreover, the prospective use of the obtained product might be much wider. The sweet syrup is mainly the flavour enhancement additive while the birch sap beverages could be meant for the direct consumption or become the basis for further processing.

It could be believed that the new trend, in which raw birch sap becomes regarded as a valuable starting material for more complex products, is unstoppable. The consumption of natural untreated birch sap has had a long tradition. It has been used in the folk tradition both as medicine and as an important element in cosmetic procedures [10]. However, from the commercial point of view raw sap has one major drawback, i.e. its rather bland taste. In order to overcome this drawback, the market has been filled with artificially sweetened birch-sap-based beverages or other highly unnatural products. Thanks to the reverse osmosis, the consumers will get an interesting alternative. The prospect of an increase in the naturally occurring sugars concentrations accompanied by taste improvement by modern and non-deconstructive technology (RO) seems to be especially attractive.

The aim of this work is the application of simple reverse osmosis laboratory apparatus for birch spring sap concentration and the estimation of energy consumption and thus the operational cost of the tested small pilot-scale installation. The obtained results will give an insight into the future development of this technology and could potentially help to scale-up the discussed device for the industrial implementation.

MATERIALS AND METHODS

Birch sap collection

The birch sap was collected from the silver birch (*Betula pendula* Roth.) in the Łukawiec village (50.097559, 22.168178), in accordance with the well know procedure of trunk drilling [14]. A drill bit with the diameter of 16 mm was used and the hole depth was 4-5 cm. The sap from four trees was collected, mixed and then frozen.

Concentration procedure

The raw sap was concentrated using the previously-described device [13]. Briefly, in this procedure the pressure applied to the semi-permeable membrane enforces the permeate flow (pure water). Almost all the solutes are retained and concentrated in feed solution. Due to the technical reasons the permeate flow is perpendicular to the feed flow. The obtained concentrate becomes the feed and circulates in the closed system. The concentration process is conducted batch-wise. The scheme of the reverse osmosis apparatus is presented in Figure 1.

In order to minimise the pressure fluctuations the manometer was placed between the reverse osmosis membrane and the throttle valve. The relocation of the manometer was the sole modification of the original concept. The working pressure was set to 3 bar. Each batch of the concentrated sap was around 5 kg.

Measurement of the energy consumption and the physico-chemical analysis of the samples

The energy consumption was monitored with the digital wattmeter with the precision of the 0.1 Wh. The physical parameters of birch sap, concentrate and permeate were tested using the HI 9811-5 multiparameter meter and the HI 96801 digital refractometer in accordance with manufacturers recommendations. Before the measurements the conductivity meter had been calibrated with the standard solution of the known conductance (1413 uS/cm at 25°C µS/cm; manufacturer Hanna Instruments). The samples were weighed using the Vibra SJP balance.

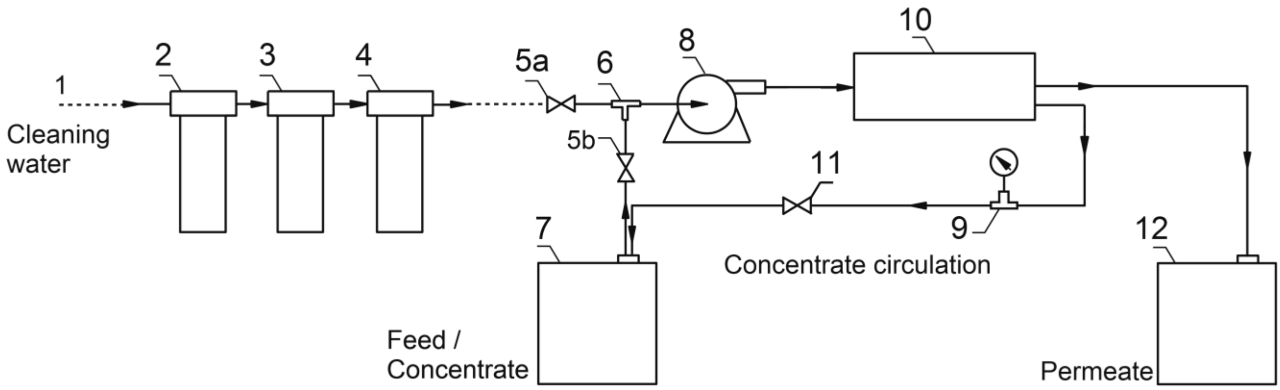

Fig. 1. Scheme of the reverse osmosis apparatus used for the birch sap concentration: 1 – cleaning water supply; 2 – string wound filter 10 µm; 3 – string wound filter 1 µm; 4 – carbon filter; 5a,b – ball valves 1/4"; 6 – tee connector; 7 – feed/concentrate storage container; 8 – diaphragm pump 50 GPD; 9 – manometer; 10 – reverse osmosis membrane 50 GPD; 11 – throttle valve; 12 – permeate storage container

RESULTS AND DISCUSSION

The progress of the concentration process was closely monitored by two independent techniques: refractometry and electric conductivity measurements. The weight of the obtained permeate and the energy consumption was determined in equal intervals. The changes of the measured parameters for the representative sample have been plotted in Figure 2. As can be seen, the concentration of the sugars and minerals in the feed solution increases during the concentration process. The permeate flow gradually decreases as the driving force of the reverse osmosis i.e. the applied pressure less effectively outweighs the increasing osmotic pressure.

The crucial information regarding the economic analysis of the discussed process comes from the measurements of the energy consumption by the pump. The obtained data are presented in Figure 3.

During the discussed process the total energy consumed increased (Fig. 2A) because the power of the working pump remained constant. The permeate flow decreased (Fig. 1D) but the energy was drained out and used for the concentrate circulation. Energetic economy shows that at some point the cost of the recovery of the unitary mass of the permeate becomes outstandingly high. A further increase of the concentration of the product becomes questionable. In the conditions of our experiments it is possible to suggest that the threshold of around 50% - 60% of the removed water from the raw sap defines the boundary of the economically justified sap enrichment. Beyond this line the specific energy consumption increases gradually from around 10-14 Wh/kg to much more than 50 Wh/kg. Obviously, if the high concentration of the final product is a priority then the process could be continued.

The presented conclusion has been drawn for the isobaric concentration. The permeate flow can be intensified by the application of a higher pressure. However, this action can cause some technical problems. First of all, higher throttle settings will result in a higher strain on the pump and higher energy consumption. Secondly, at the beginning of the process the high permeate flow may exceed the safety limits. The high ratio of the permeate flow to feed flow can destroy the osmotic membrane (high permeate recovery) [12].

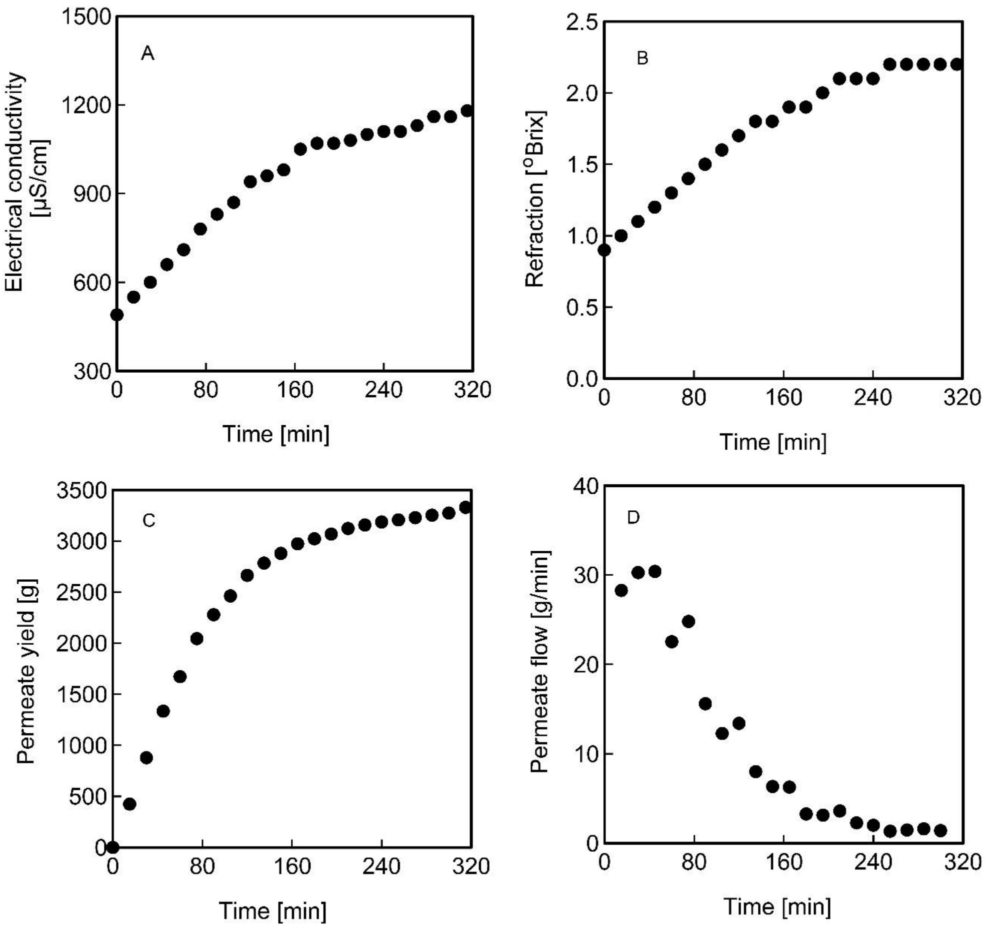

Fig. 2. Changes of the (A) electric conductivity of the concentrate, (B) refraction of the concentrate, (C) total permeate yield, (D) permeate flow during the sample concentration.

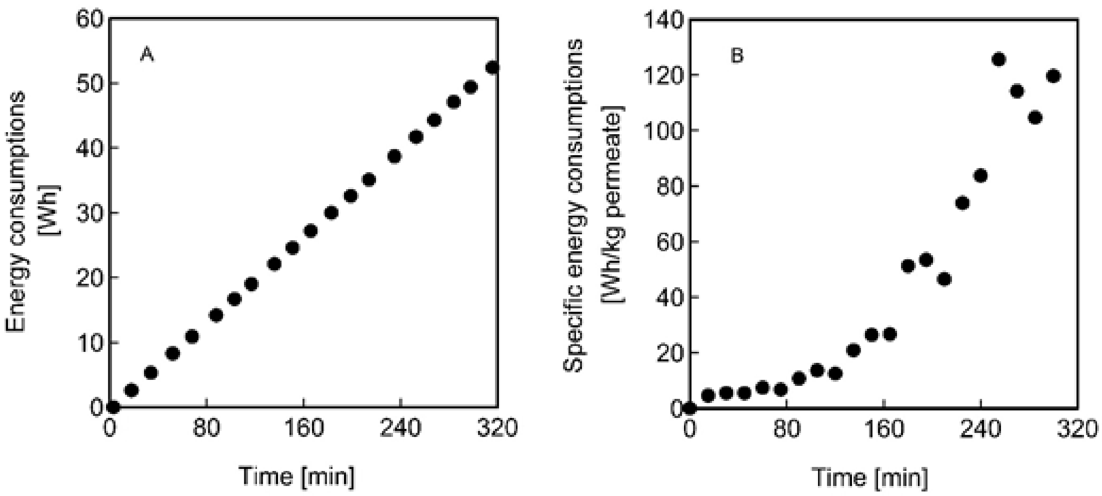

Fig. 3. Plots of the (A) energy consumption, (B) energy consumption recalculated for one kilogram of permeate.

The results obtained in the present work permit to make a crude comparison as to the energy demands between the reverse osmosis process and the other methods used for water removal from the solutions. If we accept the proposed threshold value for the water removal, the mean energy expenditure for the RO process ranges from 6 to 7.5 Wh/(kg of permeate) (kWh/ton of permeate).

In theory, the energy needed for the distillation, at the atmospheric pressure, of the equivalent water mass could be calculated from the trivial equation:

$$Qs = (m_{tot} \cdot c_p \cdot \Delta T + m_{per} \cdot \Delta H_{vap})/m_{per}, \quad (1)$$

where:
Qs - specific heat consumption needed for evaporation,
m_{tot} - total mass of the feed solution,
m_{per} - mass of the permeate,
ΔT - increase of the temperature from room temperature to boiling point,
c_p - heat capacity at the constant pressure ($\approx$ 4.183 kJ/kg·K),
ΔH_{vap} - heat of evaporation ($\approx$ 2259 kJ/kg).

The calculated value Qs = 2767 kJ/(kg of permeate) translates into around 765 Wh/(kg of permeate). In industrial practice this value would be much lower. A part of the energy can be recovered in heat exchangers. The heat of evaporation is partially reused when the vapour condensates, the obtained hot condensate preheats the fresh solution, and so on. However, despite the effort, the amount of energy consumed in the water removing process remains high. The energy requirements for different techniques of water separation are collected in Table 1. The presented literature data were accepted for water desalination.

Table 1. The specific energy consumption in the water removing process for various desalination technologies [9, 5]

Technology	Specific energy consumption [Wh/kg]
Mechanical vapor compression	7-15, 48
Multi-stage flash	21-59
Multiple effect distillation	15-57
Multi-effect boiling	30-79
Vacuum distillation	79
Freezing	48
This work	*6 - 7.5*

As can be seen, the energy consumption for our small scale apparatus is even 10 times lower than for the traditional techniques. Apart from that, the RO is a low temperature process and thus the natural composition of the sap could be preserved.

CONCLUSIONS

The experimental data have shown that the reverse osmosis technology is an efficient method of water removal. It is a non-destructive low-temperature process that allows to preserve the natural birch sap composition. Additionally, the RO is an energy saving solution, provided that the process is stopped just after the threshold value of the water removal has been reached. Alternatively, the process could be conducted at a higher pressure or the pressure could be increased at a certain concentration of the product.

The application of reverse osmosis for birch sap concentration is an excellent technical solution to achieve the desired objectives. We believe that the obtained new product, which has a much higher concentration than raw sap but much lower than birch syrup, could potentially fill the market niche and attract the attention of the consumers searching for natural food products.

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