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Concentration of natural aroma compounds from fruit juice hydrolates by pervaporation in laboratory and semi-technical scale. Part 2. Economic analysis

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ABSTRACT

The second part of a two-article series presents an economic analysis of the production of concentrated apple juice hydrolates *via* pervaporation. The average permeability of the membrane and the results obtained for the semi-pilot scale studies presented in the first part of the paper allowed for the determination of the required membrane area for the separation of aroma compounds from apple hydrolate. The simulation was divided into the base case scenario and sensitivity analysis for both batch and continuous process configurations. The economic indicators made it possible to calculate the cost-effectiveness of the implementation of the proposed solution. Both the base case scenarios and their sensitivity analysis revealed that the continuous production generates significantly higher revenues over the batch case. The results of the economic analysis demonstrated that pervaporation is a profitable and feasible option for aroma recovery from fruit hydrolates.

1. Introduction

The acceptance of the consumer of foodstuffs or cosmetics depends largely on their appropriate fragrance, which incidentally indicates quality. There are three types of aromatic compounds used in the food and cosmetic industries: (1) natural, (2) identical with natural, and (3) synthetic. Natural fragrances are derived directly from natural sources, e.g. as a result of dearomatization, that is, separation and concentration of natural aromatic found in pressed fruit juice. Identical to natural aromas are produced synthetically, but their chemical structure and properties are identical to their natural equivalents. The cheapest method of aromatic compounds production, but also the least acceptable by consumers, mainly as a result of the increasing ecological awareness, is the synthesis of compounds of similar chemical structure, but with the same sensory profile as that of their natural equivalents (Ben Akacha and Gargouri, 2015). Recent global trends show that consumers prefer food additives identified as natural reflecting the price of the different types of flavours. At the same time modern society requires that the food industry has to provide to the market with a right amount number of products with specific nutritional value, good taste and the lowest possible price. Since the concentrations of the essential sensory plant components in the treated raw materials are generally low, only a few mg per kg of raw material. Therefore, the isolation and preparation of sufficiently large amounts of aroma from natural sources in a sufficiently large amount is low not very much productive, energy-intensive and costly. Therefore, the price of the compounds of natural origin is many times higher than that of the same chemically identical products obtained by chemical synthesis although from the chemical point of view there is no difference between them.

Hydrolates (hydrosols), which are the water mixtures that remain after the essential oils and aromas have been extracted from raw materials (juice and plants), with a fragrance concentration of up to a few percent are co-produced during the distillation of

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aromatic plants or dearomatization of fruit juices. Since they contain trace amounts of fragrances, hydrosols are commonly used for aromatherapeutic and cosmetic purposes (Lante and Tinello, 2015). In Poland, hydrosols are usually discarded, thus their economic potential is simply expandable (Rao, 2012).

Methods commonly used for the aroma recovery of aroma, such as extraction, adsorption or steam distillation, have several drawbacks, which include: (1) the use of additional solvents, adsorbents and associated impurities of the final product, (2) degradation of certain aromatic compounds with due to the use of drastic conditions of the process, e.g. high temperature, and (3) energy consumption. The alternative for listed above processes can be the pervaporation. Pervaporation in the aroma recovery from raw materials is characterized by high selectivity, low power consumption, high process efficiency, and consequently lower operating costs while maintaining high process efficiency (Bourseau et al., 2014; Lipnizki et al., 2002a; Dawiec et al., 2015) and may be implemented by food producing companies. An excellent advantage of pervaporation is that this method is very efficient even when the concentration of organic compounds in the solution is very low. Thus, this membrane process has a great potential in concentration of hydrolates.

The aim of the paper is to present an economic analysis of implementation of the separation of aromatic compounds through pervaporation on the example of apple hydrolate. The economic analysis of hydrolate pervaporation can help in assessing if the proposed process for concentrating aromas in hydrosols is economically feasible.

The calculations presented in the paper have been divided into the analysis of the base cases scenarios and their sensitivity analysis. In order to select between batch and continuous pervaporation units, firstly base cases were developed for each. For both of the base cases and sensitivity analysis the number of 7920 annual operating hours (24 h per day, 330 days in a year) were assumed (Tusé et al., 2014).

To evaluate the viability of the investment, the economic indicators such as the net present value (NPV), internal rate of return (IRR) and return on investment (ROI) are generally used, which allowed for the estimation of the cost-effectiveness of the implementation of the proposed solutions. The simplest indicator for economic evaluation is the payback time which shows a time at which the total investment of the project pays for itself and is calculated as the ratio between total investment and average annual cash flow. However, generally this is not the same payback time indicated by the cash-flow diagram, as it assumes that all the investment is made in year zero and revenues begin immediately and do not change over the analysed time (Towler and Sinnott, 2013). Therefore, more sophisticated methods in economic analysis are used such as the net present value (NPV). Nevertheless, which method is used it is necessary to base on the cash flow (CF) which stands for the difference between whole acquire income and expenditures in a specified period, for instance annual. Generally, the ROI can be calculated as the ratio of net annual profit (average annual cash flow $\overline{CF}_n$) and total investment (TI) (Towler and Sinnott, 2013):

$$ROI_n = \frac{\overline{CF}_n}{TI} \cdot 100\% \quad (1)$$

The net present value (NPV) is a sum of discounted cash flows for n number of years, of lasting the project, and is calculated according to Eq. (2). The NPV calculations includes discount rate i, which represents the cost of benefit which could be acquired if the financial resources would be alternatively invested. In other words, discount rate represents the earning power of money (Towler and Sinnott, 2013).

$$NPV_n = \sum_{j=1}^{n} \frac{CF_j}{(1+i)^j} \quad (2)$$

Based on the definition of internal rate of return (IRR), that it is the discount rate at which the net present value of the project is equal to zero. Therefore, the calculation of IRR required the numerical solving of Eq. (3)

$$0 = \sum_{j=1}^{n} \frac{CF_j}{(1+IRR)^j} \quad (3)$$

The economic simulation helped determine an annual production cost of concentrated aroma solution from the apple hydrolate and that of the production of 1 kg of aroma with a specific enrichment factor.

2. Materials and methods

2.1. Membrane selection

The pervaporation studies of apple hydrolate in the semi-pilot plant scale were carried out with use of the commercial membrane PerVap 4060 made by Sulzer (nowadays Deltamem AG), with the active layer consisted of PDMS (polydimethylsiloxane) polymer. The characteristics of that membrane and the unit price per square meter are presented in Table 1. The presented price of the module is for the plate-and-frame pervaporation unit with membrane area exceeding 10 m^2. Therefore, the needed membrane area was determined on the required product flow rate and according to that the cost of the membrane module was appropriately calculated with the step of 10 m^2. The selection of appropriate parameters of the membrane and its price was determined based on mathematical modelling of permeability and selectivity of the membrane. This method was adapted from the approach proposed and developed by Lipnizki et al. (2002b), who performed economic analysis of pervaporation for aroma compounds recovery from apple juice.

Based on the obtained results in the semi-pilot scale, which is discussed in details in part 1 of this article, the most important membrane properties – permeability, selectivity and enrichment factor (EF) of fragrances – have been determined for pervaporation of apple hydrolate aroma compounds (Table 2). The compositions of the raw material (i.e. feed) and the permeate were determined by the SPME (solid phase microextraction) technique, which gives information on qualitative sensory analysis in the solution, rather than the non-quantitative composition of the aroma, in the solution, but a qualitative sensory analysis, which from the point of view of the consumer is far more important, hence the data from the SPME analysis was used in next calculations.

Concentration and flow rates of all process streams were obtained from experimental data; afterwards, they were used to achieve the desired permeate flow rate. The required membrane

Table 1
Membrane properties and costs.

Membrane parameter	Value	Unit
Type	PerVap 4060	–
Thickness	10	μm
Price	300	€/m^2
Life span	2	year
Module price	750	€
Active layer component	polydimethylsiloxane	–