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Process intensification on membrane-based process for blackcurrant juice concentration

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Abstract

Juice concentrate production is a field where process intensification and novel concentration processes needs to be implemented. The paper presents a systematic approach for process synthesis based on membrane processes for the concentration of blackcurrant juice, exemplified by the aroma recovery using combinations of vacuum membrane distillation and traditional distillation. The paper further suggests a novel method for the combination of nanofiltration, reverse osmosis and membrane distillation for the concentration of the dearomatized juice.

Keywords: Blackcurrant juice, process intensification, membrane distillation, nanofiltration, reverse osmosis, juice concentration

1. Introduction

Production of fruit juice concentrates is recognized worldwide as a way to preserve fruit juices and save transportation costs when producing, storing and exporting fruit juices. World blackcurrant production in 2001 was at the size of 658.7 billion tones fruit primarily produced in Europe and Russia. In view of process technology for juice concentrate production, there are two major factors to be considered for the development and design of juice production processes: one is product quality and the other is process economics.

The conventional evaporation-based juice concentration processes are featured with high-temperature at 90°C and severe energy consumption, which incur several disadvantages in terms of production technology: loss of aroma and nutrients such as vitamins and antioxidants, induction of cooked odor due to furfural formation, coloring due to Maillard-reactions, foam formation, last but not least, large amount of energy needed for water removal. To reduce the processing temperature and thus improving product quality, membrane-based process offers a promising way for producing juice concentrates at a temperature below 60°C.

In this work, process intensification for membrane-based processes for blackcurrant juice concentration is studied. A systematic procedure is approached to synthesize the intensified process alternatives incorporating the membrane-based processing steps. First, the characterization of the properties of the raw materials and product quality is conducted. Then, the process phenomena in terms of both transport phenomena and process parameters are abstracted by exploring the existing processing operations for juice concentration. The ranges of major operating parameters are also specified in terms of product quality and production requirements. In the third step, the processing operations incorporating membrane principles are proposed within the constraints of the specified ranges of the process parameters. Finally, three intensified membrane-based

processes for the production of the qualified juice concentrates are obtained by combining the membrane operation with other operations in the whole process.
The intensified membrane-based processes are compared with the conventional juice production processes both qualitatively and quantitatively on the basis of the defined list of criteria, which includes product quality and process economics. To confirm the major operations in the intensified processes, some laboratory and pilot scale tests have been performed which have provided the data for the comparison purposes.

2. A systematic procedure for juice concentration process intensification

A four-step procedure for intensification of juice concentration processes is formulated which is presented in Figure 1.

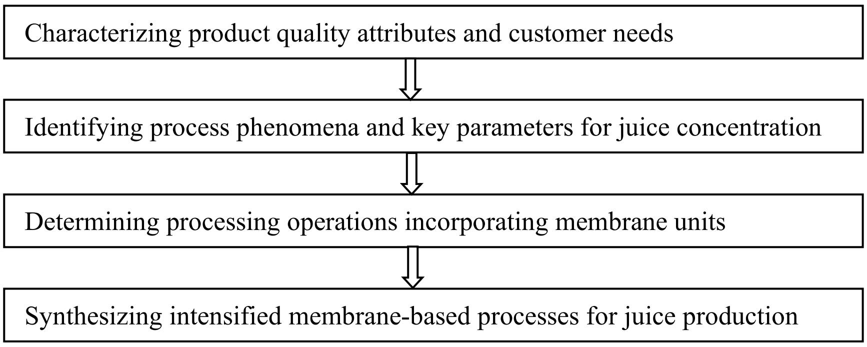


Figure 1. A systematic procedure for juice concentration process intensification

2.1. Characterization of juice quality and customer requirements

The customers for blackcurrant concentrate are mainly juice factories, where the original juice concentrate is mixed with sugar and water before being sold as a dilute juice concentrate to the retailers. The juice factories prefer a juice concentrate with high acidity, dry matter content and an aroma content as close as possible to the original blackcurrant. As opposed to for instance apple juice the aroma is not reconstituted in order to obtain a consistent juice flavor for the final product. This is not necessary as blackcurrant aroma in itself does not vary much within production year and species. The typical composition of fresh pressed juice is around 10-12% sugars, mostly fructose and glucose, 0.5-1% organic acids, mainly citric acid, and a characteristic mix of aroma components. The major Blackcurrant concentrate parameters are therefore a dry matter content around 65-68% (65-68 °Brix), the majority of which is glucose, fructose and citric acid, and an aroma recovery from the concentration process of at least 40% (D. Alves et al, 2006).

2.2. Major process phenomena and parameters for juice processing

Traditional juice concentration is carried out by evaporating water from the juice in falling film evaporators at around 90 °C. During the evaporation process most of the aroma compounds evaporates with the water vapor and have to be recovered by condensation and distillation of the aroma from the condensate. This aroma is later added to the juice concentrate. During the evaporation process minor amounts of hydroxy methyl furfural is formed by the acid catalyzed dehydration of fructose. This can lead to a slightly baked taste in the juice concentrate. Treatment of blackcurrant juice at 90 °C for 2.5 min. leads to a significant negative change in aroma and sensoric profile. Contrary heating blackcurrant juice for up to 60 min. at 60 °C shows no negative change in the sensoric profile (Varming et al, 2004).

2.3. Membrane-based processing operations for juice concentrates

Membrane processes offers a way of concentrating juice at temperatures under 60 °C. Aroma stripping from blackcurrant juice has been carried out at temperatures between 10 and 45 ° using vacuum membrane distillation (VMD) (R. Bagger-Jørgensen et al, 2004), while pervaporation has been used for recovery of strawberry aroma (Ischi et al, 2006). The aroma recovery for VMD is up to 70% and the flux 10 times higher than for pervaporation. Concentration of blackcurrant juice has been carried out in the authors' laboratory using direct contact membrane distillation (DCMD) and osmotic membrane distillation (OMD). The fluxes at 40 °C varied from 1.5 L/m^2/h at 10 °Brix to 0.5 L/m^2/h at 68 °Brix. Concentration of blackcurrant juice have also been carried out using reverse osmosis (RO) at 40 °C to a concentration of 25 °Brix, the flux varying between 24 L/m^2/h at 10 °Brix and 0.5 L/m^2/h at 22 °Brix when a pressure of 50 bar was applied (Bánvögyi et al, 2009). Furthermore, Warczok et al (2004) has demonstrated, that nanofiltration (NF) can be used to produce apple juice concentrates with a brix of apparently 30 °Brix at 30 °C and a pressure of 12 bar. The dry matter retention though was only 92%.

2.4. Process integration for the whole juice production processes

Based on these findings a set of possible process scenarios can be suggested for the concentration of blackcurrant juice to 68 °Brix at temperatures around 30 to 40 °C. To obtain a final concentration of blackcurrant juice of 68 °Brix the final concentration step has either to be DCMD or OMD. As the laboratory experiments showed that neither of these processes can retain the aroma components in the concentrate and the fluxes are virtually the same, DCMD is the obvious choice as this process leads to the simplest process design for the final concentration step. As the aroma cannot be retained in the concentrate during the concentration steps the overall process can be divided into two major steps: The aroma removal and recovery, and the concentration of the dearomatized juice. In order to obtain the aroma recovery specified and a sufficiently high aroma concentrate, the aroma removal can either be carried out using a series of VMD-countercurrent steps as used in membrane gas separation units or as a single VMD-step followed by a concentration of the aroma using standard aroma distillation. The concentration steps following the dearomatizing step should further be carried out with the highest flux possible in order to reduce the membrane and operation costs. This leads to a natural choice of combining reverse osmosis with nanofiltration to reach a brix around 30 before doing the final concentration with DCMD.

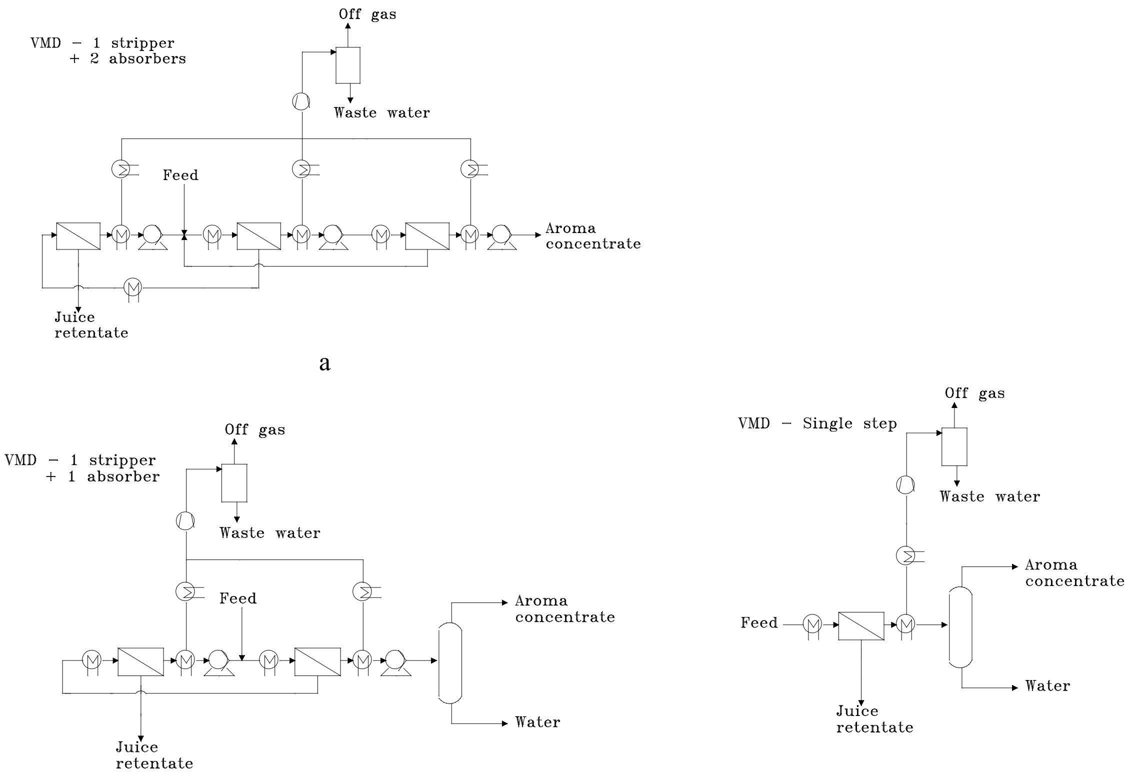
3. The intensified membrane-based juice concentration processes

From the discussion above three alternatives have been identified, their main difference being the aroma recovery step.

Alternative 1: Aroma recovery by VMD: 1 enricher + 2 strippers (figure 2a). Concentration by NF, RO and DCMD (figure 3).

Alternative 2: Aroma recovery by VMD and distillation: two step VMD and distillation (figure 2b). Concentration by NF, RO and DCMD.

Alternative 3: Aroma recovery by VMD and distillation: single step VMD and distillation (figure 2c). Concentration by NF, RO and DCMD



b c

Figure 2 a. Aroma recovery by VMD: 1 enricher + 2 strippers. b. Aroma recovery by VMD and distillation: 2 step VMD and distillation. c. Aroma recovery by VMD and distillation: single step VMD and distillation.

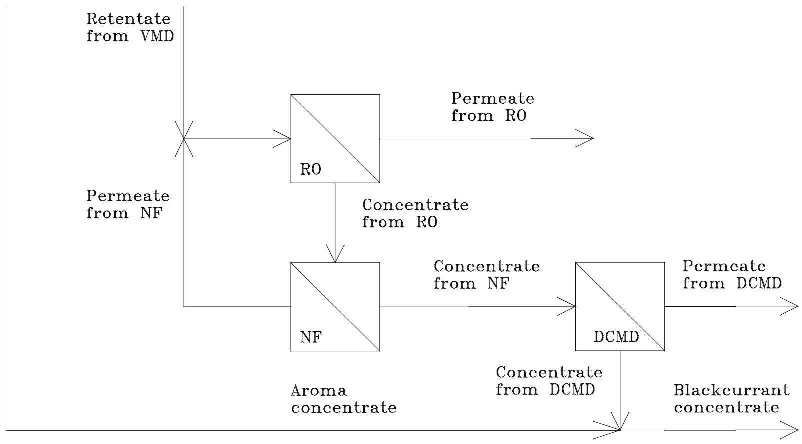


Figure 3. Concentration step for dearomatized blackcurrant juice and remixing of juice and aroma concentrates.

4. Process comparison and analysis

The whole process was simulated using a combination of MathCad, Excell and Aspen Plus for a plant processing 280 m^3 juice per day using data from the mentioned literature. Equipment cost and utility costs were estimated using Aspen Icarus and data from Peters et al (2003). As the concentration step for the dearomatized juice is identical for all the listed alternatives, only the aroma stripping scenarios needs to be compared in order to chose between the three alternatives. The Criteria on which the process evaluation was done is shown in table 1. Based on these criteria alternative 3 seems most promising. Even though the aroma recovery is low, it is sufficient as compared to traditional juice concentration plants.

Table 1. A list of criteria for process alternatives comparison

Comparison criteria	Alternative 1	Alternative 2	Alternative 3
Aroma recovery	79%	85%	66%
VMD membrane area	1220 m^2	1100 m^2	540 m^2
Equipment Costs	1,608,000 €	1,507,000 €	786,000 €
Operating cost	172,000 €	192,000 €	126,000 €
Technology maturity	Low	Low	Medium

5. Conclusion and future work

The proposed combination of membrane processes is able to produce a 68 °Brix juice concentrate using a process temperature of around 40 °C. This makes it possible to avoid formation of hydroxy methyl furfural thus producing a juice with a taste closer to the original fresh pressed juice. Furthermore, the energy consumption is expected to be lower. These findings though need to be verified by pilot scale experiments for the combined process and further process simulations based on improved experimental data should be carried out in order to get a better estimate of the economic potential for the whole plant design.

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