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Whey cryoconcentration and impact on its composition

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Abstract

Whey is a source of food ingredients of high nutritive value. Quality of proceeded whey components depends on the type of the process used and the operation conditions. In this paper, a new method for whey concentration was developed and impact on the physico-chemical properties of the final product was studied. Whole cheese whey was concentrated by a cryoconcentration method. A freezing process was carried-out at -10 ± 1, -20 ± 2 and -40 ± 2 °C and the defrosting procedure at 18 ± 2 °C. The procedure was achieved in five levels (stages). Each concentrate of a preceding level (stage) was used as initial solution for the following cryoconcentration stage. The concentrated and ice fractions were analyzed at each cryoconcentration level (stage). It was possible to concentrate the whey up to 35% of dry matter after four levels. Total proteins were concentrated up to 20% of the total dry matter. Lactose was found to be more concentrated in the ice fraction, whereas the proteins were more concentrated in the unfrozen (defrosted, cryoconcentrated) fraction. Concentration efficiency of the process decreased by increasing the cryoconcentration level (stage). Ice recycling seems to be possible to improve the process efficiency. Process optimization by a mathematical modeling showed that the optimum cryoconcentration level (stage) is 3.

Keywords: Whey; Cryoconcentration; Protein content; Lactose; Process efficiency; Dry matter

1. Introduction

The food liquids such as fruit juices, milk, whey (lacto-serum), extracts of tea or coffee, are complex aqueous solutions in which water constitutes the major part (Grishine & Karpovich, 1991; Osthoff, Hugo, & de Wit, 2006; Welch, 1997). Water accounts for approximately 75–95% (Osthoff et al., 2006). For the purposes to reduce the storage costs while preserving the best quality of these food solutions, it is important to concentrate these solutions to reduce water activity and thus to avoid microbial growth. This means to eliminate part of water contained in these products (Komyakov, Reitblat, Osipko, & Uryash, 1986). In a simplified way, the concentration of these food liquids can be carried out by three principal methods: evaporation, reverse osmosis, and cryoconcentration (freeze concentration). All these methods aim to increase the shelf life of the food liquids by decreasing water activity (Ezhov, Filatkin, Plotnikov, Fedotov, & Emelyanova, 1976).

The process of evaporation is one of the most well-studied processes for aqueous systems concentration, and undoubtedly, it is the most used in the food industry. This is probably due to the fact that the design of the evaporation units is relatively simple and the cost of the operation is limited insofar as one can implement multiple effects or use economic heat pumps. On the other hand, the interest of this process is extremely debatable if one considers its effects on the organoleptic and nutritional qualities of the concentrated food products (Lewicki, 2006). For example, the exposure of the thermo-sensitive food liquids to temperatures above 60 °C causes important losses of the volatile and aromatic compounds, water-soluble vitamins such as vitamin C and thermolabile proteins like whey proteins (Fryer & Robbins, 2005). It is also necessary to mention

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the problem of the clogging of the heat exchangers when they operate under high temperatures and complex food products containing a considerable amount of minerals. This phenomenon limits the quality of the heat exchange and contributes to increase the specific energy consumption of the evaporation process.

On the other side, reverse osmosis is a technique, which draws mainly its effectiveness from the selectivity of the membranes (Dova, Petrotos, & Lazarides, 2007). This method is based on the principle of an application of a pressure gradient between two adjacent compartments; one containing the feed aqueous solution to concentrate, the other one containing pure water. This process is based on a forced migration of water from the food aqueous solutions to the pure water compartment. The effectiveness of this operation is a function of the applied pressure compared to the osmotic pressure. It also depends of the intrinsic properties of the reverse osmosis membranes used. A good membrane lets pass the major part of water (solvent) and retains all the solids and volatile compounds. Unfortunately, it is not always the case. Certain reverse osmosis membranes let pass molecules such as sugars, free amino acids, and water soluble vitamins. Also, reverse osmosis membranes are subjected to the fouling. This phenomenon is responsible of the effectiveness decreases of the separation process and requires periodic stops for membrane cleaning. However, it should be noted that reverse osmosis is very effective from an energy point of view.

Cryoconcentration is a technique, which becomes of topicality, consists in crystallizing part of water of a liquid food, then to separate these water crystals from the concentrated solution (Burdo, 2005; Sakly & Gibert, 1983). From the point of view of quality, cryoconcentration is certainly the process of dehydration, which makes it possible to preserve a maximum of organoleptic and nutritional qualities of the liquid food products (Heist, 1979; Hindmarsh, Russell, & Chen, 2007; Kiss & Farkas, 1972). It draws its advantages owing to the fact that the chemical and biochemical reactions, which are responsible of the product quality deterioration, are very slow at low temperatures. Sometimes, certain researchers estimate that cryoconcentration is an expensive process. They are not completely true if one compares the orders of magnitude of the total needed energy to crystallize 1 kg of water (Burdo, 2005). They are approximately of 335 kJ/kg by cryoconcentration, while they represent approximately 2260 kJ/kg by traditional evaporation process (Sakly & Gibert, 1983). Moreover, in freeze-drying technology witch is very expensive procedure, cryoconcentration technology can be used as a preparative operation in combination with freeze-drying to reduce the energy costs of the freeze-drying process. It could be used as a pre-concentration process in order to accelerate the freeze-drying operation. The fact of operating at low temperature avoids any microbial contamination and preserves the nutritive qualities of the treated product. Cryoconcentration is a process which implies concentration of complex food liquids by partial water freezing (Heist, 1979). Thus, the remaining solution becomes more concentrated. The fact of operating at low temperatures makes it possible to preserve a maximum amount of the aromatic and volatile compounds. This is practically impossible to obtain by using the traditional techniques of concentration such as evaporation. Moreover, the use of low temperatures gives the advantage of obtaining products with a definitely improved organoleptic characteristics and nutritive values. This is carried out by the safeguarding of vitamins, polyphenols and thermolabile proteins. It was reported that the use of cryoconcentration in cognac industry offers prospects to obtain new aromatic bouquets, which are not yet known in this field (Burdo, 2005). It was also reported that from fruits and vegetables by-products, cryoconcentration procedure permits to develop new products with very interesting properties. Products rich on proteins, vitamins and polyphenols were obtained from grape by-products like the grape peels which remain following the grape juice and wine manufactures. Chicory extracts with initial 20% dry matter were cryoconcentrated up to 35–40% by fractional crystallization on a cooled surface (Komyakov et al., 1986). The effects of mixer rotation rate, temperature of the solution, and cooling rate on the rate of crystallization and distribution coefficient were thus determined. A high crystallization rate was achieved using optimal parameters and the losses of soluble substances were minimal (Komyakov et al., 1986). An increase of the dry matter content from 20% to 40% resulted from 22% to 25% shorter drying time and 50% higher yields of the product with 4% moisture. Energy consumption was 1.5–2 times lower then by a traditional evaporation process (Ezhov et al., 1976). Cryoconcentration of hop extract and beer was studied, together with the relation between the equilibrium solidification temperature and concentration of extractive substances in the product and the quality indices of the concentrated and initial products; the composition of the resultant solids phase was determined in order to establish whether components of the concentrated product were entrapped by the ice. Results in this study (Ezhov et al., 1976) indicated that cryoconcentration of hop extract and beer was feasible. With contents of extractive substances of approximately 53%, the process had no detrimental influence on product quality and its composition. Cryoconcentration of high-extractive beer concentrate caused proteins coagulation and isohumulone content reduction (Ezhov et al., 1976). In these cases, the quality, and the crystals ice size determined the effectiveness of the process (Huige & Thijssen, 1972; Olowofoyeku, Gil, & Kramer, 1980; Raventos, Hernandez, Auleda, & Ibarz, 2007; Van Pelt, 1975).

From a thermodynamic point of view, a cryoconcentration operation can be defined as being a process of liquid–solids separation that takes place during a molecular separation based on a difference in temperature of crystallization (Burdo, 2005). There are two essential phases that