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Concentration and purification of whey proteins by ultrafiltration

C. Baldasso *, T.C. Barros, I.C. Tessaro

Laboratory of Membrane Separation Processes Departamento de Engenharia Química, Universidade Federal do Rio Grande do Sul R. Eng. Luiz Englert, s/n. CEP: 90040-040, Porto Alegre, RS, Brazil

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ABSTRACT

Whey is a liquid by-product of the dairy industry produced during the manufacture of cheeses and casein. As a raw material, it has many applications in food technology due to the functional and nutritional properties of its proteins. Membrane technology, especially ultrafiltration (UF), has been used in the dairy industry to produce whey-protein concentrates, because this technology allows the selective concentration of the proteins in relation to the other components. In this context, the objective of this work was to concentrate and to purify the whey proteins using UF in association with discontinuous diafiltration (DF). The two strategies were tested by changing the volumetric-concentration factor (VCF), the DF water volume and the number of DF steps. The results showed that the UF process is adequate for the production of protein concentrates; in the best experimental strategy, the protein concentrate obtained was greater than 70% by weight (dry basis).

1. Introduction

Whey, the by-product of cheese or casein production, is of relative importance in the dairy industry due to the large volumes produced and the nutritional composition; the production of 1–2 kg of cheese yields 8–9 kg of whey. Whey contains more than half of the solids present in the original whole milk, including whey proteins (20% of the total protein) and most of the lactose, minerals, water-soluble vitamins and minerals [1,2].

Worldwide whey production is estimated at around 180 to 190×10^6 ton/year; of this amount only 50% is processed. The whey can be considered a valuable by-product with several applications in the food and pharmaceutical industries; however, it is often treated as a dairy wastewater. The treatment of whey represents a serious problem due to its high organic load, which can reach a chemical oxygen demand (COD) of 100,000 mg O_2 L^{-1} [3,4].

Many techniques have been developed to selectively concentrate whey proteins, because the whey is not a balanced source of nutrients, containing a high lactose content compared to the protein, and thus does not have the nutritional benefits of more typical protein sources.

Whey proteins have a high nutritional value, due to the high content of essential amino acids, especially sulfur-containing ones [5]. Besides the nutritional properties, the whey proteins have functional properties which impart beneficial physical properties when used as ingredients in food, mainly due to its high solubility, water absorption, gelatinization and emulsifying capacities [6]. Due to the higher specificity of the product, and the excellent functional and nutritional value, the commercial value of whey protein concentrate is from 3 to 40 times greater than that of whey powder [3].

The conventional method of whey concentration is by thermal evaporation. The main disadvantages of this method are the high energy consumption and the high content of ashs and lactose that remains in the concentrate; additionally, the heat treatment can change the characteristics of whey components, mainly the proteins, which are thermolabile and can lose their nutritional and functional properties during heating. Ultrafiltration (UF) is a very attractive alternative method, as it does not use heat and as a consequence does not involve a phase change, which makes the concentration process more economical. UF is a membrane separation process (MSP) typically used to retain macromolecules, and has been used in the dairy industry in the recovery and fractionation of milk components. UF allows a variation in the ratio of concentration between the whey components, due to the retention of protein and selective permeation of lactose, minerals, water and compounds of low molar mass [7].

Diafiltration (DF) is used for the production of whey-protein concentrate (WPC) with a high protein content. DF is used for protein purification to eliminate problems association with high concentrations in the retained product, generating high purification, while retaining good performance process [8]. Also, it should be pointed out that the addition of small DF volumes several times is more effective than a big volume at one time only.

The operability studies provide important information about the capabilities and limitations of the whey ultrafiltration process. The whey ultrafiltration process is well designed to deliver the desired total solids and protein concentrations for the production of whey protein concentrates. However, the process becomes less capable of delivering the desired product specifications after long hours of operation when long-term fouling is more significant [9,10].

* Corresponding author. Fax: +55 51 3308 3983.
E-mail address: cbaldasso@gmail.com (C. Baldasso).

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Further studies involving ultrafiltration operated diafiltration mode are needed to reveal diafiltration volumes that are effective. More than that, which may take into account what level and how many cycles diafiltration are needed, one can optimize the work. The desired total solids and protein concentrations cannot be achieved if the volume concentration ratio alone is used to control the flowrate and composition of the product stream.

The limitations of the whey ultrafiltration process highlight the necessity for direct monitoring of the total solids and protein concentration in the product stream during the production of whey protein concentrates. Monitoring of total solids and protein concentration also helps determine how the amounts of diafiltration water and recycled permeate need to be adjusted to achieve the desired product flowrate and composition from the ultrafiltration plant. Such adjustments are necessary either after deviations from the desired specifications are observed or after changes in the desired specifications are made.

Furthermore, the development of technologies capable of solving the problem of whey utilization can bring economic and environmental benefits as the whey is a good source of protein for human consumption, thus justifying and studying the possibility of using it commercially. In this context, the aims of the present work were the concentration and purification of whey proteins by UF associated with DF. In this work, different strategies were tested, including varying the volume of water added to the concentrate and the number of DF steps and modifying the volumetric concentration factor (VCF; the ratio of the initial volume of the whey solution and volume retained). Thus, the main objective is to obtain a large protein purification, with the minimum DF solution (in this case water).

2. Materials and methods

2.1. Whey

The sweet whey powder used in this study was supplied by *Eleva Alimentos* (Teutonia, RS), from the manufacture of mozzarella cheese, with a total solids content of approximately 6%. Liquid whey was reconstituted by manually dissolving the whey powder in distilled water at neutral pH and a temperature of 50 °C. The initial volume of whey for ultrafiltration was approximately 30 L (29.6 L water and 1.86 kg whey powder). The average initial contents of lactose, protein and ashs were 42 kg m^{-3} (72.4% - w/w), 9 kg m^{-3} (15.6%) and 7 kg m^{-3} (12%), respectively; the amount of fat was considered negligible, since it is removed before the whey was dried in a spray dryer.

2.2. Membrane

The UF membrane was UF-6001, made of polyethersulfone, in a spiral module manufactured by Koch Membrane Systems. The molar weight cut-off was 10 kDa, the feed spacer was 80 mils (thousandths of inch) and permeation area was 0.28 m^2.

2.3. UF equipment

Experiments were performed in a pilot plant, WGM-KOCH PROTOSEP IV, shown schematically in Fig. 1.

The pilot plant comprises the following equipments:

feed tank (1), stainless steel, with a volume of 75 L, manufactured by SULINOX. The tank has an agitator and a temperature-control system that operates in the range of 25 to 150 °C;

pneumatic pump (2), diaphragm type, model Versamatic VM50, operated with compressed air through a system comprising an FLR kit (filter, air regulator and lubricator);

pre-filter (3), manufactured by CUNO, consisting of a PVC housing and a polypropylene filter element with a nominal pore size of 1 μm;

housing for module spiral membrane (5), 30 cm in length and 5.8 cm in diameter, of 316 stainless steel;

manometers (4) and (6), 316 stainless steel, scale from 0 to 10.5 bar.

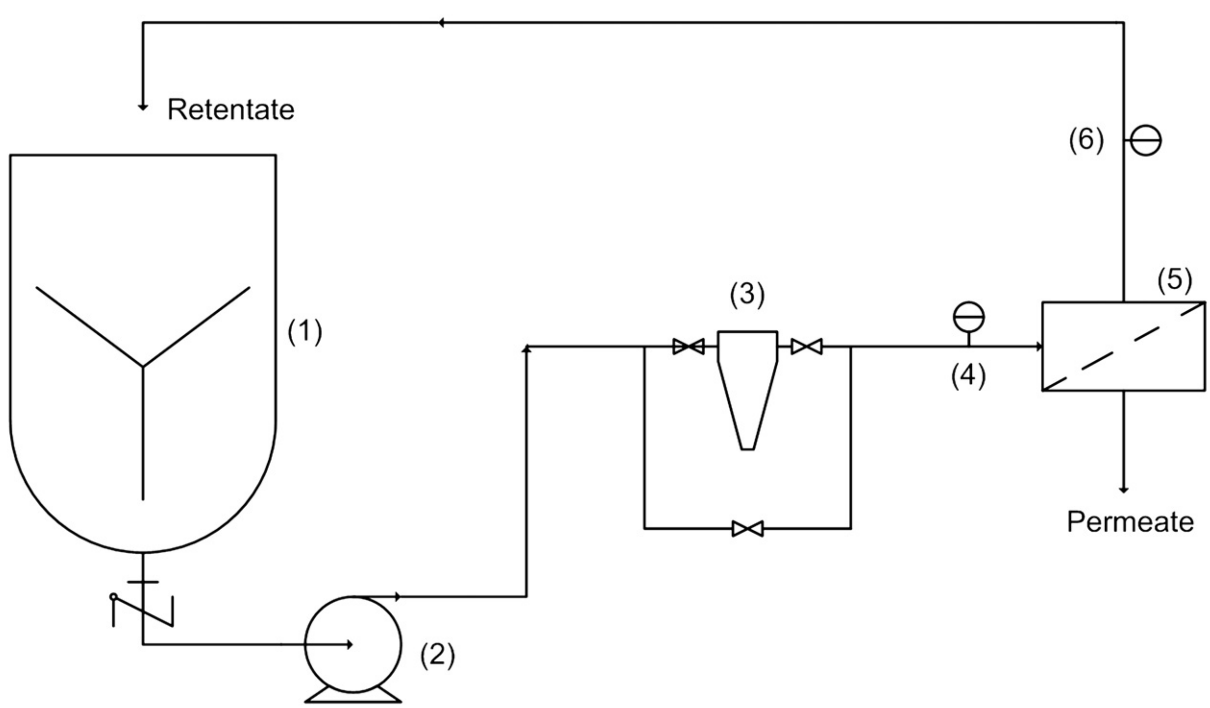

Fig. 1. Schematic of the membrane unit used for the experiments. (1) tank, (2) pump, (3) pre-filter, (4) and (6) manometers, (5) membrane module.