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Recovery of whey proteins and lactose from dairy waste: A step towards green waste management

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ABSTRACT

Whey is produced as a by-product during cheese and casein manufacture containing some important components such as lactose and protein. In this study, ultrafiltration process was adopted to separate lactose and protein with high yield and purity from whey using hollow fiber module. Ultrafiltration in a diafiltration mode was used in order to improve the yield of protein in the retentate, which was then freeze-dried to get the end product in dried form. Nanofiltration of the permeate stream from ultrafiltration was done to concentrate the lactose part and was similarly freeze-dried. To assure that after freeze–drying the quality of both the protein and lactose was not affected, FTIR analysis was done. The performance of both ultrafiltration and nanofiltration was characterized in terms of permeate flux. The influence of transmembrane pressure on both ultrafiltration and nanofiltration membranes was studied. The effect of fouling was also studied on both ultrafiltration and nanofiltration membranes and it was observed that the fouling effect was less in case of both the membranes and as such the membranes could be re-used for several times for effective separation of those components. The quantitative measurements were done for lactose and protein and it was observed that up to 90% of lactose and 80% of protein recovery could be achieved using the advanced separation technology. Therefore, the present article represents a novel approach for separation whey proteins and lactose from dairy waste to meet the socio economic requirements as well as to mitigate waste disposal problem.

1. Introduction

Whey is the principal by-product of dairy industry which is produced during the manufacture of cheese and casein from milk during coagulation process. Due to the huge production of whey and its high organic content, exhibiting a biochemical oxygen demand (BOD) ranging from 30 to 50 $g L^{-1}$ and a chemical oxygen demand (COD) ranging from 60 to 80 $g L^{-1}$, this liquid whey is commonly regarded as the "environmental problem" and is creating a great difficulty for the dairy industry in their disposal (Domingues et al., 1999). Whey contains a number of important nutrients such as lactose (4.5–5% w/v), soluble proteins (0.6–0.8% w/v), lipids (0.4–0.5% w/v) and mineral salts (8–10% of dried extract) (Gonzfilez Siso, 1996), so it can be exploited as a resource of a number of valuable end products rather than as a waste stream.

Since, whey is a waste product; so it can be utilized as a cheap source of lactose and protein and those can be used in food, dairy and pharmaceutical industries. Lactose can be either directly fermented or it can be hydrolysed to produce glucose and galactose, whereas proteins are widely used in food and pharmaceutical products, because they possess high nutritional value and versatile functional properties (Jayaprakasha and Yoon, 2005). Therefore, the recovery of lactose and protein can help to reduce the BOD and COD loading of whey and can help in solving the problem of environmental pollution being caused by the disposal of whey.

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In last few decades, membrane filtration is routinely used for a number of applications within the dairy industry. The recovery of proteins can be done efficiently via ultrafiltration with high yield and purity (Atra et al., 2005). Microfiltration is a process by which whey is being pre-treated before ultrafiltration to remove suspended fat and casein particles to reduce the fouling of the ultrafiltration membrane (Cancino et al., 2006). Nanofiltration is used to remove ions from the feed solution and can be used to concentrate valuable components of whey. Usually, the flow pattern through the membranes can be classified into two categories; dead-end filtration and cross-flow or tangential flow filtration. However, in tangential flow, the feed flows parallel to the membrane surface and is more attractive of the two because it causes less deposition of solutes on the membrane and helps in alleviating the particles deposited on the membrane surface (Baker, 2005). Ultrafiltration in a diafiltration mode using water as a buffer is a useful technique which helps to increase the concentration of solutes such as proteins, lactose or other biomolecules and has an advantage of economical permeate flux (Chollangi and Hossain, 2007; Cuartas-Uribe et al., 2009). Among several types of membrane modules, hollow fiber membrane (HFM) is more acceptable than other modules, due to its high membrane packing density, structural integrity, construction and thus it can withstand high permeate backpressure (Kuriyel, 2000; Cheryan, 1998; Nielsen, 2000). Hollow fiber membrane modules have several significant advantages over other conventional membrane modules considering its recovery of flux after cleaning of the membranes (Cheryan, 1998; Nielsen, 2000). Moreover, being a compact module, its structural configuration allows a high membrane surface area resulting in the increase of the output through the process, while utilizing minimal space, with low power consumption (Nielsen, 2000; Winston Ho and Sirkar, 1992). Whey contains different proteins with different molecular weight and can be easily separated through ultrafiltration with different molecular weight cut-off of membranes (Spălăţelu, 2012).

The present experimental work is an attempt to develop an effective process for separation of proteins and lactose with a high yield and purity, from whey using hollow fiber module. The present article also includes ultrafiltration with diafiltration mode to enhance the yield as well as the performance of ultrafiltration. In order to concentrate the lactose solutions obtained during the diafiltration process, nanofiltration (in diafiltration mode) was carried out where almost clear water along with ions were obtained in the permeate and lactose was obtained in the retentate. During microfiltration, ultrafiltration and nanofiltration, the effect of transmembrane pressure on permeate flux was studied. Freeze–drying of the concentrated protein and lactose solutions was performed to ensure the better quality of the end products, which can be directly utilized commercially for different purposes. Overall, the current research work enlightens the recovery and purification of the valuable components from dairy waste by-product, whey, resulting in a reduction of pollution load on the environment due to its disposal.

2. Materials and methods

2.1. Chemicals

The whey sample was a gift from a local sweet industry, Hindustan Sweets Pvt. Ltd, Jadavpur, India. Lactose was purchased from Loba Chemie Pvt. Ltd, Mumbai, India. The chemicals: Sodium hydroxide (NaOH, MERCK, Mumbai, India), Sodium hypochlorite (NaOCl, MERCK, Mumbai, India), orthophosphoric acid (MERCK, Mumbai, India), sulphuric acid (H_2SO_4, MERCK, Mumbai, India), phenol (MERCK, Mumbai, India) were of analytical grade.

2.2. Experimental set-up

The hollow fiber membrane module was used for our experimental work. The whole setup was purchased from local manufacturer. Hollow fiber microfiltration membrane with average pore diameter of 0.45 μm and ultrafiltration membrane with MWCO (molecular weight cut-off) of 8 kDa having average surface area of 0.028 m^2 were used. The solution was fed to the system using a pump and the inlet and outlet pressures were adjusted using globe valves. The schematic representation of the whole setup has been shown in Fig. 1.

2.3. Experimental method

The whey sample was collected and cold centrifuged at 11,000 rpm for 10 min to remove residual casein particles and fat. Hollow fiber membranes are extruded in an in-house extrusion machine. The centrifuged whey was filtered using hollow fiber microfiltration (MF) membrane to further remove the suspended casein and fat particles to minimize the fouling of membrane during ultrafiltration. The microfiltration study was done at different transmembrane pressure e.g. 0.5, 0.75 and 1 bar. In the subsequent stage the microfiltered whey was subjected to ultrafiltration using the hollow fiber membrane module with 8 kDa molecular weight cut-off (MWCO). The experimental runs were conducted in a system where permeate was collected in a separate tank while the retentate from the membrane is recycled back to the feed. The schematic representation of experimental methodology has been shown in Fig. 2.

The ultrafiltration was carried out by collecting the permeate stream in a separate tank until the volume concentration factor (VCF) becomes 2, i.e. feed solution volume was reduced to 50% of its initial volume. The VCF was determined as the ratio between the initial ($V_{initial}$) and final volumes (V_{final}) in the feed tank as shown in the following equation:

$$VCF = \frac{V_{initial}}{V_{final}} \quad (1)$$

In the subsequent stage, equal amount of distilled water was added to the ultrafiltration retentate and the first stage of diafiltration was carried out. The process was stopped until

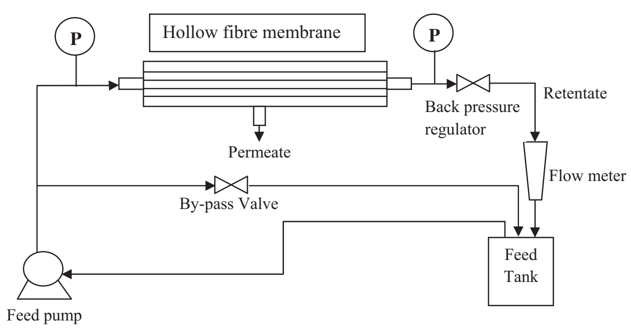

Fig. 1 – Schematic representation of hollow fiber module setup.