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Journal of Biotechnology 119 (2005) 212–218
Journal of BIOTECHNOLOGY
www.elsevier.com/locate/jbiotec

A new innovative process to produce lactose-reduced skim milk

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Received 17 June 2004; received in revised form 29 March 2005; accepted 31 March 2005

Abstract

The research field for applications for lactose hydrolysis has been investigated for some decades. Lactose intolerance, improvement for technical processing of solutions containing lactose and utilisation of lactose in whey are main topics in development of biotechnological processes. In this article, the establishment of a hollow fiber membrane reactor process for enzymatic lactose hydrolysis is reported. Mesophilic β-galactosidases were circulated abluminally during luminal flow of skim milk. The main problem, microorganisms growth in the enzyme solution, was minimised by sterile filtration and UV irradiation. In order to characterise the process parameters, such as skim milk concentration, enzyme activity and flow rates were varied. In comparison to a batch process, enzyme activity could be used longer and enzyme rest into the product should not occur. Furthermore, the three-dimensional separation of the substrate from the enzyme solution minimise blocking and washing out effects, which restrict processes with immobilised enzymes. A conversion rate of 78.11% was achieved at a skim milk flow rate of $9.9\,l\,h^{-1}$, enzyme activity of $120\,U\,ml^{-1}$ and a temperature of $23 \pm 2\,^{\circ}C$ in a hollow fiber reactor with a membrane area of $4.9\,m^2$.

Keywords: Enzyme technology; Lactose hydrolysis; β-Galactosidase; Diffusional reactor

1. Introduction

Every year 3.2 million tonnes of lactose, dissolved in whey, is accrued by the cheese production world-wide (Ruttloff, 1994). Almost half of this amount is used for human and animal nutrition. The rest is waste that is difficult to dispose of and adds to the environmental pollution. Therefore, there is a need for investigation about further utilisation possibilities of lactose from whey. One of these applications with a high technological and dietetic interest is the enzymatic hydrolysis of lactose, whose economic importance has been increasing ever since the 1960s.

Next to the medical aspect of lactose intolerance, some very important technological advantages result from the lactose hydrolysis into glucose and galactose.

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doi:10.1016/j.jbiotec.2005.03.018

For example, the solubility increases from 18 to 55% (w/v) at 80% conversion and the sweetness rises up to 70% related to sucrose. Furthermore, there is a lowering of the freezing point, an increase of the probability for non-enzymatic browning reactions and a faster fermentation process in lactose hydrolysed medium. Thus, the production of self-sweetening products or products with less sucrose addition would be possible by using lactose hydrolysed milk or whey. Also, positive effects on the crystallisation and process properties would be achieved after lactose hydrolysis (Zadow, 1992).

In general, there are several technologies for enzymatic hydrolysis of lactose (Pivarnik et al., 1995; Mahoney, 1985; Gekas and Lopez-Leiva, 1985). The easiest way is the discontinuous batch-process. After reaching the aimed conversion, the reaction is stopped by heating, which causes enzyme denaturation and consequently the loss of enzymatic activity. Furthermore, the enzymes become product components after the process.

The immobilisation can be employed to use the enzyme's activity for as long as possible. It can be affected by physical or chemical binding on a solid matrix like glass surfaces, cellulose acetate or oxirangel (Richmond et al., 1981). High cost of the immobilising steps, the activity loss during immobilisation and the occurrence of hygienic problems because of the fat and protein content in milk and whey (Reimerdes, 1985) has a detrimental effect on the decision to choose this process.

The third possibility is the "physical immobilisation" by separating enzyme solution from the substrate flow via ultrafiltration membranes (Czermak et al., 1988). This system causes workable and cheap enzyme fixation with little loss of the catalytic activity of the enzyme. Further advantages of this process are the continuous operation of the reactor at low pressure and the selectivity control by selection of suitable membranes. High enzyme concentration application, easy replacement and regeneration of spent enzyme solution and little loss of enzymes due to wash out effects are possible. A drawback is, that the diffusion resistance of the hollow fiber membrane seems to be the limiting factor at high conversion rates.

Ultrafiltration modules were constructed as steam sterilisable plastic membranes by Czermak et al. (1990) and Czermak (1992), whose development and production are too expensive for reaching the economic aim to be at least as cheap as the batch process. Thus, it is necessary to find another solution to control the microbiological growth in the system.

2. Material and methods

2.1. Functional principles of the bioreactor system

An ultrafiltration unit (called module) consists of a bundle of small hollow fibers. The outside (shell side) compartment is constructed as a closed circulation and is filled with the enzyme solution. A continuous flow of the substrate (skim milk) is applied to the inside (tube side) of the hollow fiber membranes. The spatial enzyme separation from the substrate solution is guaranteed by the selected membrane cut-off value (Fig. 1).

In this way, continuous, enzymatic lactose hydrolysis is possible without inherent problems of immobilised enzymes. The driving force for this system is the lactose diffusion, which mainly depends on the concentration gradient, the temperature and the flow rates of the substrate and the enzyme solution.

Fig. 2 shows the standard flow sheet of the newly developed plant. The reactor is a hollow fiber module (43 in. module, 10 kDa cut-off and 4.9 m^2 membrane area), which consists of a bundle of capillaries made of polysulfone membrane. The shell side volume is about 2.5 l and the tube side volume is about 0.65 l. Skim milk is pumped through the hollow fiber module. Before enzymatic conversion takes place in the hollow fiber module, skim milk passes a heat exchanger, a manometer and a thermometer. After the end of the module, the lactose-hydrolysed product can be collected.

The enzyme solution is pumped in a closed circulation. Temperature of enzyme solution was adjusted with a waterbath located before the hollow fiber's shell side. Czermak and Bauer (1990) have constructed ultrafiltration modules as steam sterilisable plastic membranes. Development and production costs seemed to be too high for commercial use compared to the batch process. Thus, it is necessary to find another solution to control the microbiological growth in the system. In order to sufficiently reduce germs presence a UV irradiation module and a sterile filtration unit were included in the enzyme circulation. To our best knowledge, the use of a commercially available UV-unit (Visa, Austria)