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Simulation of the xanthan gum production in continuous fermentation systems

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ABSTRACT

This work is focused on the simulation of the bioproduction of xanthan gum in continuous fermentation systems. We evaluated the cell and gum productivities in a continuous system without cell recycling and in continuous systems with internal and external cell recycling. Results demonstrated that the continuous system can improve the production of gum, since the gum productivity obtained in the systems with external and internal cell recycling were 2.57 and 3.62 g L^{-1} h^{-1}, respectively, which was about 12–17 times higher than obtained in the reactor without cell recycling.

1. Introduction

Xanthan gum is widely used in food industry as thickener to control the quality of final products (Yoon and Gunasekaran, 2007). Several works in literature report xanthan gum production (Silva et al., 2009; Mesomo et al., 2009; Kalogiannis et al., 2003; Rosalam and England, 2006; Chaitali et al., 2003; Casas et al., 2000; Amanullah et al., 1998), including the fermentation in a continuous recycled packed fibrous-bed (Yang et al., 1996; Rosalam et al., 2008). The growth of the microorganism and xanthan production are influenced by factors such as the type of bioreactor used, the mode of operation (batch or continuous), the medium composition (Letisse et al., 2001, 2002, 2003; Kalogiannis et al., 2003; Faria et al., 2010), and the culture conditions such as temperature, pH, dissolved oxygen concentration (Letisse et al., 2003; Casas et al., 2000; García-Ochoa et al., 2000b; Bangalore and Bellmer, 2006).

The industrial scale production of xanthan is carried out using inexpensive substrates and nutrients. Carbohydrate sources such as sucrose, sugarcane molasses and whey (Silva et al., 2009) have been successfully used in the production medium. The product is then recovered and purified using alcohol precipitation. The main steps of the recovery process are deactivation and removal of the microbial cells by centrifugation, precipitation of the biopolymer, dewatering, drying and milling. Processing must be done without degrading the biopolymer (Palaniraj and Jayaraman, 2011).

During inoculum buildup the aim is to increase the cell concentration but minimize the production of xanthan, because xanthan around the cells blocks mass transport of nutrients and extends the lag phase of growth (García-Ochoa et al., 2000a). In this way, the continuous system arises as an alternative to achieve maximum cell production and, by maintaining them at a constant level, obtain higher xanthan gum productions. The continuous system consists of a continuous substrate feed and withdrawal of fermentation broth to maintain the reaction volume constant.

The continuous operation can be carried out with or without cell recycling. Systems with cell recycling are very common in the fermentation industry. The main function of cell recycling is to increase the cell concentration inside the bioreactor, increasing the rate of substrate conversion. Industrially, this recycling is done with centrifuges, usually when the microorganism is yeast, or by microfiltration, when the microorganism is a bacterium. In the case of reactors in series, this operation can be performed in any reactor, returning the microorganism to the most appropriate reactor, demonstrating the large flexibility of operation available.

The interest in this process depends on the possibility of minimizing the operating time, keeping the process under conditions of high performance and free of contamination (Rosalam

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et al., 2008). With production of xanthan gum by *Xanthomonas campestris* in a nutrient medium, the cells productivity could be improved by the increase of average cell concentration through the stepwise increase of growth limiting nutrients in the medium (Rye et al., 1988).

The economics of xanthan gum production by continuous fermentation are favored when a batch fermentation process is employed. It has been shown that the economics of continuous xanthan fermentation are sensitive, at least in part, to the specific productivity at which the culture is operating. Therefore, any process improvements which enhance specific productivity will improve the overall economics. For example, at a dilution rate of 0.08 h^{-1}, increasing the specific productivity from 0.12 to 0.2 g xanthan/g cells can lower the per pound price of xanthan by as much as 20% (Rogovin and Silman, 1970).

In this sense, the main objective of this study was to simulate the process of xanthan gum production in continuous fermentations systems without cell recycling, and consider internal and external cell recycling. We evaluated the influence of initial cell and lactose concentration on the productivity.

2. Model simulations of xanthan gum bioproduction

The present study is part of a broader project for production of xathan gum using cheese whey as carbon source (Silva et al., 2009; Mesomo et al., 2009). The data analysis obtained by Mesomo et al. (2009) revealed that the highest production of xanthan gum was obtained at conditions of superficial gas velocity and stirring speed of 16.7×10^{-6} m s^{-1} and 6.5 s^{-1}, respectively. In this sense, these conditions were maintained constant for all the strategies investigated in this work.

Although the increase in the superficial gas velocity and stirring speed promote a sharp increase in the volumetric mass transfer coefficient, k_{La}, there are several impacts on cellular viability due to shear stress effects. Silva-Santisteban and Maugeri (2005) verified that the inulinase activity and biomass dropped and the viability reached zero after 72 h of fermentation at 550 rpm. Although the stirring speed has a positive effect on k_{La}, was not reflected in the enzyme production, since the shear stress affects the cell viability. The authors concluded that the interaction between oxygen transfer and mechanical stress seems to define the enzyme production and that both shear stress and k_{La} should be considered in the cases of process optimization and scaling up. The sensitivity to shear stress being an intrinsic characteristic of microorganisms and varying sometimes greatly from strain to strain, in some cases it can turn out to be a limiting factor in optimization, as well as in scale up of processes. In practice, the oxygen-transfer rate (OTR) is problematic in all fermentative processes, due to mass transport between the gaseous and aqueous phases mainly due to drastic decrease of the concentration of the dissolved oxygen in equilibrium with the partial pressure of oxygen in gas phase. In the literature, there are several works reporting the influence of stirring speed and

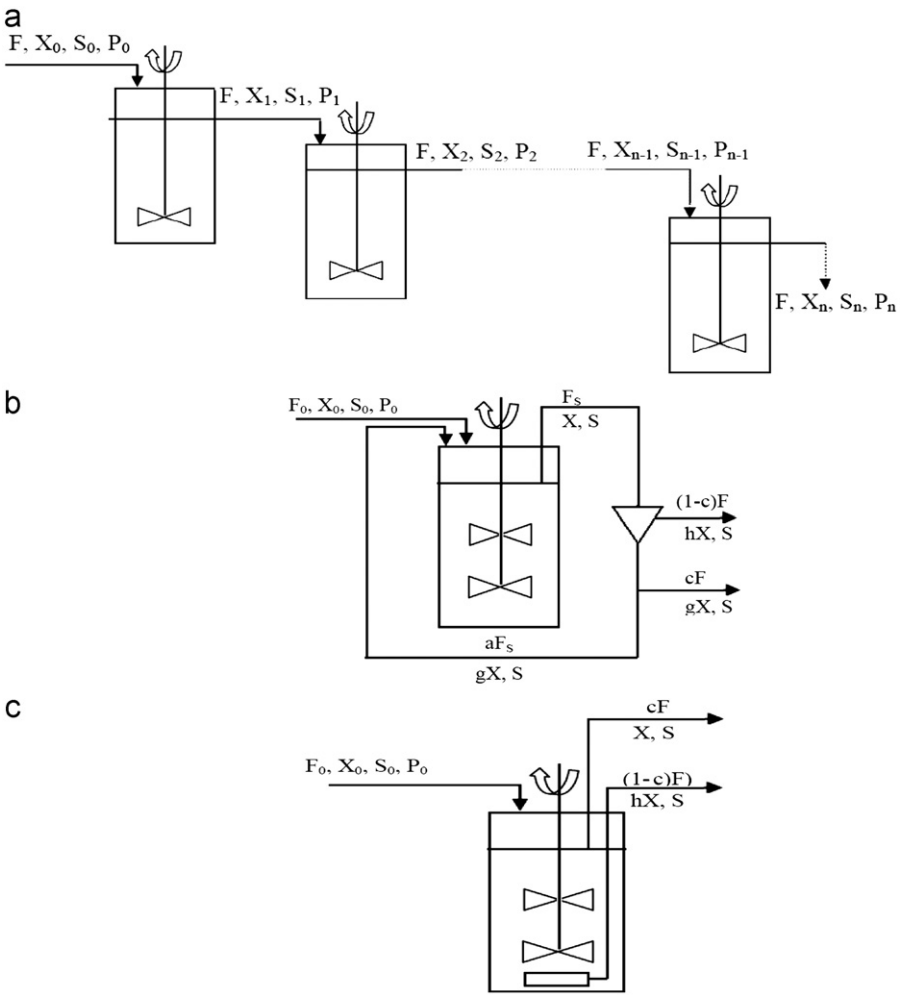

Fig. 1. Schematic diagram of continuous fermentation systems with *n*-bioreactors in series (a) without cell recycling, (b) external cell recycling, and (c) internal cell recycling.