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REVIEW

Immobilisation of *Clostridium* spp. for production of solvents and organic acids

Igor Dolejš, Martin Rebroš*, Michal Rosenberg

Institute of Biotechnology and Food Science, Faculty of Chemical and Food Technology, Slovak University of Technology in Bratislava, Radlinského 9, 812 37 Bratislava, Slovakia

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This review summarises the high potential of immobilised cells systems for the fermentative production of compounds, mainly produced by representatives of the *Clostridium* genus. Microorganisms of *Clostridium* species are recognised as good producers of a wide range of chemicals in almost every sector of industry. The combination of this microorganism with its immobilisation opens up new possibilities and renders the fermentation process more sophisticated than in a free-cell system. This review provides a comprehensive summary of techniques used in immobilisation of *Clostridium* species with regard to specific products and types of fermentation. In addition, comparisons of particular types of immobilisation techniques used in fermentation processes are summarised by specific products.

Keywords: *Clostridium*, immobilisation, solvents, acids

Introduction

Immobilisation is one of the methods most extensively used to improve the fermentation process. In the field of biotechnology, it is defined as the technique used for the physical or chemical fixation of cells, organelles, enzymes or other proteins (e.g. monoclonal antibodies) onto a solid support, into a solid matrix, or retained by a membrane, in order to increase their stability and facilitate their repeated or continued use (IUPAC, 1997). The immobilisation of whole cells is based on the retention of catalytically active cells within the restricted region of a bioreactor. That the immobilised cells may be alive leads to unique effects in this form of heterogeneous catalysis, taking into consideration the individual conditions of the fermentation process which depended on the selected immobilised microorganism (Karel et al., 1985). One example of that specific process is the immobilisation of anaerobic microorganisms, which presents new possibilities in fermentation, insufficiently investigated to date. In the immobilisation it is more difficult to maintain the cells activity of anaerobic microorganisms than the cells activity of aerobic microorganisms, because it is performed in an anaerobic atmosphere. One of the methods for achieving success in the immobilisation of anaerobic microorganisms is to induce sporulation, the process when spores, the most resistant stage of the cell, are formed (Burns & Minton, 2011).

Conventional fermentations with free cells encounter a number of difficulties such as low cell-density, nutritional limitations, batch-mode operations with high downstream times, higher costs of microbial recycling and installation, high contamination risks, susceptibility to environmental variations, and limitations of the dilution rate in continuous fermentation due to wash-out (Ramakrishna & Prakasham, 1999; de Vasconcelos et al., 2004). The immobilisation process eliminates most of the constraints faced by the free-cell systems.

Since the early seventies, when Chibata's group announced their success in operating the continuous fermentation of L-aspartic acid (Tosa et al., 1973), nu-

*Corresponding author, e-mail: martin.rebros@stuba.sk