Classification system for immobilization techniques

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Abstract  Biotechnological processes call for an overall process optimization. One of the major possibilities of optimizing biotechnological processes lies in immobilization technologies, which may increase productivities and product concentrations. This paper gives a systematic approach to the various immobilization techniques reported in literature. The most important levels of influence on overall process performance are considered within a classification system by three criteria: Substrates and products flow pattern criterion, catalyst criterion and apparatus criterion. Some important immobilization systems are discussed, and the classification system is applied to these examples.

1 Introduction

Modern biotechnology is developing fast into a major process industry. On this way it is confronted with the requirements of larger scale industrial processes, mainly economic and ecologic limitations. This calls for an overall process optimization, including the upstream processes, conversion, and downstream operations. Classical biotechnological processes are usually linear processes, where the mass flows proceed from raw material treatment to conversions and on to product separation and purification. This relatively simple process morphology more often than not results in low productivities, low product concentrations (which in turn tend to increase the efforts in down stream processing), and large amounts of waste, especially highly loaded waste water streams. This makes biotechnology ill equipped to rival other process technologies on economic and ecologic terms.

Overall process optimization leads almost inevitably to process intensification. This has been shown by the development of chemical process technology, which today shows much more complicated (and more optimal) process morphologies than present biotechnological processes. One of the major possibilities of optimizing biotechnological processes lies in immobilization technologies, which may increase productivities, product concentrations, and to some extend, conversion of raw materials. There are only a few papers dealing with systematic approaches to the various immobilization techniques available in literature. One of them used the traditional chemical engineering approach and brought the understanding of immobilized whole cells to the level of heterogeneous catalysis [1]. Most literature gives a demonstration of feasibility or list the various immobilization techniques [2–4].

In order to get a hold on the influences of different immobilization techniques it is a necessity to devise reliable methods to classify and analyse them, and hence to create taylor-made solutions for certain processes. This paper will give a systematic approach to the problem, concentrating on process related parameters.

2 Criteria for classification of immobilization techniques

The main purpose of classification of techniques is to facilitate the use of analogies and to transfer the experiences gained in one process to the planning and design of other processes. It is therefore necessary to classify complex processes (and cell immobilization and retention are complex techniques) along lines, which

– cover most applications,
– take into account the most important aspects and
– allow clear distinction between different approaches according to the influences which govern their performance.

In order to come to a workable classification system it is necessary to define the most important levels of influence on the overall performance of immobilization techniques. Immobilization is here seen in a very broad sense, including all techniques which confine or localize biological catalysts (organisms, part of organisms or enzymes) in a way that permits their reuse in the conversion step of the same process. Biological conversions are in their own right complex phenomenons and immobilizing the catalyst adds to this complexity. Any classification has to cut a compromise between very detailed description of its groups, which will eventually lead to the description of all technologies with no classification at all, and too coarse description. The latter will lead to a situation, where no information is transferable between the members of the groups, since they include too disparate techniques. A good possibility to reach an effective

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compromise is to define the most important aspects to evaluate a technique and then to establish classes which correspond to the processes which predominantly describe the situation.

In the case of immobilization techniques for biocatalysts, the following three criteria are important from a process engineers point of view:
A) What do the substrates and products of the conversion experience in the immobilization system? (substrate/product flow criterion)
B) How do the catalysts experience their immobilization? (catalyst criterion)
C) How does the equipment handle the immobilization? (apparatus criterion)

All these three aspects have various implications on technological level. The main dimension of these implications are mass transfer, physiology and apparatus configuration. These technological dimensions in turn define economic (and ecologic) performance parameters as costs, retention effectiveness and various others.

3 Definition of classes of immobilization techniques

As stated before, a good way to obtain a classification system is to define criteria for evaluation first and then build the groups within the criteria on the base of considerations which laws govern the predominant processes responsible for the performance of a technique. This will now be discussed along the line of the above stated criteria. Any technology will then be characterized by the groups to which it corresponds within the criterion. Hence immobilization techniques according to the classification proposed here are defined by three group names (see Fig. 1).

Although this seems to be a coarse classification, it gives important hints with respect to performance potential, bottle necks and cost estimation. There is also a possibility to transfer knowledge and technological solutions within a group to different technologies, since the groups are defined along the lines of the most important laws governing the respective processes.

3.1 Criterion A: Substrate/products flow pattern

3.1.1 Group A 1: No mass transfer limitations

This group comprises technologies in which substrates and products do not have to overcome sizable mass transfer resistances on their way to and from the catalyst during conversion. The resistance to cross the boundary layer around the catalyst itself is not taken into account here, since it has to be crossed anyway. Also not taken into account are mass transfer resistances not caused by immobilization (e.g. in aerobic fermentation). This group comprises technologies which either employ only one phase (like technologies with external cell recycle) or two and more phases, where the interphase does not pose a strong resistance (like in aqueous two phase systems).

The main characteristics of this group are:
- Conversion rates are exclusively defined by kinetic expressions for the conversion itself, given the concentration of substrates, products and viable cells in the conversion broth.
- Productivities depend on conversion rates and the available volume for the conversion broth (which might be smaller than the given apparatus volume, e.g. if another phase is present).
- Truly continuous processes are possible if "growing" catalysts (like microorganisms) are continuously purged.

3.1.2 Group A 2: Mass transfer limitations due to catalyst

In a number of technologies substrates and products have to pass through layers of catalyst (like in microbial flocs) in order to reach other portions of the catalyst. Examples are flocculating cells, biofilms or cake forming on membranes. The fact that the catalyst itself poses the main obstacle in the way of substrates and products to and from the catalyst has some important implications. Among them are:
- These processes inherently tend to exhibit gradients in the activity and/or selectivity of the catalyst. Depending on the location within the catalyst mass (film, cake or floc) the catalyst sees different concentrations of substrates and products. Therefore models describing the performance of conversion system have to take into account the spatial dimension (or its distribution) within the catalyst mass.
- Biocatalysts, especially organisms, may adapt to their environment by changing their metabolism and hence their selectivity. When designing such systems, physiological impacts of the varying environment different portions of the catalyst experience may here to be taken into account (e.g. in the form of byproduct formation).
- For "growing" catalysts, regardless if that growth comes from accumulation (as in filter cakes) or physiological growth, these processes show a change of performance over time. The more the catalyst grows, the stronger the mass transfer resistance meet by substrates and products will be, leading to stronger variations in the spatial concentration profiles.
- The processes are mostly either batch or intermediant (like in membrane processes). To keep processes for growing catalysts continuous, the geometrical parameters of the catalyst must be kept constant in the conversion system (e.g. by controlling the film thickness by shear or by removing flocs exceeding a certain size).
- Compared to catalysts in free suspensions, the performance is clearly lower in these systems due to mass transfer limitations.