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Review

Immobilized enzymes bioreactors utilizing a magnetic field: A review

Zakaria Al-Qodah[a,*], Mohammad Al-Shannag[b], M. Al-Busoul[c], I. Penchev[d], Wasim Orfali[e]

[a] Chem. Eng. Depart. Al-Balqa Appl. University, Faculty of Eng. Technol., Amman, Amman
[b] Chem. Eng. Depart. School of Engineering, University of Jordan, Jordan
[c] Mechanical Engineering Department, Al Balqa Applied University, Amman, Jordan
[d] Chem. Eng. Depart, Sofia University of Chemical Technology and Metallurgy, Sofia, Bulgaria
[e] Elec. Eng. Depart., Taibah University, Saudi Arabia

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ABSTRACT

The main objective of this article is devoted to reviewing all previous contributions concerning immobilized enzyme bioreactors utilizing a magnetic field. These reactors used magnetic supports or beads with immobilized enzymes as the solid phase. All published researches from the early beginning after the middle of the last century to the present time are discussed and analyzed. These papers used the magnetic field for several purposes including mixing, attracting the particles to prevent their washout from the column and to operate with higher substrate velocities to enhance mass transfer processes. It was found that axial magnetic field is the most preferable for most researchers. In addition, most of the magnetic particles were prepared by entrapment. Many enzymes such as Glucose oxidase, Urase and Hydrolase were immobilized on different supports in these reactors. In most applications, the magnetic field indirectly enhances the immobilized enzymatic activity and the conversion rate. This enhancement is attributed to the improved mass transfer process between the liquid medium and the immobilized enzyme since the applied magnetic field enables an intensive mixing or the operation with higher medium flow rates. Some comments were presented at the end of the review which shows the gaps in this promising application.

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1. Introduction

Currently, two or three-phase fluidized beds are successfully being applied in several chemical and petrochemical processes [1,2]. In addition, these multiphase reactors have found many applications in bioprocesses with immobilized enzymes and whole cells [3,4]. Fluidized bed reactors are characterized by their low friction forces in comparison with stirred tank reactors. In addition,

* Corresponding author. Present address, Chem. Eng. Depart., Taibah University, Saudi Arabia. Permanent address: Chem. Eng. Depart., AlBalqa Applied University, Jordan.
E-mail addresses: z_alqodah@hotmail.com, zqudah@taibahu.edu.sa (Z. Al-Qodah).

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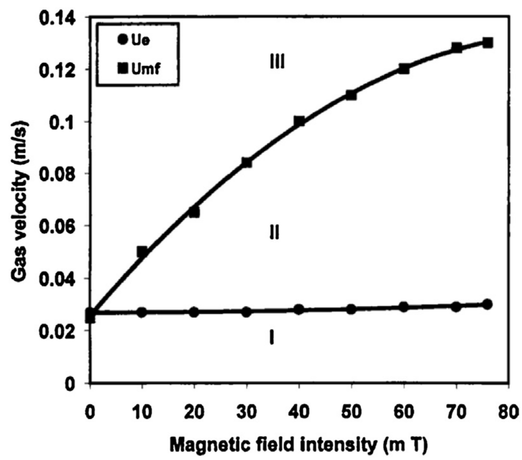

Fig. 1. Phase diagram for magneto airlift reactor (magnetizing first mode): I-packed bed, II-stabilized bed, and III-fluidized bed (Al-Qodah [6]).

they have many advantages such as good mixing and isothermal conditions compared to the packed beds [5–8].

However, fluidized bed reactors usually suffer from bubble coalescing problem up the bed. This problem produces relatively large gas bubbles that lead to different residence time of these bubbles, poor contact between the different phases that reduces the substrate transfer rate [9]. Accordingly, the performance of the fluidized bed reactors should be improved via preventing bubble coalescing and to keep constant bubble sizes [10]. These amendments could be obtained by using a static mixer in the column or by the application a magnetic field to stabilize a bed consisted of magnetic particles [11–13]. It had been shown experimentally that magnetic field on a bed magnetic particles stabilizes them and suppresses their movements due to the induced magnetic forces. These forces arrange the magnetic particles along the magnetic field lines [14]. One of the most important consequences of this stabilization is the suppression of large bubble formation in the bed [15].

Kirko and Filippov [16] reported the first contribution in which a magnetic field was applied to a bed of magnetic particles. They applied a constant axial magnetic field on a static bed of iron powder and described the bed behavior after increasing the water flow as a fluidizing medium. They pointed out that the bed stayed stationary while increasing the liquid velocity until a certain value. Beyond this velocity, the bed began a process of homogeneous expansion and they termed this state as a “pseudo polymerized state”. Nekrasov and Chekin [17] described the performance of a gas fluidized bed under the effect of a horizontal magnetic field. Subsequently, Rosensweig [18] and Burns and Graves [19] reported that the application of a magnetic field on a fluidized bed causes unique improvements on bed behavior that comprises the best characteristics of packed and fluidized bed reactors.

After these important findings and during the last four decades, hundreds of papers have been published that describe the principle and applications of magnetic stabilization as a new possible approach for carrying out different types of processes [20,21]. These contributions have recently been summarized by Hristov and Ivanova [22] and Hristov [23]. These applications in bioprocesses include magnetic separation, filtration of enzymes and cells, immobilized enzyme and cells reactors, plant cell culture, cell suspension processing, affinity chromatography, protein recovery and adsorption.

The application of a stabilizing magnetic field on bioreactors using biocatalysts in the form of immobilized enzymes or cells seem to be a very attractive approach. The properties of the stabilized bed including the jelly fluid like structure with the absence of shear forces make the bed a host medium for sensitive biocatalyst such as enzymes [4,11,22,23]. Hristov and Ivanova [22] and Hristov [23] published two reviews concerning magnetic stabilization of fluidized beds. These reviews were devoted to summarizing the content of previous publications dealing with all magnetically assisted bioprocesses in general. However, a specific review for immobilized biocatalysts under the effect the magnetic field has not been cited before. It seems that such review is very necessary in order to provide the reader with all necessary information about this important application. For this reason, the objective of this paper is to review and analyze all contributions concerning immobilized enzymes reactors under the effect of magnetic field. Immobilized cells bioreactors utilizing a magnetic field will be reviewed separately since the biocatalyst and reactor performance in the two cases are widely different [24,25] This review will concentrate on the bioconversion performance of the magnetized beds in addition to the mass transfer and kinetic models used to describe bioprocesses in these systems.

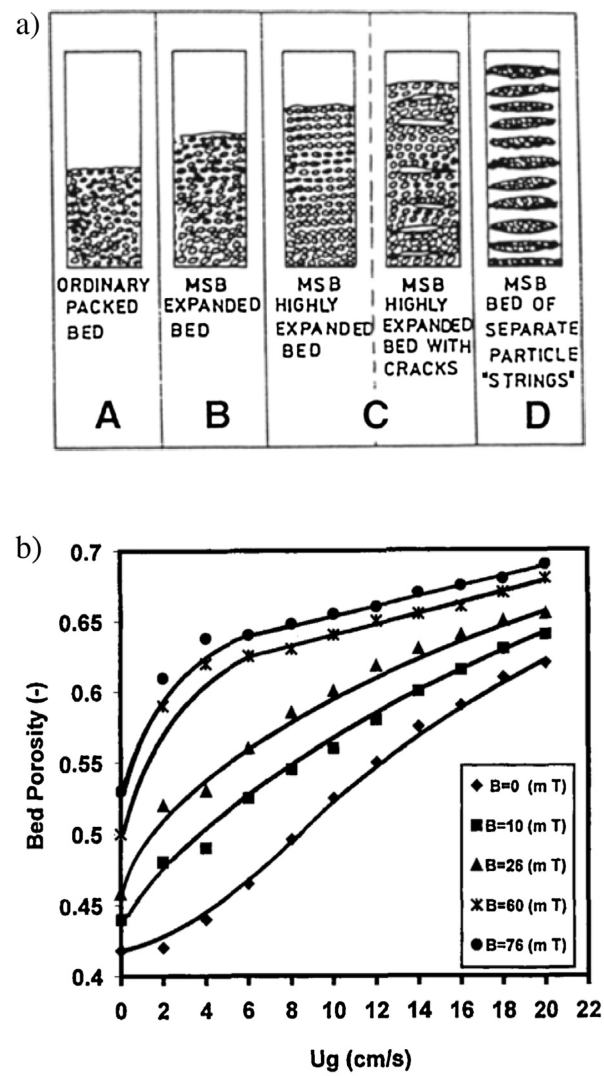

Fig. 2. Particle arrangement in the bed as a function of the field intensity (Ivanova et al. [54]).

2. Important hydrodynamic parameters of magnetically stabilized fluidized beds

The application of a magnetic field to a fluidized bed of ferromagnetic particles has been reported as a very attractive approach to improve the performance of fluidized beds [22]. In these mag-