Process-Intensified Recovery of Proteins from Aqueous Media

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Various adsorbent types could be employed for adsorptive separation, wastewater treatment and recovery or removal of various pollutants from aqueous media. Process-intensified recovery or adsorption of proteins from aqueous media was studied via the utilization of novel adsorbents as process intensification (PI) methodology.

process intensification water treatment adsorption protein recovery

1. Introduction

Process intensification (PI) research in chemical engineering applications has attracted considerable interest recently. The applications have led to several innovations in most chemical industries due to the satisfaction of the requirements both in an environmentally friendly manner and in remaining cost competitive. PI is aimed towards substantially smaller, energy-efficient, safer sustainable technological developments, in which the major tools involve the reduction in the amount of equipment via the integration of process steps and functionalities; miniaturization; heat and mass transfer improvements by novel mixing strategies, supplementary energy input, external force fields or improved surface configurations; novel energy and separation techniques; batch to continuous mode process transformations to reduce process volumes; and integrated optimization and control strategies [1][2][3][4][5].

Process-intensifying strategies are usually studied under two main classifications, namely PI equipment and methods [3][5][6][7]. Process-intensifying equipment, also called hardware, mainly involves rotating packed beds, catalytic packings, microreactors, and structured reactors. Various other examples of equipment types are structured packed columns; static mixers; microchannel, spinning disc, loop, oscillatory baffled, spinning tube-in-tube and heat-exchange reactors; and compact heat exchangers. Process-intensifying methods, also referred to as software, involve hybrid separations, such as membrane absorption and absorptive distillation; functional materials, such as ionic liquids; alternative sources of energy, such as ultrasound, microwaves, solar energy and centrifugal fields; and multifunctional reactor systems involving reactive extraction and chromatographic reactors. Combining intensified reactors together with renewable energy sources such as solar energy could provide higher motivation for the achievement of green processing targets. A decrease in material and energy consumption would lead to a direct reduction in capital costs [3][6][7][8].

Ramshaw's research group initiated PI application by developing a rotating packed bed (RPB) for reactive distillation [3][4][8][9][10][11]. Since then, PI has received considerable appreciation and significance due to its potential

for more innovative and viable process design options. Significant developments have been achieved in the field over recent years and have resulted in both successful industrial applications and expanding research interests [5][7][12]. PI has emerged as an integral part of the retrofit design and provided intensified environmental and economical benefits. Significant efforts have been devoted to expressing it better for the satisfaction of the requirements of various industrial sectors, including essentially the manufacturing, energy and chemical sectors [8][13].

Various definitions proposed for PI [1][2][3][6][7][9][10][14][15][16][17][18][19][20][21][22][23][24][25] during the years starting in the early 1980s have been discussed in detail [5]. Although the emerging definitions were quite diverse in nature, they were commonly focused on innovation. The European Roadmap of Process Intensification ERPI [17] presented PI as a set of intensely innovational principles in process as well as equipment design benefiting process and chain efficiency, operational and capital costs, quality, process safety and wastes. Baldea [25] defined PI as chemical engineering developments leading to substantially smaller, energy-efficient, safe, cleaner technologies or those integrating multiple operations into fewer devices. PI is a growing trend in chemical engineering and should satisfy the requirements of markets and shareholders [6][15][26]. As the concept will be evolving continuously, it will involve challenges and requirements until a universal definition is determined [13].

2. Process-Intensified Recovery of Proteins from Aqueous Media

Protein–nanoparticle interactions are important for the investigation of the potential utilization of specific particles in drug delivery systems. The parameters influencing protein–nanoparticle interactions, involving temperature, pH, concentration, particle size, modifier type, cytotoxicity and biocompatibility, need to be explored extensively [5][27][28][29][30][31]. In the following examples, process-intensified recovery or adsorption of proteins from aqueous media was studied via the utilization of novel adsorbents as PI methodology.

2.1. Process Intensification System and Strategy: Novel Adsorbents

Ling and Lyddiatt [32] studied PI for the adsorption system of a dye-ligand and an intracellular protein from bakers' yeast extract in a fluidized bed for the investigation of the performance of a steel–agarose pellicular adsorbent (UpFront, 51–323 μm). They studied the recovery of glyceraldehyde 3-phosphate dehydrogenase (G3PDH). Kopac et al. [33] investigated the interactions and enhanced adsorption of bovine serum albumin (BSA) protein with double-walled carbon nanotubes (DWNTs). The study involved the investigation of protein adsorption equilibrium and kinetics on DWNTs.

The adsorbent used by Ling and Lyddiatt [32] comprised a stainless steel core (nonporous, 60 μm) coated by a porous agarose layer (20 μm), having an adsorptive coating depth corresponding to 40% of the particle radius and a steel core/agarose volume ratio of 1:3.5. Cibacron Blue 3GA dye was immobilized on the adsorbent particles and tested as an affinity ligand for the selective recovery of the protein from the yeast extract.

DWNTs synthesized via the catalytic chemical vapor deposition (CCVD) method using a MgO-based catalyst were utilized and protein adsorption on carbon nanoparticles was examined by Kopac et al. [33] using a batch technique at optimized process conditions (pH 4, 40 °C) for the highest adsorption efficiency. Interactions of positively charged protein molecules with negatively charged nanotubes were examined to understand the electrokinetic properties.

2.2. Process Intensification Achievements

In the study by Ling and Lyddiatt [32], the adsorbent particle density was increased by incorporating a stainless steel core in agarose. A high throughput was obtained by the high-density adsorbent derivatized with Cibacron Blue 3GA, which minimized the adsorption period and maximized the process efficiency. The process of fluidized bed adsorption was enhanced, allowing sufficient time for the protein molecule to diffuse into the pores of sorbent particles. The matrices designed for the optimization of the solid phase required small particle sizes and increased density in order to have a reduced diffusion path and a high superficial velocity for the improvement of film mass transfer. The dynamic binding capacity was enhanced with an increase in bioload as a result of the enhanced driving force for mass transfer. The process was capable of capturing a target protein molecule without predilution of unclarified feedstock with minimized processing time and maximized process efficiency [32].

In the study by Kopac et al. [33], interactions of positively charged protein molecules with negatively charged nanotubes indicated electrostatic attractions. The maximal protein adsorption capacity of carbon nanoparticles was 1221 mg/g. Thermodynamic parameters indicated an endothermic physisorption process of protein adsorption on DWNTs, exhibiting the largest protein adsorption capacity on DWNT samples in comparison to the single-walled CNTs, multiwalled CNTs or metal oxides [34][35][36]. Using this novel adsorbent significantly intensified the protein adsorption [33].

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