



Immobilization of carbonic anhydrase for CO₂ capture and its industrial implementation: A review

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ABSTRACT

Minimal cost per ton of captured CO₂ and associated environmental impacts are considerable barriers for the industrial implementation of post-combustion CO₂ capture. Aqueous solvents promoted with the enzyme carbonic anhydrase are a promising alternative to replace energy intensive and environmentally unfriendly amine-based solutions, which are currently benchmark solvents in CO₂ absorption. However, using free enzyme in solution requires significant amounts of enzyme in addition to its possible denaturalization. Enzyme immobilization appears as a rational approach to develop a novel CO₂ capture system using aqueous solvents. In the recent literature, efforts are focused on the development and characterization of different carriers and immobilization strategies to achieve good activity and stability compared to free enzyme in solution. In the laboratory and the industry, immobilized carbonic anhydrase have been already tested in a variety of configurations including packed columns, gas-liquid membrane contactors, dynamic devices and selective membranes. This article reviews the developments, opportunities and limitations found at laboratory scale as well as in the industry, and brings them together in order to identify the key challenges and perspectives in the industrial implementation of immobilized carbonic anhydrase for CO₂ capture.

1. Introduction

Global warming is a major concern. The alarming increase of atmospheric CO₂ levels is fostering the research community and the industry to look for solutions to stop the steady increase of global temperature and its drastic consequences. Our high and continuously increase of energy demand and our reliance in a fossil fuel energy stock makes this problem a huge challenge [1]. A significant amount (more than 40%) of global greenhouse emissions are caused by the energy industry, mainly heat and power generation [2]. Emissions from this sector are gases generated by combustion of fossil fuels, the so-called flue gases. Because they are localized point emissions compared to other major contributors to global warming such as transport, the application of CO₂ capture strategies becomes a tentative choice. Two main alternatives are possible after the CO₂ has been captured: geological storage or utilization [3]. Regardless the final use of CO₂, post-combustion CO₂ capture is a difficult task considering that CO₂ is a stable molecule [4], it has a low partial pressure (10–20%), the flue gas has high temperature (100–250 °C) and CO₂ is accompanied by other compounds (H₂O, NO_x, SO_x, etc.) [5,6]. For CO₂ separation, chemical

absorption using amines is the most popular separation technology due to its high efficiency, low cost and maturity [7,8] (Fig. 1a). However, it has been indicated that chemical absorption with amines, although technically feasible, does not represent an attractive solution for CO₂ separation from flue gases in a global scale [9]. In addition to the CO₂ emissions related to the production process of the amines, several drawbacks in the use of amines as absorption solvent can be pointed out: high toxicity, corrosively, degradability, high volatility [8,10–12] (Fig. 1b) and the large energy required to regenerate the solvent and to recover the CO₂ [13]. Despite of these disadvantages, most reported cases of post-combustion CO₂ capture are using amine absorption [14].

Other solvents than amines have also been suggested, such as aqueous solutions of Na₂CO₃, K₂CO₃, ammonia, amino acids, etc [13]. Although requiring less energy for regeneration [13], they are generally limited by the low reaction rate of CO₂ in the liquid phase. This is due to the slow CO₂ hydration kinetics [15]. One of the current trends to solve this issue is the use of carbonic anhydrase because it catalyzes the reversible hydration reaction of CO₂.

Carbonic anhydrase (CA) is an ancient metalloenzyme ubiquitous in Nature [16]. In fact, it is one of the most active enzymes with a turnover

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