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Operating considerations of ultrafiltration in enzyme enhanced carbon capture

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Abstract

Today, enzyme enhanced carbon capture and storage (CCS) is gaining interest, since it can enable the use of energy efficient solvents, and thus potentially reduce the carbon footprint of CCS. However, a limitation of this technology is the high temperatures encountered in the stripper column, which can deactivate the enzymes. One solution to this challenge is the use of ultrafiltration to retain the enzyme in the absorber unit. In this report, a base case of a CCS facility is used to model the impact of such membranes for use in a full scale CCS commercial plant. The base case has an approximate capture capacity of 1 MTonn CO_2/year, and is here operated for one year continuously. This publication compares soluble enzymes dissolved in a capture solvent with and without the use of ultrafiltration membranes. The membranes used here have an enzyme retention of 90%, 99% and 99.9%. Enzyme retention is the amount of enzyme that is retained in the absorption column in each cycle. These membranes were modeled with five stripper temperatures 60 °C, 70 °C, 80 °C, 90 °C and above 100 °C. Enzyme deactivation follows a 1st order rate and increases with increasing temperatures. It was found that for all stripper temperatures used in this model, deactivation rates were too high for continuous operation over 1 year, without adding additional enzyme, if an activity of at least 50% should be maintained. With increasing stripper temperatures the membrane retention requirement increased. To retain over 50% activity over a whole year at 70 °C stripper temperature required a membrane of 90% or higher enzyme retention, at stripper temperatures of 90 °C a membrane of 99.9% retention was required for the same result. Finally, it was investigated if stripper temperatures over 100 °C, where instant deactivation was modeled could be used. It was found that with enzyme retention of 99.9%, with instant deactivation, after 1 month 50% of the activity is lost. Thus the use of membranes in enzyme enhanced CCS might be restricted to temperatures below 100 °C, or temperatures the enzyme can withstand for shorter time periods.

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1. introduction

To limit further climate change, atmospheric CO_2 among other greenhouse gases must be reduced. One option for doing so is carbon capture and storage (CCS). This paper will focus on enzyme enhanced CCS, using carbonic anhydrase (CA) EC 4.2.1.1. Enzymes are beneficial for such processes since they enhance reaction rates, especially for bicarbonate forming solvents[1]. However, enzymes are not designed to operate under process conditions encountered in a CCS capture facility. Therefore one of the challenges encountered when using enzymes in such processes is the stability under these conditions, where enzymes may lose activity over time. Previous work has explored this by investigating the stability of one CA, especially suitable for CCS in terms of pH, temperature and solvent type at CCS relevant conditions. Although, the enzyme in question was significantly more stable than most enzymes under such conditions, long term studies (over several months) found that the enzyme was sensitive to higher temperatures[2,3]. Here the impact of these results, if these enzymes were to be used on an industrial scale, are investigated by modeling the stability of such enzymes in a theoretical commercial plant. Enzyme stability within a model framework for stripper temperatures ranging from 60 °C to over 100 °C compared for soluble enzymes with and without the implementation of ultra-filtration membranes. The membranes are explored with enzyme retentions up to 99.9%. The results are modeled for 1 year continuous operation of the facility.

The enzyme CA catalyzes hydration of CO_2 into bicarbonate (Reaction 1). It is therefore particularly useful in solvents which form bicarbonate, such as tertiary and hindered amines, and carbonate salts. These types of solvents have the advantage in that they have relatively low energy for desorption requirements, compared to solvents like primary amines, because they do not form covalent bonds with the absorbed CO_2. However, they are often impeded by slow absorption kinetics, which can either result in poor capture capacity or increased operating and capital costs due to a bigger absorber column. The addition of CA or another catalyst can alleviate this effect by enhancing reaction kinetics. Just like a conventional chemical catalyst, the enzyme does not change the thermodynamics of the reaction, it simply speeds up the reaction rate. This publication does not investigate reaction kinetics, since excellent examples of this can be found in literature[4–6].

Reaction 1:

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

Nomenclature

CCS	Carbon capture and storage
CA	Carbonic Anhydrase

2. Model framework

The base case is defined in Table 1 and illustrated in Figure 1, this is based on some publically available data from the Boundary Dam CCS facility, and is supplemented with information from experts in the field.