Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 63 (2014) 595 – 604

Energy Procedia

GHGT-12

Energetics of electrochemically-mediated amine regeneration

Aly O. Eltayeb[a], Michael C. Stern[a], Howard Herzog[b], T. Alan Hatton[a,**]

[a]*Chemical Engineering Department, Massachusetts Institute of Technology, 77 Mass. Ave, Cambridge 02139, USA*
[b] *Energy Initiative, Massachusetts Institute of Technology, 77 Mass. Ave, Cambridge 02139, USA*

Abstract

Cost-effective, large-scale carbon dioxide capture is a critical technology for mitigating greenhouse gas emissions, and current capture technologies are energy intensive and difficult to deploy in existing power plants. We have previously introduced a novel electrochemically-mediated process for amine regeneration, and demonstrated its feasibility with a proof-of-concept system that can efficiently modulate amine affinity to carbon dioxide under the effect of redox-responsive molecules. The electrochemical process is simple to install, obviating the need for expensive retrofits. In addition, due to its targeted nature, the process has the potential for lower energy consumption as compared with the thermal amine capture process. In this work, we analyze the energy consumption of the electrochemical process, building from thermodynamic lower bounds, and addressing electrochemical kinetics, transport requirements as well compression and pumping energy. The analysis suggests that the electrochemical process can generate carbon dioxide at the conditions required for transportation with an electrical energy consumption of less than 50 kJ per mole of carbon dioxide captured and compressed. The electrochemical process efficiency can be further improved by optimizing flow design and utilizing additives to reduce activation overpotentials.

Peer-review under responsibility of the Organizing Committee of GHGT-12

Keywords: Carbon Capture and Sequestration, Electrochemical Kinetics, Amine, Copper

1. Introduction

Overwhelming evidence for the detrimental impacts of CO_2 emissions on the environment is well documented by a number of groups, including the Intergovernmental Panel on Climate Change and the National Research Council, which recommend significant reductions in carbon emissions. [1,2] Carbon capture and sequestration (CCS) has

* * Corresponding author. Tel.: +1-617-253-4588; fax: +1-617-253-8723.
E-mail address: tahatton@mit.edu

Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.064

been identified as a necessary component of any environmental policy that aims to achieve significant reduction in emissions over the next few decades.[3,4] To this end, the International Energy Agency predicts that over 100 GW of coal-fired power plant capacity will need to be retrofitted with carbon capture capabilities. [5] Currently, retrofit costs for existing thermal amine scrubbing technology, the benchmark for CO_2 capture in CCS applications, are prohibitive. [6] There are two main elements to the retrofit cost: the high energy consumption of the thermal process that significantly derates the power plant electrical output, and the high capital cost associated in part with the required internal reconfiguration of the steam turbine train; this reconfiguration is required to enable extraction of low pressure steam for the stripping operation.[7,8]

Recently, our group introduced a novel approach to CO_2 capture that requires only the application of an electrical driving force for the stripping operation, freeing it from the need for large-scale steam extraction and disruption of the power plant internal steam cycle. The electrochemically-mediated amine regeneration process utilizes redox responsive materials to modulate the affinity of amine solvents for CO_2, under the action of electric voltage. [9,10]

This electrochemical approach offers several advantages over the thermal stripping process, the first of which is that it is driven by electricity rather than steam, obviating the need for expensive retrofits to the steam configuration in the power plant. Second, due to its more targeted nature and ability to operate under high liquid pressures, the electrochemical approach can potentially be more energy efficient than thermal stripping. In previous work, we demonstrated a proof-of-concept system that utilizes copper metal and sustained control of CO_2 capture rates with the cycling of electric current. [9]

In this work, we provide an analysis of the energy consumption of the electrochemical process, based on our most recent kinetic experiments results. This analysis serves to explain the energy landscape of the process, to highlight its advantages and to create a roadmap for future development and research needs.

Nomenclature

C_j^{bulk}	Bulk concentration of species i
F	Faraday's constant
ΔG	Gibbs free energy of reaction
ΔH	Enthalpy of reaction
i	Current density (A/m^2)
K	Equilibrium constant for CO_2/amine complexation
R	Universal Gas Constant
ΔS	Entropy of reaction
T	Temperature (K)
P_a	Partial pressure of CO_2 on the anode side of the electrochemical cell
P_F	Partial pressure of CO_2 in the flue gas
u_x	Flow velocity of fluid in the direction perpendicular to the electrodes
ν_j	Stoichiometric coefficient of species i
W_{CO_2}	Work of capture per mole of CO_2

2. Theoretical Basis and Experiments

In this section, energy consumption and losses of the electrochemical capture process are outlined, with a brief discussion of relevant models and experiments required to estimate and measure these losses.