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Rate-based approaches for the carbon capture with aqueous ammonia without salt precipitation

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Abstract

The aim of this paper is the evaluation of the influence of the kinetic of the NH_3-CO_2-H_2O reactions in the absorber with respect to the electric power losses due to the steam bleeding from the turbine for the regeneration of the solvent. The results exposed conclude that there are few works about the kinetic of the aqueous reaction of the system NH_3-CO_2-H_2O and data from the literature are not in agreement among them probably due to a dependence of the kinetic constants on the ammonia concentration in the liquid. The kinetic parameters have a strong influence on the specific electric power losses.

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Keywords: carbon capture; CO_2 capture; aqueous ammonia; kinetics; absorption rate; rate-based simulation;

1. Introduction

The world energy production is expected to turn more and more sustainable in the future. The post-combustion carbon capture with aqueous solutions can be a viable option for mitigating the emission of carbon dioxide from fossil fuel power plants because of its applicability to both existing and new plants with moderate modifications to the power block. These carbon capture technologies can be accomplished by chemical absorption.

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Nomenclature

Equipment abbreviations		Symbols	
ABS	Absorber	K	Ammonia to carbon dioxide ratio [-]
CL	Air-cooler	$\%NH_3$	Ammonia initial concentration [-]
HX	Heat exchanger	rec.	Recycling fraction [-]
PM	Pump	k_2	Arrhenius constant [kmol/(m^3*s)]
REB	Reboiler	r	Reaction rate [kmol/(m^3*s)]
REG	Regenerator	A	Arrhenius preexponential factor [kmol/(m^3*s)]
COND	Condenser	E_A	Activation energy [cal/mol]
Acronyms		T	Temperature in Kelvin
CAP	Chilled Ammonia Process	R	Universal gas constant
USC	Ultra Super Critical	C_i	Concentration of *i* specie

Currently, the state of the art is the post-combustion layout based on the chemical Monoethanolamine (MEA) as reported in the document of the EBTF [1]. Alternatively to amines, the process named Chilled Ammonia Process (CAP) is considered a feasible option. Previous works proposed by Valenti *et al.* [2] show more attractive results for an ammonia-based capture plant with respect to a MEA-based one.

The chilled conditions of those studies include salt precipitation that can represent a complication in the management of the plant. Bonalumi *et al.* [3] show attractive results for an ammonia based capture plant operating in cooled condition that, contrary to the Chilled Ammonia Process, has not salt precipitation without losses in efficiency. Bonalumi *et al.* [3] show also a parametric investigation on a layout simulated in Aspen Plus with an equilibrium approach of chemical reactions in order to find the set of parameters that minimize the electric losses.

The objective of this work is the evaluation of the influence of the kinetic of the NH_3-CO_2-H_2O reactions in the absorber with respect to the electric power losses due to the steam bleeding from the turbine to the regenerator reboiler in order to provide the heat for the regeneration of the solution. A parametric analysis of the process determinates how strong the influence is of the kinetic parameters on the results and if the equilibrium approach to simulate the absorber applied by Bonalumi *et al.* [3] returns the same trend.

This work reviews first the bibliography about the kinetic of the absorption reaction in the NH_3-CO_2-H_2O system. Only few experimental works are available in literature: Pinsent *et al.* [4,5], Puxty *et al.* [6], Wang *et al.* [7] and Jilvero *et al.* [8] studied the kinetic of the NH_3-CO_2-H_2O system.

The information retrieved from the literature is employed in the Aspen Plus environment to assess the influence of the different values of the kinetic parameters on the performance of the carbon capture plant. The Aspen Plus model is composed by a conventional absorption-regeneration layout. In contrast, the steam turbine of the USC power plant is modelled in an approximate manner to calculate the electric loss of the steam turbine due to the steam bleeding.

2. Bibliographic review on kinetics

This paragraph contains a bibliographic review about the kinetic of the reaction of the system NH_3-CO_2-H_2O in order to summarize the results retrieved from the literature. There are few works about the kinetics studies about the chemical system NH_3-CO_2-H_2O. The system has rigorously a large amount of reaction, however, only the kinetic of two of these influences significantly the kinetic of the overall. In fact, Jilvero et al. [8] consider only the kinetic of the reaction *(1-4)* in order to implement them in the adsorption column model.

$$CO_2 + OH^- \rightarrow HCO_3^- \quad (1)$$

$$HCO_3^- \rightarrow CO_2 + OH^- \quad (2)$$

$$NH_3 + CO_2 \rightarrow NH_2COO^- + H^+ \quad (3)$$

$$NH_2COO^- + H^+ \rightarrow NH_3 + CO_2 \quad (4)$$