Aerosol growth in an absorber for a post combustion CO2 capture using the 2-Amino-2-methyl-1-propanol/ Piperazine (CESAR 1) solvent

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Abstract

A blend of 2-Amino-2-methyl-1-propanol (AMP)/ Piperazine (Pz), at a certain amine ratio, known as the CESAR 1 solvent, was studied as a possibly better solvent for post combustion CO2 capture (PCCC). In lab-scale, equilibrium properties [1] were studied together with solvent stability toward degradation and corrosion [2]. Environmental properties as bio-degradability and toxicity were also reported [3]. On larger scale, campaigns in different pilot facilities were conducted [4, 5]. Modelling and simulation for the different campaigns have been interpreted and reported [5, 6]. Overall results shows that the CESAR 1 solvent has improved energy requirements compared to the state-of-the-art solvent for post combustion CO2 capture i.e. 2-ethanolamine (MEA 30 mass% solvent).

Even though many aspects of the CESAR 1 solvent are well studied and reported, when it comes to solvent losses via the treated gas, very little can be found. Amine emissions are intensified by undesired aerosol formation in the absorber. This is a complex phenomenon in gas-liquid separation and the seriousness varies with solvent volatility, solvent stability toward oxidative degradation, impurities in the treated flue gas, operational conditions, and absorber / plant configuration. Some efforts have been made to study the mechanisms of aerosol formation [7] from its supersaturation point. Further, pilot scale tests to study how amine emissions are affected by impurities in the flue gas was reported together with a counter-measure technique [8]. Very recently, work was reported on modelling and characterization of aerosols, droplet internal compositions, particle growth, effect of amine volatility and increasing amine emission due to gas phase amine depletion caused by aerosol formation [9-11].

To study the performance of the CESAR 1 solvent, especially how it can affect aerosol formation and emissions, the recently developed model [9-11] will be used. The model was generated from mass and energy balances for components involved in the system as seen in Figure 1.
Figure 1. Dynamic representation of mass and heat transfer in aerosol, gas and liquid phases in a differential volume element.

The differential equations for the gas phase express a balance between the inflow of a component from the bulk fluid minus the flow rate of the same component from gas to the droplet phase:

\[
\frac{\partial n_x^g}{\partial t} = \dot{n}_x^f - \dot{n}_x^d \tag{1}
\]

\[
\dot{n}_x^f = a_f K_{g,x}^{overall} (P_x^* - P_x^g) \tag{2}
\]

\[
\dot{n}_x^d = N_x (C_N a_d) \tag{3}
\]

Where \(n, \dot{n}, K_{g,x}^{overall}, P_x^*, P_x^g, a_f, a_d, N_x\) represent mole numbers of the gas volume, molar flow in/out of the gas volume, overall mass transfer, liquid phase equilibrium pressure, gas phase pressure, bulk liquid interfacial area, droplet interfacial area, molar flux and particle number concentration, respectively.

The energy balance for the gas volume is expressed as:

\[
\rho_g V_g C_p \frac{\partial T_g}{\partial t} = h_{lg}^f (T_f - T_g) - h_{lg}^d (T_g - T_d) \tag{4}
\]

Where \(\rho_g, C_p, V_g, T_f, T_g, T_d, h_{lg}^f, h_{lg}^d\) are respectively density, heat capacity, gas volume, fluid temperature, gas temperature, droplet temperature, liquid-gas side heat transfer coefficient and droplet side heat transfer coefficient.

For the droplet, the internal concentration and temperature profiles are expressed as:

\[
\frac{\partial c_x}{\partial t} = \left( \frac{D_x}{k^2} \right) \left[ \frac{2}{\xi} \frac{\partial c_x}{\partial \xi} + \frac{\partial^2 c_x}{\partial \xi^2} \right] - r_g^x - \frac{3 c_x \partial T}{\partial t} \tag{5}
\]

\[
\frac{\partial T}{\partial t} = \frac{k}{\rho C_p R^2} \left[ \frac{2}{\xi^2} \frac{\partial T}{\partial \xi} + \frac{\partial^2 T}{\partial \xi^2} \right] + \frac{r_g^H}{\rho C_p} \tag{6}
\]

Where \(c_x, D_x, R, r_g^x, T, \rho, C_p, \Delta H\) represent of concentration, diffusivity, droplet radius, the considered reactions, temperature, density, heat capacity and heat of reaction.

The partial differential equations are solved along the absorber height together with four equations for the initial and boundary conditions based on available data from the campaign test and simulation results [4, 6]. From the developed equations, it is obviously that physical properties, kinetic model, mass and heat transfer models, calorimetric data and an equilibrium model must be available prior to the aerosol modelling.

For an MEA case as an example, some modelling results are shown below[11]:
In the final presentation, the developed droplet growth model will be used to study the effect of absorber temperatures, solvent volatility and reactivity in an absorber by comparing 30 mass% MEA and CESAR1 solvents.

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Reference