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Analysis of flexible operation of CO_2 capture plants: Predicting solvent emissions from conventional and advanced amine systems

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Abstract

Due to the penetration of renewable intermittent energy in most energy systems, it is foreseen that CO_2 capture plants will need to operate flexibly; in particular, to adapt to changes in flue gas load and stream conditions in order to efficiently abate CO_2 emissions from power plants. The flexible operation can impose additional operational constraints on the plant, such as emissions permit limits, that cannot been addressed during the design stage. Accurate models to predict the emission of volatile components like mono-ethanolamine (MEA) and ammonia, which are linked to solvent evaporation and degradation, are of great importance. There is currently a lack of data and understanding of volatile emissions, which may lead to overdesign and inherently large investments in mitigation technologies, which can probably be avoided with process optimization.

This study helps to accelerate the process and development of a second generation solvent CESAR-1 (a mixture of 2-Amino-2-Methyl-1-Propanol (AMP) and Piperazine (Pz)) by providing both missing experimental data and accurate models on volatile emissions during flexible operation. The AMP/Pz mixture is investigated and proposed as a new benchmark for carbon capture applications as it requires much lower regeneration energy and amount of solvent (in comparison to the well-studied MEA solvent), which may lead to lower solvent emissions and degradation (Kvamsdal et al., 2011; Mangalapally and Hasse, 2011). The experimental data of CESAR-1 are obtained during the transient operation of the RWE capture pilot facility at Niederaussem. The experimental data resulted from a parametric study based on single step perturbations of the most relevant plant variables that have an impact on solvent emissions. A mathematical model developed in Aspen Plus is used to predict the capture plant performance, including solvent emissions, at steady states of the transient scenarios. In addition to the steady state predictions, second order response functions are used to evaluate the dynamic response of solvent emissions during single step changes of plant parameters. Figure 1 illustrates the dynamic response of MEA emissions during a step decrease in the flue gas flow rate of the RWE pilot plant at Niederaussem. The MEA emissions data in Figure 1 is obtained from the use of the

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MEA+H_2O mixture and results are available in Moser et al., 2020. The following step response function (Ogunnaike, 1994) is used to evaluate the dynamic response of MEA emissions

$$y(t) = y_0 + KM\left[1 - \left(\frac{\tau_1 - \xi}{\tau_1 - \tau_2}\right)e^{-\frac{(t-\vartheta)}{\tau_1}} - \left(\frac{\tau_2 - \xi}{\tau_2 - \tau_1}\right)e^{-\frac{(t-\vartheta)}{\tau_2}}\right],$$

where y_0 represents the initial value of the response function $y(t)$, K is the steady-state gain ($K = \Delta y/\Delta u$), M denotes the magnitude of the input function $u(t)$, τ is the time constant, ϑ is the time delay, ξ refers to the lead-time constant, and t is the time. In this example, $y_0 = 3.25$ [mg/m^3] (STP), $\Delta u = -540$ [kg/h], $\Delta y = 3.5$ [mg/m^3] (STP), $\tau_1 = 55$ min, $\tau_1 = 60$ min, $\vartheta = 0$ [min], and $\xi = 35$ (Moser et al, 2020). The same methodology is applied to the solvent emissions (AMP, Pz and ammonia) data obtained from the use of the CESAR-1 solvent.

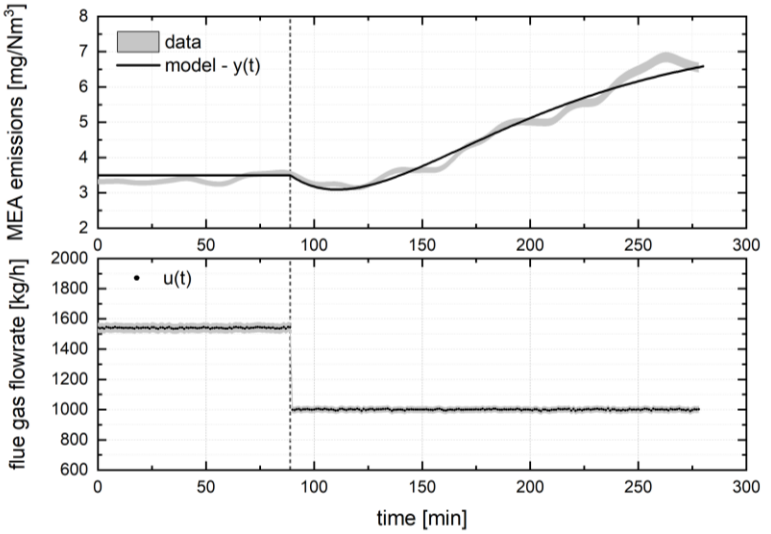

Figure 1. MEA emissions profile for the step change in the flue gas flowrate from 1540 kg/h to 1000 kg/h. Abbreviations: ● step change function $u(t)$ – experimental data, ■ experimental data with 2% error, and ▬ second order response function $y(t)$ – model (Moser et al. 2020).
Note: The MEA emissions data have been filtered using the low-pass filter in Mathematica (Wolfram Research 2019).

Future work aims to develop a dynamic mathematical model to predict capture performance in transient scenarios considering mass and heat transfer in the absorption and stripping columns in the AMP/Pz/CO_2/water system. The mass transfer will be described by the two-film theory and rigorous rate-based approach (Gáspár et al., 2011; Kvamsdal et al., 2009). The performance of the proposed model will be evaluated using the obtained experimental data and the results obtained for the step response functions. This model will provide measurable improvements in the environmental performance of PCC plants and the integration of cost-effective amine emissions control systems. Such models are also essential for eliminating the uncertainty in the up-scaling of a capture plant.

Keywords: CO_2 capture; flexible operation; solvent emissions; predicting emissions; pilot plant data; dynamic testing

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