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Dynamic modelling and testing of two water washes in series.

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Abstract

An amine-based CO_2 capture plant may cause harmful emissions to the atmosphere, and it is important to measure and control the emissions of amines and products resulting from their degradation during the process. The present work is a part of the SCOPE and AURORA projects and presents modelling and experimental results from the SINTEF CO_2Lab pilot plant located in Trondheim, Norway [1]. The focus of the present work has been on a water wash system in the pilot plant. This water wash system is located downstream the absorber, consisting of two external sections (see Figure 1).

The gas from the top of the absorber is about 60°C and is directed to the two sections AW3 and AW4 before it leaves the plant at about 35°C. This outlet temperature must be close to the outlet temperature of the DCC such that the water balance in the pilot plant is maintained. Each section consists of 1.5m of structured packing using circulating water with cooling for temperature control. The cooling of the gas provides water condensation in the packing and increases the liquid level in the sumps. In AW4, the excess liquid is pumped to section AW3. The water in that section will then be diluted. The excess liquid in AW3 is pumped back to the absorber.

In both projects, the CESAR1 solvent with 1.5 M piperazine and 3 M AMP has been used. The thermodynamic data and models developed in these projects have been useful for all the modelling activities in the projects. For the understanding of the water wash systems, it has been important to establish a dynamic model that describes the conditions in the water wash sections such that it is able to predict the outlet gas concentrations of amines also under transient conditions.

The model assumes that only volatile based emission is present, i.e. there are no significant aerosols that contribute to the emissions. For the SINTEF CO2Lab pilot plant, this is usually a good assumption when using flue gas from the propane burner. If aerosols are introduced into the gas stream, the difference between the total measurements and the model predictions can be interpreted as "aerosol contribution" to the emissions.

Some of the model assumptions are as follows:

- The water in each section is considered being an CSTR.
- The flue gas is considered as plug flow.
- The gas leaving a section has a certain approach to equilibrium with the water composition.
- The dynamics in the liquid are based on the total hold-up of water in the section and mass balance.
- The gas composition in the first section is based on the lean liquid composition and the temperature in the absorber top.

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The equilibrium conditions between the gas and liquid in each water wash section is as follows:

$$p_{\mathrm{Am}} = \gamma_{\mathrm{Am}} P^{\mathrm{o}}_{\mathrm{Am}} x_{\mathrm{Am\_free}}$$

Here $P^{\mathrm{o}}_{\mathrm{Am}}$ is the vapour pressure of pure amine, $x_{\mathrm{Am\_free}}$ the mole fraction of amine in the water in free form, i.e. not reacted with CO_2 or in ionized form, and γ_{Am} is the activity coefficient for the amine in the liquid solution. These parameters are calculated from the thermodynamic equilibrium model.

The vapour pressure of a pure component is a function of temperature and can be predicted by the following empirical equation:

$$\ln P^{\mathrm{o}}_{\mathrm{Am}} = b_1 + b_2/T + b_3 \ln(T) + b_4 T^{b_5} \quad (2.2)$$

where $P^{\mathrm{o}}_{\mathrm{Am}}$ is gas pressure in Pa and T is the temperature in °K.

The model calculates the amount of water condensed and that leaves the two water washes based on the temperature measurements into and out of the sections. Knowing the total amount of water operating in each section and having a much higher circulation rate compared to excess streams, the model assumption of two mixing tanks is considered reasonable.

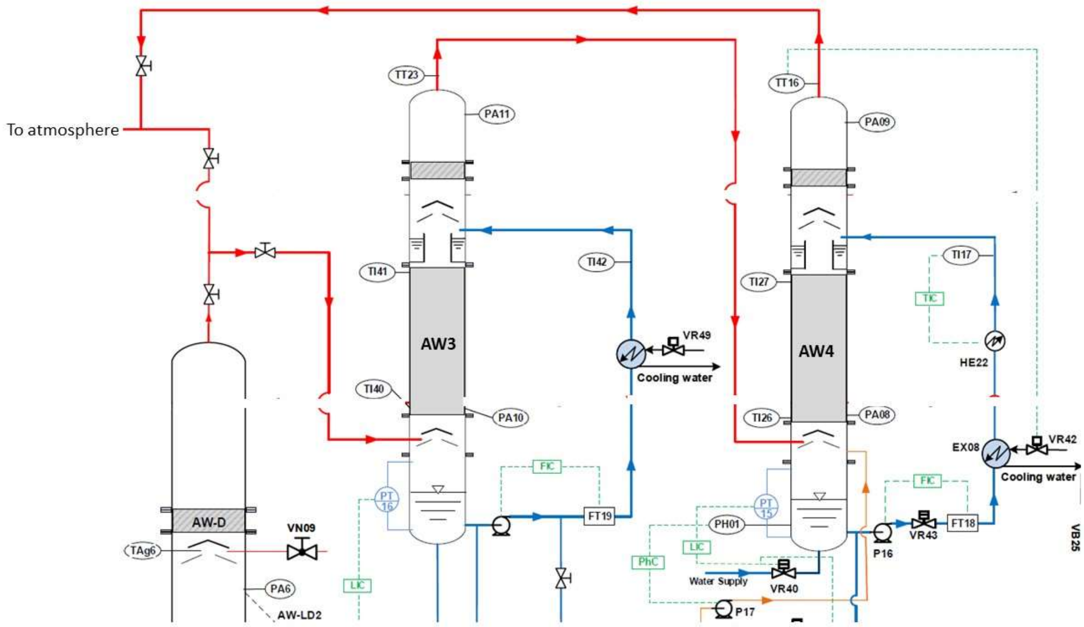

Figure 1: The top of the absorber with the two external water wash sections.

During the CESAR1 campaigns at SINTEF CO2Lab pilot plant, several water wash tests were conducted:

- Test where the initial state was pure water in the water washes. The gas from the absorber was first released without any washing and then re-routed to the two external washing sections.
- Test with step changes in liquid water wash temperatures
- Test with step change of flue gas velocity
- Test where aerosols are introduced into the flue gas [2].

A comprehensive number of measurements was done during the tests

- The outlet gas was continuously measured by FTIR
- Gas phase measurements of amines and ammonia at various locations using impinger trains.
- Dynamic gas sampling based on the ACEMS system developed by SINTEF [3]
- Dynamic liquid samples from the two washing sections, analysed for amines, CO_2, and pH.

One example from the first test is shown in Figure 2, where the amine concentration in the circulated two water washes is shown as a function of time.

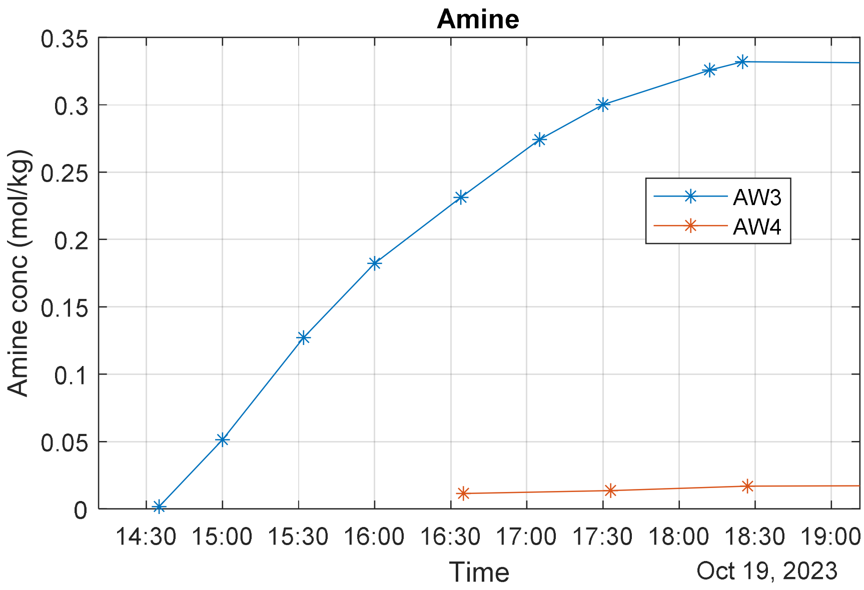

Figure 2: The amine concentration in the two water wash sections denoted AW3 (first) and AW4 (second)

The presentation will show that the model and the experimental data are very similar and that the model can be used to distinguish between aerosol and volatile based emissions. The model also gives valuable information about the dynamics of the water wash system that is important for running the plant. For example, the time required to get a new steady state condition in the washes when changes are made.

Keywords: Absorption, pilot plant, dynamic modelling, emission measurements

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