GHGT-12

Reducing amine aerosol emissions from carbon capture systems using colloidal gas aprons

Jesse G. Thompsona,*, Xiaobing Liab, Kunlei Liua

aUniversity of Kentucky Center for Applied Energy Research, Lexington, KY 40511
bSecond affiliation, Address, City and Postcode, Country

Abstract

During CO₂ capture processes from coal-derived flue gas with amine solvents small entrain small solvent droplets can be formed and emitted from the system leading to high solvent emission levels. The entrained mist will lead to significant solvent make-up rates and the associated costs and may have significant secondary environmental impacts. In order to combat this issue and reduce the emissions of amine mist droplets from CO₂ absorber, a novel method using an anionic surfactant to generate charged colloidal gas aprons (CGA) was developed. MEA emission reduction through a CGA absorption process was optimized by adjusting variables including capture temperature and stirring speed of the CGA generator. A significant reduction of close to 50% in MEA emissions in the flue gas stream exiting the absorber column was achieved from a pilot scale CO₂ capture pilot unit.

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

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

Keywords: Colloidal gas aphron; Amine emissions; Mist elimination; CO₂ capture; Amine aerosols

1. Introduction

The capture and control of CO₂ from major industries such as cement and steel mills, and coal fired power plants is considered the most effective solution in tackling climate change caused by CO₂ accumulation in the atmosphere. Among the common capture approaches, chemical absorption and desorption is perhaps the most promising option for separating CO₂ from fossil-fuel flue gas due to its simple operation, high absorption efficiency, cost-effectiveness and technological maturity.

* Corresponding author. Tel.: 1-859-257-0355; fax: 1-859-257-0220.
E-mail address: jesse.thompson@uky.edu

© 2014 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

Peer-review under responsibility of the Organizing Committee of GHGT-12
doi:10.1016/j.egypro.2014.11.104
In a CO2 absorber column where gas and liquid come into contact the gas stream can entrain fine liquid droplets and be emitted from the system. These entrained droplets, or mist, can lead to significant solvent losses during the CO2 capture process and [1]. From a process and economic standpoint it is important to reduce or eliminate amine solvent emissions from the outlet gas streams. Reducing or eliminating solvent emissions can have several important benefits including: (a) reduced loss of valuable solvent, (b) elimination of fugitive emission, and (c) reduction in negative environmental impacts [2].

There are several commercially available mist reduction systems such as vane mist eliminators, mesh mist eliminator, and cyclone based systems. However at present, a mist elimination process has yet to be developed specifically for incorporation into amine based carbon capture systems. One new approach to reduce or eliminate amine mist emissions from carbon capture system is using a surfactant-based separation technique by generating charged colloidal gas aphrons (CGA) [3]. CGA micro-bubbles form a double layer of surfactant molecules with a thin surfactant film encapsulating the trapped gas core [4-6]. The adsorption selectivity of the CGA micro-bubbles can be varied by selecting an alternative surfactant such as cationic, anionic or non-ionic. The outer surface of the CGA micro-bubble will become positively, negatively or non-charged respectively, to which oppositely or non-charged molecules can be adsorbed onto the surface [7].

The application of CGAs is increasing in recent years due to the unique and variable characteristics the micro-bubbles can possess including having a relatively large surface area, low viscosity and high bubble stability. CGA have been previously used in wastewater treatment and the removal of toxic wastes from soil and for flotation separation processes [8-11]. However, the application of CGA for amine mist emission reduction has not yet been explored to date. The primary objective of this study was to evaluate the performance of CGA micro-bubbles to reduce MEA mist emissions from a pilot scale CO2 capture process.

2. Experimental Methods

2.1. CAER CO2 Capture Pilot Operating Conditions

UKy-CAER operates a 0.1MWth pilot-scale CO2 capture facility with a coal-fired flue gas generator (FGG). The CO2 capture facility consists of a 7.3 m (24 ft) tall by 10cm (4") ID scrubber with a 25.4 cm (10") ID solvent recovery column downstream, a 4.3 m (14-ft) tall stainless steel stripper, and a condenser for solvent recovery in the stripper exhaust. The FGG is a coal combustion system designed to deliver flue gas to the CO2 capture pilot plant with a thermal design capacity of 200,000 Btu/hr. Flue gas exiting the combustor enters a high-temperature cyclone to remove particulate matter. After the cyclone, the SO2 concentration is lowered in the gas stream with a wet flue gas desulphurization (WFGD) unit. Additional pilot information can be found in Frimpong et al. [12]. The amine solvent used in the current test campaign was aqueous 30% wt monoethanolamine (MEA). The average gas conditions are as follows: 14% CO2, 8% O2 and 70-100 ppm SO2.

2.2. CGA Capture System

The CGA generation and capture apparatus includes a disperser inside a generation cell, a peristaltic pump and a capture cell. The disperser consists of a homogenizer (model: Pow Gen 500, 115V) and a sawtooth generator (model: 10×195 mm), driven by a high-speed electric motor. The generation cell is made of plexiglass with an internal diameter of 8 inches and a height of 10 inches. The capture cell is also made of plexiglass with a diameter of 8 inches and height of 12 inches. The CGA experimental apparatus schematic is shown in Fig. 1.
Fig. 2. Schematic of the experimental CGA capture system with CGA generating stirring cell and gas contacting adsorption cell

Commercially available surfactants were used to generate the CGA micro-bubbles. The CGA (Fig. 2a) were generated with 1L distilled water and a measured amount of the surfactant with stirring speeds in excess of 6000 rpm in the generating cell (Fig. 2b). The CGA were then pumped into the adsorbing cell by a peristaltic pump through an emulsion tube.

The capture process works in a counter-current fashion in the adsorbing cell where the flue gas was introduced at the bottom through a tube with a diameter of ¼ inches. The flue gas exits the elimination cell before entering the gas sampling apparatus. The temperature of the capture cell was adjusted by placing it into a temperature controlled water bath. The adsorption of the droplets by the charged CGA micro-bubbles is believed to be through a collision and attachment type mechanism as shown in Fig. 3.
2.3. MEA Emissions from CO₂ Absorber Column

MEA emissions were measured after the CO₂ absorber column in the flue gas exit line. The gas sampling apparatus consisted of a sampling console with a dry gas pump connected to a 4-impinger sampling train in an ice bath containing 0.05 M sulfuric acid, along with an inline binder-free quartz filter to keep coal fly ash from entering the impinger train. Sulfuric acid is used to absorb the basic ammonia and MEA emitted in the gas stream exiting the absorber column. The sampling lines were not heated (ambient conditions) during the sample collection period.

The MEA emission reduction efficiency of the CGA system was evaluated during a 30% (wt) MEA solvent test campaign in the CAER pilot CO₂ capture unit. During CGA testing, a control (reference) gas sample was collected from a sampling port location before the CGA capture apparatus at the same time as a gas sample was collected after the CGA apparatus. The reference sample was used to evaluate the reduction in emissions and to normalize the results (representing % MEA emission reduction) for comparison purposes.

The collected impinger sulfuric acid samples were diluted 10 times and analyzed by cation ion chromatography using a Dionex ICS-3000 system (Dionex-ThermoScientific Sunnyvale, CA) with an autosampler. The cation IC system consisted of an CSRS 300 suppressor, EGC III MSA (methanesulfonic acid) eluent generator, IonPac CS17 analytical column and an CG17 guard column operated at 30°C. The conductivity detector was maintained at 35°C with a sample injection volume of 20 μL. An isocratic mobile phase of methanesulfonic acid (2.5 mM) at a flow rate of 0.8 mL/min was used. MEA quantitation was performed using a calibration curve from pure MEA (+99%, Alfa Aesar, Ward Hill, MA) standards.

3. Results and discussion

3.1. Effect of stirring speed on CGA bubble generation

The stirring speed of the surfactant solution is a major operating variable for generating CGA micro-bubbles. Slower speeds may lead to an insufficient amount of micro bubbles generated, while higher speeds can cause excessive foaming and large unstable bubbles. This trade-off can be attributed to the variable energy input, with a higher input at higher stirring speed resulting in smaller bubbles and increased surface area. At relatively small sizes, the CGA bubbles have high stability and sufficient surface area to volume ratios and can facilitate attachment of the oppositely charged particles (i.e., MEA) to their surfaces by coulombic forces. However, further increasing
the stirring speed can result in a higher amount of bubble coalescing and breakage, thereby diminishing their adsorption potential. A good compromise between these two competing issues was found at 18,000 rpm. This optimal stirring speed was used for all subsequent CGA experiments.

3.2. Effect of the temperature on CGA emission reduction

At higher adsorption temperatures, the kinetic energy of the amine mist droplets and CGA should increase temperatures resulting in a slightly higher probability of mist droplet and CGA collisions. However, at higher temperatures the MEA will have a higher vapor pressure causing evaporation from the droplets into gas phase. Likewise, temperature can also influence the stability of CGA micro-bubbles. Therefore, the temperature of the capture cell can significantly influence the performance of the CGA capture system.

The CGA system was evaluated at three different temperatures corresponding to the ambient temperature near the top of the absorber where the CGA system apparatus was installed (25°C), the average flue gas temperature at the absorber exit (45°C) and at a temperature in between these two values (35°C). In this test no identifiable temperature trend was observed, therefore the remaining CGA capture testing was conducted with an average recorded temperature of 25°C in the adsorbing cell.

3.3. MEA emission reduction in the CAER pilot

In order to investigate MEA adsorption and capture by CGA micro-bubbles system, a series of samples were collected over the course of several weeks during normal operating conditions in the pilot CO2 capture unit. First, the capture potential of water (as an experimental apparatus blank) was evaluated by filling the adsorption cell with 1L of water while the flue gas flowed through the cell at the same rate and for the same time duration as with the CGA capture experiments. Next, the capture cell was filled with a solution of surfactant, but without generating the CGA in the generation cell, and again the flue gas flowed through the cell at the same rate and for the same time duration as with the CGA capture and elimination experiments. Lastly, CGA were generated from a surfactant solution on the generation cell and pumped into the adsorption cell while the flue gas flowed upward through the CGA micro-bubble solution. The MEA emissions from the CGA adsorption cell were measured during each experiment. As previously mentioned, an absorber MEA emission sample was collected in parallel with all experiments to serve as a reference from the pilot unit to evaluate MEA emission reduction by the CGA system.

Figure 4 shows the MEA emission reduction with the different capture medium; water, surfactant solution and CGA micro-bubbles. The emission level with the water, similar to a water wash, was very low at near 3%. The surfactant solution alone was able to show a small (22%) but definite reduction in MEA emissions. This can likely be traced to the generation of some charged bubbles as the flue gas flowed through the solution. The amount and size of the generated bubble was not analyzed in this work. Lastly, the CGA micro-bubbles showed a significantly lower emission level with a reduction of near 48%, relative to the reference MEA emission levels. This suggests that when compared to water alone, the MEA capture is enhanced by the electrostatic interactions of the MEA with the charged CGA micro-bubble. As suggested earlier, the adsorption of the MEA droplets is believed to be through a collision and electrostatic attachment type mechanism with the charged micro-bubble. However, the exact mechanism has not been experimentally verified and will be investigated as part of future experiments.

4. Conclusions

A new fine mist/droplet capture system using charged colloidal gas aprons was developed to reduce amine solvent emissions from a CO2 capture system. The initial results suggest that fine MEA droplet emissions in the gas steam exiting the absorber column can be reduced using charged micro-bubble CGAs. Additionally, when compared to a conventional style water wash, the CGA system appears to have greater MEA emission reduction capabilities and the potential for larger scale reductions with further optimization. This system can potentially be applied mist emissions reduction in larger CO2 capture systems that use aqueous amine as the CO2 capture solvent.
Acknowledgements

This work was supported by the Carbon Management Research Group (CMRG) with members, including: Duke Energy, East Kentucky Power Cooperative (EKPC), Electric Power Research Institute (EPRI), Kentucky Department of Energy Development and Independence (KY-DEDI), Kentucky Power (AEP), and LG&E and KU Energy.

References