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Enhancement of CO_2 capture absorber performance and improved solvent wetting

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Abstract

Challenges are still present in post-combustion CO_2 capture with a clear need to significantly advance the deployment of enabling technologies through the design and testing of advanced components. This is especially true for natural gas combined cycle (NGCC) CO_2 capture plants where the relatively lower CO_2 concentration in the flue gas reduces the driving force. Critical elements of the CO_2 capture process still need to be examined, including how to increase CO_2 mass transfer in the absorber column with liquid to gas ratios of <1.2, while reducing the size of the absorber column to reduce capital costs. Research using advanced additive manufacturing techniques can be utilized towards the development of enhanced CO_2 capture reactors that can lead to safe, reliable, and low-cost carbon capture technologies. The objective of current R&D is to develop and test novel carbon capture materials components that contribute to increased CO_2 mass transfer through increased turbulent gas-liquid interface and improved solvent wetting on the packing within the absorber.

There has been significant effort extedned toward enhancing the mass transfer (K_G) of CO_2 in the absorber by developing high efficiency packing, intensifying gas/liquid mixing, and modifying solvent properties to improve effectiveness of the gas-liquid contact surface. To further enhance CO_2 mass transfer the development of absorber reactor packing was targeted to enhance surface wetting and local mechanical mixing inside the absorber column to increase liquid/gas transport for faster mass transfer. This was accomplished using the inherent solvent physical properties including viscosity and surface tension coupled with packing material fabricated with unique surface structures and properties. Packing surface sub-structures and patterns can enhance solvent wetting and destabilize the stable liquid film and bring fresh unreacted amine from the bulk to the surface interface. The improvements in CO_2 capture using these novel reactor concepts are most applicable to diffusion-controlled solvents (most of 2nd-gen aqueous amine solvents and current non-aqueous and water-lean solvents), as opposed to kinetically controlled solvents, where the primary action is to increase the effective diffusion rate of CO_2 into the solvent through increased wetting and intra-solution turbulence on the packing surface. This impact translates to increasing the volumetric

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productivity of the absorber column. With the application of additive manufacturing, also known as 3D printing, fabrication of polymer-based packing with unique designs and surface sub-structures can also result in favorable wetting profiles on the packing surfaces leading to a significant benefit by increasing mixing and CO_2 mass transfer. One benefit of using 3D printing technology is the potential for unlimited design options together with the speed at which prototypes can be produced and tested.

One key aspect of absorber packing development that the project team has identified is the importance of optimized wetting of the solvent at the gas/liquid interface. Wetting is measured in terms of contact angles as the primary data, which indicates the degree that a liquid will spread or wet a solid surface. Small contact angles (<< 90º) correspond to high wettability, while large contact angles (>>90 º) correspond to low wettability. The contact angle of low viscosity aqueous amine solvents on steel is generally between 20-40º. The contact angle on Nylon is in the same general range of 20-50º. It is anticipated that more viscous solvents will have poor wetting due to their thicker liquid film. These solvents should benefit from the development in novel designs, geometries and configurations that may increase intra-solvent mixing and better wetting on the packing surface. Beyond increasing liquid wetting, other benefits can be achieved when using polymer packing. Conventional Stainless Steel packing have a traditional embossing texture and a smooth packing surface. 3D-printed polymer packing in contrast can have a wavier sub-surface texture, which is generated by size, movement, and temperature of the printing nozzle. The sub-milliliter ribbed texture is uniform on the surface, which can be modeled as a consecutive curve with certain wavelength and amplitude. The larger texture amplitude will generate stronger local turbulence within the liquid. Based on the microscope images of the 3D printed polymer packing prototypes, can be up to 1.04 and 1.16 times higher than the steel packing. Since the primary purpose of the packing within an absorber column is to provide surface area for gas/liquid contact, the creation of additional surface area on the polymer packing surface will translate to more gas/liquid interaction and enhanced CO_2 mass transfer.

These advacned absorber reactor components were developed and tested that increase CO_2 mass transfer for high viscosity non-aqueous and water-lean solvents (> 5 cP), where CO_2 diffusion requires more driving force, through increased turbulence on the gas-liquid interface and improved solvent wetting on the polymer packing surface using three-dimensional (3D) printing technology. Polymer packing designs were created with different patterns, geometries and packing configurations using different 3D printer nozzles, printing speeds and temperatures. First, the potential durability of the different polymer materials in a model water-lean solvent (WLS) environment, was evaluated at relevant absorber temperatures (40-60 C) for 5000 hrs. Physical changes to the polymers such as an increase in weight and size were monitored periodically by mass measurements using a balance and physical measurements using calipers, respectively. Any changes in surface properties were monitored through periodic measurement of contact angle versus the WLS and water (as a reference). Polymers with long-term solvent stability were advanced for continued evaluation and scale-up, while those that were not stable were removed from future testing. Next, different patterns, geometries, and packing/distributor configurations were created using different 3D printer nozzles, printing speeds and temperatures. The packing was examined and modeled for wetting enhancement. Smaller packing void volumes (larger packing densities) lead directly to larger gas-side pressure drop as it requires higher energy input to push the flue gas upwards through the absorber column. Packing void volumes of less than 80% and pressure drop less than 1 inHg were targeted for prototype production. Packing volume were measured through a water displacement method and pressure drop was measured using a differential pressure gauge during lab-scale testing.

Lastly, the lab-scale testing was conducted using a integrated bench-scale CO_2 capture unit with simulated NGCC flue gas. Different packing materials and configurations were examined for enhancement in CO_2 removal rates and increases on CO2-riching loading as evidence of increased CO_2 mass transfer into the solvent. A CO_2 removal efficiency of 97% was targeted at different liquid to gas (L/G) ratios. A techno-economic analysis (TEA) was completed using the experimental data showing how the proposed technology decreases capital costs by reducing the size of the absorber column and the amount of packing required for high CO_2 capture rates.

Keywords: CO_2 capture, Absorber packing, Water-lean solvent, Additive manufacturing