Review of Recent Pilot Plant Activities with Concentrated Piperazine

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Abstract

Concentrated (30 wt%) piperazine (PZ) with the advanced flash stripper regeneration configuration is a second generation amine-based process for CO₂ capture. Piperazine has a moderately high heat of absorption (70 kJ/mole) and is both thermally and oxidatively stable. 5 m PZ has a CO₂ absorption rate approximately 2.5 times that of 7 m MEA and a 10 to 20% better energy performance than 7 m MEA. 5 m PZ eliminates the rich CO₂ loading solubility limitation of 8 m PZ and expands the lean solubility window. 5 m PZ has a viscosity comparable to 7 m MEA and 3.6 times lower than 8 m PZ. 5 m PZ also retains the benefits of high temperature stripping at 150 °C.

Testing at the pilot scale with concentrated piperazine has been completed in five separate campaigns since 2008 at the SRP pilot plant. The SRP pilot plant has the equivalent capacity of a 0.1 MW coal-fired power plant and consists of an intercooled absorber and simple stripper column. Both columns have an inner diameter of 16.8-inches and each column is typically filled with 20 feet of packing. The facility uses synthetic flue gas consisting of air and CO₂, which provides the flexibility to test at CO₂ concentrations for both coal (12 mol%) and gas (3 mol%). A new high temperature and pressure two-stage flash regeneration skid was designed, fabricated, and operated in 2010 and 2011 and successfully regenerated 8 m PZ at 150 °C and 14 bar.

The advanced flash stripper with cold and warm-rich bypass was developed from initial pilot testing using the two-stage flash and warm-rich bypass configuration, which was evaluated at the University of Texas of Austin Separation Research Program (SRP) in October 2011. The high temperature advanced flash stripping process at 150 °C exploits the high thermal stability of piperazine and results in a much higher regeneration pressure (5-10 bar). The new configuration uses a gas-liquid heat-exchanger to recover the heat from the overhead vapor by cross-exchanging it with the cold-rich bypass stream. The advanced flash stripping process offers a smaller footprint, more simple design, and lower capital costs than a conventional packed stripper column.

In March 2015, SRP pilot plant testing was completed with 5 and 8 m PZ and the advanced flash stripper. The 2015 pilot plant campaign demonstrated reliable operation and improved energy performance of the advanced flash stripper with cold and warm rich bypass, and improved energy and absorber performance for 5 m PZ relative to 8 m PZ (Figure 1).
The absorber was operated with two gas rates: 350 and 500 acfm. The liquid to gas ratio (L/G) was varied from 2.3 to 5.0 lb/lb. The absorber was packed with 20 feet of RSP 250 structured packing divided into two beds. The intercooling stream was typically maintained at a temperature setpoint of 40 °C, with one run that had a 35 °C setpoint. The lean CO2 concentration was varied from 0.18 to 0.26 mol CO2/mol PZ equivalent. The CO2 composition of the inlet flue gas was 12 mol% with one run conducted at 6% CO2. The CO2 removal rate in the absorber varied from 69 to 97%.

The advanced flash stripper was operated at temperatures and pressures that varied from 135 to 149 °C and 46.1 to 87 psig, respectively. The cold rich bypass was varied from 0 to 13% of the total volumetric feed flow. The warm rich bypass was varied from 17 to 41% of the total volumetric feed flow.

Seventeen runs were operated with 5 m PZ and four runs were completed with 8 m PZ. 5 m PZ gives 20% better heat transfer performance than 8 m PZ on the LP cross exchanger and resulted in a lower process heat duty because of lower viscosity. Seventeen runs with optimized rich solvent bypass rates achieved process heat duties from 2.1–2.5 GJ/tonne CO2. Four runs with unoptimized rich solvent bypass rates had a 15% higher process heat duties. This campaign demonstrated that using the advanced flash stripper reduced the energy requirement by 25% compared to the previous two SRP campaigns with the two-stage flash configuration.

The pilot plant rated-based Aspen Plus® absorber model is able to reasonably capture pilot plant-measured column temperature profile behavior of different intercooling configurations within ±11% average percentage error, with 14 runs less than ±3%. Analysis of the pilot plant experimental data demonstrated a material balance closure of +/- 2% around the absorber column. The campaign results indicated that 5 m PZ outperformed 8 m PZ at comparable absorber operating conditions due to enhanced mass transfer rates in the absorber.

SO2 was injected at a concentration from 26-83 ppmv during six separate aerosol tests. PZ measured at the absorber outlet by FTIR increased 0–2.6 moles per mole of SO2 added when compared to the baseline value. H2SO4 was injected at a concentration from 10-13.7 ppmv during four separate aerosol tests. PZ measured at the absorber outlet by FTIR increased 0.9–6.7 moles per mole of H2SO4 added when compared to the baseline value.
A new 3rd generation custom built Phase Doppler Interferometer (PDI) was used to characterize the PZ aerosols generated by the SO$_2$ and H$_2$SO$_4$ injections. The PDI was successfully able to measure particle size distributions from 0.1–10 μm at high total density (10$^6$ part/cm$^3$).