Analysis on regeneration energy of NH₃-based CO₂ capture with equilibrium-based simulation method

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Abstract

As a promising way for reducing the huge CO₂ emissions from power plants, CO₂ capture using aqueous ammonia is receiving increasing attentions. Process simulation is an important method for evaluating its technical performances. Currently, there are two simulation methods for this process, namely equilibrium- and rate-based method. The equilibrium-based method assumes the vapor and liquid phases flowing out of each stage reach equilibrium, while the rate-based method considers the actual heat/mass transfer rates. For the rate-based calculations, the column height is required, and the different stages are similar to one-dimensional grids for numerical calculations. For the equilibrium-based calculations, the column height is not required. Since lots of results for NH₃-based CO₂ capture are based on the equilibrium- and rate-based methods, it is quite necessary to give quantitative comparisons on the calculation behaviors of two simulation methods. Further, based on the equilibrium-based simulation method, analysis on the regeneration energy of NH₃-based CO₂ capture was carried out.

Fig. 1 shows the schematic diagram for equilibrium curve and operating curves of NH₃-based CO₂ absorption process. The equilibrium curve is a concave curve, which is determined according to the equilibrium partial pressures of CO₂ in the vapor phase at different CO₂ loadings of the liquid phase. A₁, A₂, A₃, … represent the operating curves, which are straight lines with a same slope and their two ends all locate at the two lines of Yₐₙ=Yₙ and Xₐₙ=X₀, respectively. This can be explained from the governing equation for the operating curves, which can be determined according to that the CO₂ absorbed from the vapor phase totally gets into the liquid phase. Here, the governing equations for the operating curves can be expressed as Y=L(X-X₀)/V+Y₀,i, which is equivalent to Y=L(X-Xₐₙ)/V+Yₙ, where L and V are the molar flow rates of the vapor and liquid phases flowing into the absorption column respectively, and Yₙ and X₀ are the mole fractions of CO₂ in the vapor and liquid phases. The increase of the stage number means the operating curve is more close to the equilibrium curve, and therefore the value of Y₀,i is more small. Therefore, the CO₂ removal efficiency increases with the stage number for equilibrium-based calculation. But, when the operating curve reaches the intersections of equilibrium curve with Yₐₙ=Yₙ or Xₐₙ=X₀, although the stage number can be increased, but the value of Y₀,i reaches its limitation, namely the CO₂ removal efficiency reaches the maximum value.
Fig. 1. Schematic diagram for equilibrium curve and operating curves.

Fig. 2 presents the CO₂ removal efficiencies at different stage numbers for equilibrium-based calculations under different liquid gas ratios. The liquid gas ratio is the mass flow rate of the lean solvent flowing into the absorber from the top to that of the flue gas flowing into the absorber from the bottom. It can be found that the CO₂ removal efficiency increases with the stage number for the equilibrium-based calculation when the liquid gas ratio keeps constant, and the CO₂ removal efficiency increases with the liquid gas ratio when the stage number keeps constant. For the case that the liquid gas ratio is 8.61 kg/kg, the CO₂ removal efficiency almost reaches a nearly constant high value of 99% when the stage number is equal to and larger than 75. But for the case that the liquid gas ratio is 11.95 kg/kg, the CO₂ removal efficiency almost reaches a nearly constant high value of 99% when the stage number is equal to and larger than 5.

Fig. 2. CO₂ removal efficiencies at different stage numbers for equilibrium-based calculations under different liquid gas ratios.