

Carbon Dioxide Capture by Chemical Absorption: A Solvent Comparison Study

by

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Abstract

In the light of increasing fears about climate change, greenhouse gas mitigation technologies have assumed growing importance. In the United States, energy related CO₂ emissions accounted for 98% of the total emissions in 2007 with electricity generation accounting for 40% of the total¹. Carbon capture and sequestration (CCS) is one of the options that can enable the utilization of fossil fuels with lower CO₂ emissions. Of the different technologies for CO₂ capture, capture of CO₂ by chemical absorption is the technology that is closest to commercialization. While a number of different solvents for use in chemical absorption of CO₂ have been proposed, a systematic comparison of performance of different solvents has not been performed and claims on the performance of different solvents vary widely. This thesis focuses on developing a consistent framework for an objective comparison of the performance of different solvents. This framework has been applied to evaluate the performance of three different solvents – monoethanolamine, potassium carbonate and chilled ammonia.

In this thesis, comprehensive flowsheet models have been built for each of the solvent systems, using ASPEN Plus as the modeling tool. In order to ensure an objective and consistent comparison of the performance of different solvent systems, the representation of physical properties, thermodynamics and kinetics had to be verified and corrected as required in ASPEN Plus. The ASPEN RateSep module was used to facilitate the computation of mass transfer characteristics of the system for sizing calculations. For each solvent system, many parametric simulations were performed to identify the effect on energy consumption in the system. The overall energy consumption in the CO₂ capture and compression system was calculated and an evaluation of the required equipment size for critical equipment in the system was performed. The degradation characteristics and environmental impact of the solvents were also investigated. In addition, different flowsheet configurations were explored to optimize the energy recuperation for each system.

Monoethanolamine (MEA) was evaluated as the base case system in this thesis. Simulations showed the energy penalty for CO₂ capture from flue gas from coal-fired power plants to be 0.01572 kWh/gmol CO₂. The energy penalty from CO₂ regeneration

accounted for 60% of the energy penalty while the compression work accounted for 30%. The process flexibility in the MEA system was limited by degradation reactions. It was found that different flowsheet configurations for energy recuperation in the MEA system did not improve energy efficiency significantly.

Chilled ammonia was explored as an alternative to MEA for use in new coal-fired power plants as well as for retrofitting existing power plants. The overall energy penalty for CO₂ capture in chilled ammonia was found to be higher than in the MEA system, though energy requirements for CO₂ regeneration were found to be lower. The energy penalty for 85% capture of CO₂ in the chilled ammonia system was estimated to be 0.021 kWh/gmol CO₂. As compared to the MEA system, the breakdown of the energy requirements was different with refrigeration in the absorber accounting for 44% of the energy penalty. This illustrates the need to perform a systemwide comparison of different solvents in order to evaluate the performance of various solvent systems.

The use of potassium carbonate as a solvent for CO₂ capture was evaluated for use in Integrated Reforming Combined Cycle (IRCC) system. With potassium carbonate, a high partial pressure of CO₂ in the flue gas is required. Different schemes for energy recuperation in the system were investigated and the energy consumption was reduced by 22% over the base case. An optimized version of the potassium carbonate flowsheet was developed for an IRCC application with a reboiler duty of 1980 kJ/kg.

In conclusion, a framework for the comparison of the performance of different solvents for CO₂ capture has been developed and the performance of monoethanolamine, chilled ammonia and potassium carbonate has been compared. From the standpoint of energy consumption, for existing power plants the use of MEA is found to be the best choice while for future design of power plants, potassium carbonate appears to be an attractive alternative. An economic analysis based on the technical findings in this thesis will help in identifying the optimal choices for various large, stationary sources of CO₂.

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