Technical University of Denmark

Carbon Dioxide Capture Processes: Sensitivity Analysis for Optimization and Control

Zamman, Muhammad; Lee, Jay H.; Gani, Rafiqul

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Carbon Dioxide Capture Processes: Sensitivity Analysis for Optimization and Control

Tuesday, October 30, 2012: 4:20 PM

324 (Convention Center)

Muhammad Zaman[1], Jay H. Lee[1] and Rafiqul Gani[2], (1)Chemical and Biomolecular Engineering, KAIST, Dajeon, South Korea, (2)CAPEC, Department of Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark

Abstract

Carbon dioxide is responsible for 60 percent of the global warming caused by greenhouse gases (GHGs). Most of the CO_2 emissions are due to burning of fossil fuels, and power production in particular accounts for roughly 40 percent of the total CO_2 emissions, the main contributor of which is the coal based power generation. According to the International Energy Agency's roadmap, 20 percent of the total CO_2 emissions should be removed by carbon dioxide capture and sequestration (CCS) by year 2050. Hence the capture of CO_2 from power plants, mainly from coal based power generation is very significant for greenhouse gas reduction. The major difficulty in the post-combustion capture is the low concentrations of carbon dioxide in the flue gas and hence the larger volumes that need to be treated. Since this low concentration cannot be treated by physical absorption with reasonable absorption capacity, chemical absorption is commonly employed. Carbon dioxide capture by monoethanolamine (MEA) is a very mature technology for post-combustion capture. The major limitation with the amine-based absorption process is its parasitic power requirements including the steam requirements for the regeneration of the solvent, for CO_2 capture, and for compression. Other difficulties with MEA based CO_2 capture is the degradation of MEA and corrosion.

The main objective of this paper is to present a steady-state sensitivity analysis of the CO_2 process and to relate it with operability and control of the process to find the optimal design, operating conditions and control strategies. This design should be able to work at its optimal operating point in the presence of disturbances; this last item is to be verified through closed-loop dynamic simulations.

In this paper, an integrated process design and controller design methodology consisting of four steps including base case design, steady state sensitivity analysis, optimization problem & control structure selection, and optimization & control system validation, is presented. First a consistent simulation of the process verifying a base case design is performed, using an appropriate process simulator (Aspen Plus 7.2 is used). Thermodynamic properties play an important role in these simulations - an equilibrium based model with the electrolyte-NRTL model for the vapor liquid equilibrium and associated property models are used. Simulations are performed to investigate the sensitivity of the cost function to changes in the design variables and disturbances in the property model parameters. This sensitivity analysis using the base case design as a reference point helps to identify the cost function and the important variables, such as actuator (design) variables, control (process) variables, disturbance (input) variables, for future operability and control studies after developing the dynamic model of the process. The values for various cost functions, calculated in terms of the relative variations from their base case values for different values of the perturbed design variables and property model parameters are analyzed to identify the most sensitive design variables and model parameters.

Based on the sensitivity analysis, process optimization problems are defined and solved and, a preliminary control structure selection is made. The selected cost function is the cost of energy used by the process and the design variables affecting it most are the L/G ratio and the steam flowrates in the reboiler. The important process variable selected is the lean loading (moles of CO_2/moles of MEA in the lean solvent). The cost function (indirectly, the heat duties) and equipment parameters such as the stripper column diameter are also found to be sensitive to the stripper pressure, to positive variations of the vapor pressures as well as the flowrates of the hot utilities. The important disturbances in the process are found to be the flue gas flow rate, stripper pressure, and the lean solvent temperature. The formulated optimization problem therefore minimizes the cost of operation subject to selected design variables (L/G ratio and steam flowrates in the reboiler); fixed process specifications (lean loading, CO_2 recovery goal, condenser temperature; upper limit on solvent loss, etc.) and additional constraints (mass and energy conservation, i.e., the process model). Pairing the design variables (which are also actuators for the control problem) with the process specification variables (which are the measured variables in the control problem) helps to define control structure. According to the selected control structure, lean loading is controlled by manipulating steam flowrate to the reboiler of the stripper to ensure the optimum performance (reboiler duty). Alternatively, easily measured variable (e.g. stripper stage temperature) can be control variable, and both cases can be compared for better performance and control.

In the final step, the optimization problem is solved through the established steady state simulation model and the control structure is validated through a developed dynamic process model. As preliminary results, compared to the base case, the process is further improved by 7.3% in terms of operating costs and the control structure is shown to reject disturbances also at a minimum operating cost.

Extended Abstract: File Not Uploaded

See more of this Session: Modeling, Optimization and Control of Sustainable Processes
See more of this Group/Topical: Computing and Systems Technology Division