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Control structure design for CO_2 absorption processes for large operating ranges

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Coal-fired power plants are operated flexible over a large operating range. Processes for post-combustion CO_2 capture have to follow the power plant operation load and have to separate the carbon dioxide in every operating point with minimal energy demand. In this work control structures for chemical absorption processes were designed using self-optimizing control. The derived control structures allow the separation of 90% of CO_2 over an operating range of 40 – 100% load with acceptable energy requirements

Keywords: control structures, large operating range,chemical absorption, self-optimizng-control

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1. Introduction

Research activities concerning chemical absorption processes were focused mainly on solvent development, design of process configurations and process modeling. The next step in the development of these processes is the design of a control and operation strategy what is not sufficiently investigated up to now. Post-combustion capture processes have to treat all of the flue gas coming from the power plant. Due to the increased usage of renewable energy sources coal-fired power plants are operated dynamically over a large operating range. The power plant load performs enormous changes over one day and the capture process has to separate the carbon dioxide in every operating point with minimum energy demand. For meeting these requirements the control structure plays an important role. In this work control structures for a chemical absorption process were systematically designed to separate CO_2 over an operating range of the power plant of 40 – 100% with minimum energy demand.

2. Process simulation

As shown in Schach et al. 2010 the standard configuration of the chemical absorption process with absorber intercooler has a very good performance in terms of cost of CO_2 avoided in comparison with other configurations. Therefore this process was taken as an example and a control structure was designed in this work. The process was simulated using Aspen Plus 2006.5 with monoethanolamine (MEA) as solvent and the amine package MEA-REA which provided the reaction model considering both kinetically controlled and equilibrium reactions. For the absorber and stripper columns the RadFrac model with rate-sep calculation was used. The control structure was

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designed for an operating range of the power plant of 40 to 100% load. Four different operation points were considered: 40, 60, 80 and 100% load. The mass flow of the flue gas for the 100% case was 750 kg/s with the following composition: x_{CO2} = 13.5 mole-%, x_{N2} = 71.5 mole-%, x_{O2} = 3.5 mole-% and x_{H2O} = 11.5 mole-%. In part load the mass flow decreases and the composition changes. Since in part load the coal is burnt with excess air the concentrations of CO_2 and water decrease whereas the concentrations of oxygen and nitrogen increase.

3. Control structure design

In terms of energy requirements a control strategy based on online optimization would lead to the best results. Since these strategies are still under development, the industry uses feedback control. For the design of a feedback control structure the self-optimizing control concept of Skogestad 2000 was applied. The objective is, based on stationary simulations, to select controlled variables which when kept constant lead to minimum loss even if disturbances occur. For the analyzed process this means that the control structure has to maintain an energy efficient separation of 90% of the CO_2 over the whole regarded operating range. The loss is defined as the difference between the energy demand of the process using online optimization and feedback control.

The number of control loops is determined by the degree of freedom of the process, which was calculated using a methodology of Konda et al. 2006. The process is subject to a certain number of process constraints which reduce the degree of freedom of the process since the constraints have to be controlled (Figure 1). Additionally levels and pressures have to be controlled to maintain a safe operation, which reduces the degree of freedom to 3: solvent mass flow, mass flow of heating steam and mass flow of cooling water in the intercooling stage. For those three manipulated variables controlled variables have to be found leading to an energy efficient separation process over the whole operating range. Out of 29 different controlled variables those were selected which minimize the loss. For the selection of these variables the minimum singular value rule (Halvorsen et al. 2006) was applied.

Table 1: Selection of the best sets of controlled variables

Set	C1 ($M_{RichSolvent}$)	C2 ($M_{Heating\ Steam}$)	C3 ($M_{Cooling\ Water}$)
I	$M_{CO2,\ Feed}/ M_{RichSolvent}$	$M_{Heating\ steam}/M_{CO2\ Feed}$	$T_{18,\ Absorber}$
II	$M_{CO2,\ Feed}/ M_{RichSolvent}$	$x_{CO2,\ Sweetgas}$	$T_{18,\ Absorber}$
III	$M_{CO2,\ Feed}/ M_{RichSolvent}$	loading lean solvent	$T_{18,\ Absorber}$
IV	$M_{CO2,\ Feed}/ M_{RichSolvent}$	$M_{Heating\ Steam}/M_{CO2\ Feed}$	$M_{Cooling\ Water}/M_{Flue\ Gas}$

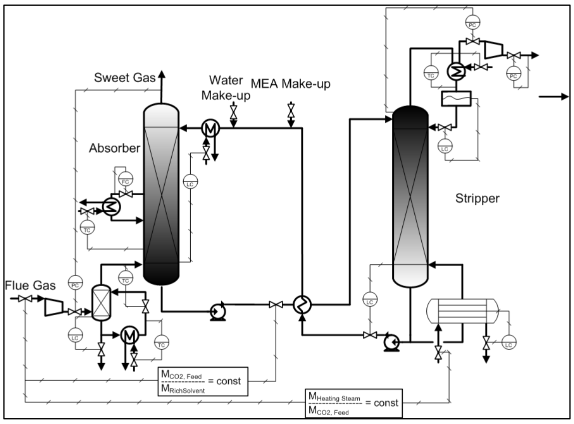

Figure 1: Flowsheet with control structure according to set I

Table 1 shows a selection of the best sets of controlled variables which maintain an economic separation of the CO_2 over the whole operating range. Controlling ratios of mass flow of CO_2 in the flue gas to other process parameters leads to effective control structures.

The process with the control structure according to set I is shown in Figure 1. Control loops for the process constraints and for a safe and stable operation are also included.

Evaluation of the loss in all operating points revealed that with these structures the maximum loss is 2%. This shows that the developed control structures can be applied for an energy efficient CO_2 separation over a large operating range.

4. Literature

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