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Transient Behavior of a Post Combustion CO_2 Capture Process

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Background

Modeling of the dynamic behavior of post-combustion CO_2 capture process and subsequent integration with power cycles and industrial processes is a topic which currently is gaining increasing interest. The transient behavior of the CO_2 absorber and the solvent regenerator with respect to liquid to gas flow rates, capture rates and heat requirements need to be controlled while, at the same time, the operation of the capture unit must comply with the operation and control of the power plant. Also, the importance of control strategies for dynamic operation increases in base load thermal power plants when the requirements for load flexibility increase, e.g. as a result of more wind power and other intermittent power sources in the energy system. Furthermore, the capture cycle may also be used to reduce the load variation of the power plant by storing CO_2 rich solvent during peak demand, which then may be regenerated during periods of low demand [1]. Numerous steady-state analyses of the post-combustion capture process with MEA have been published (see e.g. Wang et al. [2] and the references therein), however less work has been carried out focusing on the dynamic behavior of the process. Kvamsdal et al. [3] presented a study of transient behavior of the absorption column in the capture system with respect to capture efficiency, liquid-to-gas (L/G) ratio and solvent loading during start-up and load reduction. The study includes cases with no process control as well as capture efficiency control. Lawal et al. [4] applied a rate-based dynamic model of the complete capture process. Different cases of process disturbances were investigated, such as reduced reboiler duty and increased flue gas flow to the system, and the effects on the capture efficiency, solvent loading and heat requirement of the process were studied. The previous work mostly focuses on the transients observed in the capture system while the interactions and consequences for the connected processes, the power plant/industrial process and the CO_2 transportation network respectively, are rarely discussed. This work includes the capture process and the connection to a power plant process with the aim to evaluate the transient behavior of the capture system with respect to typical load-change ramp rates in modern coal power plants as well as to discuss the consequences for the steam cycle and the CO_2 transportation network connected to the capture system.

Method

The transient behavior of a Monoethanolamine (MEA) based post-combustion CO_2 capture system is characterized for two load-change scenarios in coal-fired power plants: reduced load and peak load conditions. The scenarios are typical for base load power plants which currently are subject to increasing requirements for flexible operation. The transient behavior of the capture system with respect to capture efficiency, reboiler heat duty, L/G ratio, solvent

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loading, steam flow to the capture system and outlet flow of CO_2 is investigated during the two load-change scenarios. In addition, process-control strategies are developed in order to maintain stable operation as well as to minimize the energy penalty of the process during dynamic operation.

In the present work, a time-resolved rate-based model of MEA post-combustion is used which is based on the model presented by Prölß, K. et al. and Åkesson, J. et al. [5-6]. The two connections between the power plant and the capture system, that is the flue gas train and the steam extraction, are treated as boundary conditions. In the simulations, the flue gas mass flow is assumed to change correspondingly to the load changes. The flue gas composition is assumed constant in all simulations together with the lean loading of the solvent. There is no restriction on the steam extraction from the power cycle. In the low-demand scenario, three control strategies are investigated. The controllers applied in these strategies are closed loop PID controllers. The first strategy (denoted “No control” in Figures 1-2) is the reference case where only a lean-solvent-loading controller is active. The second strategy (“Capture efficiency”) includes an additional controller that minimizes the variation of the capture efficiency (kg CO_2 captured per kg CO_2 in the flue gas) by varying the flow rate of the solvent-circulation system. The third strategy (“L/G”) is to control the L/G ratio in the absorber to a set value by varying the flow rate in the solvent-circulation system. Both the capture efficiency and L/G ratio are critical parameters in post-combustion capture systems. The capture efficiency is an important process parameter which is often used as a reference parameter for process control. The L/G ratio has been shown in the literature (e.g. [3-4]) to be of great importance to the performance of the absorber and the energy requirement for solvent regeneration in the desorber.

Results and Conclusions

Figures 1 and 2 show the influence on the capture efficiency and reboiler duty (MJ per kg CO_2 captured) when the power plant load is reduced from full load, down to 60% load at a rate of 5 percentage points per minute. This value is a realistic rate of load change in modern coal fired power plants [7]. At full load, the system operates with 90% capture efficiency and a heat duty of 3.5 MJ/kg CO_2 captured. Without any additional control strategy, the capture efficiency increases to around 98% when the load is decreased due to a higher L/G ratio. However, an increased L/G ratio causes the rich solvent loading to decrease which leads to a higher energy demand in the reboiler. As a result, the reboiler duty with respect to solvent regeneration increases from 3.5 to 4.9 MJ/kg CO_2 captured. The control of the capture efficiency and the L/G ratio results in similar process performance. The control of the L/G ratio generates a minor increase in capture efficiency while the reboiler duty is the same in both cases: it decreases slightly after the load reduction. The reason is that the rich solvent loading instead increases slightly after the load reduction, while the lean solvent loading remains constant. This results in an increased driving force for solvent regeneration in the desorber and, consequently, a slightly lower reboiler duty. From the part load simulations it is evident that in order to minimize the energy penalty of the capture process, during transition and at the new steady state, a control strategy is required. The results from the peak demand scenario are similar. The capture efficiency of the capture system is decreased in all control strategy cases as less energy is available for solvent regeneration. However, when a process controller is implemented the system shows a reduced response time, slightly higher capture efficiency, and lower reboiler duty compared to a case without control.

The results also show (Figures 3 and 4) that the capture system acts as a buffer with respect to the connected processes in most cases. It takes 10 to 20 minutes for the steam and the outlet flow of CO_2 to reach a new steady state values after the load reduction is completed. The CO_2 flow is reduced with a rate between 2 and 4.7 percentage points per minute. In the case without process control, the steam flow is reduced with around 1 percentage point per minute until it reaches steady state while in the cases with process controllers the steam flow is decreased with around 5.5 percentage points per minute. The response time of the system is generally lower in the cases where a control strategy is implemented. This implies that a more stable and flexible operation of the capture system can be achieved by using either one of the developed control strategies. On the other hand, this requires that the connected processes are able to handle these more drastic changes in operating conditions. For the steam cycle, this applies especially to the low pressure turbine from which the steam is extracted.

To conclude, the simulations of load variations scenarios show that the CO_2 capture cycle responds to load changes within a reasonable time; within a minute in all cases investigated. Furthermore, the implementation of control strategies results in better capture system performance with respect to capture efficiency and reboiler duty but also puts higher demands on the response of the connected systems. Future work should include a more detailed study of the interactions between all the different processes, that is, the power plant, the capture system and the CO_2 transportation system.

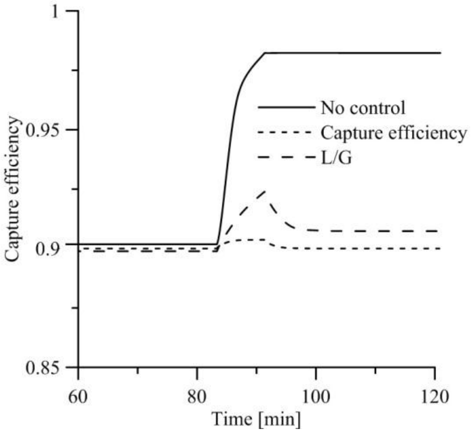

Figure 1: Effect of load reduction from 100% to 60% load on capture efficiency for the three cases investigated.

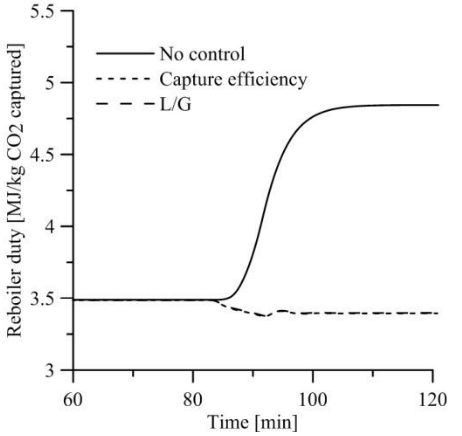

Figure 2: Effects of load reduction from 100% to 60% load on reboiler duty for the three cases investigated.

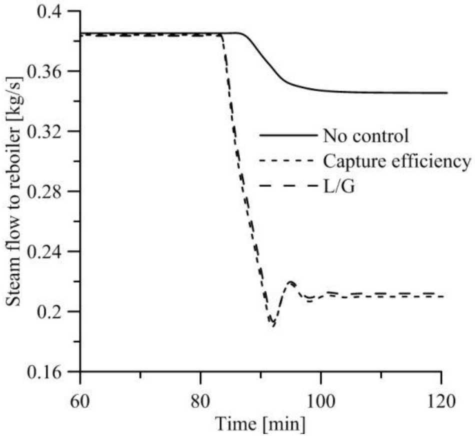

Figure 3: Effect of load reduction from 100% to 60% load on steam flow to reboiler for the three cases investigated.

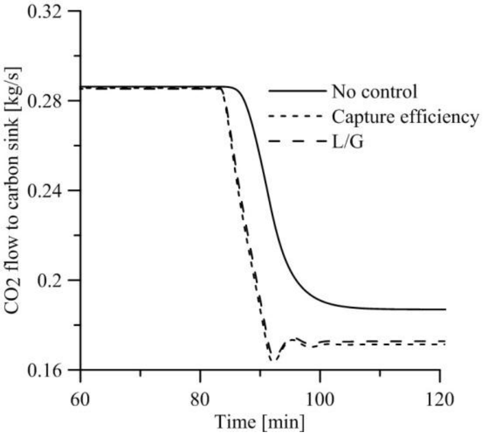

Figure 4: Effect of load reduction from 100% to 60% load on the outlet flow of CO_2.

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