Dynamic Simulation of a Conceptual 600MWe Oxy-fuel Combustion power plant

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1. Introduction

Oxy-fuel combustion is one of the energy utilization technologies for CO₂ capture which is ready for commercial demonstration. System steady-state simulation is an effective tool to help us understand the thermodynamic properties and adjust operation conditions of oxy-fuel combustion system. Moreover, dynamic simulation is essential for understanding the dynamic characteristics of the system, which will help to design/improve control system, to develop operation strategies and to construct safety system, etc. This paper presents the dynamic simulation of a 600MWe oxy-fuel combustion system which consists of cryogenic air separation unit (ASU), pulverized coal-fired boiler and flue gas processing unit (FGU). At the beginning, a steady-state model, using a mixture containing hydrocarbon, oxygen, nitrogen and sulfur to substitute the coal, is successfully transformed into Aspen Dynamics model after adding some equipment parameters and control strategies. Then, switching process from air-combustion to oxy-combustion is studied, and some planned disturbances in air in-leakage, load, oxygen concentration, oxygen ratio and recycle ratio are imposed to investigate the effects of these distributed factors on the characteristics of oxy-fuel combustion system. The simulation running on the common simulator Aspen Dynamics is very useful to gain an insight into the dynamic behaviors of the complete oxy-fuel combustion system.

2. Steady State and Dynamic Simulation

Coal is an unconventional component that can not be handled in Aspen Dynamics. Actually, the fundamental chemical difference among the hydrocarbon raw material of coals is the atomic ratio of hydrogen to carbon [1]. Therefore, we use a mixture which includes hydrocarbon, sulfur, nitrogen and oxygen currently found in Aspen component library to represent the coal. In such a way the barrier that the unconventional component (coal) can not be supported in Aspen Dynamics is solved. A detailed steady-state simulation of a 600MWe oxy-combustion system is carried out in Aspen Plus, the schematic of which is shown in Figure 1. The simulation results are consistent with those from literature[2]. The steady-state model is then exported into Aspen Dynamics for dynamic simulation.

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In order to conduct dynamic simulation, all equipments have to be sized and some specific controllers should be added. At the conceptual design level, there is a simplified method for gaining the approximate estimates of equipment parameters. With respect to gas cleaning unit, for example, the principle of “50 percentages, 5 minutes” [3] is applied to calculate its volumetric parameters. Control structure of the oxy-combustion system is essential for studying its dynamic behaviors (under disturbances) and operation strategy (air-to-oxy switch). With respect to different control requirements, there are different configurations being used. Considering the recycle ratio as the primary variable, for example, two flow controllers are added to keep the oxygen and coal unchanged.

Operation experience of switching between air-combustion and oxy-combustion mode is of crucial importance for large-scale demonstration of oxy-fuel combustion plant. The switching process is studied and shown in Figure 2. The results are consistent with those of the 30 MW<sub>a</sub> Schwarze Pumpe lignite pilot plant[4]. As with the results, the system is operated steadily under air-combustion mode for 3 hours before switch. Then, we adjust the sequence of injecting oxygen, recycling flue gas and cutting off air, keep the load and coal flow rate, and regulate the furnace pressure (micro-positive pressure or traditional negative pressure) to complete the switch process. When the oxygen flow is enough to support the combustion at the beginning of switch, the time of injecting oxygen can be postponed about 3 hours compared with those of recycling flue gas and cutting off air. The dynamic model switches automatically under a specific switch strategy after 17 hours. Under the oxy-combustion mode, some parameters (recycle ratio, oxygen concentration in primary and secondary RFG, etc) should be adjusted to keep a similar heat transfer profile with air-combustion and operate steadily.

To gain insight into the dynamic behaviors, some planned disturbances including O<sub>2</sub> concentration, load, recycle ratio, air in-leakage, and oxygen ratio in primary and secondary RFG (recycled flue gas) are imposed to the system using the TASK module in Aspen Dynamics. Simulation results show that changes in different parameters have different effects on the same variable. The disturbance in recycle ratio (changing from 0.691 to 0.703 within 15 hours) is taken as an example to illustrate the dynamic process. As shown in Figure 3, before the stable operation under dynamic model, there are slight fluctuations occurred in the system. After 3 hours, a disturbance in recycle ratio is added to the system, and the parameters of interest change with variation of recycle ratio.
increasing of the recycle ratio, the concentrations of CO₂, SO₂, and CO increase, while these of NOₓ, SO₃, N₂, and O₂ in primary and secondary RFG decrease. Then, some variables continue to change as recycle ratio is continued to change after momentary stable state. Therefore, some measures should be adopted to keep the recycle ratio stable after the disturbance, and it is also necessary to maintain O₂ concentrations in final flue gas, primary and secondary RFG at specified levels during the change of the recycle ratio.

![Figure 2](image)

(a) flue gas composition  
(b) flow rate

Figure 2 Switch process from air-combustion to oxy-combustion mode

![Figure 3](image)

(a)  
(b)

Figure 3 Effects of planned disturbances (here recycle ratio changing from 0.691 to 0.703)

3. Conclusion

Dynamic simulation of a 600MWe oxy-fuel combustion plant using the common simulation platform Aspen Dynamics is for the first time realized, which can be used for a wide range of investigations such as control system design and optimization, mode switching, operation optimization, safety analysis, etc. On the one hand, switching process from air to oxy-combustion is successfully realized, which will help to gain operation experience and optimize control strategy. On the other hand, some factors as disturbances are studied to gain insight into the dynamic characteristics of oxy-fuel combustion plant. It is found that the dynamic model runs well, the PC system can be switched smoothly from air to oxy-combustion, and the oxy-PC plant can bear normal variations. Further work will concentrate on improving and optimizing the model approaching to actual oxy-PC plant, and exploring more useful information for engineering.

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References