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Energy Management and Efficiency Improvement for Oxy-fuel Power Generation Systems with CO₂ Capture: An Exergy-based Approach

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1. Introduction

It is estimated that a large quantity of anthropogenic CO₂ emissions comes from fossil fuel power generation systems. Apart from the CO₂ emissions, these power plants also emit other pollutants such as nitrogen oxides (NOₓ), sulphur oxides (SOₓ), mercury (Hg) and other trace metals. There are different approaches for capturing CO₂ and controlling the emissions of other pollutants from power plants. However, all capture processes are associated with high energy penalty and hence overall efficiency loss. There are also different areas in a power plant where energy is lost in the form of heat that, if it is utilized, will help to improve the efficiency. However, to make tangible improvement in energy efficiency, extensive process modeling and analysis need to be done in order to validate and optimize the new design concepts before their implementation. The effort will be more elaborate if it involves novel approaches to integrate relevant sub-sections of a power plant to minimize heat losses and increase energy efficiency of the plant. This is the case for advanced oxy-fuel power plants with CO₂ capture that are expected to be deployed at large scale in the next few decades. Exergy analysis could be one of the approaches to identify the potential heat losses in different sections of these power plants and, accordingly, necessary measures could be developed for their energy management and efficiency improvement.

2. Oxy-fuel combustion

Various studies have indicated that oxy-fuel power generation with CO₂ capture is very competitive compare to other power generation processes with CO₂ capture [1, 2]. The oxy-fuel power generation systems are currently being experimented at pilot demonstration level and no commercial industrial unit is operational yet. Combustion in an oxy-fuel system takes place in pure oxygen environment and in the absence of nitrogen associated with using air.

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in conventional air-fired units. As a result, the flue gas from the oxy-fuel combustion process contains mainly CO₂ and water vapour, along with some minor impurities. Figure 1 represents an oxy-fuel power plant with CO₂ capture system. The high concentration of CO₂ in the exhaust stream makes it easier for CO₂ separation and capture by physical compression and cooling only. However, the additional sub-systems of an oxy-fuel power plant, such as the CO₂ capture and compression unit, provide new opportunities to improve the efficiency of the plant if judicious integration of these sub-systems are done to minimize heat losses and develop a proper energy management protocol for the power plant. A comprehensive exergy analysis on different sections or sub-systems of the oxy-fuel power plant identifies the heat losses from different units operation and contribute to devise new approaches for integrating these units to improve the efficiency of the overall plant.

![Figure 1: Oxyfuel power plant with CO₂ capture and air separation unit.](image)

3. Exergy Analysis

Exergy can be defined as a measure of departure of the state of the system from that of the environment. During an exergy analysis of a power plant, the thermodynamic imperfections can be quantified as exergy destruction [3, 4]. Based on the exergy destruction values, corrective measures and approaches could be suggested to improve the efficiency of the overall system. Exergy balance and analysis is performed on the major components such as balance of plant (BOP) section and the CO₂ capture and compression section of the oxy-fuel power plant. This analysis identifies the location and quantity of the exergy destruction rate for the individual components and allows for corrective measures to be devised in order to minimize the energy losses. A detailed analysis for the BOP and the CO₂ capture unit is presented in this paper, which includes all exergy destruction points together with suggestions for possible measures to improve the overall efficiency of the plant through proper energy management.

4. Conclusions

This paper presents an overall model of an oxy-fuel power plant with air separation and CO₂ capture and compression modules. The model is developed in HYSYS process simulation software. The overall model consists of 4 major modules, namely, oxy-fuel combustion loop, BOP, air separation unit (ASU), and CO₂ capture and compression unit. Exergy analysis for BOP and CO₂ capture and compression unit is presented in this paper. The result of the complete exergy analysis for the overall plant will be presented elsewhere. The proposed exergy analysis and the process model will be an effective tool to study options for combustion, emission control, and CO₂ capture processes for energy efficiency improvement of the oxy-fuel power generation plants.
5. References


