Advanced Exergetic Analysis of a Coal-Fired Cryogenic Oxyfuel Power Plant with 700°C Technology

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Cryogenic air separation represents the only available mature state-of-the-art technology to supply the required high tonnages of oxygen for coal-fired oxyfuel power stations. Although this type of CCS power plant may be considered in a semi-commercial stage, efficiency improvements in the basic power plant concept and the realization of 700°C power technology are crucial for its future commercial deployment. In this study three coal-fired power plant designs have been analyzed: the state-of-the-art supercritical 600°C reference plant Nordrhein-Westfalen, the advanced ultra-supercritical 700°C power plant, and the cryogenic oxyfuel concept implemented in the advanced plant with 700°C technology. In the first part of this work, each power plant concept is modelled using Aspen Plus® process simulation software. Process description and diagrams, main specifications and assumptions, thermodynamic data of boiler and flue gas path streams, as well as performance results (energy analysis) are presented for the modelled plants.

In the second part, the thermodynamic performance of each plant concept is assessed by:

- Conventional exergetic analysis, which determines location, magnitude and sources of efficiency losses. The main exergetic variables: exergy of product and fuel, exergy destruction, exergetic efficiency, and exergy destruction ratio are calculated for each process component and for the whole power plant.

- Advanced exergetic analysis, which complements the conventional exergetic analysis, is performed by splitting the exergy destroyed inside each component into endogenous and exogenous parts and avoidable and unavoidable parts. The combination of these splitting approaches reveals a detailed structure of thermodynamic inefficiencies. This valuable information cannot be obtained by any other method and allows to identify thermodynamic interdependencies among plant components as well as the real potential for efficiency improvements. The endogenous/exogenous and avoidable/unavoidable parts of exergy destruction are calculated at the component and full process level.

The endogenous and exogenous exergy destruction portions are calculated by the Reversible Equivalent Black Box (REBB) method, a straightforward methodology recently developed by Castillo and Tsatsaronis at the Technische Universität Berlin. This method is suitable for complex power stations with a large number of process components.

The structure of the exergy destruction rate for each plant component (unavoidable, avoidable-endogenous and avoidable-exogenous) is presented and compared between the modelled plants. Special attention has been paid to the avoidable-endogenous part because it can be reduced by betterments in the efficiency of the component. Lastly, an improvement priority ranking for relevant components, as well as suggested changes in process layouts are presented for the studied power stations.