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Editorial

Operation Optimization of Circulating Fluidized Bed Boilers Integration of Variable Renewables

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In response to the effects of climate change, China pledged to raise the share of non-fossil fuels in the primary energy consumption to around 25% and bring the total installed capacity of wind and solar power to over 1.2 billion kW by 2030. The rapid increase of the proportion of renewable sources in overall power generation presents a serious challenge to the efficient integration of variable renewables. To ensure the safe and stable operation of the power system, coal-fired power plants have become an important tool for the peak regulation of the power grid, and thus higher requirements for the operation of plants have been proposed. Moreover, as a vital part of the existing coal power fleet in China, circulating fluidized bed (CFB) units have an inherent disadvantage in the operational flexibility due to features such as large inertia and strong nonlinearly. Under the circumstances, scholars apply a variety of methods, such as field testing and modelling, to determine the appropriate strategies for better operational performance. In this Special Issue entitled "Operation Optimization of Circulating Fluidized Bed Boilers Integration of Variable Renewables", we provide a comprehensive view of the efforts to improve the operation of CFB boilers from different aspects to raise research interest in this topic.

This Special Issue on "Operation Optimization of Circulating Fluidized Bed Boilers Integration of Variable Renewables" covers ten research papers focusing on enhancing the operational performance of CFB boilers under different conditions ranging from steady-state operation [1–6], to load variation process [7–9], and, finally, co-combustion of biomass with coal [10].

A brief summary of the main content of each selected paper belonging to this Special Issue is shown below:

In the work by Liu et al. [1], with the help of the self-developed coal comminution energy consumption calculation method and a modified 1-D CFB combustion model, a fluidization-state-specification-based CFB combustion technology was developed that was capable of reducing the auxiliary power consumption and improving the reliability of large-scale CFB boilers. The authors also pointed out the combustion efficiency of CFB boilers took on a non-monotonous trend with the variation of bed pressure drop and feeding coal size and that there existed an optimal bed pressure drop under which the lowest gross power supply cost can be achieved.

On the other hand, a comprehensive step-wise methodology incorporating the actual operational data and AI algorithms was adopted in Ashraf et al. [2] to pursue the minimum fuel cost of power generation and enhance the thermal efficiency of coal-fired boilers. From the test results of two AI-based techniques, namely the artificial neural network (ANN) and least square support vector machine (LSSVM), the ANN model was determined to be significantly more effective. A detailed investigation at different loads showed that a saving in the heat input value up to 8.60% can be realized. Although their study did not take the CFB boiler as a research object, it can provide a direct reference for the implementation of AI-based techniques in the optimization of the performance of CFB boilers.

Moreover, efforts have also been made to achieve a high combustion uniformity in the CFB furnace and reduce the carbon content in the fly ash. In Zheng et al. [3], an Eulerian-Eulerian based numeric model was applied to investigate the influence of secondary air (SA) uniformity on the jet penetration and gas-solid diffusion in a 600 MW supercritical CFB boiler. Aided by a self-established prediction model on the penetration depth of the thermal SA jet, the authors found out that a more even SA distribution can bring about a smaller deviation of the SA penetration depth and solid concentration, especially in the region below 10 m from the air distributor. In addition, an increase in the penetration depth and lateral diffusion distance of the SA jet was observed at higher loads. However, the highest uniformity of SA diffusion was achieved at 80% BMCR load.

Nie et al. [4] took this one step further by attempting to optimize the design of the SA ducts in a 660 MW ultra-supercritical CFB boiler based on the field test data derived from a boiler with similar furnace structure and corresponding simulation results. The SA distribution appeared to be basically uniform in the furnace. Even so, the oxygen concentration decreased gradually along the width direction and reached its minimum in the middle of the furnace; the deviation between the internal and lower SA was about 17%. Therefore, measures such as adjusting the layout of SA branch pipes, adopting separate air inlet pipes, and optimizing the pipe diameter were adopted, which successfully reduced the velocity deviation between each nozzle by less than 3%.

In addition, pollution control has always been concerned as a vital part of the operation of CFB boilers. To improve the economy of the selective non-catalytic reduction (SNCR) process, Yan et al. [5] carried out a detailed investigation on the two-dimensional distribution of the flue gas composition at the SNCR inlets in a typical 300 MW CFB boiler. Combined with the auxiliary test conducted in the dilute phase zone, regions with extremely high NOx concentration were observed for the first time, which was close to the inclined edge of the SNCR inlets. Based on the experimental findings, a preliminary optimization of urea injections was implemented, resulting in a 15.7% saving in the urea solution consumption, which pointed out the direction of future improvement. Aside from ensuring ultra-low emission of NOx, Miao et al. [6] paid attention to the catalytic removal technologies of N_2O. After a comprehensive review and analysis of the existing catalytic removers, such as the noble metal, molecular sieve, and metal oxide, the authors concluded that metal oxide catalytic technology, especially the oxygen carrier-aided combustion, was likely the most suitable N_2O removal technology for CFB boilers (owing to its technical and economic feasibility).

With their focus shifting to the operational flexibility of CFB boilers, Shen et al. [7] analyzed the dynamic characteristics of the residual char in the circulation loop during the load variation process to obtain insights into the large inertia and hysteresis in the boiler system. These authors gave an accurate estimation of the residual char according to the coal feeding rate, ash discharging rate and furnace calorific value derived from the simulation results of a computational-particles-fluid-dynamics-based model. It turned out that the residual char was in a dynamic balance under stable operation conditions, accounting for about 4% of the total bed inventory. Besides, the residual char stock during the load increasing process was higher than that during the start-up or load decreasing process, and it was determined that a reasonable residual char stock can ensure the rapid transition between different load conditions.

Furthermore, in Yang et al. [8], a more comprehensive analysis on the dynamic characteristics of industrial-scale CFB boilers was presented by establishing a full-scale dynamic model of a 660 MW ultra-supercritical CFB boiler. A “core-annulus” sub-model was adopted to simulate the gas-solid flow behavior in the boiler furnace, and a “six-equation” model was applied for the prediction of the hydrodynamics in the water-steam system. After calibrating and verifying the model at the 100% BMCR condition, the dynamic response of the boiler at a 5% decrease of air flow rate, coal feeding rate, or feedwater flow rate was illustrated. However, the model has not yet been validated with transient-state field test data.

Finally, to harmonize the CFB boiler's slow response with the steam turbine's fast dynamics and meet the load-tracking requirement of the power grid, Zhang et al. [9] proposed the so-called burning carbon based decentralized active disturbance rejection control strategy for the operation of supercritical CFB boilers. From the analysis of the dynamic response of supercritical CFB boilers on the basis of step response, it was determined that the burning carbon in the furnace responded faster than the steam pressure at the throttle when varying the coal feeding rate. In light of this, the authors took advantage of the burning carbon information to compensate the impact of the large inertia of CFB boilers. A genetic algorithm was utilized to optimize the parameters of the controllers for the multivariable CFB unit. Through simulation results, it was indicated that the application of the proposed strategy can reduce the regulating time and system overshoot at the same time.

Additionally, attention has also been paid to the fuel flexibility of CFB boilers. In Peters et al. [10], refuse-derived fuel and straw pellets were co-fired with low-rank lignite at different loads (full and partial) in a 1 MW pilot plant to examine the operational performance of co-combustion. Despite its perceivable influence on several key parameters, the feasibility of direct co-combustion in CFB boilers was determined with the field test data from three fuels of distinct physical and chemical properties, offering a possible low-cost solution to cut CO_2 emissions and mitigate climate change.

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