Abstract

Circulating Fluidized Bed (CFB) boilers, which burn fossil and renewable fuels, have so far not required post-combustion methods for the removal of gaseous pollutants (NO_X and SO_X). However, since August 2021, new and existing CFB boilers must be adapted to the hydrogen chloride emission levels in accordance with BAT conclusions. According to current data, many of the operating units have been granted exemptions from the applicable emission limits, which makes the issue of modernization of existing facilities with flue gas cleaning systems still relevant.

Low allowable limits for pollutants from energy facilities require the installation of dust removal equipment in boiler units, which not only ensures compliance with low emission limits for particulate matter, such as fly ash or heavy metals, but also increases the efficiency of systems for removing gaseous emissions. The optimal solution to meet these requirements is the use of the Dry Sorbent Injection (DSI) method in combination with a fabric filter.

As part of the "Doktorat Wdrożeniowy" project, researches were conducted on four CFB boiler units equipped with flue gas cleaning systems. Three of these units were equipped with electrostatic precipitators (units A, B, and C), while two were equipped with fabric filters (units A and D). In each of these units, a dry sorbent injection (DSI) system using hydrated lime was applied.

Continuous emission measurements behind the boiler units, as well as laboratory analyses of fuel samples and fly ash composition, allowed for the development of knowledge regarding the processes occurring in fluidized bed boilers. It was observed that there is practically no correlation between the fluorine content in the fuel and the hydrogen fluoride emissions at the CFB boiler outlet. Regardless of the fluorine content in the fuel, HF emissions from CFB boilers remained below the required limits. However, the hydrogen chloride concentrations behind boilers burning fuel blends with low calcium content were very close to the values calculated from the stoichiometry of the fuels. Any reduction in HCl, caused by the reaction with calcium oxide derived from $CaCO_3$ introduced into the combustion chamber, which was not fully utilized during the desulfurization process, may occur in the second pass of the boiler due to appropriate temperature values. However, the efficiency of this reaction mainly depends on the amount of material collected on the surface of the heat exchangers in the second pass. It was noted that immediately after the cleaning process, the measured HCl emissions behind the boilers were equal to the values obtained from calculations based on the fuel composition.

In the next section of the thesis, the focus was on the operating parameters of the Flue Gas Cleaning Installation. Based on the analysis of the results, a correlation between the removal efficiency of SO_2 and HCl was identified, which is independent of other parameters such as temperature or the concentration of both acidic gases at the inlet. It should be emphasized that this correlation, without the influence of other factors, applies only when the reaction occurs in the reactor as a flue gas channel, and has not been described by other researchers so far. The main advantage of the proposed correlation is the ability to predict the reduction of one pollutant based on the reduction of the other process gas. In the case of bag filters, the relationship between the removal efficiency of sulfur dioxide and hydrogen chloride is additionally influenced by the composition of the dust layer and the cleaning sequence of the filter bags. Furthermore, it was confirmed that for the reaction occurring within the solid bed (e.g., on the filter fabric), a pseudo-equilibrium exists between the post-reaction products, and this correlation is independent of other factors.

Based on the collected data, correlations between the values of the stoichiometric excess ratio and the percentage reduction of pollutants were determined. The larger the dose of sorbent introduced into the system (i.e., the reaction occurred at a higher stoichiometric excess ratio),

the higher the percentage reductions of pollutants were achieved. However, when comparing characteristics from different test periods, it was observed that an important parameter was also the concentration of the reduced pollutant at the inlet to the Flue Gas Cleaning Installation. The lower the concentration of acidic gas at the Flue Gas Cleaning Installation inlet, the more difficult it was to achieve the desired percentage reduction, and the stoichiometric excess ratio was noticeably higher than in cases where the inlet pollutant concentration was high.

The impact of the type of sorbent used on the efficiency of acidic pollutant removal was also verified. Comparing the effects obtained when using two types of hydrated lime (with standard and increased specific surface area), no impact on the efficiency of HCl reduction from flue gases was observed. However, it was found that the sorbent with a higher specific surface area allowed for higher reductions in SO_2 emissions.

In the further analysis, attention was focused on the operating parameters of the bag filter, particularly the pressure drop caused by the dust layer. Based on this, the relationships between the porosity and permeability coefficient of the layer and the mass concentration of solid material on the surface of the filter bags were determined.

Considering the laboratory data on the tested filter bags and the chemical composition of the material collected from under the bag filter, experimental values of the cleaning process efficiency were determined depending on the mass concentration of the material settled on the bags. Additionally, the influence of the geometry of the dust removal device and the depth of the sorbent lance insertion into the flue gas channel on the even load of solid material on the bag filter was determined.

Next, data related to the dry sorbent injection system were analyzed to determine the activation energy values for the reaction of the sorbent with hydrogen chloride. For the reaction occurring on the surface of the filter bags, the effect of the thickness and porosity of the dust layer on the kinetics of the reaction was also verified. It was determined which process (mass transfer, diffusion through post-reaction products, or chemical reaction) is crucial for the process. It was found that the dominant process depends on the concentration of sorbent in the system and the degree of gas pollutant reduction.

Finally, all the collected data were compiled, and a program in Python was developed, which allows for calculating the composition of flue gases behind a CFB boiler based on the fuel composition, determining the concentrations of pollutants at the Flue Gas Cleaning Installation outlet, or the required stream of sorbent injected into the system to achieve the desired emission values at the Flue Gas Cleaning Installation outlet, as well as the operating parameters of the fabric filter (pressure drop) while considering the impact of the DSI method.