Dynamics of single coal particle combustion process in atmosphere enriched with oxygen

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Summary

Reduction of carbon dioxide emission is a major goal for new technologies, oriented at clean electricity production from fossil fuels. One of promising proposals, that would reduce the environmental impact of coal utilization for energy purposes, is to carry out the combustion process in an atmosphere of oxygen and recycled flue gas combined with capture of formed CO_2.

This dissertation analyzes the differences in coal combustion process resulting from air's nitrogen replacement by recirculated flue gases, that is a mixture of water vapor and carbon dioxide or carbon dioxide only in the case of dried flue gas. The main objective of the study was to compare and describe the impact of composition of the oxidizing mixture on the sub-processes that can be distinguished during coal combustion. Analysis of the issue was carried out experimentally and by theoretical analysis, as well as numerical simulations of the combustion process. The object of the investigations presented in the study was a single fuel particle of a size about 1-2 mm. Laboratory experiments were boiled down to combustion of manually prepared fuel particles in a controlled working conditions of the reactor, a given temperature and composition of the gas atmosphere. During the observed sequential combustion of coal, the temperature of the particle and the combustion time were measured. Based on the temperature profiles, individual stages of particle burning were determined, which allowed for a comparison of the influence of the gas atmosphere on the distinguished sub-processes of coal combustion. In addition, experiments were recorded by a high-speed camera, showing changes in the flame size, as a fynction of the composition of the gaseous atmosphere in which the experiments were conducted.

In the laboratory studies four coals were used, that have different properties and are used for energy purposes in power industry. For the two of the analyzed fuels an initial pyrolysis in nitrogen were conducted, then the resulting chars were also experimentally combusted. Thus, the paper presents a complete range of results, differentiated not only due to the oxidizing atmosphere composition, but also to the fuel type. Complementary to the experiments conducted in a dedicated laboratory reactor, thermogravimetric studies were also performed, again for single

particles of fuels considered in the work. TGA experiments analyzed the processes of coal devolatilization in CO_2 and N_2 and the combustion process of therefore resulting chars. On this basis, kinetics of the devolatilization and the combustion processes of the studied fuels has been estimated. The results complemented the analyzes of ignition delay and the stage of char residue combustion.

Experimental studies of single coal and char particle combustion shown that the influence of the atmosphere on the combustion process is different for various fuels. In the greatest extent the combustion process in the presence of CO_2 and H_2O is changed for high-grade metamorphosed coals and for lignite coals. In the first case - in an atmosphere of O_2/CO_2 a reduced combustion temperature caused a deceleration of the surface reactions rate, resulting in an extended particle combustion time. In the latter case - despite the lower temperature, a significant reduction in char residue combustion time was observed. This was due to the high reactivity of this type of fuel in CO_2 atmosphere and an activation of the gasification reaction, resulting in an accelerated char consumption. Addition of H_2O to the air decreased the combustion temperature similar as in the CO_2 case. However, in the case of oxy-fuel atmosphere, the addition of water vapor resulted in faster char ignition and increase of particle combustion temperature. Significant influence on each stage of the fuel combustion is also due to the O_2 concentration. An increase of oxygen concentration, both in air and oxy-fuel atmospheres was responsible for an increase in the combustion temperature, thereby also for a shortening of particle combustion time. Based on the experimental results it was concluded that the increasing of the concentration of O_2 and the presence of H_2O in the oxy-fuel atmosphere, may allow to outweigh the differences observed with respect to the process carried out in air.

The experiments shown that the char temperature depended most strongly on the composition of the surrounding atmosphere. Consequently, char temperature was chosen for further analysis carried out by numerical simulations of the combustion process. The calculation results showed that the change of the atmosphere from air to oxy-fuel mixture of O_2/CO_2 and H_2O contributes to the combustion temperature reduction, primarily due to the char gasification reactions that take place in the presence of CO_2 and H_2O. Oxygen diffusion, described by the binary diffusion coefficient and the concentration of O_2 in the gas, has been identified as a second most important factor influencing the temperature of coal particle combustion. Parameters reflecting the physicochemical properties of the atmosphere did not contribute to a noticeable changes of the particle combustion temperature for calculations taikng into account the char gasification reactions and carefully modelled diffusion of oxygen. This means that in the analyzed combustion experiments a secondary importance can be attributed

to the gas physicochemical characteristics when differences in particle combustion temperature are investigated.

Experimental data analysis combined with numerical simulations of the combustion process, that is proposed in this work, can be extended for the case of smaller coal particles and industrial combustion conditions. Then, in a similar way as presented in the work, the analysis would help to predict factors related to a composition of an oxidizing atmosphere and responsible for changes in the combustion process resulting from oxy-combustion.