CFD modelling of a large-scale pulverized coal MILD-OXY combustion boiler

A. Klimanek[1], S. Sładek[1], W. Adamczyk[1], A. Szlęk[1], Nils Erland L. Haugen[2], Øyving Langørgen[2]

1. Istitute of Thermal Technology, Silesian University of Technology, Gliwice, Poland
2. SINTEF Energi A.S., Sem Saelands vei 11, Trondheim 7034, Norway

Introduction

In this study a previously developed CFD model of a pulverized coal fired concept boiler [1] was improved to study the effects of selected sub-models on various operational parameters and predicted flow fields in the combustion chamber. The boiler is operated under MILD and oxy-combustion conditions, which is a combination of two technologies whose coupling brings certain benefits. The schematic diagram of the concept boiler operated under MILD-OXY combustion is presented in Fig. 1. MILD combustion is characterized by increased combustion

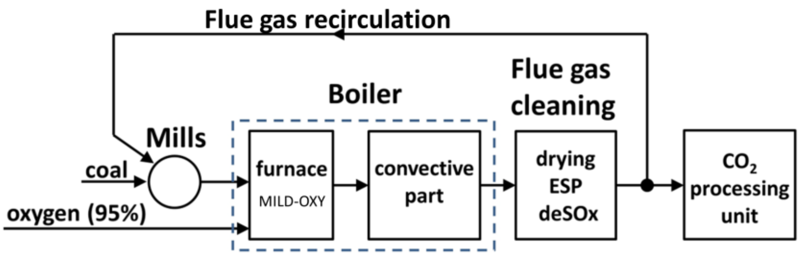

Fig. 1. Schematic diagram of the concept MILD-OXY combustion boiler

efficiency and lower NO_X emissions, while oxy-combustion is considered as one of the best CO_2 separation techniques. It is therefore expected that coupling of these two combustion technologies will increase of the efficiency of the power plant, when compared to standard oxy-combustion. The reason for that is better mixing, longer residence time of the coal particles and strong internal recirculation of the flue gases, which reduce the oxygen excess ratio. The same positive effect is expected due to reduced production of oxygen in the air separation unit. Furthermore, the internal recirculation of flue gases in the chamber reduces the amount of flue gases that needs to be recirculated in the external loop in standard oxy-combustion, which leads to lower pumping costs in this loop. A better fuel flexibility is also expected when this technique is applied. MILD-OXY combustion technology allows to obtain high CO_2 concentration at the outlet of a combustion chamber. Due to reduction of external flue gas recirculation and decreasing of air excess ratio, thermal efficiency of the boiler was increased. By the virtue of the technology also NO emission was reduced [1]. Separated injections of fuel and oxidizer as well as the geometry of the combustion chamber were designed to obtain strong internal recirculation of the flue gas. Fuel and oxidizer inlets are separated by the distance which does not allow for fast mixing of both streams. All injections as well as outlets of flue gas are located on the top wall of combustion chamber. These assumptions allowed to achieve MILD mode of combustion in combination with OXY technology. Previous study [1] showed that such organization of combustion process allows to reduce the external flue gas recirculation in comparison with standard OXY combustion and improve the efficiency of the power plant by 3%.

corresponding author: *Adam Klimanek (adam.klimanek@polsl.pl)*

The CFD model

Geometry of the furnace of the boiler is shown in Fig. 2. The furnace consists of 8 identical segments separated by heat absorption screens, allowing for firing each segment independently. Each of the segments contains 2 fuel inlets, 2 oxidizer inlets and 1 outlet. The presented numerical model considers one single segment of the boiler.

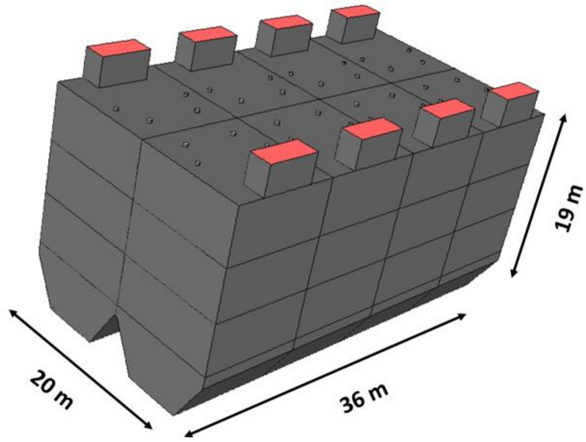

Fig. 2. Geometry of analysed concept of boiler [1]

The CFD model described in detail in our previous study [1], was developed with several assumptions, whose influence on the final results was not examined. In this study the model was improved by applying other sub-models, whose influence on final results was verified. In particular, instead of the Eddy Dissipation Model (EDM), which is valid for high Damköhler numbers, the Eddy Dissipation Concept (EDC) model, with a global reaction mechanism was used. The global mechanism was the Lindstedt-Jones mechanism adjusted for MILD conditions by Wang et al. [2]. Furthermore a more detailed approach to devolatilization modelling was used. The standard constant rate devolatilization model of ANSYS Fluent was calibrated using the Chemical Percolation Devolatilization model, which also allows to predict the volatiles yield and composition. Therefore the reactions of volatiles breakup and oxidation of produced tar were added to the homogeneous reaction mechanism. Finally the effect of turbulence on the mass and heat transfer during char burnout was taken into account by means of the model proposed by Haugen et al. [3].

Results

The obtained results confirmed that there is a relatively large influence of the selected modelling approach on the obtained maximum T_{max} and outlet T_{out} flue gas temperatures, however only a small influence on average heat flux to the combustion chamber walls, carbon conversion CC and thermal efficiency η has been observed (see Table 1). The predicted relatively low CO and NO_x concentrations by means of the new approach (EDC) showed that the boiler can be efficiently and environmentally friendly operated at the proposed conditions. These emission factors were not calculated for the EDM model. As can be observed in Table 1 a considerable reduction of carbon conversion for the small excess air ratio case ($\lambda = 1.05$) with the new approach was obtained, which affected also the efficiency η. It should be stressed that the efficiency is not the overall efficiency of the boiler but the efficiency of the MILD-OXY furnace, which is operated without the convective part of the boiler. Work is going on validation of the proposed approach. Since the analyzed boiler does not exist, experimental data are not available, however a small scale furnace operated under MILD conditions will be used for this purpose.

	λ	T_{out} K	T_{max} K	q kW/m^2	η %	CC %	O_2 % vol.	NO_x mg/MJ	CO mg/MJ
EDM	1.05	1407	1788	111.2	73.7	96.5	3.16	-	
EDC	1.05	1362	1838	117.1	73.3	90.6	3.21	19.6	2.51
EDM	1.15	1320	1854	116.1	77.0	97.9	6.75	-	
EDC	1.15	1343	1858	120.8	77.2	97.6	8.0	22.0	1.19

Table 1. Comparison of selected results obtained from the CFD simulation by means of the EDM [1] and EDC models

Conclusions

The obtained results confirmed that there is a relatively large influence of the selected modelling approach on some of the analyzed operating parameters. The new approach applied in this study should improves the treatment of the turbulence-chemistry interaction, the homogenous reactions mechanism and the devolatilization process. The proposed approach will be validated against experimental results obtained from small scale facility operated under MILD conditions.

References

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