Brandenburg University of Technology Cottbus

CHAIR OF POWER PLANT TECHNOLOGY

Challenges of oxyfuel combustion modeling for carbon capture

Tanin Kangwanpongpan*, Dr.-Ing Matthias Klatt, Prof. Dr.-Ing Hans Joachim Krautz

Chair of Power Plant Technology, Brandenburg University of Technology Cottbus (BTU Cottbus), Germany

1. Introduction

From the policies scenario from Internal Energy Agency in 2010, global energy demand for coal climbs from 26% in 2006 to 29% in 2030 and most of demands for coal comes from the power-generation sector [1]. According to the new Copenhagen protocol [2], Global CO_2 emission is rising from power generation due to an increasing world demand of electricity. For Energy-related CO_2 emission in 2009, 43% of CO_2 emissions from fuel combustion were produced from coal [3]. Therefore, CO_2 capture from coal is the key factor to reduce greenhouse gas emission.

Oxyfuel combustion [4] is one of the promising technologies for capturing CO_2 from power plants and subsequent CO_2 transportation and storage in a depleted oil or gas field or saline-aquifer. The concept of Oxyfuel combustion is to remove N_2 from the combustion process and burn the fuel with a mixture composed of O_2 and CO_2 together with recycled flue gas back into combustion chamber in order to produce a flue gas consisting mainly of CO_2, easily purified, compressed and transported to storage sites. At present, Oxyfuel plants are still in the phase of pilot-scaled projects [5] and combustion in Oxyfuel conditions must be further investigated for a scale-up plant.

2. Mathematical modeling (CFD model)

Computational fluid dynamics have been an efficient tool for decades in Oxyfuel combustion researches [6] to provide predictions of temperature, heat transfer, and product species in furnace. However, an insight into mathematical models for Oxyfuel combustion is restricted due to many unknown parameters such as devolatilization, volatile reaction mechanisms, turbulent gaseous combustion, char reactions, radiation properties of gases and heat transfer. Heat transfer drastically changes due to an increasing proportion of H_2O and CO_2 in these Oxyfuel conditions because both gases have higher thermal heat capacity than N_2 in air-firing and are a good emitter and absorber of radiation [4].

Volatile reaction mechanisms (Global 3-steps model)

$$C_mH_nO_xN_yS_z + (m/2 + z - x/2)O_2 \rightarrow mCO + (n/2)H_2 + (y/2)N_2 + zSO_2$$

$$CO + 1/2O_2 \rightarrow CO_2$$

$$CO_2 \rightarrow CO + 1/2O_2$$

$$H_2 + 1/2O_2 \rightarrow H_2O$$

Char reaction (Baum & Street model)

$$C + 1/2O_2 \rightarrow CO$$

$$C + 1/2CO_2 \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

Gas radiation (WSGG model)

$$\varepsilon = \sum_{i=1}^{N} w_i \left[1 - \exp(-\kappa_i PL)\right]$$

$$w_i = \sum_{j=1}^{J} c_{i,j} (T/T_{ref})^{j-1}$$

3. Laboratory-scale oxyfuel simulation (100 kW_{th})

The numerical models of lignite combustion under oxy-fuel conditions are first investigated in a 100 kW_{th} laboratory scaled oxyfuel furnace applying correlations for weighted sum of gray gases (WSGG) model for the predictions of radiation properties of oxy-fuel gas mixture [7]. The mentioned mathematical models are investigated using numerical CFD software (ANSYS FLUENT 12.0) to provide predictions of aerodynamics, thermo-chemical and heat transfer quantities.

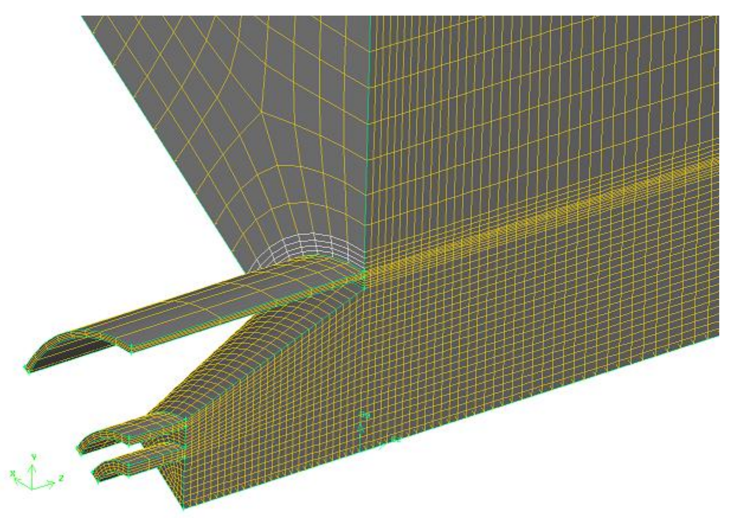

Figure 1. 100,000 computational cells for a 100 kW_{th} oxy-fuel furnace (1/6 model).

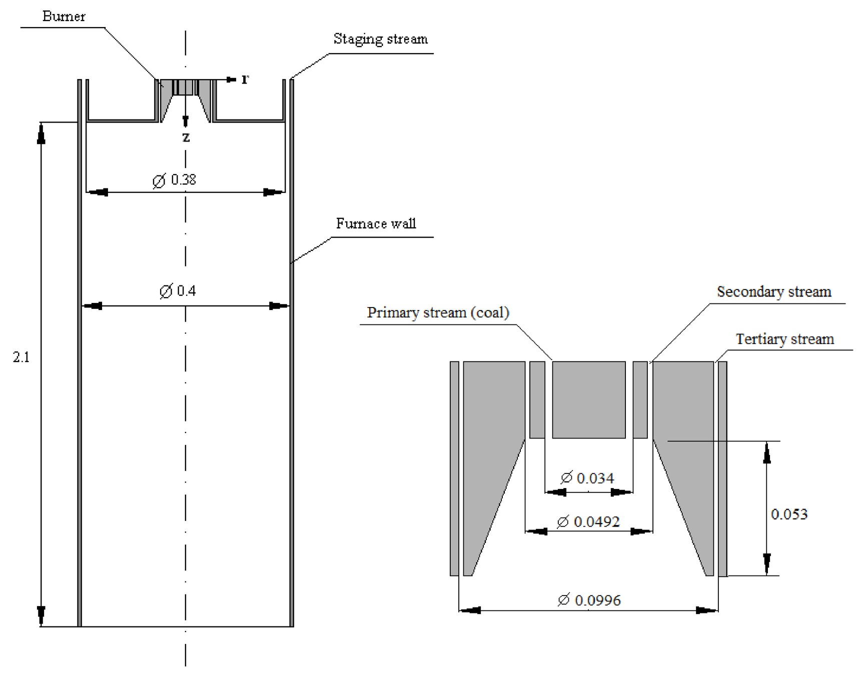

Figure 2. Oxyfuel furnace (Drawing).

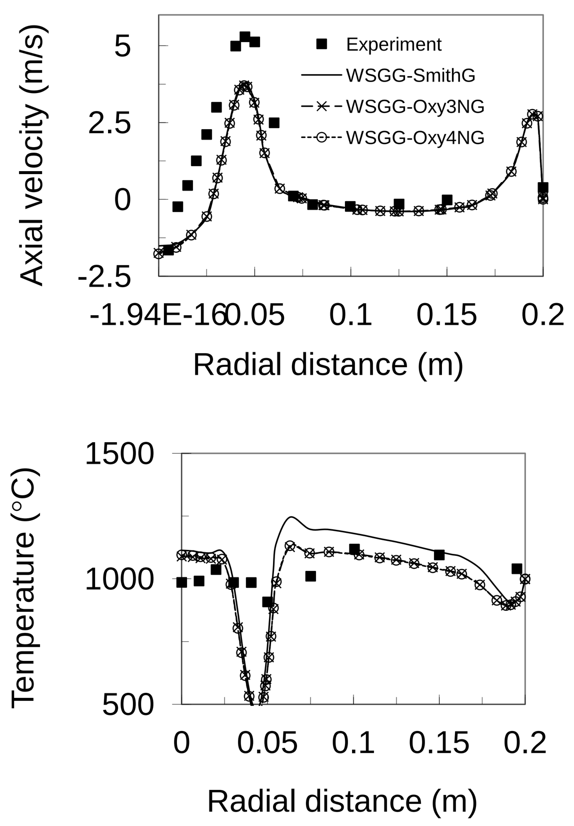

Figure 3. Axial velocity and temperature at 0.05 m distant from burner.

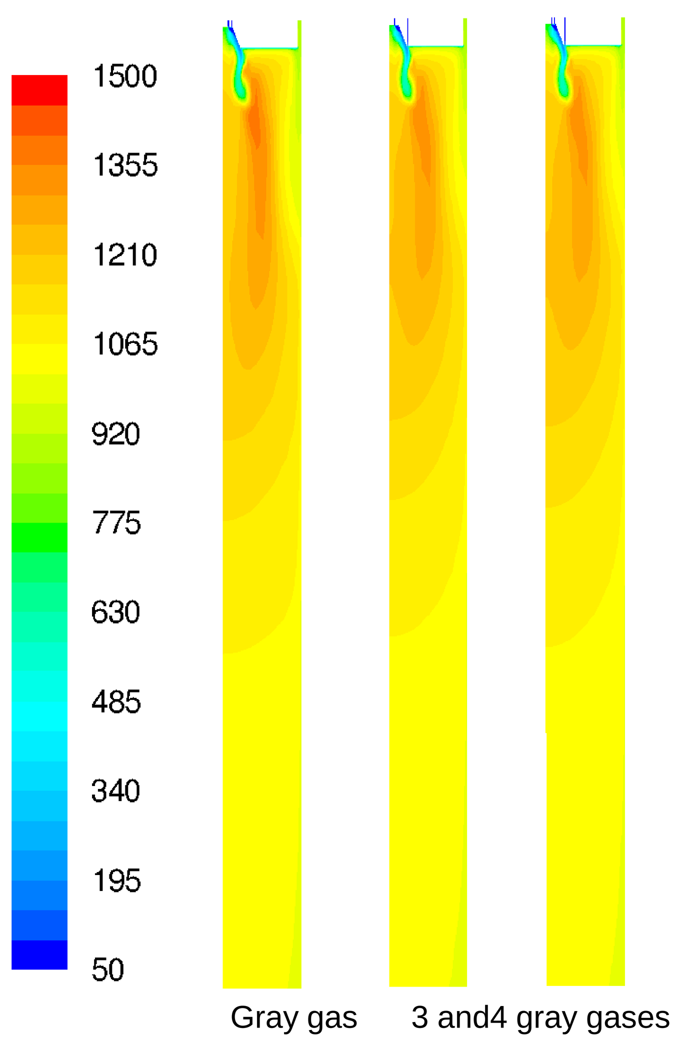

Figure 4. Temperature contour (°C).

4. Pilot-scale oxyfuel simulation (0.4 MW_{th})

The developed numerical models from 100 kW_{th} laboratory-scale oxyfuel furnace are further used for the predictions of temperature, hemi-spherical incident intensity and species concentrations (O_2, CO_2, H_2O) for a 0.4 MW_{th} oxy-fuel furnace at BTU Cottbus.

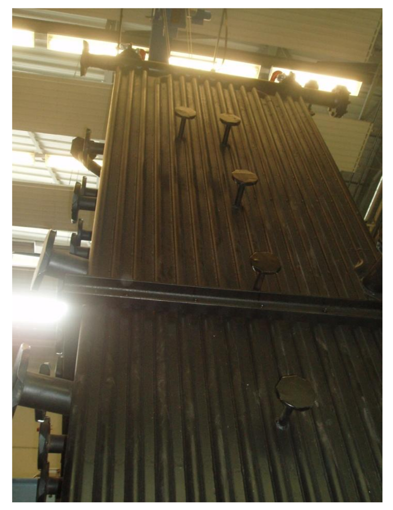

Figure 5. Oxyfuel boiler

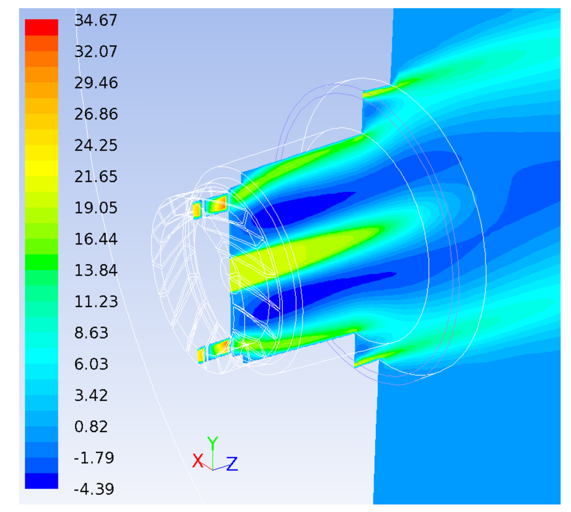

Figure 9. Velocity (m/s).

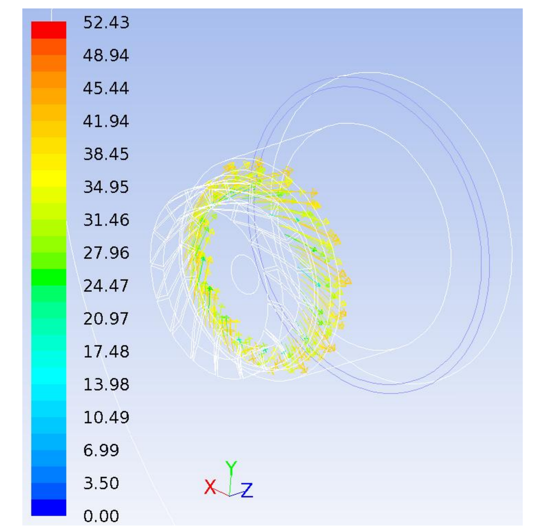

Figure 10. Swirling velocity vector (m/s).

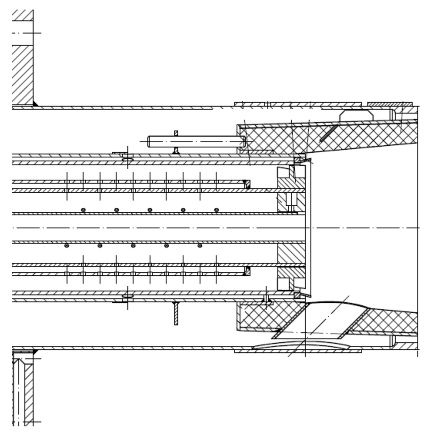

Figure 6. Burner (Drawing).

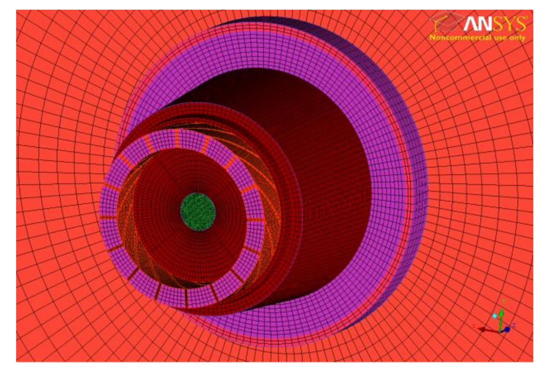

Figure 11. Burner's mesh.

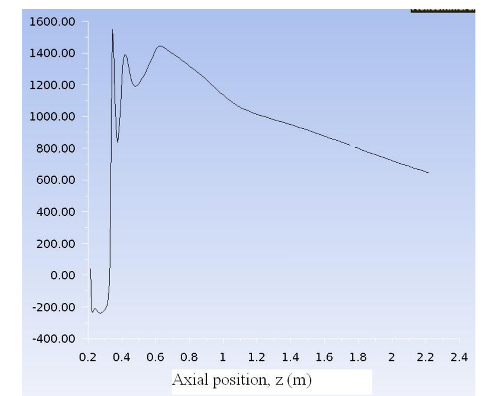

Figure 12. Temperature plot (°C).

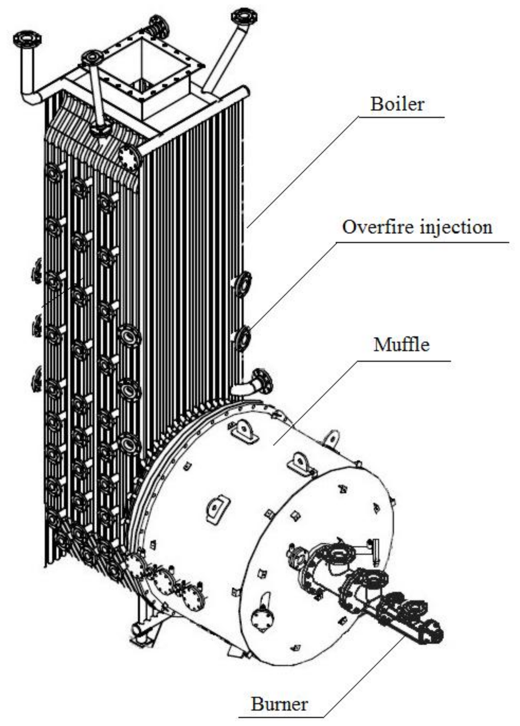

Figure 7. Oxyfuel boiler (Drawing).

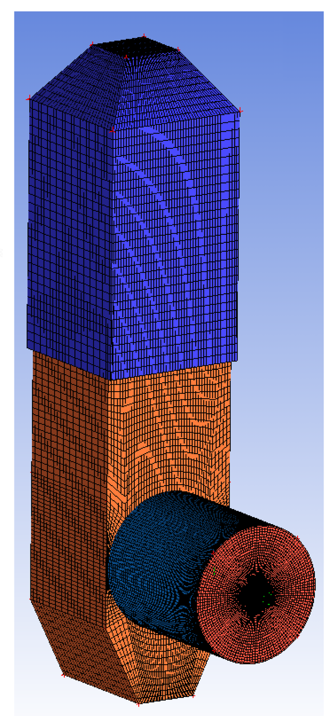

Figure 8. Boiler's mesh (1 Million cells).

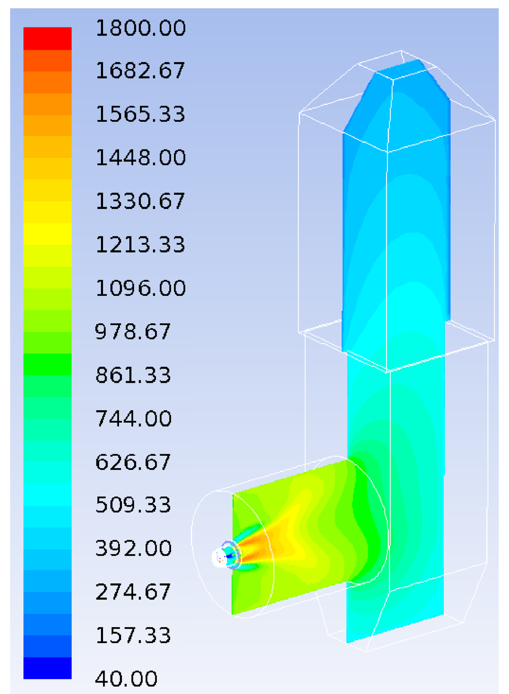

Figure 13. Temperature (°C).

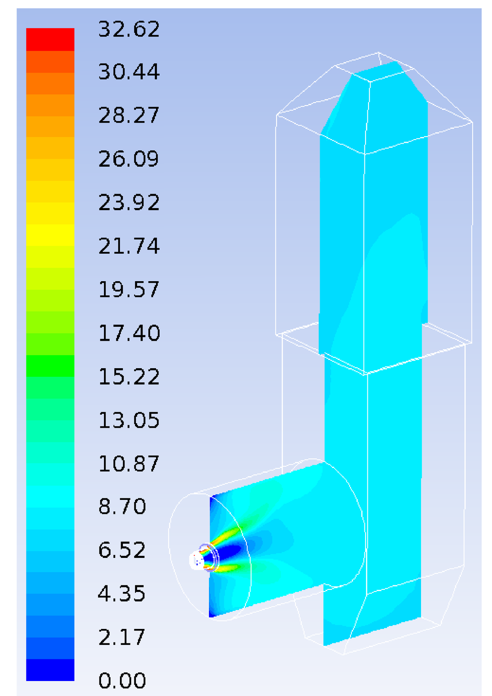

Figure 14. O_2 concentration (% Vol.).

Acknowledgements

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References

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* Corresponding Author: Tel. +49 (0) 355 69 5060 / Fax +49 (0) 355 69 4011 / E-mail kangwtan@tu-cottbus.de / Website: www.kwt-cottbus.de