# Detailed Numerical Three-dimensional and Transient Analysis of a Grate Firing Combustion Process by Innovative High Performance Computing

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## 1 Aims and 3D model approach

The global warming of our planet is pushing us to find other sources of renewable and alternative energy. Biomass as a renewable carbon-based energy source is a sustainable alternative for generating power and therefore continues to grow in popularity to reduce fossil fuel consumption for environmental and economic benefits [1]. Numerical simulations are therefore used in order to anticipate and improve the efficiency and gas emissions [2].

In the present contribution, the combustion chamber of a 16 MW geothermal steam superheater, which is part of the Enel Green Power "Cornia 2" power plant, is being investigated with high performance computing methods. For this purpose, the eXtended Discrete Element Method (XDEM, [3]) developed at the University of Luxembourg is used in a high-performance computing environment, which includes both the moving wooden bed and the combustion chamber above it. The XDEM simulation platform is based on a hybrid four-way coupling between the Discrete Element Method (DEM) and Computational Fluid Dynamics (CFD) [4]. In this approach, particles are treated as discrete elements that are coupled by heat, mass, and momentum transfer to the surrounding gas as a continuous phase. For individual wood particles, besides the equations of motion, the differential conservation equations for mass, heat, and momentum are solved, which describe the thermodynamic state during thermal conversion. The grate system has three different moving sections to ensure good mixing of the biomass parts and an appropriate residence time. The primary air (PA) enters from below the grate and is split into four different zones (sections). Furthermore, a secondary air (SA) is injected at high velocity straight over the fuel bed through two circular nozzles. A Flue Gas Recirculation (FGR) is present and partly injected through two jets along the vertical channel and partly from below the grate (see Fig. 1). The geometric data and operating conditions of the biomass furnace can be found in the master thesis [5].

The numerical 3D model presented in this paper is based on a multi-phase approach. The combustion of the particles on the moving beds in the furnace is processed by XDEM through conduction, radiation, and conversion [6] along with the interaction with the surrounding gas phase, accounted for by CFD. The coupling of CFD-XDEM as an Euler-Lagrange model is used in this paper, the fluid phase is a continuous phase handled with an Eulerian approach and each particle is tracked with a Lagrangian approach. Energy, mass and momentum conservation is applied for each single particle and the interaction of particles with each other in the bed and with the surrounding gas phase are taken into account. An individual particle can have a solid, liquid, gas or inert material phases (immobile species) at the same time. The different phases can undergo a series of conversion through various reactions that can be homogeneous, heterogeneous or intrinsic (drying, pyrolysis, gasification and oxidation). Further details about the model can be found in [7]. The consistency of the numerical results with the actual system performance as preliminary results are asserted here to determine the potentials and limitations of the approach.

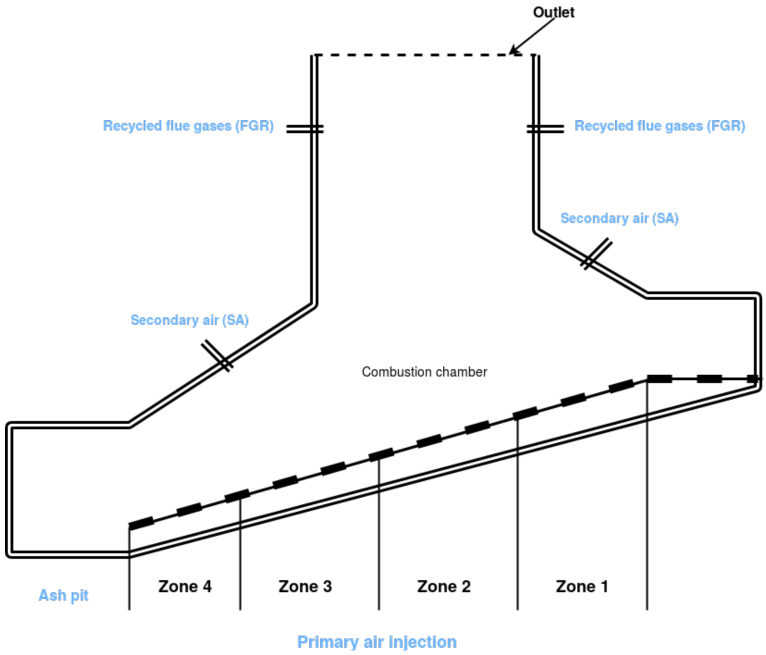


Figure 1: Biomass furnace design.

## 2 Scientific innovation and relevance

The model we propose above to predict the entire biomass process is very challenging because it involves multi-scale, multi-phase and multi-species phenomena including bed motion, turbulence, chemical reactions and heat radiation. The fuel bed behaviour including its motion and different conversions are solved with XDEM which is a novel and innovative numerical simulation technique that extends the dynamics of granular materials or particles as described through the classical DEM by additional properties such as the thermodynamic state, stress/strain for each particle. The interaction of the fuel bed with the surrounding air is then taking into account throught a CFD approach with the OpenFOAM software. The coupling of XDEM-OpenFOAM offer high computing precisions and performances with the use of high level optimization and parallelization techniques [8](MPI for OpenFOAM and hybrid MPI/OpenMP for XDEM).

The purpose of this study is to propose a numerical approach that combines low computational costs through the use of high computing efficiency, allowing the realistic use of the design with a sufficient accuracy of the results for industrial applications such as the Enel Green Power Cornia 2 power plant. Currently the plant is operated at nominal conditions for most of the time and the power production is sufficiently steady. Nonetheless there are still some elements of the plant that could be significantly improved. For instance, the presence of some unburnt carbon in the bottom ashes and some slag may form in the cold zones of the super-heater are eventually observed. The model presented in this paper will help to identify the different anomalies detected in the combustion chamber and can be used to improve the design and the combustion process by proposing an industrial scale 3D numerical model.

## 3 Preliminary results and conclusion

Our first results show that the particles at the outlet contain on average 44% of char and 66% of ashes by wt., meaning that there remain some unburnt carbon (approximately 5% of the dried biomass) resulting from an incomplete combustion. The remaining char corresponds to a residual char being 5.0% of the dry biomass in the feeding. These results are consistent with actual data obtained from the sampling of the residual solid in the industrial plant. As shown in Fig. 2, our model is able to predict gas flux behaviour inside the furnace, particularly the flue gas recirculation on the combustion process injection.

We presented a full 3D CFD-XDEM model (with industrial plant size and scale) to investigate biomass combustion in a large-scale reciprocating grate. In our coupling model, the XDEM software is used to simulate the granular flow along the grates (with dynamic and conversion), and

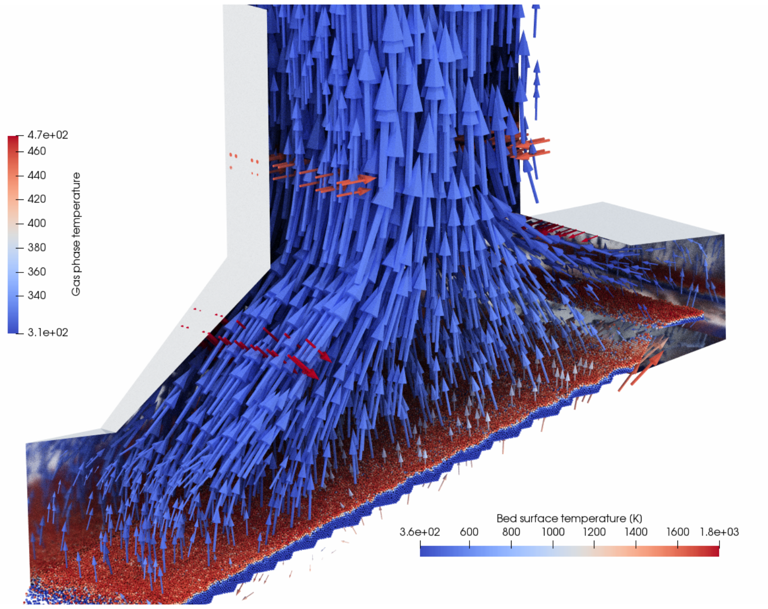


Figure 2: Velocity array, bed surface temperature and gaseous phase temperature.

OpenFOAM dealt with the surrounding gases. We were able to spot the level of unburnt carbon, i.e. approximately 5%, that was in consistency with evidence in the real plant. Therefore, the expected thermal field complied with the few provided experimental data, acknowledging a proper consideration of the interaction between chemical kinetics and turbulence. In particular the model allows to understand the effect of flue gas recirculation on the combustion process injection. First and foremost, the computational cost was relatively reasonable for a 3D real plant scales due to the feature of the multi-phase CFD-XDEM model, the parallelization of the XDEM code and the high performance computers. This is a fundamental aspect to suggest the use of the present numerical model for the practical operation of a biomass real plant.

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