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An integrated CFD-Process model for Oxy-coal combustion

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1. Introduction

Oxy-coal combustion is one of the leading technologies for carbon capture from coal-fired power plants. System simulation is a vital tool in the development of the novel technology. However, a fundamental challenge in modelling oxy-coal technology is accounting for the impact of increased concentrations of carbon dioxide and water vapour in the combustion gases on heat transfer. This can be done by incorporating a spectral model for the gaseous radiative properties within a CFD combustion model.

In order to investigate the impact of an oxy-coal boiler on the power plant operation, this work covers the development of an integrated CFD-Process model for oxy-coal combustion. The model links a detailed CFD calculation of combustion and heat transfer in the furnace, with the steam cycle and overall plant performance which are calculated in a process model. The models are linked by the boundary condition: in the CFD model, the water/steam temperature and the overall heat transfer coefficient from the outer tube fouling surface to the water/steam are required as input parameters. Detailed heat flux data from gas to steam are calculated in the CFD model and are reduced to functions of height for the water walls and various tube arrangements at the top of the boiler using regression techniques. These heat fluxes are used to drive steam generation and superheating in the main radiative superheaters in the full plant process model.

2. Integrated numerical modelling and results

The process model has been developed in gPROMS software, and consists of a number of model components. Each component has been written and coded into gPROMS process language, with input and output streams defined as either: gas, water, steam or heat flow. The process model is an extension of our previous work [1.]. The heat exchanger components have now been further developed to include a higher level of detail, to extend their applicability to oxy-coal, and to be applicable to different plant designs. The process flow diagram is illustrated in Figure 1, and a brief description of the main heat exchanger components is supplied in Table 1.

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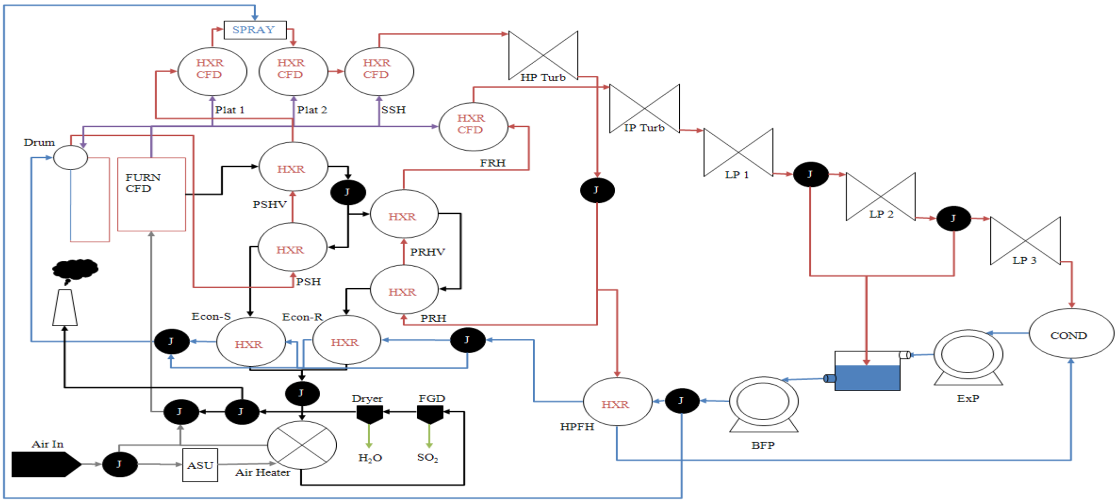

Figure 1: Process flow diagram (for air or oxyfuel)

HXR	*Two stream heat exchanger.* Often comprised of a number of layers of tubes, reflecting the complex layout. Each layer of numerous tubes is modelled, with the water/steam in plug flow (axial variations) and the gas treated as well mixed.
HXR CFD	*CFD heat exchanger* Often comprised of a number of layers of tubes. Each layer of tubes is modelled, with the water/steam in plug flow (axial variations), and the heat flux from the gas side is applied as an axial distribution of the 3D fluxes calculated in the CFD model.
FURN	*CFD Furnace* This is the link between the process model and the CFD model. The gas inlet properties are assigned to the CFD model, and the calculated heat flux data to the boiler surfaces is regressed and polynomial coefficients sent back to the process model, along with the final gas exit properties (at the reheater exit).
Drum	*Drum / Water walls* An overall enthalpy balance is performed to calculate the steam generation rate at the input heat duty. The heat input comes from the CFD calculation, and is applied as a 1D regressed function of height This heat duty from the furnace partially evaporates the fluid in the tubes, generating a thermosyphon loop. The pressure profile around the loop is calculated, allowing for the static head, The circulation flow around the loop is calculated through pressure and enthalpy balances.
	Air heater A rotary regenerative heat exchanger (Ljungstrom type) is modelled, assuming a periodic solution (pseudo steady state) and constant boundary conditions. Both streams are assumed to be in plug flow, and a fixed fraction of the incoming air leaks to the gas side.

Table 1: Model components for heat transfer

The model accounts for the change in combustion environment through the CFD link. Heat transfer in the furnace and the main radiative heat exchangers is calculated using a detailed ANSYS CFD model of the furnace, illustrated in Figure 2. The modelled geometry covers over 5,000 m^2 including 36 firing burners and numerous heat transfer surfaces. The mesh covers half of the furnace due to symmetry and contains approximately 3.2 million cells, with over half of these situated in the burners and the near-burner zone. The modelling approach taken is similar that described in our previous paper [1.], with two-step chemistry, RANS turbulence closure and Discrete Ordinates RTE solver. A spectral model is used to calculate the radiative properties of H_2O and CO_2 is used, which has been coded and optimised for CFD combustion calculations [2.]. In the latter parts of the boiler, convection is assumed to dominate heat transfer (at the reheater exit, where the CFD model ends, the gas temperature is approximately 1050 K and the steam temperature is 840 K). The thermal properties of the combustion gases are calculated by an external physical properties package as a function of composition and temperature thus accounting for the change in combustion environment.

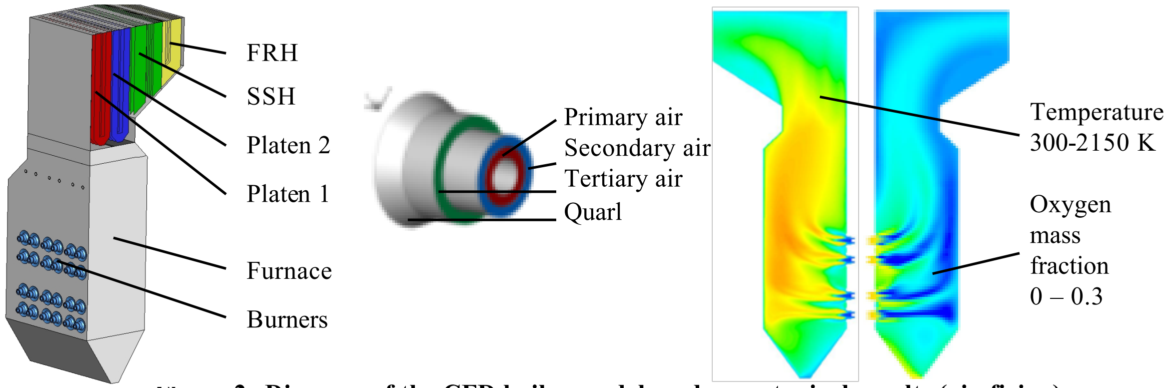

Figure 2: Diagram of the CFD boiler model, and some typical results (air firing)

Given the input data from the process model, and approximate values for the steam / water properties (temperature, heat transfer coefficient), the CFD model calculates the heat flux data. The 3D flux data is then regressed and applied in the process model for each layer of tubes as a polynomial function of height. In the hanging tube arrangements at the top of the burner, typical R^2 values are between 0.8 – 0.9, as illustrated in Figure 3. This data contains valuable information on the complex gas flow properties, for example the relative importance of radiation and convection heat transfer processes, and is not available from measurements or process models.

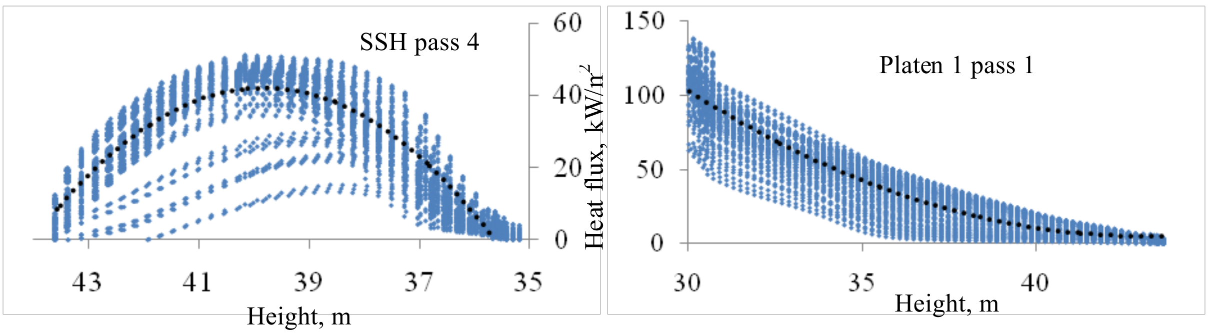

Figure 3: Heat flux data from CFD

The integrated model provides vital information on the operation of the power station under air-fired or oxy-coal conditions, and can be used to identify optimum operating modes as well as potential problems associated with oxy-coal. Recalculation of the water wall heat fluxes using the steam temperature and heat transfer coefficient distributions calculated by the process model produced a flux distribution which was almost identical to the original calculation, indicating that little if any iterations of the system are required. This is because heat transfer in the boiler and the main radiative heat exchangers is dictated by thermal radiation on the gas side, and the resistance to heat transfer is dominated by the gas-side fouling factor.

Further investigation of this system intends to repeat the calculations for oxy-fuel, and aims to explore CPU efficiency savings, for example the use of a load factor on the process side to investigate load change without further CFD calculations, and the development of multidimensional polynomials which automatically vary the flux distribution and magnitude with recycle ratio and excess oxygen value, thus creating a reduced order model which does not require time-consuming CFD calculations. The resulting model provides a detailed approach to full system simulation of the oxy-coal process.

References

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