

A Modelling Appraisal of OxyCoal Combustion in Utility Power Plant

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Simulations of a utility plant furnace operating under air and oxyfuel conditions have been completed. Test data from a Drop Tube Furnace and predictions from a coal science simulation program were used to generate the CFD input. For the scenario studied, oxyfuel firing was found to be compatible with existing plant.

Introduction

Oxyfuel firing, the combustion of fuel in a medium comprising injected oxygen plus recycled flue gas, offers a means of generating carbon dioxide rich flue gas requiring minimal treatment prior to sequestration or beneficial application.

Doosan Babcock is leading a number of collaborative projects [1] that are investigating the following pertinent items:

- Oxyfuel combustion fundamentals and underpinning technologies
- Demonstration of a full-scale (40 MW_t) oxyfuel burner
- Development of oxyfuel-fired power plant operating strategies

The projects are part-funded by grants from the UK government bodies BERR/TSB. The project participants comprise Air Products plc, E.ON UK plc, RWE npower plc, BP Alternative Energy International Limited, University of Nottingham, Imperial College London, Scottish and Southern Energy plc, ScottishPower Energy Wholesale, EDF Energy plc, Drax Power Limited, DONG Energy A/S and Vattenfall AB. Each project features different groupings of participants.

The combustion of coal in oxyfuel atmospheres is known to influence flue gas composition in terms of the concentration of intermediate species such as CO, and pollutant species such as NO_x. Char gasification reactions with CO₂ and H₂O become significant and their reactivity varies with char type. Diffusivity limitations are also important. The increased concentrations of

carbon dioxide and water vapour will affect the radiative and convective properties of the flue gas, potentially causing a redistribution of heat release within the furnace. As a result of these coupled processes it is anticipated that flame characteristics for oxyfuel will differ from air firing.

Theory

Computational Fluid Dynamics (CFD) modelling represents an integral part of Doosan Babcock's research and development philosophy. Having been successfully applied in the past for air firing; low NO_x burners and in-furnace NO_x control systems; it is intended that a commercial CFD code, ANSYS Fluent, be used to further the understanding of the effects of oxyfuel process parameters on coal burnout, flame stability, gaseous emissions and thermal performance. In order to achieve this, appropriate models must be selected and relevant coal input data sourced.

Volatiles combustion was modelled as a 2-step reaction with CO intermediate. Gas radiation and particle radiation interaction were accounted for using the Discrete Ordinates model, with an Exponential Wide Band Model (EWBM), developed and implemented by National Technical University of Athens and ANSYS [2], being applied for the calculation of gas absorption coefficient. Volatile release was modelled as a single first order rate of release, whilst the particle surface reaction model was used to represent char conversion by oxidation and gasification by CO₂ and steam.

Experimental

The development of a preliminary modelling approach for oxyfuel combustion was based on laboratory data made available from Drop Tube Furnace (DTF) testing at University of Nottingham during the OxyCoal-UK Phase 1 project. Devolatilisation and char conversion were investigated in air (N₂) and oxyfuel (75% and 100% CO₂) atmospheres for a suite of six coals of bituminous ranking, to a maximum temperature of 1300°C and residence time of 600 ms.

The results from the DTF tests were fairly consistent in showing increased volatile yield and char conversion under oxyfuel conditions at high temperature, attributable to the reactions of CO₂ with volatiles and char, although some interesting anomalies were observed.

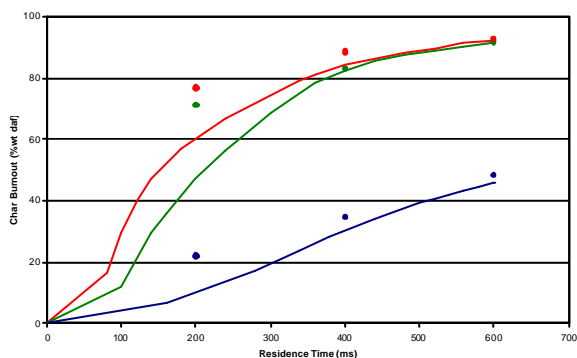
A coal science program, PC Coal Lab [3], was used to generate appropriate data for devolatilisation rates in conventional atmospheres and to evaluate its predictive capability with respect to devolatilisation, char burnout and char gasification characteristics.

Results

PC Coal Lab was found to produce a satisfactory prediction of volatile yield and was used to provide devolatilisation rates.

First order kinetic rate parameters were derived for the burnout of chars (10% O₂ in N₂). During the analysis, a 2d CFD model of the DTF was employed to feed back combustion parameters to provide an improved fit.

The predictions made by PC Coal Lab's Carbon Burnout Kinetics (CBK) module were encouraging.

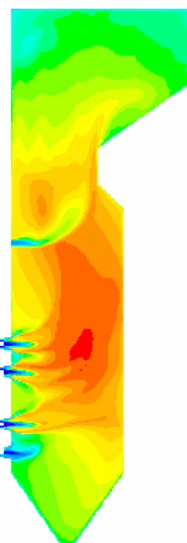


PC Coal Lab Predicted (solid lines) and Measured Burnout versus Time

The minor and fluctuating contributions of gasification at low temperature, together with the simultaneous oxidation and gasification occurring during char conversion, precluded the derivation of equivalent CO₂ gasification rates for all chars. Instead, standard relationships for

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gasification by CO₂ and steam were taken from literature [4].



Gas Temperature (Air Firing)

A half-furnace model of a 500 MWe front wall fired utility boiler was constructed featuring a burner suitable for conventional air firing and oxyfuel operation. The thermal conditions of the baseline air fired model were calibrated to known boiler performance and applied to the oxyfuel scenario. Coal input data derived for a typical UK bituminous coal was used.

Despite lower peak temperature due to increased heat capacity, the oxyfuel case showed increased burnout and conversion of CO.

Comparable heat absorption and flame shape suggest that oxyfuel firing may be accommodated by existing furnace designs.

Conclusions

Drop tube furnace testing by University of Nottingham has shown enhanced volatile yield and char conversion under oxyfuel conditions for a variety of coals.

A combination of test, CFD and coal simulator program data was used to generate modelling input.

The preliminary simulation of a utility plant in both conventional air staging and oxyfuel firing modes shows that oxyfuel firing at this condition is compatible with existing plant. Further improvements to the modelling method are required.

References

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