dti

ADVANCED COAL COMBUSTION MODELLING

PROJECT SUMMARY 288

CLEANER FOSSIL FUELS PROGRAMME

OBJECTIVES

The principle aim of the University of Leeds 'Advanced Coal Combustion Modelling Project' is to deliver a more fundamental model of carbon burnout with the objective of increasing the accuracy of these models. The project consists of the following stages:

- Develop a model to estimate the amount of char produced during devolatilisation.
- Develop a char burnout model using the estimation of the amount of char produced in the devolatilisation step.
- Incorporate the results into an overall char burning model suitable for combustion in a drop tube or a simplified power station combustor.

The overall approach taken was so to be able to predict the char burn out in a combustion chamber from the properties of the fuel and the given properties of the furnace that are derived from a furnace model or from a CFD model.

SUMMARY

A model (termed the Leeds Char model) has been produced containing the appropriate parameters to predict the combustion process in a drop tube or power station furnace for which the combustion conditions are defined. Also defined are the parameters for the calculation for both devolatilisation and char combustion sub models that can be used in models for the calculation of char burnout. The output of this work has been documented and delivered to the project partners in milestone reports 1, 2 and 3 and a final report. This work has provided the basis for the accurate prediction of the combustion behaviour and carbon burnout in a power station boiler. However there are certain cases where prediction is still difficult and these are: (a) coals containing high levels of inertinite where the reactivity of the inertinite is

difficult to predict, and (b) blends containing small amounts of low reactivity material and whose adverse properties are swamped by the bulk properties of the major component.

INTRODUCTION

This Project was undertaken in the Department of Fuel and Energy at the University of Leeds by Professor Alan Williams, Professor Mohammed Pourkashanian, Dr Jenny Jones and Dr Raymond Backreedy. The Project was operated in parallel with a wider project coordinated initially by Dr Martin O'Connor and then Dr Peter Stepenson of Innogy.

This research project was a result of the considerable attention that has been paid to the burnout of carbon in pulverised fired power stations in recent years. The degree of carbon burnout is important because it is linked with the efficiency of the plant, the emission of solids and the suitability of the pf ash for construction purposes.

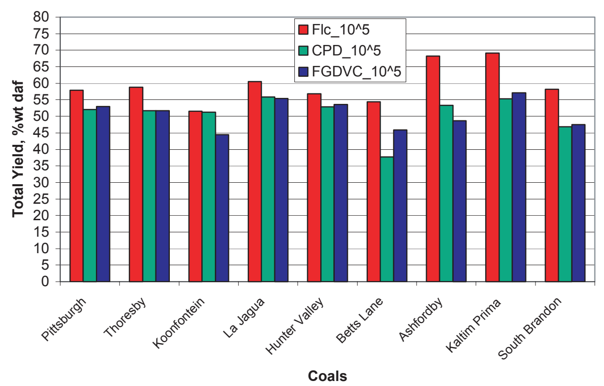
The use of computational fluid dynamic (CFD) methods in such systems has been aided by the availability of fast computers and improvements in computational methodology. Thus significant advances have been made in the CFD modelling particularly in fluid flow and coal combustion models. Despite these advances it is still not possible to use CFD methods for detailed design purposes or for the selection of coals especially when these differ greatly from those coals which the plant was designed to use. Indeed confidence in the use of mathematical models has decreased in recent years when some of the internationally traded coals are concerned especially when they are blends.

Most power plant combustion chambers utilise low NO_x burners that are sophisticated in operation and complicated in geometric design. Often in CFD models these features are very much simplified and yet this complex geometric construction plays a vital role in controlling the combustion process.

There are thus numerous reasons for improved mathematical models to be developed. A successful coal CFD model must be able to handle all of the complexities of combustion from the details of the burner inlet through to the formation of NO_x and the unburned carbon. These are complicated by features that are specific to an individual plant such as the performance of mills and in-leakage of air. However, in many cases all these effects are summarised in global coal combustion models. In this project we have outlined a more detailed and accurate way in which this can also be achieved. Examples of applications are given including a range of power station types and coals and test furnaces.

THE DEVELOPMENT OF THE COMPUTER MODELS

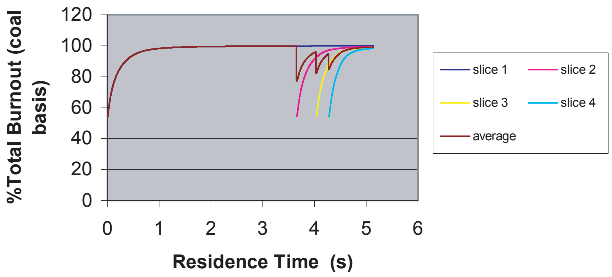
A number of coal combustion models have been developed by various groups and some developed specifically for the determination of unburned carbon in ash. In the light of the wider usage of coals with greatly different combustion characteristics any model used here has to account for these effects in both the devolatilisation and the char combustion stages.



Network Models predicted total weight loss (after 150ms at 105K/s)

In the case of the devolatilisation of coal particles a number of computer models that are available have been examined, namely, FG-DVC, CPD and the FLASHCHAIN coal network devolatilisation models. The applicability and accuracy of these models are important as they impact on the prediction of the amount of char produced. We tested them under a common set of conditions that were shown to be applicable to the devolatilisation conditions in a pulverised coal flame, namely, a final temperature of 1773 K, a residence time of 0.15 s, and a heating rate of 10 5 K/s.
It was found that all three models gave predictions of volatile yields that were consistent with experimental measurements made by Alstom using a drop tube furnace method for a range of internationally traded coals from Australia, South America, South Africa and Russia as well as UK coals. As long as the conditions are carefully controlled this experimental method gives results consistent with the behaviour in real pf coal flames. We also re-examined data from the previous DTI low NO_x project and arrived at the same conclusions. However in this project, where a wider geographical range of coals were considered, some difficulties emerged in the volatile yields predictions with coals containing high inertinite contents, and the errors associated with these were slightly higher than those coals with a high vitrinite content. The values of char yields obtained in this way could be incorporated in the char models with reasonable confidence. In the case of coals that fall outside the network models capability further work should be done to extend the database range so to enable for more accurate predictions of volatile yields when considering these coals.

A char model has been used based on the intrinsic char combustion model developed by Dr I. Smith and others originally at BCURA. It uses as a computer format the CBK8 model developed by Professor R. Hurt at Brown University in the USA. The major char combustion processes are well established but a detailed understanding is still lacking about the role of macerals and the influence of ash on the combustion process. As the original coal particle burns the char formed changes in surface area and ultimately the carbon in it may become annealed. This effect reduces the reactivity of the char and this can result in higher unburned carbon. In addition the ash content in the burning char particle increases and this can have an inhibiting effect on the char reactivity. As the temperature reduces towards the end of the combustion the combustion regime may change from zone II to I and thereby further affecting char reactivity. At these reduced reaction temperatures catalytic effects become more influential, and the presence or absence of catalytic reactions can play a significant role.



Computer output showing the amount of unburned char (coal basis) through the different stages of the furnace using the Leeds char furnace model

Such a model is used here but we have particularly introduced the effect of variable surface and different surface areas for the coals with different maceral contents. It is therefore possible to estimate the rates of char burnout from the fundamental steps involved but there are considerable uncertainties in that calculation. Thus we used experimental data provided by Alstom Power in order to fix these char properties within experimental error for high vitrinite coals and this we do by means of a calibrating reactivity constant, alpha*. Corrections for macerals are done via a term Fmac, which allows for the nature and amount of the macerals content on char combustion to be taken into account; of course the maceral content of the coals have to be determined experimentally. A further feature is that the drop tube furnace have to modelled using a CFD method to give the correct temperature profile, residence time and oxygen concentrations for use in the char model, and data on this was available from Innogy. Using this approach gave good predictions of data obtained for the range of coals.

APPLICATION TO TEST CASES

The models have been tested against a number of results obtained from power stations and from a set of results obtained from the Combustion Test facility at the Powergen research facility and on Ratcliffe Power Station. These results were provided via the parallel research project operated by Alstom Power and Innogy Plc.

In the case of the power stations (and combustion test facility) a set of data were provided by Alstom using their slice model on the reaction conditions for a number of sections or slices of the power station. This consisted of temperatures, oxygen concentrations and residence times. Using this information it was possible to calculate the levels of carbon burnout for a range of coals. Generally agreement was within an accuracy range of 10-15% except in the case of the high inertinite-containing coal where the observed plant burnout was lower. Generally the models worked well in predicting the amount of unburned carbon although some further refinements are necessary for a wider range of coals.

COST

The total cost of the project was £102,400 with a contribution of £50,400 (49%) from the DTI.

DURATION

30 months starting on the 1st May 2000

COLLABORATORS

Other organisations involved were Innogy (formerly National Power Plc.) acting on behalf of a consortium consisting of Alstom Power Ltd (formerly ABB Combustion Services Ltd), Eastern Generation Ltd, Mitsui-Babcock Energy Ltd, PowerGen Plc and Scottish Power Plc. Other Universities involved were Imperial College of Science Technology and Medicine and University of Nottingham.

Further information on the Cleaner Coal Technology Programme, and copies of publications, can be obtained from:
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