dti

IMPROVEMENT OF COMBUSTION EFFICIENCY IN UTILITY BOILERS

PROJECT SUMMARY 294

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

- Review previous work to predict combustion efficiency.
- Identify how prediction can be made faster and more reliable than existing methods.
- Develop the ability to predict how a coal will perform on a given boiler (to include ability to allow for specific plant features, eg mills and coal fineness, air ingress).
- Provide a predictive tool which can be used to quantify combustion improvement from proposed plant modifications.

SUMMARY

The drive to reduce the environmental impact of power stations is increasing the pressure to improve efficiency of power plant. This is coupled with the drive to reduce costs through the use of a wider range of fuels. Prediction of combustion efficiency (or carbon burnout) in pulverised fuel (pf) fired utility boilers is of increasing importance to UK based power generators and manufacturers.

The overall aim of the project was to develop new tools for the reliable and rapid prediction of combustion efficiency of coals in pf-fired utility boilers. This would give the ability to improve fuel selection and chose the most appropriate burner and boiler design for a given fuel.

It is concluded that laboratory-scale and drop tube furnace results are invaluable in providing detailed understanding of the processes occurring during coal combustion and in providing input data for computer models of full scale furnaces. Both Innogy and Powergen have tested sufficient coals on their test rigs and on actual power stations to know how to extrapolate results. A new empirical correlation has been developed to enable burnout to predicted for a particular rig or power station.

Figure 1: Didcot – a Coal-Fired Power Station

A range of computer models of burnout in actual power stations has been tested. The models combine a comparatively simple representation of the furnace with detailed devolatilisation and char burnout models. One such model has been developed during the project, using open-source components, and has been supplied to and tested by project participants. It is concluded that such methods show major promise as they can, in principle, model both coal-specific and plant-specific effects for specific coals and power stations. However, more work is needed before they are sufficiently reliable and accurate. Recommendations are therefore made for further work to achieve this.

BACKGROUND

There are three main reasons why a plant operator would wish to minimise the carbon-in-ash levels. The first is the environmental and economic advantages of improving the overall cycle efficiency. The second is that power station fly ash can, in general, be sold only if the carbon-in-ash is below a certain level, which varies between stations and between uses for fly ash. If the carbon-in-ash exceeds that level, the plant operator has to pay for fly ash disposal and, in the UK, has to pay a landfill tax. The third reason is that, if the carbon-in-ash level is too high, the removal efficiency of the electrostatic precipitators will drop. With the permitted limits in particulate emissions being progressively reduced, this third reason for reducing carbon-in-ash can be the most important to a plant operator.

REVIEW BURNOUT PREDICTIONS AND DATA

Existing information concerning plant experience was collected. A database was developed to include the plant arrangement, dimensions, coal analysis, operating conditions and performance (including carbon-in-ash). The database includes ‘public domain’ data and data offered by utility partners as part of their contribution to the project. Data from test rigs have been included.

COAL SELECTION

A range of commercially available coals was chosen to be fired in power station trials and at rig and laboratory scale. It was crucial in the coal selection to ensure that comparisons could be made between different power stations, between power stations and rigs and between different rigs. This meant that coals had to be chosen for which data could be obtained from a number of power stations and rigs. In total, data were located for about 40 coals and about 15 power stations, plus laboratory scale, Drop Tube Furnace (DTF), and Combustion Test Facility (CTF) results.

POWER STATION TRIALS

In total, 13 new sets of power station trial data were obtained as part of this project. A further 18 sets of trial data were provided by the participants as in-kind contribution, and 5 sets were included from the earlier DTI NO_x project. The power station data covered a range of UK and world-traded coals, and the power stations included the three main firing types (front wall, opposed wall and tangential).

RIG TESTING

A range of coals was tested on Innogy's 0.5 MW Combustion Test Facility (CTF) and Powergen's 1.0 MW Combustion Test Facility. Innogy's CTF was also used in the DTI funded project 'The effects of coal blending on combustion performance'. Powergen's CTF was also used in the DTI funded project 'The effects of coal blending on NO_x emissions and carbon burnout in pulverised coal fired utility boilers'. In total, 15 new data sets were obtained as part of this project, together with 7 existing data sets from these earlier DTI-funded projects.

Drop Tube Furnace (DTF) tests were the responsibility of Alstom and were subcontracted by them to Powergen, who used their DTF. The char from four coals, namely Ensham, Welbeck, Prodeco and Goedehoop, were tested under simulated furnace conditions in a DTF. The work was carried out in order to provide burnout data in a specified environment under controlled temperature conditions. The burnout data were used to calculate the reactivity of the chars which were then used in models of plant and test rigs. Coal samples were taken from the coal prepared for the Powergen CTF. The chars were prepared in the Drop Tube Furnace under standard conditions. The DTF tests were then carried out at different temperatures and oxygen levels. The chars and burnout were characterised using the thermogravimetric apparatus. Additional tests were carried out to compare the burnout of char made in the DTF and from the Powergen Rig using Welbeck coal.

The laboratory scale testing by Imperial College London was to obtain a greater understanding of the particular reasons why the char in any given fly ash (from both plant and rig-scale) did not burn. The laboratory scale analytical work concentrated largely on testing pairs of pulverised coal and corresponding PFA produced from full-scale plant as well as rig tests undertaken by the industrial partners within the project.

The work at Nottingham University concerned the correlation of coal and char properties derived from laboratory testing with data from full-sized boiler plant and combustion test facilities. The investigation included petrographic analysis of a series of coals and chars supplied by Powergen, Innogy, TXU Europe and Scottish Power. The power station and rig data provided by the power generators were compared with laboratory measurements on the suite of coals. From this, correlations between unburnt carbon in ash levels and coal properties were presented. In addition, coal milling trials were undertaken using a mill/classifier system in an attempt to reproduce PF size distributions from several of the project coals on a laboratory scale. The results obtained showed that realistic PF size distributions could be produced.

The Leeds modelling of char burnout was based on the latest version of the Char Burnout Kinetic Model (CBK8), developed by Hurt and colleagues. The Leeds Model Development was based on CBK8 with the following developments.

- The intrinsic activation energy was changed to 38 kcal/mol, as this improved the level of agreement between DTF measurements of burnout and CBK8 predictions for a number of coals.
- The char surface area was permitted to vary with the degree of burnout. The variation was determined by matching the computed burnout curves with measured data.
- The char properties were then correlated with the coal petrographic analysis.

Predictions from CBK8 and from the Leeds Model were compared with measured data from power stations and from Powergen's CTF. Furnace predictions, required as input data, were taken from the Alstom in-house slice model and from Innogy's version of the FURDEC furnace design code. Predictions were based on measured PF fineness, assumption of equal coal and air distribution between burners and an estimate of fuel, air and leakage flows.

APPRAISAL OF PC COAL LAB

PC Coal Lab is a commercially available software package which aims to simulate the performance of two advanced coal characterisation experimental techniques, namely the drop tube furnace and the high temperature wire mesh. In general, PC Coal Lab was found to be more successful at predicting high temperature volatile yield than at predicting burnout. However, it was shown that PC Coal Lab could be used as a way of predicting the relative burnout performance of an unknown coal when the performance was known for a reference suite of coals in the same power station.

APPRAISAL OF AN IN-HOUSE PREDICTOR

The Mitsui Babcock (MB) in-house Carbon-in-ash (CIA) predictive model is a simple PC based package for the estimation of burnout in utility furnaces. The model can simulate the main in-furnace NO_x reduction technologies (low NO_x burners, air staging, reburn) where there is a potential impact in combustion efficiency. Predictions were compared with a large range of plant data. Most of the predicted CIA values were within + or -50% (relative) of the measured CIA. Generally the level of agreement was better where fewer assumptions had to be made with the input data. It was felt that the shortcomings of the predictive method as a whole lie in the specification of the input data to the model rather than the capability of the model itself.

DEVELOPMENT OF A BURNOUT MODEL

The generic carbon-in-ash predictor was intended to include the effects of both coal quality and operational parameters. The original intention was to provide software consisting of three main components, namely a generic furnace model that could be made available to all participants, a copy of the CBK8 code (which is public-domain software), and linking code. Two approaches were explored for the open source furnace model but neither was found to meet the project's requirements. Therefore, it was decided to avoid the need for a furnace model by using typical temperature/time histories for each boiler type (eg front-wall firing, opposed wall-firing and tangential firing). As the temperature profiles are largely determined by the first 95% of heat release, they are fairly straightforward to predict. It was also agreed that the generic carbon-in-ash predictor would be supplied to participants with generic temperature/time curves, and that it would be written in a way that enabled users to include their own temperature/time curves, where available.

The generic carbon-in-ash predictor was based on CBK8, modified by MB to allow for up to 60 multiple burners. Each burner had a unique input (eg coal and air flow rates and PF size distribution), and the overall carbon-in-ash was found by mass balance. It included a loop to calculate oxygen/time curve, which is required as input to CBK8.

MB provided an initial validation of this predictor. Plant data from three boilers of widely different geometry were used as the basis of the validation. For the wall-fired example, agreement with measured carbon-in-ash was encouraging for all three coals. For both the opposed-fired and the tangentially-fired examples, predicted values were acceptable for only one of the three coals considered. It was thought that the level of agreement achieved was as good as could be expected given the comparatively simple data input preparation undertaken.

Further validation of the generic carbon-in-ash predictor was undertaken by Alstom and Innogy. Alstom's approach was to test the predictor using data from the Kozienice Power Plant. Innogy concentrated on the Didcot/Pittsburgh#8 data from the DTI NO_x project. All the changes predicted by a sensitivity analysis were qualitatively plausible; the predicted carbon-in-ash was more sensitive to the oxygen concentrations (via the fuel/air ratio) than to any other input parameter.

COMPARISON OF METHODS FOR ESTIMATING CARBON-IN-ASH

The information from the various project activities was used to evaluate various ways of estimating the carbon-in-ash for a specific coal at a specific power station, and, where possible, make recommendations for the most appropriate methods.

The laboratory scale and DTF results are mainly useful in providing data that can be input into detailed predictor methods. A similar comment applies to the detailed network computer programs (eg PC Coal Lab) that model devolatilisation. The main laboratory-scale approach which can provide a direct indication is the % unreactives index, derived from petrographic analysis. Correlations between coal properties and carbon burnout, such as a correlation developed in this project, show promise for specific rigs or power stations. Rig tests provide an effective way of predicting the burnout performance in large plant, provided that a suitable range of coals have already been burnt both on the rig and plant itself. The various computer models of power stations investigated here all show promise. They can provide at least qualitatively plausible predictions for the effects of plant parameters, such as excess O_2, mill performance, and variation in fuel and air flow rates between burners. Some of them include the latest ideas on modelling carbon burnout (CBK8, the Leeds advanced model and the MB generic predictor). However, the comparison provided here between predictions and plant measurements indicates that further development is required before they can provide reliable results.

It must be recognised that plant factors can have a dominant impact on carbon burnout. If plant factors (eg poor mill performance) are dominating combustion, then no coal test can be expected to predict combustion performance.

CONCLUSIONS

- A review has been provided of previous work to predict combustion efficiency.
- Various ways have been identified to enable the prediction of combustion efficiency (carbon burnout) to be made faster and more reliable. This has been done partly by examining the strengths and weaknesses of existing methods within the review. In addition, the key physical processes have been identified and the currently available methods for modelling them have been tested. This has enabled the most promising methods to be further developed.
- Two new approaches have been developed to predict how a coal will perform on a given boiler. One is an empirical correlation for a single power station and the other is a computer model applicable to any specific coal and power station. The latter includes the ability to allow for specific plant problems, eg mills, air ingress. Software has been developed for such a generic carbon-in-ash predictor and has supplied to project participants and tested by them. It shows promise but requires further development.
- The generic carbon-in-ash predictor developed within the project can, in principle, provide a predictive tool which can be used to quantify combustion improvement from proposed plant modifications.
- Recommendations have been made for future projects which can build on the achievements of this project.

COST

The total cost of the project was £1,470,698, with the Department of Trade and Industry contributing £441,209 (30%). The balance of the funding was provided by the participants.

DURATION

39 months – November 1999 to February 2003

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COLLABORATORS

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(Imperial College London and Nottingham University were sub-contractors and Leeds University was linked via a parallel DTI-funded project)

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