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COMBUSTION OF LOW VOLATILE COALS

Application to Wall Fired Power Plant

PROJECT SUMMARY 344

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

- To demonstrate the combustion performance of a low volatile coal burner for wall fired furnaces by testing of a full-scale burner design in a single burner test facility.
- To optimise the furnace design and process for utility plant and burner retrofits with regard to combustion efficiency, NO_X emissions, and stability/turndown performance by means of pilot scale testing and advanced modelling techniques.

SUMMARY

The main aim of the project was to demonstrate the proposed low volatile burner at full scale in a single burner test facility and to establish its performance with regard to NO_X and combustion efficiency. Furthermore, pilot scale testing was undertaken to quantify the effect of the staged addition of combustion air. Air staging is generally regarded as an effective, mature technology for NO_X reduction from bituminous coals, but its impact on low volatile coals is less well understood.

Flame Stability is a major concern when firing low volatile coals. In light of this, laboratory scale tests to assess the flame stability properties of coals were undertaken by Imperial College London. The main analyses carried out were High Temperature Wire Mesh (HTWM) and Explosibility. The HTWM tests confirmed that the Q factor, (the ratio of high temperature volatile yield to the proximate volatile content of the coal) remains constant throughout devolatilization. This is useful for predicting the volatile release during devolatilization processes at high temperatures.

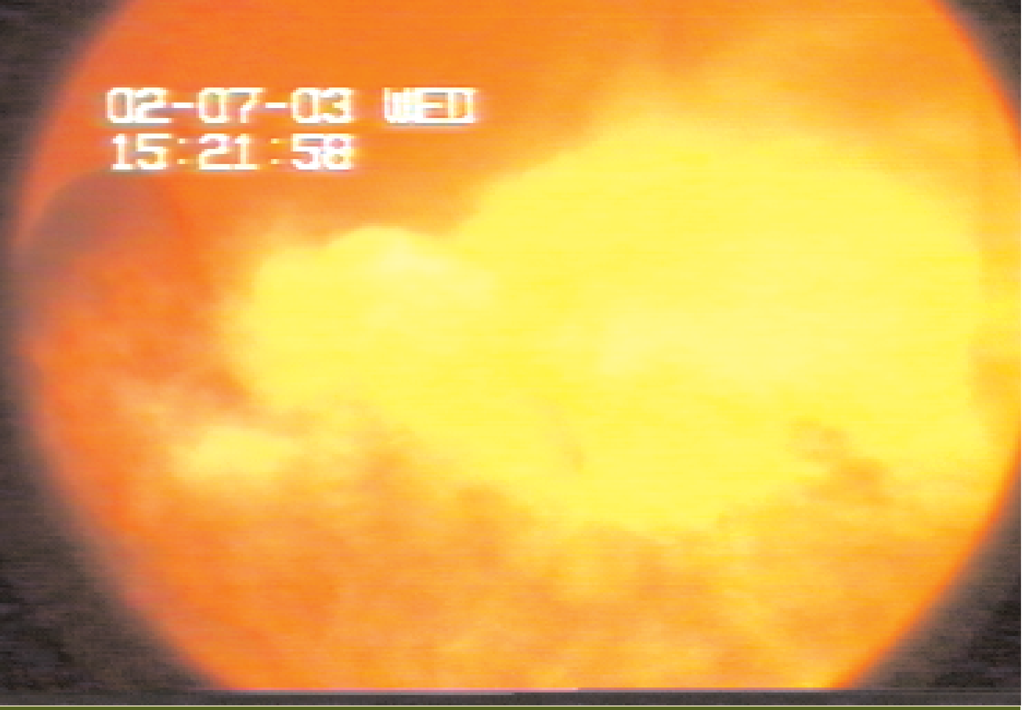

Figure 1. Low Volatile Coal Flame (courtesy of Mitsui Babcock Energy Limited)

The Explosibility tests were found to provide a new way to assess coal ignition coal properties, and supported the conclusion that early release volatiles are crucial for flame stability.

The testing and successful demonstration of the proposed low volatile burner was achieved on Mitsui Babcock Energy Limited's multi-fuel burner test facility. Two low volatile coals, volatile content of ~15% and ~10%, were fired during the testing programme. Both coal tests achieved stable and unsupported low NO_X flames.

Coal	**Chinese**	**UK**
Moisture, % as received	0.8	0.6
Volatile, % as received	12.6	9.5
Fixed Carbon, % as received	71.1	82.5
Ash, % as received	15.5	7.4
GCV, MJ/kg	26.66	32.99

Table 1. Coal properties

Additional testing was taken on Mitsui Babcock Energy Ltd's NO_X Reduction Test Facility (NRTF) to establish the effect of the main operating variables on NO_X and burnout under baseline and air staging conditions for a low volatile coal. The results indicate that further significant NO_X reduction is achievable when firing low volatile coals using Mitsui Babcock wall burners with an air staging system.

BACKGROUND

Traditionally low volatile coals and anthracites have been utilised in arch fired furnaces (often referred to as ‘downshot’ firing) so as to overcome the inherent difficulties of achieving stable and efficient combustion which arise from the lack of volatile material to aid in the ignition, and the low reactivity of the remaining char. The downshot firing system is, however, of higher initial cost than a comparable wall fired system, and if it were possible to utilise low volatile coals in wall fired furnaces there are clear economic benefits. Where the wall firing of low volatile coals has been attempted in the past (predominantly in the former Soviet Union) the experience has been poor - excessively high carbon in ash (typically 20 to 30%), high NO_X emissions (of the order of 1000 to 1300 mg/Nm^3 @ 6% O_2), and poor stability and turndown performance (oil support of around 10% of the thermal input being required to sustain the combustion, even at maximum boiler load). Such a level of performance is unacceptable from both an environmental and an economic perspective and there is a clear requirement for a burner that can be retrofitted to existing plant in addition to need for new installations (to extend the range of coals that can be utilised in the lower cost wall fired combustion system).

The overall objective is therefore to demonstrate that low volatile coals can be successfully exploited in wall fired plant. In the long-term this can only be achieved by means of full-scale plant demonstration, but an essential step towards that goal is to prove the performance of a single full-scale burner and to show how it can be integrated into an overall firing system.

In phase 1 of the project the key mechanisms for ignition and stabilisation of low volatile coal flames were identified, and these were applied in the development of a burner design that could be installed in wall fired plant. To develop the burner process design Computational Fluid Dynamics (CFD) combustion modelling, supported by detailed coal characterisation data (e.g. high temperature volatile yield and char reactivity) provided by Imperial College London (Imperial), was used. Detailed analysis allowed the optimisation of the various design parameters within the constraints of practical plant implementation to be identified. It was shown that the proposed burner design is likely to have a considerably better combustion performance than compared to the current Soviet design.

RESULTS

The laboratory scale testing investigated low volatile coals by conducting characterisation tests in the Imperial College London

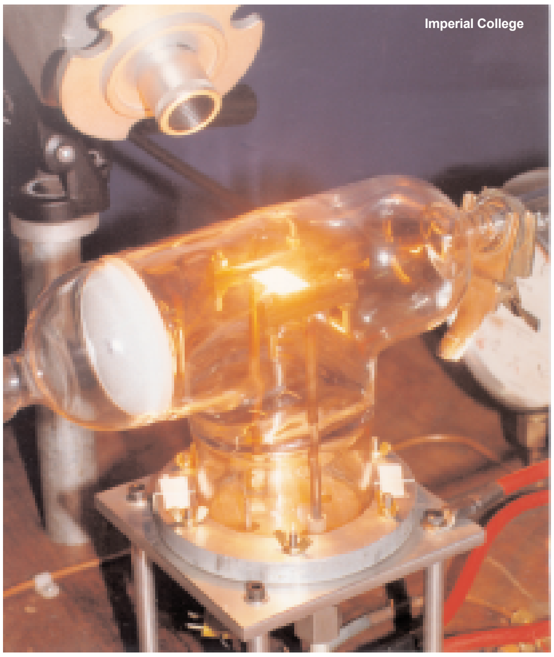

Figure 2. High Temperature Wire Mesh Reactor (courtesy of Imperial College London)

laboratory under conditions that are relevant to PF combustion (i.e. small particles, high temperatures and high rates of heating).

TGA

TGA (Thermo Gravimetric Analysis) non-isothermal analysis is a relatively simple and inexpensive method to characterize coal combustion properties. Three different kinds of profiles can be obtained using the TGA equipment: Thermal-Gravimetric (TG) showing mass loss as a function of time/temperature; Derivative TG (DTG), the derivative of TG curves showing the rate of weight loss as a function of temperature; and Differential Thermal Analysis (DTA) giving the temperature difference between the sample and an inert reference material as a function of sample temperature.

HIGH TEMPERATURE VOLATILE YIELD

The Q factor is a way to relate slow heating devolatilization (from the TGA) and rapid heating devolatilization (from the HTWM). The Q factor is defined as the ratio between the rapid heating volatile yield and the change in proximate volatile matter.

The key feature of the Q factor is that it's been found to be nearly constant throughout devolatilization for a wide range of coals. Thus while more volatiles are released under rapid heating conditions than in the proximate test, due to capture in and within the particles themselves, proportion ‘lost’ in the proximate test is constant. The constant feature of Q factor provides another means to calculate the volatile release and has a potential to be more accurate than the ash trace technique, particularly at lower extents of devolatilization and for low ash coal samples.

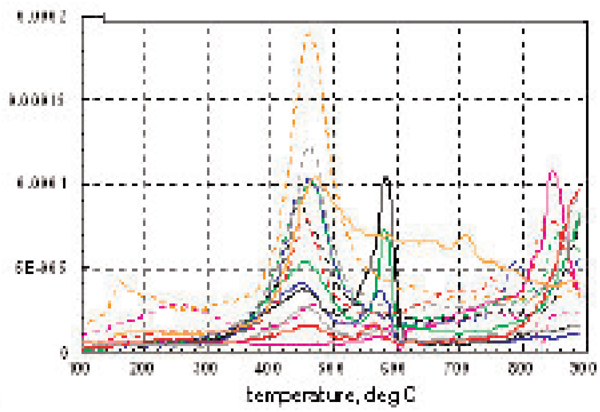

Figure 3. DTG test plot (courtesy of Imperial College London)

EXPLOSIBILITY TEST

The explosibility test is undoubtedly useful to understand the role of volatiles in the ignition process, with the environment produced inside the explosibility chamber regarded as being close to the PF combustion environment. To investigate the extent of devolatilization when coal dust was ignited, TGA analyses were carried out on char samples produced. While samples were not ideal due to ignitor contamination, the trends observed and new residue characterization methods developed were of value in understanding the ignition process. The coal characterisation undertaken was valuable in the selection of the coals to be tested in the full-scale burner, and forms the basis of a laboratory scale approach to assessing the impact of coal properties on ignition and flame stability.

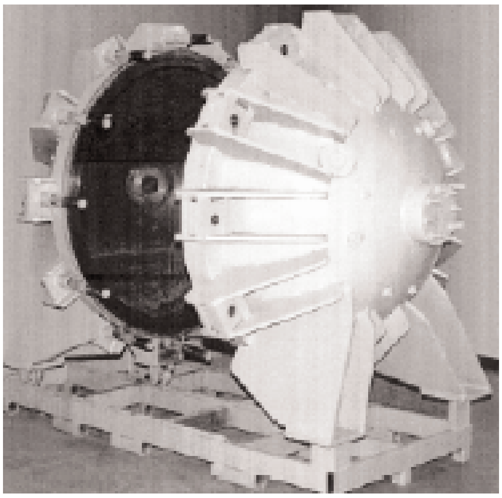

Figure 4. Explosion test bomb chamber (courtesy of NIOSH)

FULL SCALE BURNER TESTS

The proposed low volatile coal burner design was developed from existing wall fired burner technology. The burner is based on the ‘internal’ air staging concept where the combustion air is introduced concentrically around the primary air / pulverised coal in a series of separate annuli. The relative proportion of air supplied to the three combustion air annuli (Secondary, Tertiary and Quaternary) is controlled by sleeve dampers, which form the integral part of the burner design. The provision of swirled combustion air, in combination with the bluff body effect of the core air tube gives rise to a strong recirculation zone immediately in front of the burner - the hot recirculated combustion products provide the heat source required to initiate the devolatilization and stabilise the combustion process.

The objective of the testing was to define the best achievable performance in terms of flame stability and turndown, combustion efficiency and emissions of NO_X for the burner when firing low volatile coals. Parameters investigated during these tests included excess air level, burner damper and swirl settings, and firing rate.

Testing was performed on the MBTF firing a Chinese Low Volatile coal (15% daf volatile matter). NO_X emissions of 597 mg/Nm^3 at 6% O_2 and Unburnt losses of 4.3% GCV were achieved when the burner was set at its optimum geometry.

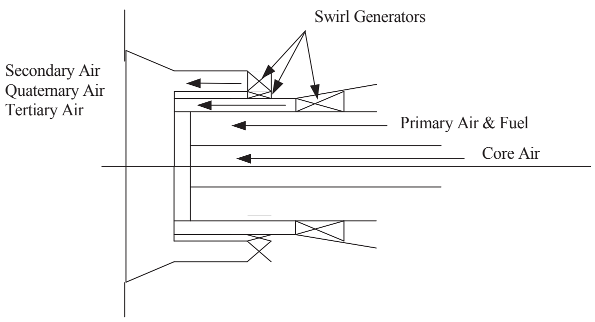

Figure 5. Burner Schematic (courtesy of Mitsui Babcock Energy Ltd)

The burner was further tested firing a UK Low Volatile coal of 10% daf volatile matter. These tests were also successful with NO_X emissions of 436 mg/Nm^3 at 6% O_2 and Unburnt losses of 11.7% GCV when the burner was set at it's optimum geometry. These unburnt loss figures of 4.3% GCV and 11.7% GCV appears at first sight to be high, but it does meet commercial plant limits when differences between the MBTF and plant burner operating Stoichiometry levels are taken into account.

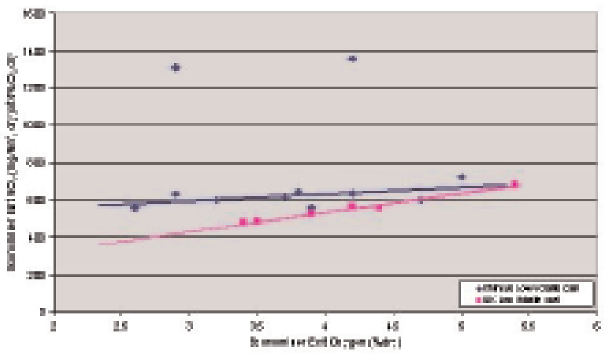

Figure 6. Plot of NO_X vs. O_2 (courtesy of Mitsui Babcock Energy Ltd)

When firing the Chinese coal a stable unsupported flame was achieved to a turndown value of 50% MCR, where as the lower volatile UK coal firing achieved a stable unsupported flame to a turndown value of 70% MCR. The turndown performance was demonstrated to be acceptable, and the results indicate a good level of inherent flame stability for this burner.

AIR STAGING TESTS

Testing was also performed on the NRTF firing a Chinese Low Volatile coal (7.1% daf volatile matter) to establish the effect of the main operating variables on NO_X and burnout under baseline and air staging conditions. The tests undertaken considered the effects of excess air, primary zone stoichiometry and residence time, and were selected to be relevant to a typical modern design wall fired furnace for this coal. The baseline NO_X was 810 mg/Nm^3 @ 6% O_2 for this coal. Reducing primary zone stoichiometry to 1.0 and 0.9 reduces NO_X to 644 and 477mg/Nm^3 @ 6% O_2 respectively.

The NO_X reduction achieved by lowering primary zone stoichiometry demonstrates that air staging is an effective NO_X reduction technology for this coal.

CONCLUSIONS

- As a result of the work carried out to date it has been proven possible to ignite and fire coals having volatile content as low as 10% daf in a wall-fired burner without the use of a support fuel. Furthermore, it is possible to achieve ignition and sufficient devolatilisation in that part of the near burner region where the suppression of NO_X formation occurs through staging to achieve reductions in NO_X emissions. However, the NO_X levels resulting from the firing of low volatile coals are generally higher than those resulting from bituminous coals under similar firing conditions.

- Appreciable NO_X reductions are achievable with air staging when firing low volatile coal using new design wall burners, even with a modest degree of air staging.
- Analytical techniques can be used to aid the assessment of low volatile coals for wall burner firing. Not only can Imperial College London apparatus provide the volatile content and peak devolatilization rates of a particular coal, they can also provide information to help understand the ignition process of that coal. In particular the Explosibilty tests were found to provide a new way to assess coal ignition coal properties and supported the conclusion that early release volatiles are crucial for flame stability and the HTWM tests confirmed that the Q factor, that links the TGA and HTWM tests, remains constant throughout devolatilization. This is useful for predicting the volatile release during devolatilization processes at high temperatures.

POTENTIAL FOR FUTURE DEVELOPMENT

- Firing a low volatile coal with volatile matter ~5% daf on the modified 70MW Mitsui Babcock Energy Ltd wall burner.
- Full Scale plant demonstration of the modified 70MW Mitsui Babcock Energy Ltd wall fired burners firing low volatile coal.
- Further develop coal characterisation utilizing an explosion chamber that has minimal ignitor contamination.

COST

The total cost of this project is £419,543, with the Department of Trade and Industry (DTI) contributing £159,427. The balance of funding was provided by the particpants.

DURATION

24 months - July 2002 to July 2004

CONTRACTOR

Mitsui Babcock Energy Limited
Technology
Porterfield Road
Renfrew
PA4 8DJ
Tel: +44 (0) 141 886 4141
Web: www.mitsuibabcock.com

COLLABORATORS

Imperial College London

Further information on the Cleaner Fossil Fuels Programme, and copies of publications, can be obtained from:
Cleaner Fossil Fuels Programme Helpline, Building 329,
Harwell International Business Centre, Didcot, Oxfordshire OX11 0QJ
Tel: +44 (0)870 190 6343 Fax: +44 (0)870 190 6713
E-mail: helpline@cleanercoal.org.uk
Web: www.dti.gov.uk/cct/

DTI/Pub FES 05/955