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COMBUSTION IN POWER STATION BOILERS

Advanced Monitoring Using Imaging

PROJECT SUMMARY 291

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

The objectives of this project were:

- To develop Self-Illuminated Video (SIV) and image analysis techniques to identify adverse combustion conditions in utility PF boilers.
- To provide a number of quantifiable parameters from video images which can be used to evaluate flame stability and combustion.
- To develop PC software to transfer key parameters to existing data logging systems in real-time.
- To develop systems to transmit and integrate video data from a number of cameras, under actual boiler plant conditions.
- To determine optimum video probe designs and locations for quantitative SIV on utility boilers.

SUMMARY

All project objectives have been achieved. As planned, video capture and processing equipment was installed and tested on actual boiler plant early in the project and the results of practical experience used progressively to inform and refine developments.

This experience has confirmed the importance of proving techniques under actual PF combustion techniques. Work by Imperial on a number of other video projects involving observations in small-scale furnaces has shown that the technical challenges involved in acquiring satisfactory video data are much more severe in full scale plant. Different combustion-related phenomena are also encountered in practice.

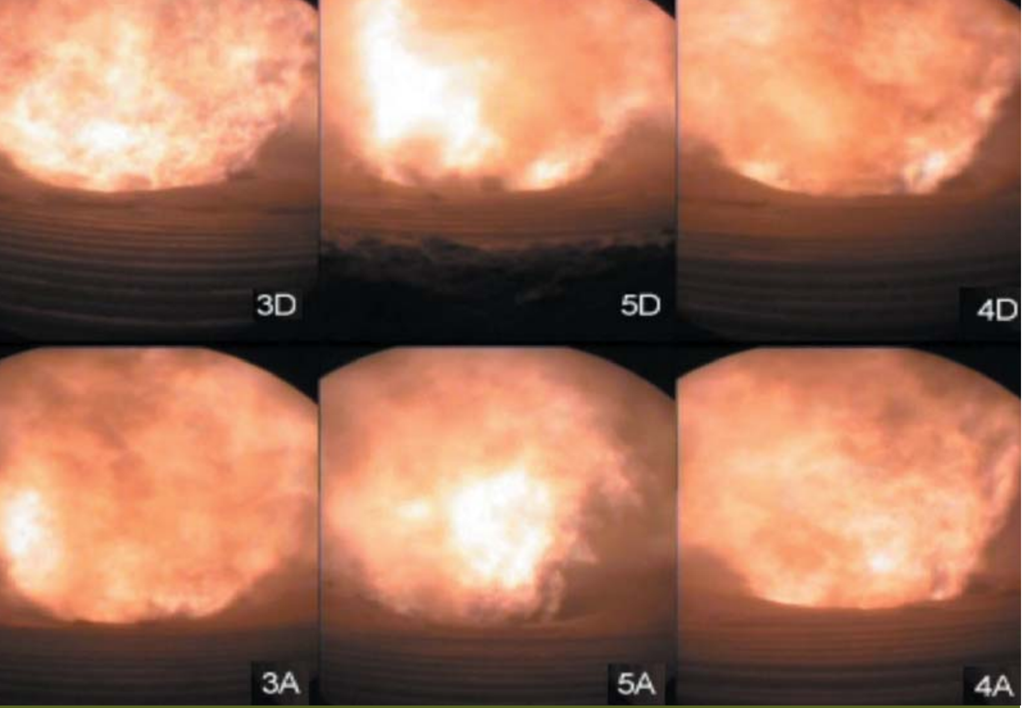

Figure 1. Composite view of six wing burners from a single 500 MW unit

A range of video processing options have been demonstrated. These include a method of classifying flame images into known categories using Principal Value Decomposition (PVD). This applies a similar technique to that employed in the field of face recognition. It was shown that the number of eigenimages used to classify the flame images did not affect the classification accuracy greatly. Additional algorithms were developed and applied to quantify localised instability in the flame root for single burner observations when suitably-detailed images became available in the last phase of the project.

The final version of the video processing was operated continuously and reliably at a utility power station for over a year.

It was demonstrated that quantitative SIV data could be obtained from cameras conventionally fitted in the rear wall of the furnace, principally to observe all burners on start up. Problems were, however, experienced when slag on the rear wall intruded into the field of view. The most viable alternative observation point was considered to be in the corner doors that are fitted at or around burner centreline height on all PF units for manual observations. Trials were undertaken on three plants, with single boiler doors modified with a camera port. These proved successful and towards the end of the project all corner doors were modified on a 500 MW wall fired unit. Specialised probe designs for this application were built and tested.

Trials were also undertaken to examine the feasibility of making short-term video observations through the oil gun tube in out-of-service burners.

BACKGROUND

Video camera probes are widely used on UK boilers, mounted on the rear wall to observe oil gun flames on the opposing front wall during start up, as a safety measure. Once the boiler is under load, the much larger coal flames from the burners extend close to the rear wall and there is a high dust loading because of the ash in the coal. As a result, no distinct flame images are visible but differences in the colour and pulsing frequency of the general 'fireball' are visible, and are sometimes used by operators as a qualitative guide to combustion conditions.

The challenges for the project would be to verify whether or not rear wall camera images did indeed contain useful information, and if so to develop hardware and software to process this data in real time under power plant conditions.

It was also considered likely that useful data on combustion performance could be obtained from side views of individual flames in the vicinity of the quarl.

It was anticipated that wing burners could be observed through corner doors, although these would have to remain accessible for manual inspections. Other methods to view inner burners would also be desirable. As well as requiring a suitable video processing computer platform for use on boiler plant, for this application new types of video probe would be required. For commercial viability, a compact probe would be required that could provide an appropriate field of view and good image quality, high reliability, but yet is designed so that the costs associated with catastrophic air supply failure are not excessive. This last criterion is essential since, while plant air supplies will usually be

Figure 2. Oil burners in a corner fired unit during the start up sequence

reliable, large numbers of cameras would be affected by air supply failure if a significant number of burners were to be monitored.

An example of long-term combustion monitoring trends obtained using the prototype system with a rear wall camera is shown in Figure 3. The plant performance characteristics and Combustion Quality Index (CQI) values for a utility power station are shown for three weeks of operation. The CQI values are shown only for periods of full load (>90%) and for the two most commonly-used mill patterns over this period. Changes in CQI during operating periods are evident, probably indicating that some aspects of combustion have still not completely stabilised over the relatively short periods at full load.

VIDEO PROBE PLACEMENT FOR COMBUSTION MONITORING

It was demonstrated that quantitative SIV data could be obtained from cameras conventionally fitted in the rear wall of the furnace, principally to observe all burners on start up. Problems were, however, experienced when slag on the rear wall intruded into the field of view. This could generally be detected automatically, but during these periods valid SIV results could not be obtained. Extensive work was undertaken to improve video probe performance, but no solution could be found for very severe slagging – a jet of air from a camera could not be guaranteed to disperse heavy slag flows occurring at some distance from the camera over a sufficiently wide angle to keep the complete field of view clear. This camera position was also limited when firing coal because only the burners immediately opposite the camera could be observed – all other burners were largely obscured by their flames. Despite the attraction of using the video probes that are already fitted to many plant, later development work therefore concentrated on finding alternative camera positions. Plants burning weakly-slagging coals might still be suitable candidates for this type of installation, but cannot be relied on for UK plants which all source a wide range of coals.

VIDEO OBSERVATIONS FROM CORNER DOOR LOCATIONS

The optimum observation point was considered to be in the corner doors that are fitted at or around burner centreline height on all PF units for manual observations. Trials were undertaken on three plants, two wall fired and one corner fired (Figure 2), with single boiler doors modified with a camera port. These proved successful and towards the end of the project all corner doors were modified on a 500 MW unit. Excellent results were obtained although, as Figure 1 shows, access to individual burner images has emphasised the inevitable complexity of multiple burner installations when single parameters are manifestly not able to represent the actual range of combustion characteristics that may be encountered in practice.

Video probes for corner door applications were developed through prototype and pre-production stages by Imperial and IST, with a number of options being tested under actual combustion conditions. For commercial viability, a compact probe is required that can provide an appropriate field of view and good image quality, has high reliability, but yet is designed so that the costs associated with catastrophic air supply failure are not excessive. This last criterion is essential, since while plant air supplies will usually be reliable large numbers of corner door cameras would be affected. Protection methods, such as a reserve air supply and automatic retraction, cannot be deployed on corner door installations, partly because of the cost for a large number of such units but also because bulky equipment cannot be installed in the corner doors which must remain accessible for manual inspections.

OIL GUN TUBE VIDEO PROBE TRIALS

Two long reach probe prototypes, using different design approaches, were tested but both were only partially successful due to the intense radiant heat load from adjacent burners and the long insertion length of five metres. Useful experience was gained, however, which it is expected will contribute to a successful design in the future.

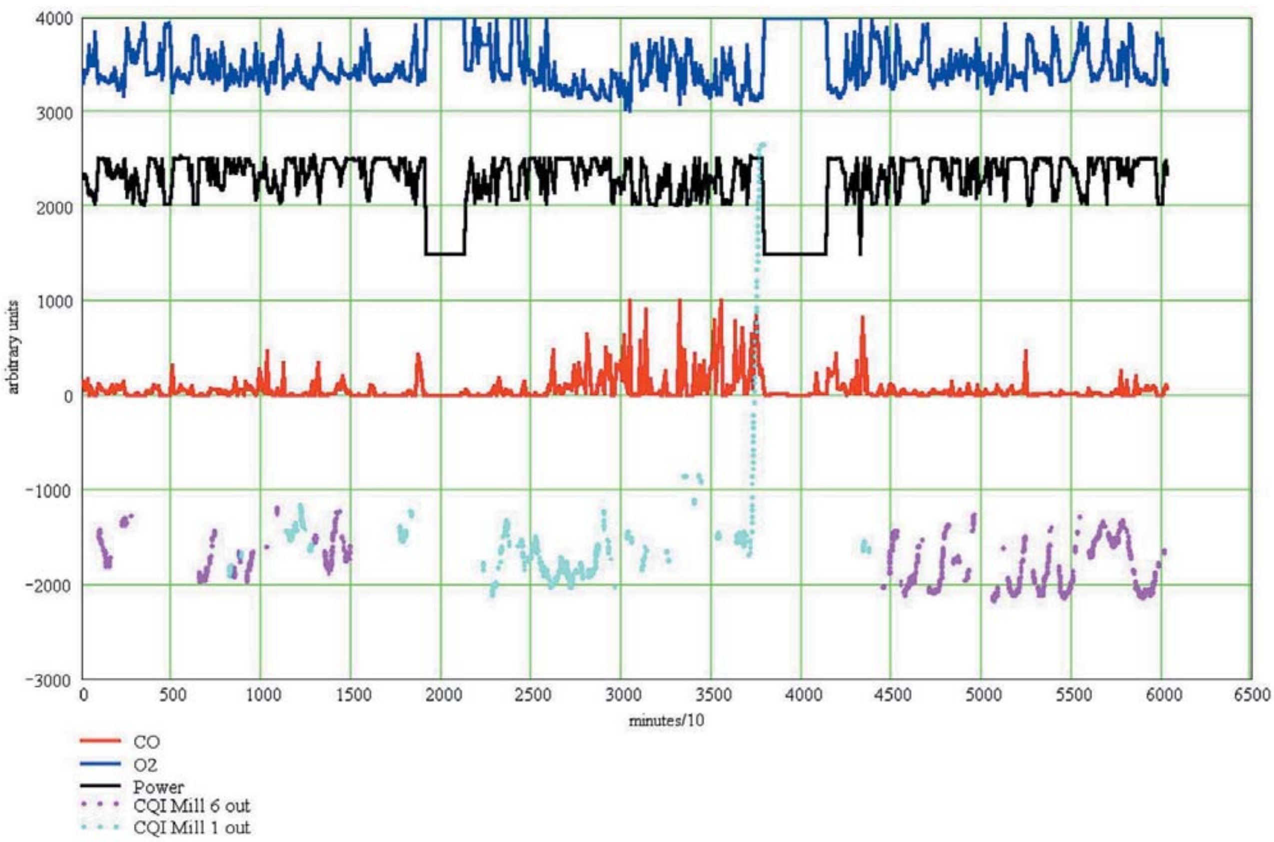

Figure 3. Combustion quality index for 500 MW unit over three weeks

CONCLUSIONS

- Video probe location is the key factor for quantitative SIV observations on utility boilers. The single furnace rear wall video probes widely fitted to observe multiple oil burners on start up are not as well-suited to continuous video analysis as video probes in corner door locations.
- Corner door cameras have been demonstrated to give reliable and useful images for quantitative combustion quality assessments. Special designs are required, however, to accommodate the need for a large number of probes that can be reinstated after a cooling air supply failure at an acceptable cost. Corner door modifications for probe mounting and satisfactory low-cost video connections under boiler plant conditions via twisted pair wires have also been demonstrated.
- Progress has been made towards a design for a novel probe to view any burner through the oil burner tube of an adjacent out-of-service burner.
- A PC-based video processing platform has been developed and demonstrated for extended periods under plant conditions. Video data from a number of sources can be processed and appropriate 4-20 mA signals generated for simple interfacing to existing plant data logging systems. Any software-based processing algorithms can be implemented.
- A range of processing algorithms to derive quantitative combustion quality data from flame video images have been developed and tested. These include advanced principal value decomposition methods that may also be used to store flame images for later inspection with very high compression ratios.

POTENTIAL FOR FUTURE DEVELOPMENT

A sound basis for the development of commercial systems has been established, although since the inception of the project the UK electricity industry has been under severe financial pressure and the immediate market for all types of advanced combustion monitoring equipment has therefore been reduced.

Depending on commercial interest, scope exists to develop both the new video probe concepts and image processing and systems methods into commercial products, either individually, or as a combined system. Video monitoring is now also established as a technique that is routinely available to complement other combustion research studies on full scale plant.

Two classes of commercial application are envisaged, for continuous monitoring and combustion optimisation respectively.

a) Continuous monitoring

- Permanent probes are installed on all corner doors to monitor wing burners.
- Probe technology allows refurbishment of multiple probes at a reasonable cost in the event of cooling air failure.
- Operators are able to gain useful information from real time video display in control room.
- Digital recording for retrospective performance analysis -able to go directly to view at any time.
- Numerical processing to derive one or more combustion quality indices provide objective measures to supplement operator judgement.

b) Combustion optimisation

- Burner viewing from all corner doors, advantageous if this viewing was simultaneous but not essential.
- Additional probes to view inner burners through oil burner tubes, with appropriate mills out of service.
- Numerical processing to give a limited number of numerical parameters is technically feasible, but almost certainly more useful to employ image processing techniques to generate complete images that highlight aspects of the flames that cannot be seen by eye (eg Gibbins, J., Lin, Y-M., Bowden, S. and Cameron, S., 2001 Video observations of full-size pulverised coal flames, Comb. Sci. Tech. 162, p263-280).

COST

The total cost of this project was £304,762, with the Department of Trade and Industry (DTI) contributing £114,451 and the project members the balance.

DURATION

44 months – March 2000 to October 2003.

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FURTHER INFORMATION

For further information about this project see contractor report URN 04/1797 R264 available from the Helpline.

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