A PRACTICAL ON-LINE SOLUTION TO CONTROL ASH DEPOSITION AND IMPROVE BOILER EFFICIENCY

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IAN S. DAVIDSON

INTRODUCTION

An important stage in the operation of plant and process boilers is the conversion of water into steam by the transfer of heat from burning fuel to the water which passes through the tubes that form the surface of the combustion chamber. Heat transfer from the flames to these surfaces is almost entirely by radiation, and thence by conduction through the tube walls to the water.

During the operation of coal and oil fired boilers significant amounts of ash/slag form on the water walls of the combustion chamber. These deposits substantially reduce the heat transfer potential of the water walls by modifying the absorptive properties of the surfaces and by establishing a layer of low thermal conductivity material over the heat transfer sections of the boiler. The formation and properties of these deposits are a function of both boiler conditions and the mineral content of fuel. Such factors as high local fuel/air ratio, flame impingement on the furnace walls and variable ash mineralisation can result in uncontrollable fouling conditions within the boiler.

The heat transfer surfaces are a major feature in the economies of fossil fuelled boilers. Poor heat transfer conditions seriously affect economic boiler operation. In a typical boiler even a small fraction of efficiency loss due to unguided heat transfer control and operation can be translated into thousands of pounds.

The BMS Furnace Cleanliness Module' is a stand alone computer system designed to control slag in all areas of the boiler. It uses heat flux sensors to measure the slag levels at positions inside the boiler. The signals from the sensors are passed to Data Acquisition Units that are mounted local to the sensors. All the signals are processed in the Data Acquisition Unit and then passed to the computer which is usually situated in the control room.

When the computer decides that a position needs to be cleaned of slag, it automatically operates the sootblower (or group of sootblowers) in that area. The ability to sootblow one area is, of course, dictated by the type of sootblowing equipment available. In order to achieve optimum results it is desirable to be able to operate furnace sootblowers individually. However modified software is available to take account of whatever sootblowing restrictions are in place. The exact time that the computer operates the sootblower is calculated using complex equations.

SENSOR DEVELOPMENT

Introduction

Any instrument designed to measure the absorbed heat flux within the boiler furnace has to fulfil a number of criteria.

The environment is severe, nevertheless any installed sensor should have an operational life at least that of the period between major overhauls, which may be as long as four years.

The presence of the device should not result in any modification of the ash deposition behaviour, or of the steam/water flow. The device should measure representative heat flux values from the clean condition to the heavily ashed state. Numerous methods have been advanced over the years for measuring boiler heat fluxes. The general method for any device is to arrange for the heat flux to develop a temperature gradient in a known geometry and this gradient is measured to determine heat flux.

Principle of Measurement

The instrument described is designed for use as a permanently installed device and employ the thermally guarded cylinder technique for measuring heat flux. This method makes use of the temperature gradient along a cylinder of known thermal conductivity when heat is applied to one end with the other end connected to a heat sink. The temperature gradient is measured by thermocouples at a known spacing along the cylinder. To ensure that the heat flux within the cylinder is axial it is surrounded by a thermal guard having a temperature gradient similar to that along the measuring cylinder.

For the practical measurement of absorbed heat flux within the boiler, the sensor heatsink is desirably the boiler tube. Thermal bonding of the sensing cylinder and guard to the tube should be as near perfect as possible and must not deteriorate during the life of the device. The combined thermal resistance of the sensor and the bond should be designed to be as low as possible to ensure minimal interference with the absorbed flux. Similarly surface projection of the device both physically and thermally must not interfere with the nature or thickness of ash deposits.

Practical Construction

The objective with the BMS 'TT Sensor' was to develop a boiler heat flux measuring instrument that was as close to the ideal as possible. The sensor has an external profile that is identical to the boiler tube, a surface temperature elevation that is minimal facilities for determining tube metal and internal fluid temperatures. All measurement thermocouples are duplicated.

The TT Sensor' is constructed from a length of boiler tube containing a locally thickened wall section within which is incorporated the measuring cylinder. This construction is achieved by dimpling and then filling the depression using an automatic spiral welding process. The measuring cylinder is accurately machined into the weld fill by electrical discharge machining. This method ensures that the walls of the parent tube are untouched and the mechanical integrity of the tube unimpaired.

It is an essential feature that its surface profile is identical to that of the undisturbed boiler tube, which in combination with the thermal bond provides the near ideal construction.

Simple modelling confirms that the device operates with a surface temperature elevation of 12.5 ^{o}C per 100 kW/m^2 of heat flux. The resultant small but predictable reduction in heat flux can be compensated for during calibration.

Calibration

With usable limits the calibration of each instrument can be theoretically established using a knowledge of the cylinder thermal conductivity and the spacing of the sensing thermocouples. During manufacture careful material selection and engineering are employed to maintain sensor conformity. Nevertheless an individual calibration is an essential requirement.

SYSTEM OPERATION

No two boilers operate in the same manner, even though they may be adjacent to each other and of the same design.

Real time boiler variables change both, a) on a short term day to day basis (eg. change in coal type) and, b) on a long term deterioration basis between overhauls.

This problem is compounded by the fact that, not only do global boiler variables affect overall boiler slag deposition, but local changes (eg. Burner tilt change, mill group change,etc) also tend to make local boiler areas unique. Therefore, a system that uses a rigid set of global principles to control the overall boiler slag build-up can be most inefficient at addressing local slagging conditions. This is made worse by the fact that normal identification of slagging is given by second order variables, such as superheater temperatures,etc.

It has been found in earlier investigations (Ref 2, Case Study 2) that there is an optimum time to operate sootblower systems. This `optimum time' is a function of various boiler parameters such as coal chemical composition, ash sintering temperature, ash thickness, furnace exit gas temperature etc. Operating boiler cleaning systems on an `optimum time' basis has been shown to provide many advantages. It is important, therefore, that a slag control system approaches each sensor area individually and on a changing basis.

The BMS FCM uses two different methods to calculate the optimum time to sootblow. A `best fit` analysis is undertaken to produce the most efficient algorithm. This means that individual boiler areas are treated on an individual basis and are always kept at their optimum cleanliness. Sootblowers can then be operated manually or automatically on instructions issued from the computer.

The ability of the system to modify its operation methods with reference to real boiler conditions means that sudden changes can be automatically accounted for. Therefore, a change to a coal type, for instance, that has a higher propensity for slagging need not cause uncontrolled slag build-ups and lead to poor boiler efficiency, particularly during this transition stage.

Optimised sootblowing.

It can be seen that removing slag selectively from the furnace walls has many benefits, but judging removal time by simple heat flux level will lead to incorrect and hence inefficient sootblower timing. In order to achieve maximum efficiency slag must be removed at exactly the right moment. The BMS FCM uses a set of changing algorithms that determine when the slag layer is in exactly the right condition for removal. This condition is when the surface of the slag just starts to sinter and the slag mass becomes interconnected as opposed to being in the particulate phase.

This 'Optimum Sootblow Time' can only be identified by using absorbed heat flux measurements on a time delayed frequency analysis basis. The data from this is then analysed using a modified Fourier method to provide an equation that is true for its local area. This equation is then compared with a linear related equation and a best fit approach, using both equations, is then applied. The effect of this optimisation routine can be seen in Fig 1 which shows a graph of 2 different sets of boiler data. The thin line shows a system where sootblowing takes place when the slag builds up to a set limit. This is an unoptimised system. It can be seen that when unoptimised sootblowing is in operation, 6 sootblows are required in the period and the total heat transfer is only 2800 kW/m^2. For the optimised sootblower system (Boiler Management Systems International

Ltd Furnace Cleanliness Module) during the same time period it can be seen that only 2 sootblows were required and the total heat transfer is 4200 kW/m^2.

The computer software calculates the correct optimisation equation by using local heat fluxes and load. The system can calculate the optimum sootblow time, (which is much dependant on ash sintering temperature, local gas conditions,etc) without the need to have these variables input.

Trials have shown conclusively that using real local slagging data will increase boiler efficiency in many areas and that the majority of boilers (even those with no apparent slagging problems) are currently operated inefficiently from a slagging/fouling viewpoint.

The furnace area of any boiler is the most important in terms of heat transfer with the majority of heat transfer taking place in this area. It therefore follows that the furnace will benefit from improved heat transfer more than other boiler areas. Optimising sootblowing in the furnace area of a boiler has the following advantages:

When a full furnace sootblow is undertaken the potential heat transfer in the furnace increase greatly and the furnace exit gas temperature will fall as a consequence of this. Regular sootblowing will cause a 'saw tooth' effect on the total furnace heat transfer. Fig 2 shows that every time a sootblow is undertaken the Superheater and Reheater temperatures fall correspondingly. Now, whenever either of these temperatures leave the turbine stop valve design temperature of 565^o C the total efficiency of the generating cycle is reduced. In Fig 2 the grey areas are a summation of losses. In this case they amount to about £97K/year. The much smoother furnace exit gas temp that is produced by the SCS causes far less disturbance of the Superheater/Reheater temps and therefore lower steam temperature losses.

The same problem of sudden change in FEGT is also reflected in the attemporation sprays. Smoothing the FEGT will remove the high spikes of spray and make very substantial savings. In the case of Fig 3, £281K/year.

*The data in Fig 2 & 3 is data from a UK Power Station.

The generation of thermal Nox is a function of FEGT temp. It has been shown that by using the BMS Slag Control System NOx levels can be reduced substantially. Appendix 1 + 2 show articles published in 'Clear Stacks' in the U.S. and give details how Dairyland Power reduced Nox levels using the Slag Control System.

Improved heat transfer in the furnace will reduce furnace exit gas temperatures and therefore will reduce the potential for 'ash carry over' into the back pass areas, thus reducing back -pass ashing.

Very large financial savings can be gained by improving furnace heat transfer due to reductions in attemporator spray rates. This is particularly pertinent for furnaces with limited surface areas.

Lower furnace exit gas temperatures will lead to lower backpass temperatures and make it possible to move closer to design temperatures at the air heaters, thus increasing efficiency.

An optimised sootblowing system, will reduce total furnace area sootblowing by only operating sootblowers when necessary, and then only in the local area where sootblowing is required. This leads to a significant decrease in steam usage (for steam sootblowers) and an increase in MTBF (Mean Time Between Failure) of sootblowing systems.

Sootblowing will only take place on fouled tubes therefore any erosion/corrosion caused by blowing clean tubes is completely removed.

SYSTEM FINANCIAL ASPECTS

Financial savings that can be gained from installing a FCM fall into two categories: those that can be quantified and those that cannot. Some areas that can be quantified are; better control over back pass temperatures, reduction in sootblower usage, increase in furnace heat transfer, reduction in back pass temperatures, reduction in back pass slagging etc. Among the areas that show improvement, but are impossible to quantify are; reduction in tube erosion, reduction in occurrence of slag bridges or slag related damage.

Also more long term advantages where very substantial savings can be made are; increases in plant availability and plant life extension. Although these improvements can be quantified in terms of numbers (i.e. 9% improvement in furnace heat transfer) it is almost impossible to quantify them in monetary terms.

CONCLUSIONS

Trials of the BMS FCM has highlighted many potential areas where boiler efficiency can be improved. These can be summarised as follows:

Changes in fundamental boiler operating parameters (eg. coal type) can cause major changes in boiler operation. These changes have proven to be much greater than has always been assumed and as such have proved to be, in some instances, the cause of many boiler problems.

The assumption that boiler slagging is random in nature is not strictly true, as it was noted that some areas showed definite slagging patterns. Sometimes these patterns lead to detrimental conditions being established and the potential for localised problems, such as tube damage, is increased. A control system using heat flux sensors can identify problem areas and in many cases can reduce, or remove, the cause.

The risk of potential slag bridges and slag related waterside tube erosion can be reduced by using a sensor based system to monitor and control slagging.

Savings of over $1.8 million have been seen in trial boilers simply by reducing spray rates and back pass temperatures.

Systems using global variables and/or fixed rule algorithms to control boiler heat transfer cannot do so accurately due to the very localised nature of the slagging process and the tendency for conditions to change quickly and without any external signs.

It has been shown that a sensor based system that controls boiler slagging reduced sootblower operations by 46% and increased overall furnace heat transfer by 9%.

A slag control system that is confined to the furnace alone can provide many `knock on' improvements in boiler efficiency in areas such as: lower back pass slagging, lower gas velocity in the back pass, better furnace heat transfer efficiency, lower inlet temperature at the air heaters. Obviously a system that includes the back pass areas will further enhance this improvement.

Substantial financial savings can be obtained by controlling boiler heat transfer surfaces, with system pay-back periods of one year easily achievable.

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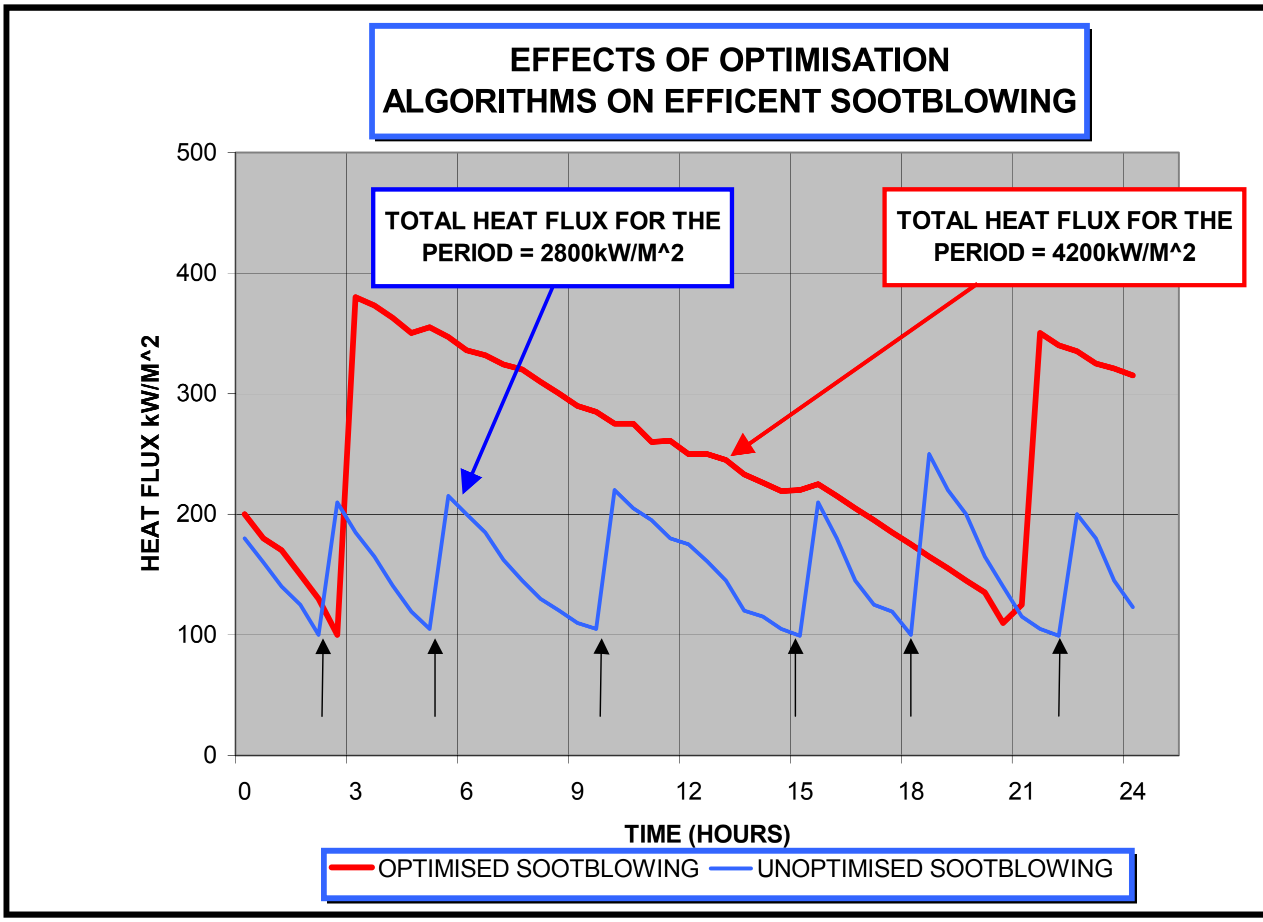
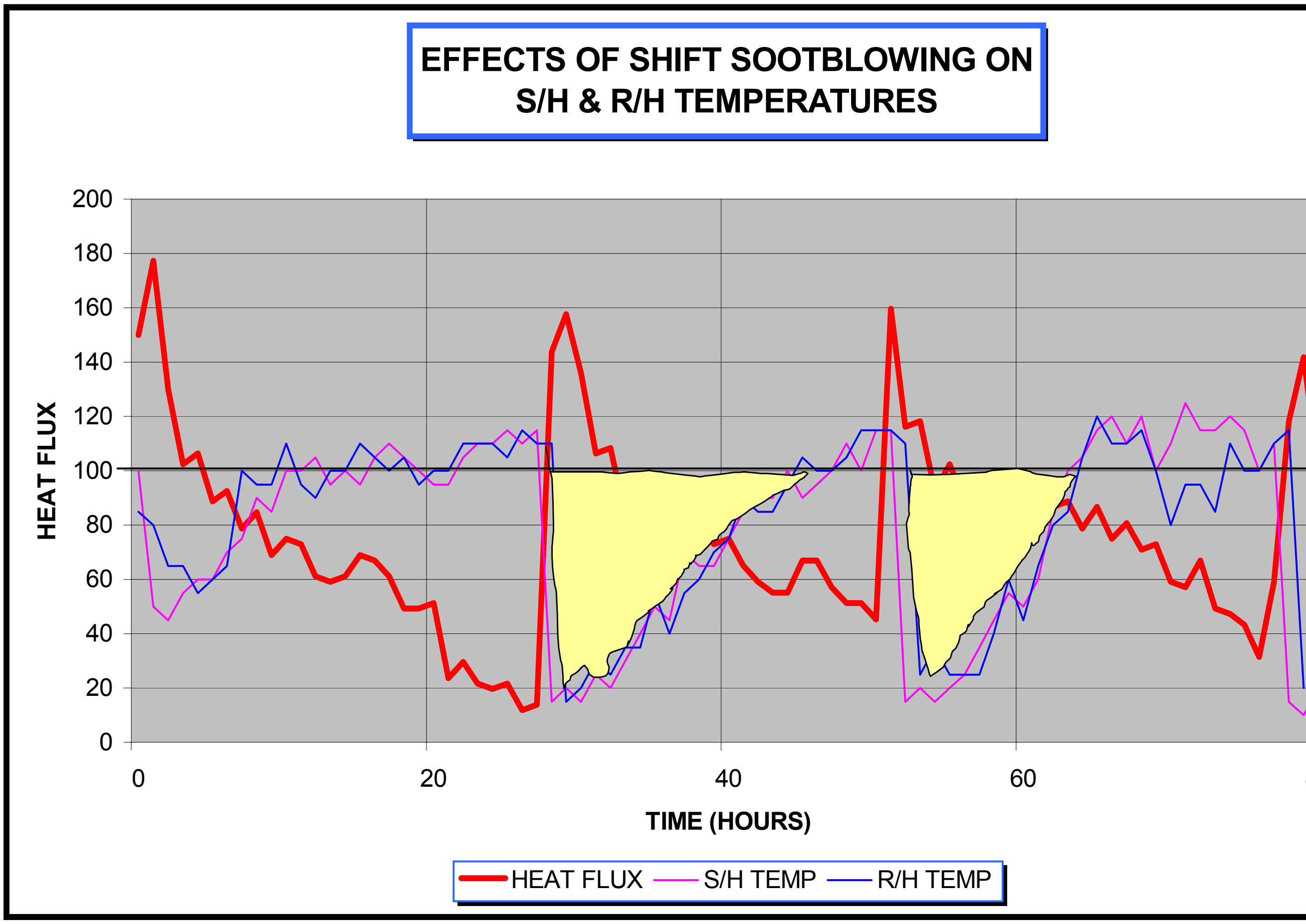


EFFECTS OF OPTIMISATION ALGORITHMS ON EFFICENT SOOTBLOWING

TOTAL HEAT FLUX FOR THE PERIOD = 2800kW/M^2

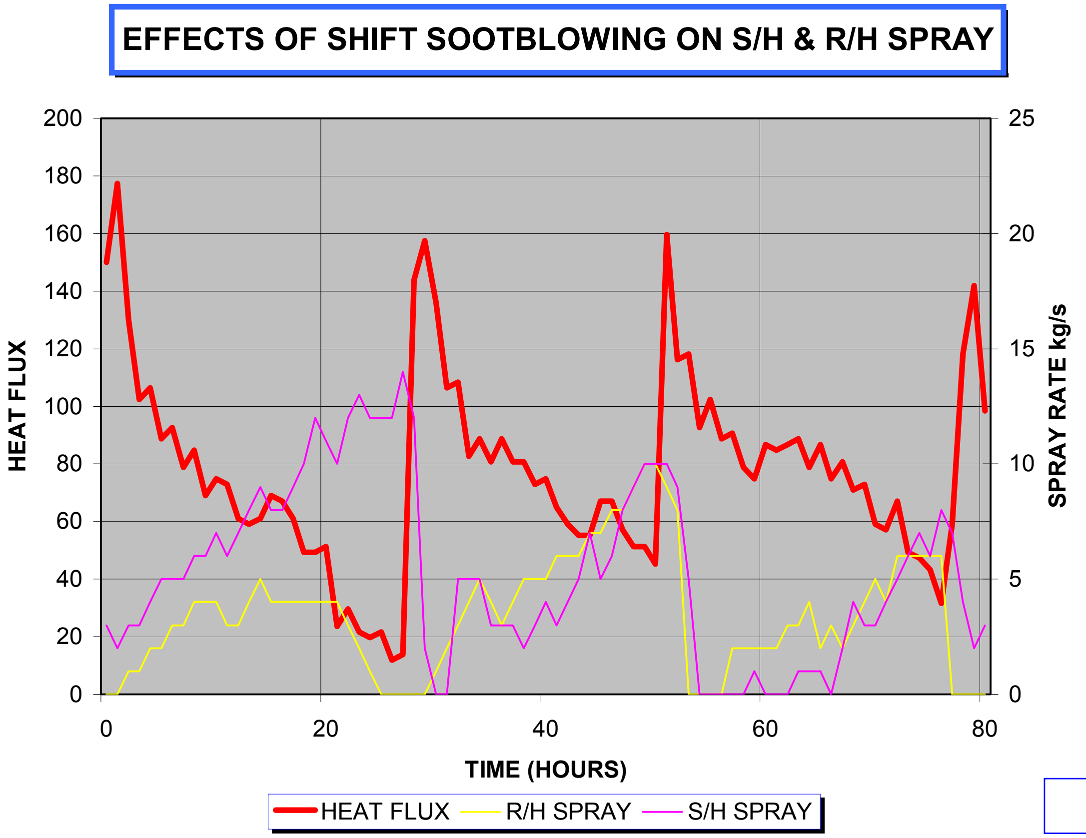
TOTAL HEAT FLUX FOR THE PERIOD = 4200kW/M^2

FIG 1



EFFECTS OF SHIFT SOOTBLOWING ON S/H & R/H TEMPERATURES

FIG 2



EFFECTS OF SHIFT SOOTBLOWING ON S/H & R/H SPRAY

FIG 3