Introduction

Corrosion and thermal scanner systems were originally developed by Rowan Technologies in the late 1990s. The driving force behind the technologies’ development was the desire by power station boiler operators to monitor, in real-time, the fireside corrosion of tube membrane walls. Excess corrosion of these walls can lead to complete tube failure, resulting in boiler shutdown for immediate repair.

The first trial scanner system was installed at Drax Power station, UK, in 1999 and, since then, around fifteen commercial systems have been installed on large power generation boilers in the UK, US and South Korea, each with between 660-880MW generation capacity.

Scanners are able to monitor the corrosion of large areas of boiler wall. They do this using arrays of sensors that are welded to the external (cold-side) tube wall faces. Corrosion/erosion measurements use electrical resistance principles where thinning of a metal increases the measured electrical resistance. The tube’s electrical resistance is also heavily temperature-dependant and so it’s necessary to measure tube temperatures and compensate for any variations.

During the original scanner trials it became clear that the scanners’ tube temperature data could be used independently of resistance measurements to monitor and map the tube wall’s thermal behaviour, including tube wall heat flux. As a consequence, scanner hardware and data quality has been improved and refined to maximise both its corrosion and thermal monitoring capabilities.

The latest scanner systems have the capability to control and monitor over 500 sensor locations, allowing monitoring of all four walls of the largest power generation boilers. Smaller scanner systems have also now been developed that are simple to install and cater for up to around 50 sensor locations.

The scanner’s hardware is also suited to other monitoring applications: not just boilers and incineration plant, but also to pipelines and storage vessels i.e. surfaces
During Resistance Measurements, Current flows through the Whole Tube Cross Section

where ‘uniform’ (rather than ‘pitting’) corrosion takes place or surface temperatures and/or heat flux need to be monitored. Systems have also been used to provide insights into the causes of tube wall cracking.

In this paper we describe the scanner’s measurement and analysis techniques and present an overview of scanner applications.

**Measurement Techniques**

Scanners use electrodes and sensor that are welded to external tube surfaces. In the case of boiler membrane walls, sensor locations are typically spaced 1-2 meters apart and arranged in rows and columns to form two dimensional sensor arrays.

Two thermal sensors are welded at each sensor location and, if corrosion/erosion monitoring is required, a separate current electrode is also welded in place.

To monitor the corrosion or erosion of the fire-side tube walls, a current is passed through the wall between adjacent sensor locations that are typically spaced 1-2 meters apart. During its passage through the wall, the current flows through both fire-side and cold-side tube walls and, as there are no physical boundaries to current flow, it has the freedom to spread out on its journey between current source and sink. As the fire-side tube wall thins due to corrosion, so the measured resistance will increase and it is these increases in measured resistance that are translated into metal loss and hence corrosion rate. Note that the corrosion is calculated assuming ‘uniform’ metal loss between adjacent sensor locations as illustrated in the diagram above.

Where sensor arrays are used, current is passed horizontally, diagonally and vertically between adjacent sensors in sequence, forming a matrix of measurement areas, until the whole array is fully ‘scanned’ top

**Resistance Measurements performed in Sequence allow Corrosion Maps to be Produced. Corrosion Rates are shown in nm/hour – Higher Rates are shown in Lighter Shades.**
Finite Element Model of Temperature Gradients through Boiler Tube Cross Section

Tube temperatures are also measured and these are used to compensate for temperature variations.

Metal loss maps are then produced that reflect increases in resistance for the whole measurement matrix. Metal loss can readily be translated into corrosion rates or tube wall remaining thickness (if the start thickness is known).

The technique described above is applicable to monitoring corrosion and erosion on a multitude of metal surfaces or membranes and indeed, the scanner hardware (described in more detail below) is suited to a variety of industrial applications. Monitoring corrosion of boiler walls is probably one of the more challenging applications due to the high and dynamic wall temperatures. Note however, that the technique does not lend itself to monitoring corrosion pitting unless the pitting is particularly severe and ‘uniform’. Monitoring of crack growth is also possible: our website has further details.

Scanners are often employed for their ability to monitor and map metal temperatures and heat flux. To achieve this, sensors are welded both to the cold-side tube membranes (i.e. between tubes) and also tube crowns. Information from these two sensors, combined with finite element heat flow modelling for the boiler in question, are used to calculate mean tube temperatures, estimated fireside tube temperatures and heat flux.

Rapid scanning of all sensor locations enables thermal maps to be processed and displayed in ‘real-time’. In the case of power station boilers these can be used, for example, to monitoring the effectiveness of tube wall cleaning. The scanner’s thermal information has also been employed to help identify the root causes of surface cracking of fireside tube walls.

**Scanner Hardware**

Two versions of the scanner hardware are now available. Our larger multi-enclosure systems are designed to cater for multiple monitoring areas with up to 500 sensor locations, whilst our smaller ‘mini-scanners’ are designed for small monitoring areas of no more than about 50 sensor locations.

**Multi-enclosure systems** have a main control unit located near the monitoring areas. This control unit may also house the data logger, however the logger can be located some distance away if fibre-based serial communications to the control unit is used. The control unit and logger communicate with electronics PCB enclosures positioned local to the monitoring...
areas. A single PCB serves one sensor location and field cables run directly from PCB to sensors.

Additional PCBs can be added to existing multi-enclosure systems to expand existing monitoring areas or to create new ones. It's also possible to incorporate both our corrosion probes and Active-HFC (Heat Flux and Corrosion) monitors into the same electronics to create a single multi-purpose system.

Using an Ethernet link, the scanner data logger can connect to plant servers and/or data analysis and presentation PCs located in a control room or office. This allows the latest scanner data to be processed and displayed in the form of maps or time-dependant traces using the company's bespoke data analysis software.

Our **mini-scanner technology** is a relatively recent development. All mini-scanner hardware is housed in a single enclosure that’s installed near the boiler wall and these systems typically serve up to 50 sensor locations. These systems are powered from a low-voltage DC supply, are simple to install and have on-board computing power. Serial or Ethernet communications allows data to be transferred to a data analysis and display PC if so desired. These systems are designed for smaller more-localised monitoring locations whilst helping to keep cable and enclosure installation to an absolute minimum.

**Drax Power Station, UK – Site of Five Scanner Installations.**

Drax has six 660 Megawatt subcritical power generation boilers, supplying about 8% of the UK’s electricity requirements. Rowan Technologies has been working closely with Drax for over twenty years and in 1999 the first scanner was installed on a sidewall of Unit 4 boiler to evaluate the performance of a small area of tube weld overlay and compare results with adjacent bare tubing.

Following this successful trial, a much larger system was installed on Unit 1 in 2001, covering large areas of both sidewalls using a total of 240 sensor locations. In 2005 a smaller scanner was installed higher up the boiler to monitor possible changes in corrosion behaviour following boiler modifications to help reduce NOx emissions. Both these early systems will remain in operation until at least 2017.
Since these early installations, Drax has now installed large multi-enclosure scanner systems on three other units at Drax, together with a smaller thermal-only scanner. The sum total of all scanner sensor locations at Drax now exceeds 1200.

Drax is undergoing a gradual transition from burning coal to burning biofuels and this was one of the driving forces behind more recent scanner installations: changing fuels changes the fireside corrosion chemistry and so the scanners are helping Drax to closely monitor any changes in fireside corrosion behaviour on the tube walls. Drax have also installed twelve of Rowan Technologies’ corrosion probes to help monitor corrosion behaviour in the superheater and reheater tubing; these probes are interfaced with the scanner hardware to create multi-purpose monitoring systems.

Drax also uses the scanners to keep a close eye on thermal behaviour of the tube walls: corrosion scans take place every 3-4 hours and these are interleaved with thermal scans at two-minute intervals and these provide maps of tube wall surface temperatures and heat flux.

All the scanners are controlled, via copper and fibre communications links, from data loggers in a central ‘logging hut’. The loggers route scanner data to a ‘virtual’ data server via the plant network. Rowan Technologies also has remote access to the data loggers, allowing regular remote system checks to be performed, data to be collected and regular reporting to be provided to Drax on corrosion and thermal behaviour.

South Korea – Seven Scanner Installations

South Korea has a number of large and modern coal-fired power plant, the latest of which have spiral-wound super-critical boilers, each with a typical generation capacity of between 660 and 1000 megawatts.

Six scanner systems have now been installed on both sub and supercritical units at three plants. Each system, typically comprising around 220 sensor locations, monitors all four boiler walls. Of primary interest is the scanner’s thermal mapping capabilities, in particular heat flux monitoring. However, the systems are also performing long-term corrosion monitoring by performing resistance scans twice a day.

The scanners perform a thermal scan of all four walls every two minutes. Scanner data, stored on a data logger local to the monitoring areas, is also made available to a PC in the boiler control room via an Ethernet link. The control room PC processes the latest data and displays updated heat flux maps within a few seconds of completion of each thermal scan.
Circumferential Cracking: Fireside Membrane Tube Walls

Yeungheung Power Station, S. Korea, Site of Two Scanner Installations

Total generation capacity in excess of 4 Gigawatts and feeds electricity directly to the country’s capital, Seoul. At the time the scanner was installed, new water cannons were also installed: scanner data is used to feedback wall heat flux information to the water cannon control system, thus creating a fully-automated wall cleaning system.

Yeungheung Power Station, S. Korea, Site of Two Scanner Installations

Brunner Island and Martin Lake Supercritical Boilers, USA

For these two 800MW power generation units, the scanner’s thermal monitoring capabilities were used to detect and evaluate possible damaging fireside tube wall conditions that might be responsible for circumferential cracking of the weld-overlaid surfaces, and was part of an EPRI-sponsored research project. The cracking, at times, resulted in complete tube failure.

Circumferential Cracking: Fireside Membrane Tube Walls

At Brunner Island, the installed scanner had two sensor arrays, each with around 90 sensor locations. The arrays were positioned in areas of tube wall that had previously experienced severe cracking. The scanner quantified and mapped possible thermally-related causal factors for crack growth, which included both high fireside tube temperatures and substantial tube-to-tube temperature differences.

Martin Lake Power Plant, Texas

Martin Lake’s scanner installation was similar to Brunner Island, also with two sensor arrays. This unit had also experienced severe cracking and various changes had been made to boiler hardware and operations to help minimise crack formation, including the replacement of wall blowers for an automated water cannon cleaning system.

Martin Lake’s scanner helped evaluate tube wall fireside...
temperatures and the effects of wall cleaning on these. The scanner’s data provided new insights into the boiler wall’s thermal behaviour and the consequences and effectiveness of water cannon activity.

**Severe Tube Wall Fouling: European Metals Smelter**

Operators of this smelter had a particular problem with slagging and fouling near the apex of a small heat recovery boiler. A monitoring system was needed to identify if the slagging was approaching a point where it might have resulted in the smelter being shut down and the slag having to be removed either by explosive or mechanical means.

A small scanner system was installed near the top of the boiler to continuously monitor the heat flux through the tube walls: some 50 sensors were positioned about 50cm apart in a closely-spaced array, in the area where severe slag build-up was most likely to occur.

Data analysis software was written for the operators that would enable them to easily identify when and where the slag was building up and persisting on the tube walls. With the help of the scanner’s data, smelting operations were fine-tuned to minimise this effect and so help avoid the need for total shut down of the plant for cleaning.

Further details of these installations, and other scanner applications, are available on our website: [www.rowantechnologies.co.uk](http://www.rowantechnologies.co.uk).