Non-Intrusive Systems for Monitoring Tube Wall Temperatures and Heat Flux in Power, Incineration and other High-Temperature Plant

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Introduction

Since 1998, Rowan Technologies Ltd (RTL) has been designing and supplying a unique range of non-intrusive systems for continuous monitoring of both tube wall integrity (corrosion, erosion and crack growth) and thermal behaviour (temperatures and heat flux)\textsuperscript{1,2,3}. These patented systems are non-intrusive because all electrodes and sensors are welded to external (cold-side) tube wall surfaces, avoiding the need for tube modifications or removal:

Our scanner technology uses rectangular sensor arrays, allowing mapping of large areas of tube wall. Systems can comprise several hundred sensors, capable of monitoring all four walls of the largest steam-raising boilers. They are now installed on a number of large (>500 MWatt) sub-critical and supercritical power generation boilers in Europe, Asia and N. America. Scanners are equally suited to smaller, more focussed applications employing less than 50 sensors.

Recently RTL has also developed smaller, fully autonomous Heat Flux and Corrosion (HFC) monitors that perform highly-focussed real-time monitoring at point locations. These low-cost systems are easy to install and can be used in place of intrusive heat flux probes.

Both scanners and HFC monitors may be suited to any tube wall where the sensors can be welded to external surfaces, be it in power generation, incineration, metals recovery or other applications. In this paper we introduce these monitoring techniques and describe a variety of applications to explore the capabilities of this technology.

Scanner Technology

Measurement and Mapping Principles

Rowan Technologies originally developed the scanner technology in the late 1990s, with the principle aim of monitoring tube wall integrity using electrical resistance methods\textsuperscript{3}. Measurements are heavily temperature-dependant
and so it’s essential to monitor temperature gradients through the tube wall and compensate for any variations. To achieve this, scanners use thermal sensors welded to the external tube face at each sensor location.

Early trials showed that the scanner’s thermal monitoring could be a very valuable tool in its own right. Comparisons of scanner data with that of commercially-available intrusive heat flux probes (which use thermocouples embedded in fireside tube walls) showed that the scanner systems were capable of providing good estimates of tube wall heat flux and fireside tube temperatures, but at a fraction of the time and cost of installing intrusive probes.

Rectangular arrays of sensors allow 2D maps of tube wall thermal behaviour in to be produced in real time. Existing installations typically use sensor locations spaced about 1-2 metres apart. The largest arrays currently installed each have 170 sensor locations, each covering more than 150 square metres of wall. Each sensor location is measured in rapid sequence (scanned) and the acquired data can be processed and mapped within a few seconds.

Scanners can be networked to plant information systems for either real-time or historical data analysis using the scanner’s dedicated data processing and presentation package.

Scanner Applications

**Wall Temperatures, Heat Flux and Wall Cleaning Operations: Sub and Supercritical Power Generation Boilers UK and S. Korea**

More than ten large scanner systems are now installed both in the UK and S. Korea on large power generation units. Their purpose is both to monitor tube wall corrosion and also to provide real-time information of tube wall cold-side and fireside temperatures, wall heat flux and the effectiveness of wall cleaning operations.

Five large scanners, along with some of our other monitoring systems, are installed at Drax power plant, UK, each with around 200-300 sensor locations covering both sidewalls of four boilers. Data from all these systems are fed back to a
Scanner Instal lion: Hadong Power Plant, S. Korea

central data logging room via fibre or copper serial data links and then stored on a central server. Data on the server can then be used for real-time mapping or to allow retrospective data analysis of historical data.

There are six installations at four coal-fired plants in South Korea, two of which have the very latest supercritical boiler designs. Data from these systems are fed via Ethernet links directly to computers in the plant control rooms.

Using the scanner’s bespoke data analysis and presentation package, data can be processed and displayed in a wide variety of formats. Real-time heat flux maps can be produced, enabling the effectiveness of wall blowing to be immediately observed. Software can also issue prompts to the boiler operators, indicating where fouling of the boiler walls is significant and which wall blowers should be activated accordingly.

As well as providing tube wall heat flux information, the data analysis package can also provide information on wall temperatures, both on the cold side and, with the help of finite element modelling, the fireside also. Data can also be presented as time dependent traces for each individual sensor locations highlighting, for example, the magnitude and frequency of slag-shedding events.

Tube Wall Circumferential Cracking: Brunner Island and Martin Lake Supercritical Boilers, USA

For these two power generation units, the thermal monitoring capabilities of the scanner were used to detect and evaluate possible damaging fireside tube wall conditions that might be responsible for circumferential cracking of the weld-overlaid fireside tube walls, and was part of an EPRI-sponsored research project.

For Brunner Island, the scanner for this 800MW supercritical unit 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.
The project involved rapid scanning of all sensor locations within around 30 seconds. This rapid scanning allowed short-term temperature transients to be identified and quantified - shorter, more dynamic transients would contribute to stress cycling of the tube walls and encourage crack initiation and propagation.

Newly-acquired scanner data was sent directly to the plant’s information storage system (or historian). To provide relevant personnel in the US and UK with real-time access to the fireside tube wall conditions, this data was immediately processed in the form of 2D maps of fireside tube wall temperatures and these were directly uploaded to internet web pages.

The scanner’s data identified several possible contributing factors to excessive tube fireside thermal behaviour. These include flame impingement, excessive cleaning operations to control wall slagging and fouling and natural slag shedding, all of which might either expose the tube walls to excessive radiant heat or result in rapid stress-inducing thermal gradients or transients.

Martin Lake’s scanner installation was similar to Brunner Island. This 850MW lignite-fired supercritical unit had also experienced similar 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.

A scanner system, with two sensor arrays, was installed to help evaluate the current ‘state of play’ regarding tube wall fireside temperatures and the effects of wall cleaning. The cannons were intended to provide more targeted and controlled cleaning than the wall blowers, so helping to minimise unwanted and possible damaging conditions such as high and dynamic wall temperatures. 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 roughly 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.

Data analysis software, especially written for this application, presented the scanner’s thermal data as linear time traces for each sensor locations and also pictorially to automatically identify locations of any persistent slag.
**Tube Overheating and Rupture: Subcritical Boiler**

On this particular 660MWatt power generation boiler, a rupture had occurred on a furnace front wall tube. During the repair, leaks were also identified on adjacent tubes and blistering and rippling were noted on other tubes in this area. The rupture was a result of creep damage due to long-term overheating and adjacent tubes also showed signs of overheating.

To help monitor both tube and coolant temperatures, and identify the root causes of the tube overheat, a thermal scanner system was installed in the area where tube damage had occurred. An array of 40 sensor locations was initially installed: each location positioned three tubes apart.

The system scanned all sensors every two minutes. Data, stored locally at the monitoring location, could be easily retrieved and analysed using a bespoke data analysis and presentation package. The package not only displayed measured surface temperatures, but also estimated fireside tube wall temperatures.

The scanner sensor matrix was later enlarged to 96 sensor locations; over 500 sensor locations to be monitored from a single control cabinet.
New Heat Flux and Corrosion (HFC) Monitors

These recently-developed monitors have evolved from the scanner technology and use refinements of the scanner’s techniques as well as incorporating new measurement methods. They use a ‘focused’ approach: measurements typically taken across 1 or 2 tubes as compared to the scanner’s typical ‘whole wall’ approach using arrays of sensors. Like the scanner sensors, the HFC sensors are non-intrusive - no access through the boiler wall is required, the sensors being welded directly to the cold-side surfaces and the monitors can be used in place of intrusive heat flux probes.

For heat flux monitoring, HFC monitors combine finite element modelling information with a dual measurement approach: the first method (a refinement of the scanner’s technique) uses passive measurement of tube surface conditions, whilst the second method (based on a novel electrical resistance technique) actively passes signals through the whole wall cross-section, including the fireside tube wall. Results from both methods reinforce each other and are combined.

HFC monitors comprise compact, fully-independent electronics with on-board computing power, all housed within a small double-sealed enclosure that can be interfaced to plant information systems using a variety of methods. Additional multiplexing creates multi-point monitoring capability. Up to around ten measurements per minute are processed in real-time, stored locally at the electronics and made available to the plant information systems via analogue, digital or Ethernet links. The systems versatility provides a range of options for real-time data acquisition and display via office or control room computers.

Robust HFC sensors are welded directly to the cold-side of the tube wall, typically around a single tube. During the measurement sequence, signals pass around both cold-side and fireside tube walls, enabling the cold-side sensors to detect fireside tube wall conditions.

Like the scanner technology, HFC monitors have the added capability of performing real-time corrosion monitoring of the fireside tube walls.
In Summary

Rowan Technologies’ thermal scanner systems can be used for:

- Monitoring and mapping of real-time or historical thermal data over large areas of boiler wall.
- Mapping of external surface temperatures, tube wall heat flux and fireside tube temperatures, providing information on slagging behaviour, flame impingement, effectiveness of wall cleaning, excessive tube temperatures etc.
- Relating thermal behaviour with boiler operations, enabling combustion conditions and wall cleaning to be optimised to help improve efficiency.
- Monitoring absolute wall temperature, temperature differential and thermal cycling data: helping to quantify tube stresses and pinpoint underlying causes of tube damage or failure.

Scanners can be:

- Configured with less than 50 sensor locations for monitoring localized areas, to over 500 sensor locations, potentially covering all four walls of the largest of power generation boilers.
- Configured for system control and data presentation from within a control room, office or from a remote site.

HFC monitors can be used for:

- More focused measurements at point locations.
- Direct replacements of intrusive heat flux probes.
- Simultaneous thermal and corrosion monitoring, as with scanner systems.
And:
- Can be configured for single or multiple point monitoring.
- Are fully autonomous with on board data storage and computing power.
- Designed for easy installation.

References


