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Inside . . .

Page

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CHTA MEMBERS COPING WITH THE IMPACT OF THE CORONAVIRUS CRISIS

Second-quarter turnover down a third on 2019

Market Movements

ANALYSIS OF QUESTIONNAIRE REPLIES RELATING TO 26 CHTA MEMBER SITES

"THIS QUARTER" =

1 APRIL – 30 JUNE 2020

= TURNOVER INDEX 100

OVERALL ANALYSIS (26 SITES)	Mean index
This quarter last year (1 April – 30 June 2019)	149.8
Last quarter (1 January – 31 March 2020)	140.8
Predicted next quarter (1 July – 30 September 2020)	121.9

Cautious optimism for third-quarter performance

Challenges and benefits of 'thru-process' temperature profiling in the heat treatment industry

Dr Steve Offley, Product Marketing Manager, PhoenixTM Ltd, UK

This article outlines the challenges and benefits of using 'thru-process' temperature profiling and survey systems in today's heat treatment industry.*

An overview is given to the principles of 'thru-process temperature profiling' where a data logger, thermally protected in a thermal barrier, is passed safely through the heat treatment process. As it travels, the data logger measures, via multiple thermocouple inputs, the temperature of the product being heat treated and/or ambient conditions in the furnace itself. The resulting temperature-profile graph 'thermal fingerprint' of the process provides all the necessary information to understand, control, improve and validate the heat treat process. The benefits of this approach are discussed in direct comparison with established techniques such as trailing thermocouples.

We examine how systems are engineered to get safely through such diverse processes as heat treatment of gear parts in low-pressure carburising furnaces with high-pressure gas quenches, monitoring gas carburising furnaces with integral oil quenches, homogenising aluminium logs, controlled atmosphere brazing (CAB) processes, and heat treatment of aluminium engine blocks in automated robotic-loaded T6 rotary furnaces. In all such cases, the specific unique designs of the profiling systems, which allow the collection of accurate product temperature through the entire heat treatment process, are discussed in detail. Many of these applications have not been previously possible to monitor with existing technology.

We look at how use of this type of system has evolved as temperature uniformity surveying (TUS) has become an ever-increasing requirement in aerospace and auto manufacturing industries. Efficient temperature uniformity survey solutions are presented to meet the requirements of CQI-9 and AMS2750E. As part of such discussion, the application of two-way RF telemetry is presented, allowing remote live real-time temperature monitoring of batch and continuous processes without the challenges of trailing thermocouples.

*Based on a paper presented at the *6th Asian conference on Heat Treatment & Surface Engineering*, Chennai, India, 5-7 March 2020.

Introduction

'Thru-process' temperature profiling in the heat treatment industry has been around for over twenty years and the principle of operation of these systems is generally well known; i.e. a multi-channel data logger (*Fig.1*) is protected by an insulated thermal barrier which allows the system to travel through a furnace together with the product(s) being heat treated (*Fig.2*). Thermocouples feed temperature data back to the data logger and, at the end of the process, the complete temperature profile can be examined and critical calculations made using purpose-built software supplied by the system manufacturer. Further developments have allowed the data to be sent out of the furnace via RF telemetry, allowing examination to be made in real time. The temperature profile obtained is basically a thermal fingerprint of the complete heat treat process. This thermal fingerprint is unique and critical to the understanding, control, improvement and validation of the heat treat process being undertaken.

Fig.1: Typical temperature data logger (up to 20 thermocouple inputs) used in a 'thru-process' system. Protected by a thermal barrier, it travels through the furnace with the product being monitored. Data are stored in memory for download post run or are transmitted live from the furnace using a RF telemetry option.

Benefits of 'thru-process' temperature profiling

Prior to the development of these systems, long 'trailing' thermocouples were often used to determine the actual product temperature profile through continuous furnaces. Feeding thermocouples through a continuous furnace had obvious disadvantages: mainly the difficulty of the operation itself, the limited number of thermocouples that could be used, disruption to production, and the accuracy of the data, given that products could not follow the test basket into the furnace (due to the trailing thermocouples), so the furnace loading decreased as the trial progressed.

As the 'thru-process' method was adopted, the monitoring operation simplified, the disruption to production was minimised, and the measurement could always be carried out in a fully-loaded furnace, reproducing actual product conditions. Data obtained from 'thru-process' profiling trials give an accurate assessment of how long a product soaked at a specified temperature, the differences in product temperature around the product basket, quench rates, etc. These data being used to calculate performance against specification, investigate process problems, and

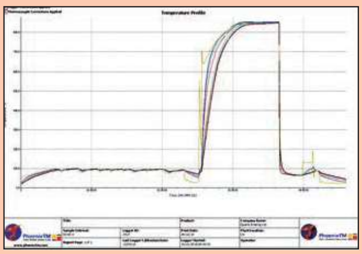


Fig.2: 'Thru-process' temperature monitoring system loaded in a charge basket, travelling into and through a continuous gas carburising furnace, and typical resulting thermal profile.

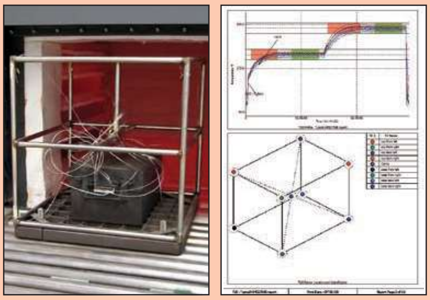


Fig.3: 'Thru-process' temperature monitoring system loaded into a batch furnace with TUS frame to complete a temperature uniformity survey. Resulting fully-documented TUS survey report.

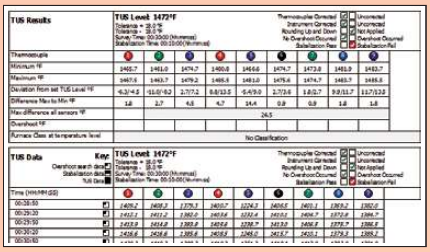


Table 1: Benefits of 'thru-process' temperature monitoring over traditional trailing-thermocouples methodology.

System	'Trailing thermocouples'	'Thru-process system'
Number measurements	Limited to 1 or 2 safely	Up to 20
Operator needed during run	Essential to allow safe cable transfer through furnace	Not needed (system travels independently as if product)
Cable length	Furnace length minimum (Cost / risk of damage)	Short (typically few feet)
Cable snagging / damage risk	Potential due to length. Automatic furnace doors may need to be overridden to prevent cable being trapped/damaged.	Minimal
Production stoppage	Yes - empty furnace needed (Probe retrieval post run!)	No - used during production run
Representative of true production conditions	No, as furnace may need to be empty	Yes, as performed during production run
Robotic product loading	Not feasible	Possible
Multiple process steps (furnace, quench, etc)	Difficult, if possible at all	Possible
Safety	Operators close to furnace to feed thermocouples (H&S)	No issues
Cost	Long thermocouples expensive to replace. Regular replacement risk.	Initial investment cost of system

optimise the process. An important development has seen these systems used as a primary method to survey furnaces to the AMS2750 specification (*Fig.3*), allowing the survey to be carried out with minimal disruption to production and saving many hours of furnace downtime, while the furnace was cooled and degassed to fit the trailing thermocouples.

A summary of the benefits of 'thru-process' temperature profiling, as opposed to trailing thermocouples, is provided in *Table 1*.

Engineering design – the 'thru-process' monitoring challenges

Although the operating principle of these systems seems relatively straightforward, with the evolution of furnace technology and drive for automated systems the design is often complex, as the 'thru-process' system needs to meet the unique challenges that come with different heat treatment processes. The main process challenge is protecting the measuring system from the heat of the process which, in some cases such as slab/billet reheat, where temperatures of up to 1250°C can be experienced for many hours, is a technical challenge in it's own right.

When designing or selecting the most appropriate 'thru-process' system, the following criteria need careful consideration:

Space or clearance in the furnace

Thermal barriers used in these processes will have a certain minimum size to withstand the process temperature and duration. Therefore, there needs to be adequate clearance at the furnace entrance and exit to allow the system through. Examination of other 'pinch points' in the furnace, such as baffles or 'knuckles' to separate heating zones, should also be made. Product loaded into the furnace in baskets may restrict the size and shape of the barrier that can be accommodated. With ever-increasing automation and multi-chamber furnace designs, space is ever becoming more limited, requiring drive to provide the most space-efficient barrier solutions.

Furnace temperature

This does not just refer to the maximum process temperature, which is used to determine the type of insulation to be used, and the thermal barrier material, but also a calculation needs to be made to determine the 'Adjusted Process Temperature' (APT). This takes into account rates of heating, cooling and soaking, at the various temperature levels, and is used by the system manufacturer to determine the actual thermal barrier size required to get the system through the process.

Process duration

The full process time within the furnace is used in the APT calculation. Added to this is the time period after exit from the furnace until the system can be accessed and the data logger removed. A safety margin is also added in case of stoppages in the process. Knowing the full process duration and the APT, the size of the thermal barrier can be determined.

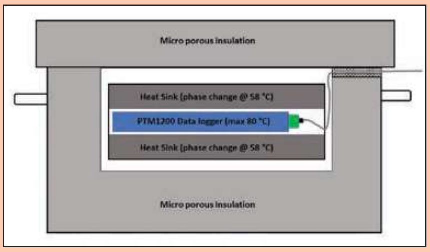
Atmosphere in the furnace

The furnace atmosphere will not only determine the material the thermal barrier will be constructed from, but may also affect the barrier's performance; e.g. a hydrogen atmosphere will lessen the thermal performance, whereas a vacuum will increase the performance. The furnace atmosphere will also determine the thermal barrier 'technology' that can be used. There are two basic technologies that keep the data logger at a safe operating temperature:

- Heat sink' technology is a 'dry' technology, where the data logger is housed in a heat sink (a container filled with a eutectic salt) which changes phase at 58°C, keeping the data logger at a stable temperature during the phase-change period. A lower-operating–temperature data logger can be used in this type of barrier.
- 'Evaporative' technology uses boiling water to keep the high-temperature data logger (maximum operating temperature

Fig.4: PhoenixTM profile system post reheat furnace. Thermal barrier (TS07-300-3, 3.2 hours protection at 1300°C) loaded on cast steel beam blank reheated prior to rolling into structural metalwork for buildings/ skyscrapers. The PhoenixTM 1220 data logger, at the core of the system, stores data measured by the thermocouples inserted into blank at varying depths along its length.

Fig.5: Photo and schematic of a conventional heat sink barrier technology.



110°C) at a stable operating temperature of 100°C as the water changes phase from liquid to steam. The advantage of 'evaporative' technology is that a physically-smaller barrier is often possible. It is estimated that, with a like-for-like size (volume) and weight, an evaporative barrier will provide in the region of twice the thermal protection of a standard thermal barrier with micro-porous insulation and heat sink.

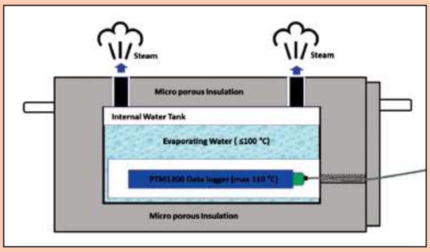
Since steam is generated as a by-product of the superior-protection evaporative barrier technology, it is prohibited from use in certain processes where the furnace environment cannot be contaminated. For such processes as carburising, nitriding, vacuum heat treatment and controlled atmosphere brazing (CAB), the heat sink technology is the only viable option.

Quench within the process

If a quench is involved, the type and duration of the quench is important. Historically, monitoring the quench was ignored and bypassed due to the technical difficulties of sending a system through. Obviously, in many processes, knowing the cooling rate of the heat-treated product is as important as knowing the time at temperature of the heating phase (soak) to achieve the correct metallurgical structure of the metal, whilst avoiding distortion and even quench cracks.

- Gas quenches in low-pressure carburising processes are common, but the thermal barrier may require a 'gas deflector', if the pressure of the quench is high (5-20bar), to prevent distortion of metalwork or damage to the thermal insulation.
- Water quenching in T6 processes requires the thermal barrier to resist full immersion in water from high temperature, and the technology for this is well established.
- The technology for passing a system through either salt or an oil quench has now been developed, combining a fully-sealed inner barrier and outer robust

Fig.6: Photo and schematic of an 'evaporative' barrier technology.



sacrificial blocks of insulation, allowing safe transfer through and monitoring of the full quench. Monitoring the oil quench process is discussed in more detail in Case 2 below.

Innovative 'thru-process' temperature monitoring solutions in the heat treatment industry

Case 1: Low-pressure carburising (LPC) – temperature profiling and TUS

Carburising is one of the most critical heat treatment processes employed in the manufacture of automotive components. Also referred to as case hardening, it provides necessary surface resistance to wear, whilst maintaining toughness and core strength essential for hardworking automotive parts.

The carburising process is achieved by heat treating the product in a carbon-rich environment, typically at a temperature of 900-1050°C. The temperature and process time influences significantly the depth of carbon diffusion and associated surface characteristics. Critical to the process, following diffusion, is a rapid quenching of the product to generate the microstructure giving the enhanced surface hardness whilst maintaining a tough product core.

Increasing in popularity in the carburising market is the use of batch or semi-continuous low-pressure carburising furnaces. Following the diffusion, the product is transferred to a high-pressure gas quench chamber where it is rapidly gas cooled using typically nitrogen or helium at up to 20bar.

In such a process the technical challenge is twofold. The thermal barrier must be capable of protecting against not only heat, during the carburising, but also very rapid pressure and temperature changes inflicted by the gas quench. From a data collection perspective, to efficiently perform temperature uniformity surveys at different temperature levels in the furnace, it is important that temperature readings can be reviewed live from the process, but without need for trailing thermocouples.

To protect the thermal barrier in the LPC process with gas quench, the barrier construction needs to be able to withstand constant temperature cycling and high gas pressures. The design and construction features include:

- Metalwork - 310 stainless steel employed to reduce distortion at high temperature, combined with internal structural reinforcement.
- Insulation - ultra-high-temperature micro-porous insulation minimises shrinkage problems.
- Rivets – close-pitched copper rivets reduce carbon pick-up and maintain strength.
- Lid expansion plate – reduces distortion during rapid temperature changes.
- Catches – heavy-duty catches eliminating thread seizure issues.
- Heat sink – internal heat sink to provide additional thermal protection to data logger.

During the gas quench, the barrier needs to be protected from nitrogen or helium gas pressures up to 20bar. Such pressures on the flat top of the barrier would create excessive stress to the metalwork and internal insulation / logger. Therefore a separate gas quench deflector is used to protect the barrier. The tapered top plate deflects the gas away from the barrier. The unique design means the plate is supported on either four or six support legs. As it is not in contact with the

Fig.7: Thermal barrier fitted with quench deflector being loaded into LPC batch furnace with TUS frame as part of temperature uniformity survey.

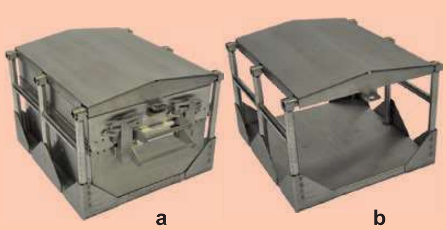


Fig.8: High-performance LPC thermal barrier: (a) combined barrier and quench deflector; (b) separate quench deflector frame (6 legs).

barrier, no force is applied directly to the barrier and the force is shared between the support legs. In addition to protecting against pressure, the quench shield also acts as an additional reflective IR shield, reducing the rate of IR absorption by the barrier in the vacuum heating chamber.

Applying the 'thru-process' monitoring technique, there is no hardwired link between the monitoring system within the furnace and the outside world, so providing already-discussed operational benefits. To achieve real time measurement, as if using trailing thermocouples, the data measurements therefore need to be transferred remotely. This is done using a high-performance two-way radio telemetry system. The temperature readings are transmitted as a RF signal from the data logger, via external barrier antenna from inside the furnace, to a receiver connected to the external monitoring PC (*Fig.9*). The two-way communication protocol allows not only data collection but also direct control of the data logger (reset/download) inside the furnace.

Provided with a high-performance 'LwMesh' networking protocol, the RF signal can be transmitted through a series of routers linked back to the main co-ordinator connected to the monitoring PC. The routers are located at convenient points in the process, positioned to maximise signal reception. Being wirelessly connected, they eliminate the inconvenience of routing communication cables or providing external power as needed on other commercial RF systems. The routers can be positioned to exactly where they are needed and be moved with ease when changes are required. Using the repeater network, multiple furnaces can be monitored either simultaneously or sequentially. Even in large plants, a chain of remote repeaters can transfer the process data direct from the furnace back to the furnace control room or office.

Performing TUS to comply with AMS 2750E/CQI-9 standards requires that the survey, analysis of data and reporting are performed in agreement with strict criteria. This can be tedious and lengthy unless using a customised TUS survey software analysis package such as the PhoenixTM *Thermal View Survey* software.

Features incorporated into the *Thermal View* software to provide full TUS capability include the following:

- TUS Level Library - set-up TUS level templates for quick efficient survey level specification (Survey temperature, tolerance, stabilisation and times).
- TUS Frames Library - show clearly exact TUS frame construction and probe location using frame library templates – frame centre and eight vertices.

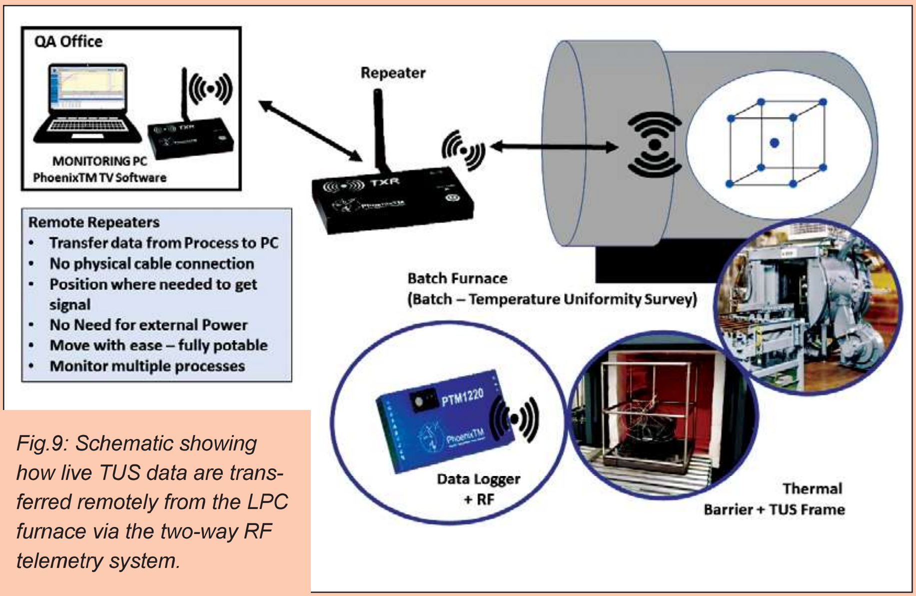


Fig.9: Schematic showing how live TUS data are transferred remotely from the LPC furnace via the two-way RF telemetry system.

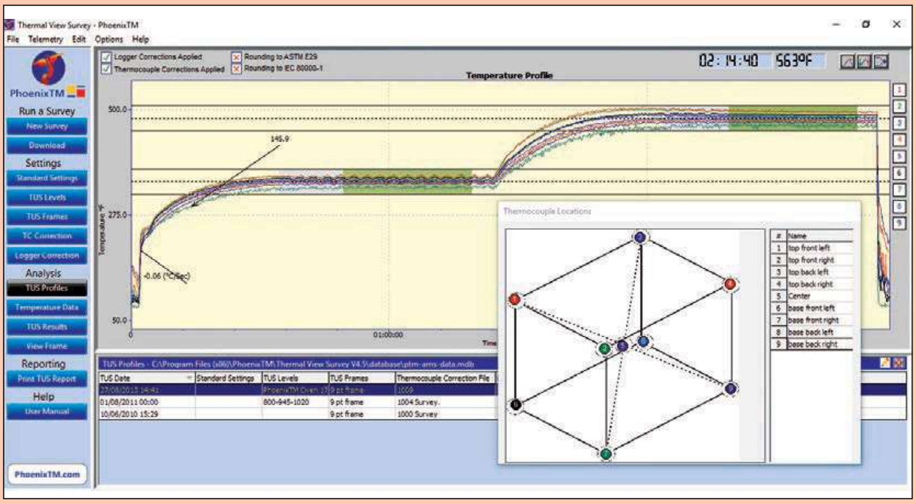


Fig.10: PhoenixTM Thermal View Survey *software showing a TUS profile at three set survey temperatures. The probe map shows exactly where each probe is located and easy trace identification. Detailed TUS report generated with efficiency.*

- Logger Correction File - create a logger correction file to compensate TUS readings automatically from the logger's internal calibration file.
- Thermocouple Correction File - create the thermocouple correction file and use to compensate TUS readings directly.
- TUS Result Table & Graph View - for each TUS temperature level see, from the graph or TUS table, full survey results instantaneously.
- Furnace Class Reporting - report the specified furnace class at each temperature level.

Case 2: Gas carburising with integral oil quench – temperature profiling

A common process in today's heat treatment industry is the carburising of steel products for use in the automotive industry, a popular heat treatment technology used being the sealed-quench gas carburising furnace with an integral oil quench. For such furnace technology, the historic limitation of 'thru-process' temperature profiling has been the need to bypass the oil quench and wash stations. Obviously passing a conventional hot barrier through an oil quench creates potential risk of both system damage from oil ingress, barrier distortion and general process safety.

In such carburising processes, the oil quench rate is critical to the metallurgical composition of the steel but also to reduction/elimination of product distortion and quench cracks; so the need for a monitoring solution has been significant. Regular monitoring of the quench is important as ageing results in decomposition, oxidation and contamination of the oil, all degrading the heat transfer characteristics and quench efficiency.

To address the process challenges, a

Fig.11: 'Thru-process' temperature monitoring system for use in sealed-quench carburising furnace: (a) barrier construction; (b) system in use.

unique barrier design has been developed that both protects the data logger in the furnace (typically 3 hours at 925°C) but also protects during transfer through the oil quench (typically 15 minutes) and final wash station (*Fig.11*).

The key to the barrier design is the encasement of a sealed inner barrier with its own thermal protection, with blocks of high-grade sacrificial insulation contained in a robust outer structural frame. Initial attempts to encase the thermal barrier in a sealed enclosure were abandoned due to internal pressure build up in a container softened by holding at the high carburising temperature.

Case 3: Homogenisation of aluminium logs in a walking-beam furnace – temperature profiling

After casting, aluminium logs are homogenised before being supplied to the end users, typically extrusion companies. This heat treatment has been carried out historically in batch furnaces but today there is an increasing move to walking-beam furnaces for continuous production. The walking-beam furnace creates a significant challenge to the temperature monitoring process as the logs rotate as they move through the furnace (12 to 13 hours at 580°C). Such rotation would make a trailing thermocouple approach to monitoring impossible but also creates a challenge for a 'thru-process' system which needs to travel though the furnace in the same way as the product.

To address the monitoring challenge, a unique cylindrical barrier design is used. As shown in *Fig.12*, the cylindrical barrier is bolted securely (prevent sagging) to the end of a cut-down aluminium log. The diameter of the barrier matches that of the aluminium log so that it can freely rotate with the product through the furnace. Long thermocouples are run along the length of the log, running within a cut-out slot, to prevent tangling, and fixed at locations and depths required.

To provide the thermal protection for the excessive heat treatment duration and space restrictions, an evaporative thermal barrier technology is the only viable option. This itself creates challenges as the design needs to prevent loss of water from the tank, as the whole system rotates, to preserve thermal protection of the data logger.

Employing the 'thru-process' temperature monitoring solution, major key casting plants have been able to measure the temperature profile of their aluminium logs in all three stages of the homogenisation process. With such critical information, it has been possible to minimise time in the soak zone to increase productivity and optimise fuel efficiency, without compromising product quality.

Case 4: Aluminium controlled atmosphere brazing (CAB)

The aluminium brazing of radiators and condensers is commonly performed using a continuous controlled atmosphere brazing (CAB) process. As part of this brazing process, the control of the product temperature is critical to achieve selective melting of the filler alloy (580-620°C) to allow it to flow and fill the joints between the parent metal. As the name of the process suggests, the atmosphere in the furnace must be inert and devoid of water vapour or oxygen. If such contaminants are present, unwanted oxidation of the aluminium surface can be experienced and formation of highly-corrosive HF from flux chemicals can be a risk to thru-process monitoring equipment.

When designing a 'thru-process' temperature profiling system for monitoring a CAB process, there are two major technology challenges to address. To allow safe passage through the conveyorised furnace, the barrier needs to be low profile, with a safe clearance to allow for deterioration / flux build-up of mesh belts with age, reducing furnace height clearance even further. Construction of the barrier and materials used should be such as to prevent outgassing of either water or oxygen into the furnace, to protect the controlled atmosphere whilst preventing chemical damage of the barrier itself.

Traditional thermal barriers are constructed with unprotected glass-cloth-covered microporous insulation. Moisture and air trapped in such materials have been shown to severely damage the barrier and reduce its working life due to hydrofluoric acid formation with flux chemicals.

To overcome such issues, a new sealed barrier design has been developed as shown in *Fig.13*. The front-loaded data

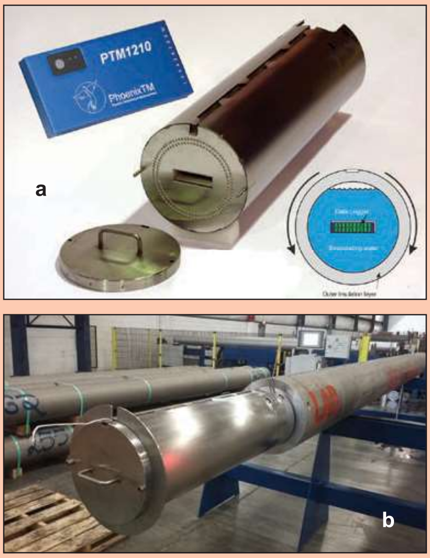


Fig.12: Cylindrical evaporative thermal barrier technology for use in walking-beam aluminium log homogenisation furnace: (a) cylindrical barrier design and water tank schematic; (b) barrier secured to test aluminium log.

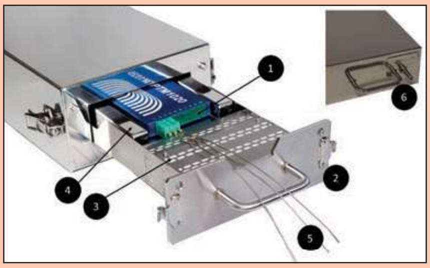


Fig.13: CAB brazing thermal barrier design: (1) data logger (6 or 10 channels); (2) front-loading logger tray with encapsulated insulation; (3) thermal breaks reduce conduction to data logger; (4) heat sink provides additional thermal protection; (5) mineral-insulated thermocouples attached to radiator fin; (6) nitrogen feed nozzle for insulation purge.

logger tray and metal construction limits exposure of insulation materials to potential HF corrosion. The barrier is available with a nitrogen purge facility to remove any risk of outgassing of oxygen into the furnace.

Implementing such construction and set-up techniques, barriers have been shown to operate successfully for in excess of 2500 runs without issue.

Case 5: Aluminium engine block T6 heat treatment in rotary furnace

In modern rotary-hearth furnaces such as that shown in *Fig.14*, temperature profiling using trailing thermocouples is impossible, as the cables would wind up in the furnace transfer mechanism. Due to the central robot loading and unloading and elimination of charging racks/baskets, the use of

Fig.14: Robot loading of combined 'thru-process' system with engine block into BSN rotary T6 furnace. The thermal barrier is designed with a combination of thermal insulation technology capable of fitting in the engine block cavity. With a thermal protection capability of 550°C for several hours, the system has the ability to monitor the complete T6 process, including solution reheat, water quench and aging.

Fig.15: The 'Hump-back' evaporative thermal barrier with stepped profile to match the product and allow direct loading by robotic gripper into the furnace with test product.

a conventional thru-process system would also be a challenge.

To overcome the loading restrictions, a unique thermal barrier was developed, small enough to fit inside the cavity of the engine block and allow automated loading of the complete combined monitoring system and product. The system allowed BSN Thermoprozesstechnik GmbH, in Germany, to commission the furnace accurately and efficiently and thereby optimise settings, to not only achieve product quality, but also ensure energy-efficient cost-effective production.

Faced with a similar robotic-loading issue, the phase-evaporative barrier shown in *Fig.15* was developed. Due to its unique form, the barrier has been named the 'Humpback' barrier. The shape of the barrier was designed purposefully to match the shape of the product being processed, so that the robot gripper could pick up the barrier and product simultaneously and load into the rotary furnace.

Summary

Thru-process temperature profiling provides today's heat treater with a safe efficient means to accurately measure both the furnace and product temperature throughout the whole thermal treatment. With modern innovations and experienced engineering design, many systems now offer real-time monitoring of processes simply not possible with a trailing thermocouple. With such information, the engineer can understand, control, optimise and validate the process being undertaken with confidence. Not only can engineers ensure product quality and drive productivity improvements, they can also perform accurate fine-tuning of furnace parameters to achieve potential energy savings.

THE AUTHOR

Dr **Steve Offley** is a Product Marketing Manager at PhoenixTM whom he joined in 2018 after 22 years experience in the industrial temperature profiling market with another well-known company.

Steve's academic background includes graduating from Coventry Polytechnic with a BSc (Hons) in Applied Chemistry and later a PhD from Loughborough University in Analytical Chemistry.

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