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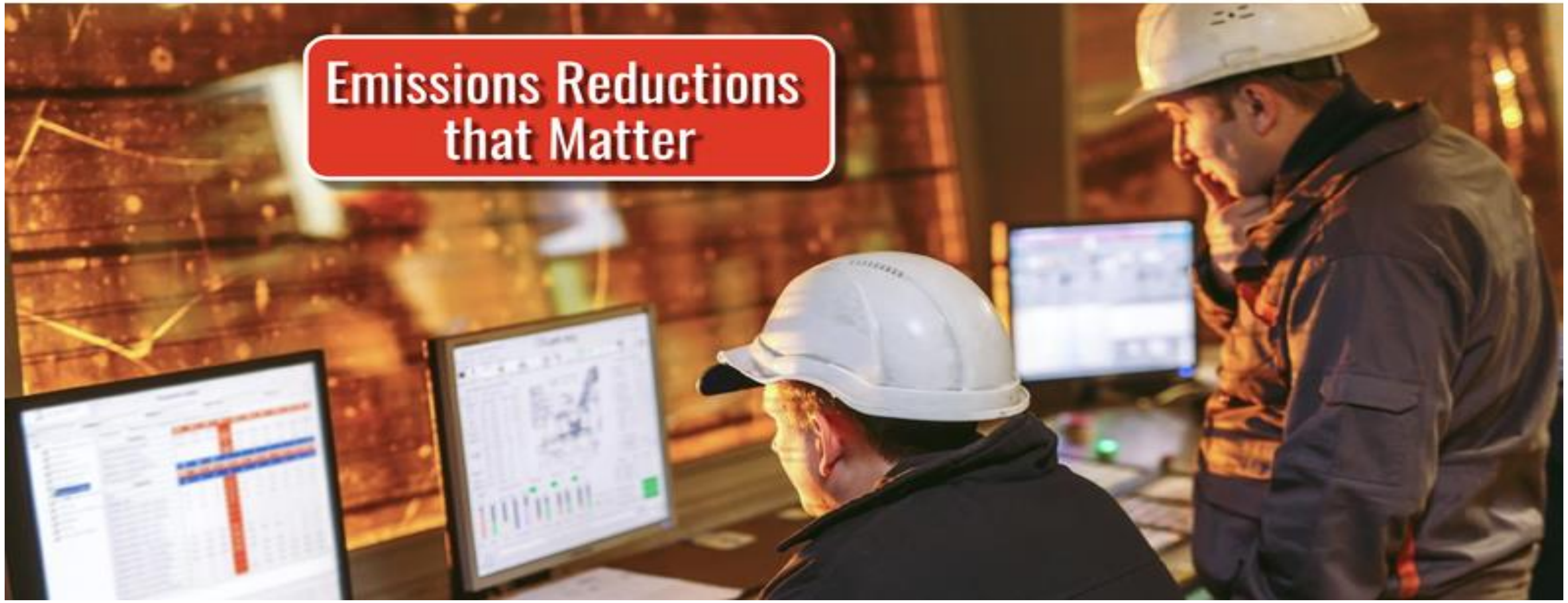

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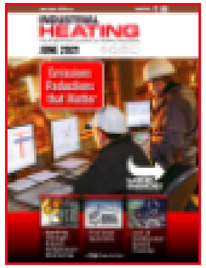

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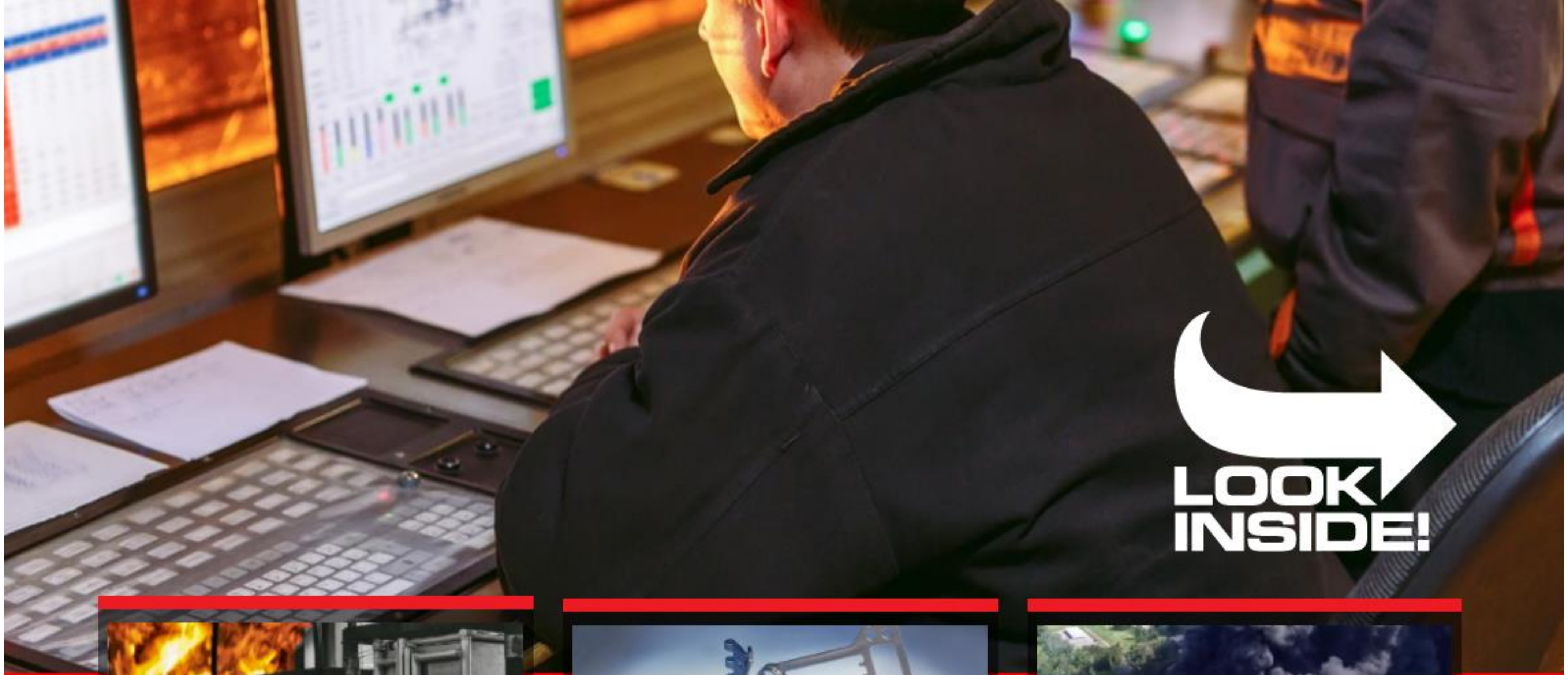

» Applying Through-Process Temperature Monitoring

» Five Smart Questions

» Lack of Combustion-System Training

A bnp media Publication

Applying Through-Process Temperature Monitoring to Fully Understand Your Complete Gas Carburizing Process

Steve Offley – PhoenixTM; United Kingdom

Using “thru-process” temperature monitoring allows you to gain a better understanding of your gas carburizing process from beginning to end.

Gas Carburization

Carburizing has rapidly become 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 while maintaining toughness and core strength essential for hardworking automotive parts.

The carburizing process is achieved by heat treating the product in a carbon-rich environment (Fig. 1), typically at a temperature of 1562-1922°F (850-1050°C). The temperature and process time significantly influence the depth of carbon diffusion and associated surface characteristics. Critical to the process is a rapid quenching of the product following diffusion, which is performed by rapidly decreasing the temperature to generate the microstructure for enhanced surface hardness while maintaining a soft and tough product core.

The outer surface becomes hard via the transformation from austenite to martensite, while the core remains soft and tough as a ferritic and/or pearlitic microstructure. Normally, carburized microstructures following quench are further tempered at temperatures of about 356°F (180°C) to transform some of the brittle martensite into tempered martensite to enhance ductility and grindability.

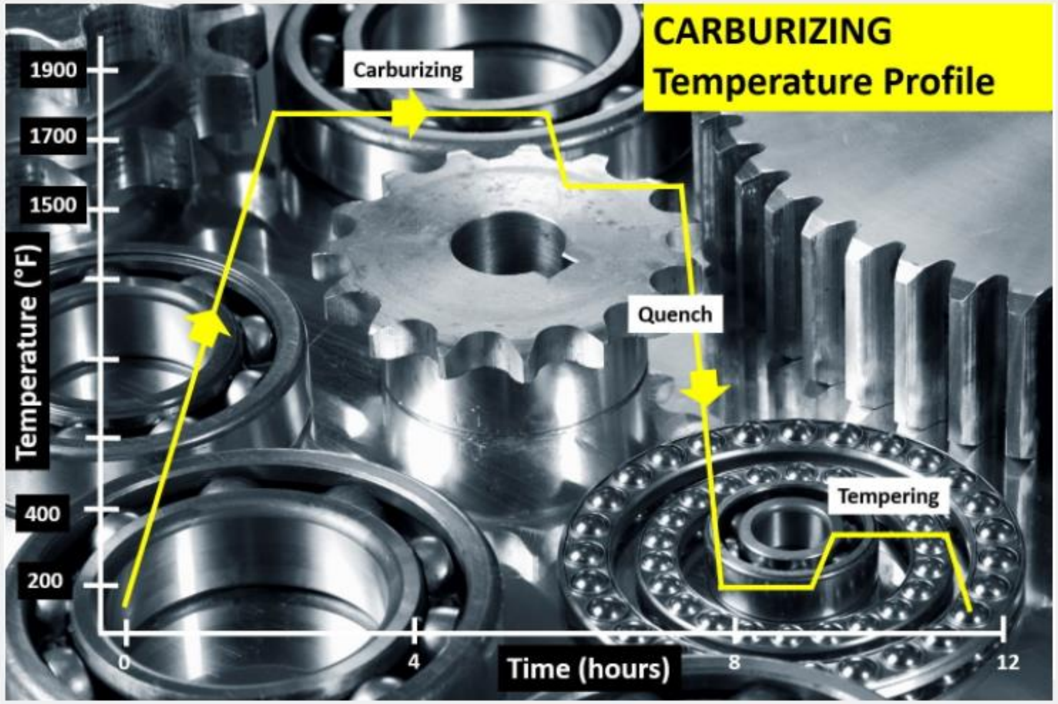

Fig. 1. Typical carburizing heat-treat temperature profile showing the critical temperature/time steps of (i) Carburization (ii) Quench (iii) Temper

Critical Process Temperature Control

The success of carburization is dependent on accurate, repeatable control of the product temperature and time at temperature through the complete heat-treatment process. Important to the whole operation is the quench, in which the rate of cooling (product temperature change) is critical to achieve the desired microstructural changes to achieve specified surface hardness. It is interesting that the success of the entire heat-treat process (hours) can rest on a process step that is so short (minutes). Getting the quench correct is not only essential to achieve the desired metal microstructure but also to ensure that the physical dimensions and shape of the product are maintained (no distortion/warping), and issues such as quench cracking are eliminated.

Since the quench is so critical to the entire heat-treat process, the correct quench selection needs to be made to achieve the optimum properties with acceptable levels of dimensional change. Many different quenchants can be applied with differing quenching performances. The rate of heat transfer (quench rate) of quench media in general follows the order from slowest to quickest: air, salt, polymer, oil, caustic and water.

Technology Challenges for Temperature Monitoring

From an industry standpoint when considering carburization, furnace heat-treat technology generally falls into one of two camps: either air quench (low-pressure carburization) or oil quench (sealed gas carburization/LPC with integral or vacuum oil quench). Although achieving the same end goal, the heat-treat mechanisms and technology employed are very different as are the temperature-monitoring challenges.

To achieve the desired carburized product, it is necessary to control and monitor the product temperature through the three phases of the heat-treat process. Conventionally, product temperature monitoring would be attempted using the traditional trailing-thermocouple method. As detailed previously,[1] the trailing-thermocouple method is difficult and often practically impossible for many modern heat-treat processes (including carburization). The movement of product/product basket from stage to stage, often from one independent sealed chamber to another, makes the monitoring of the complete process a significant challenge.

Thru-process temperature monitoring overcomes such technical restrictions.[1] The data logger is protected by a specially designed thermal barrier. It can, therefore, travel with the product through each stage of the process, measuring the product/process temperature with short localized thermocouples that will not hinder travel. The careful design and construction of the monitoring system is important to address the specific challenges different heat-treat technology brings.

Monitoring Challenge 1: Sealed Gas Carburization – Oil Quench

Presently, the most common traditional method of gas carburizing for automotive steels is often referred to as sealed gas carburizing. In this method, the parts are surrounded by an endothermic-gas atmosphere. Carbon is generated by the redox Boudouard reaction during the carburization process, typically at 1562-1832°F (850-1000°C).

Despite the dramatic appearance of a sealed gas carburizing furnace, with its characteristic belching flames (Fig. 2), from a monitoring perspective, the most challenging aspect of the process is not the heating but the oil-quench cooling. The historic limitation of thru-process temperature profiling for such furnace technology has been the need to bypass the oil quench and wash stations, missing a critical process step from the monitoring operation. Obviously, passing a conventional hot barrier through an oil quench creates potential risk of system damage from oil ingress, barrier distortion and general process safety.

Monitoring of the quench is important because aging of the oil results in decomposition (thermal cracking), oxidation and contamination (e.g., water) of the oil, all of which degrades the viscosity, heat-transfer characteristics and quench efficiency. Control of physical oil temperature and agitation rates is also key to oil quench performance. Quench monitoring allows economic oil replacement schedules to be set without risk to process performance and product quality.

To address the process challenges, a unique thermal-barrier design has been developed that both protects the data logger in the furnace (typically three hours at 1697°F/925°C) but also protects during transfer through the oil quench (typically 15 minutes) and final wash station (Fig. 2). 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 (Fig. 3).

Fig. 2. A thru-process temperature monitoring system for use in a sealed carburizing furnace with integral oil quench. (2.1) Monitoring system entering furnace with thermocouple fixed to automotive gears, product test pieces; (2.2) System exiting oil quench tank; (2.3) System inserted into wash tank with product basket

Fig. 3. Thru-process temperature monitoring system oil-quench compatible thermal-barrier design:

1. Robust outer structural frame keeping insulation and inner barrier secure
2. Internal thermal barrier – completely sealed with integral microporous insulation protecting data logger
3. Mineral-insulated thermocouples sealed in internal thermal barrier with oil-tight compression fitting
4. Multi-channel high-temperature data logger
5. Sacrificial insulation blocks replaced after each run

Quench Cooling Phases

Monitoring the oil quench in carburization gives the operator a unique insight into the products' specific cooling characteristics, which can be critical to allow optimal product loading and process understanding and optimization. Monitoring the cooling curves for different locations on a complex part, allows not only validation that the carburization has been successful over the whole surface but also control and reduction of distortion risks.

From a scientific perspective, the quench temperature profile trace – although only a few minutes in duration – is complex and unique. From a zoomed quench trace (Fig. 4), taken from a complete carburizing profile, the three unique heat-transfer phases making up the oil-quench cool curve can be clearly identified.

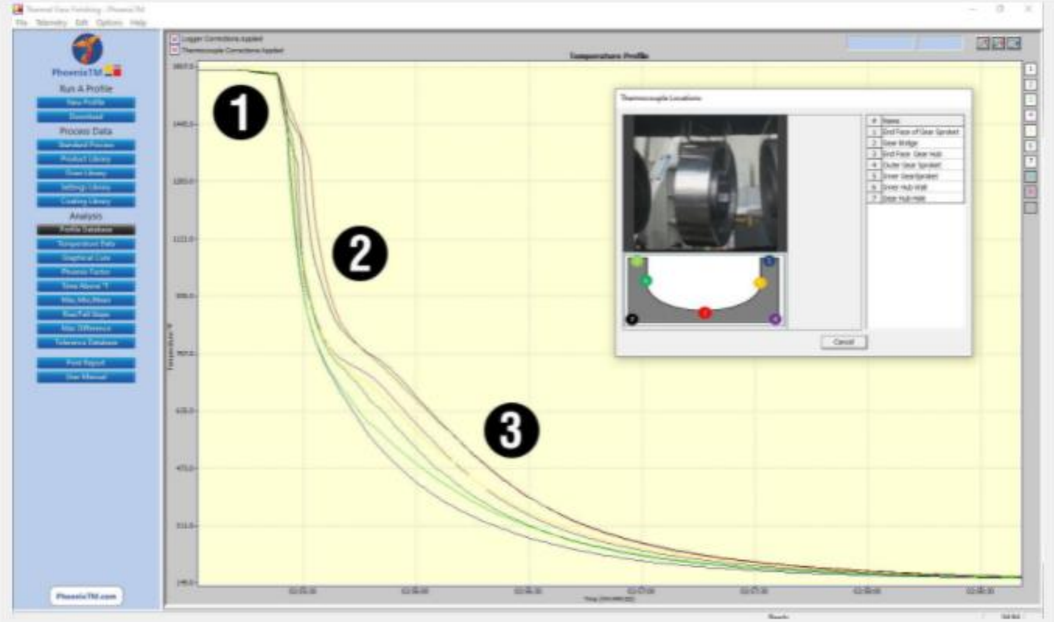

Fig. 4. Oil-quench temperature profile for different locations on an automotive gear test piece showing the three distinct heat-transfer phases: (1) film boiling "vapor blanket," (2) nucleate boiling, (3) convective heat transfer

1. Film Boiling "Vapor Blanket"

The oil quenchant creates a layer of vapor (Leidenfrost phenomenon) covering the metal surface. Cooling in this stage is a function of conduction through the vapor envelope. A slow cool rate is experienced because the vapor blanket acts as an insulator.

2. Nucleate Boiling

As the part cools, the vapor blanket collapses and nucleate boiling results. Heat transfer is fastest during this phase, which is typically two orders of magnitude higher than in film boiling.

3. Convective Heat Transfer

When the part temperature drops below the oil boiling point, the cooling rate slows significantly. The cooling rate is exponentially dependent on the oil's viscosity.

Monitoring Challenge 2: Low-Pressure Carburization (LPC) – Gas Quench

The use of batch or semi-continuous batch low-pressure carburizing furnaces is increasing in popularity. Carburizing in a vacuum with acetylene as the hydrocarbon source at 1800°F (980°C) provides a typical case depth of 0.032-0.040 inches (0.8-1.0 mm). Following the diffusion phase, the product is transferred to a high-pressure-gas quench chamber where the product is rapidly gas cooled/quenched, typically using N_2 or helium at up to 20 bars.

The monitoring technical challenge is twofold. The thermal barrier (Fig. 5) must be capable of protecting against not only heat during the carburizing but very rapid pressure and temperature changes inflicted by the gas quench. It is obviously important to protect the data logger from thermal damage, but the thermal barrier protecting the data logger needs to be robust enough to protect against physical damage in both metalwork (distortion/warpage) and thermal insulation (compaction/shrinkage).

The life expectancy of the system (regular use) requires the correct specification of materials and construction design. A key part of the design is the tapered-lid quench deflector, which protects it from potential damage from both top and bottom pressure. The lid is supported either on four or six legs with no contact to the barrier, ensuring that no force is directed through the barrier lid. The force is shared equally between the support legs.

Summary

One of the key process performance factors associated with gas carburization is the control and monitoring of the product quench step. Whether employing a gas or oil quench, the measurement of such an operation is now very feasible as part of heat-treat monitoring. Innovations in thru-process temperature-profiling technology offer specific system designs to meet the respective application challenges.

Fig. 5. Thermal barrier designed for protecting the data logger against severe temperature and pressure changes in the LPC N_2/helium gas quench at 20 bar pressure. Quench deflector shown fitted to barrier.

- **Robust metalwork**
  <2102°F/1100°C 310 stainless steel
  <2192°F/1200°C HT nickel alloy material
- **Reinforcement**
  Internal structural reinforcement to help maintain structural integrity and reduce distortion with independent quench deflector.
- **Heavy-duty catches**
  Robust, distortion-resistant with no thread seizure issues.
- **Lid expansion plate**
  Reduces distortion of thermal-barrier lid when experiencing rapid temperature changes.
- **Thermocouple wear strips**
  User-replaceable wear strips ensure thermal sealing at the barrier thermocouple exit.
- **HP thermal insulation**
  High-performance microporous insulation designed to provide reliable thermal protection and retain shape and form (no shrinkage).

The David (not Goliath) Monitoring Solution for LPC

Over the last few years, there has been a new drive to low-volume case hardening furnace design. Self-contained multiple vacuum heat-treat/quench chambers process small product trays/baskets or one-piece items often using automated robotic-loading facilities. The space-limited design of these new furnaces, with automated or semi-automated transfer of product between heat-treat phases, creates a severe monitoring challenge. New, innovative compact monitoring systems (Fig. 6) step up to meet the challenge head on.

Fig. 6. TS02-128-1 compact TUS monitoring system with compact six-channel data logger for low-volume LPC furnace technology. Shown with 310 SS thermal barrier and quench deflector (5.5 inch/140 mm high with 0.7 hours protection at 1832°F/1000°C).

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References:

1. *Industrial Heating*, June 2019, "Through-process Temperature Profiling for Heat Treat Efficiency," Dr. Steve Offley, PhoenixTM Ltd.

All images provided by the author

Check out this month's podcast with Dr. O to learn more about thru-process monitoring of your carburizing process.

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Brian Kelly from Honeywell sat down with our editor to discuss his June article titled "Emissions Reductions that Matter." If you want to save money on utilities or green-up your process, check out this podcast to find out how. And read Brian's June article to learn even more.

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Thru-Process Temperature Monitoring for Carburizing

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Technology makes the world a smaller place! Reed Miller (U.S.) sits down with Steve Offley (Dr. O) of PhoenixTM in the U.K. to discuss his June article on thru-process temperature monitoring of your carburizing process. Read his article on this topic here, and tune in to learn more.

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