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ISSUE FOCUS ///

PROCESS CONTROL / PYROMETRY

DEMAND FOR FORGED PARTS SPURS DRIVE TO REBUILD, AUTOMATE EQUIPMENT

COMPANY PROFILE ///

BASF ECMS

MARCH 2024
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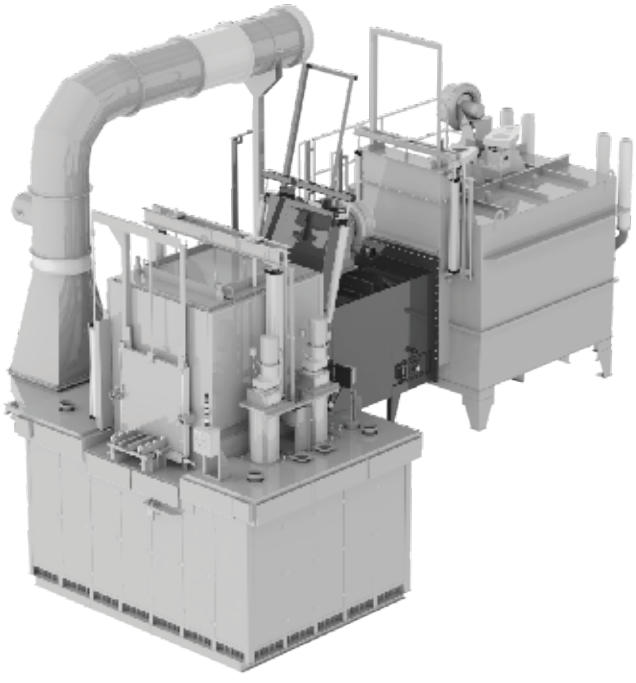
aichelin group

AFC HOLCROFT

industrial furnace solutions

Green Technology

Innovative Universal Batch Quench Austemper [UBQA] Salt Quench Systems



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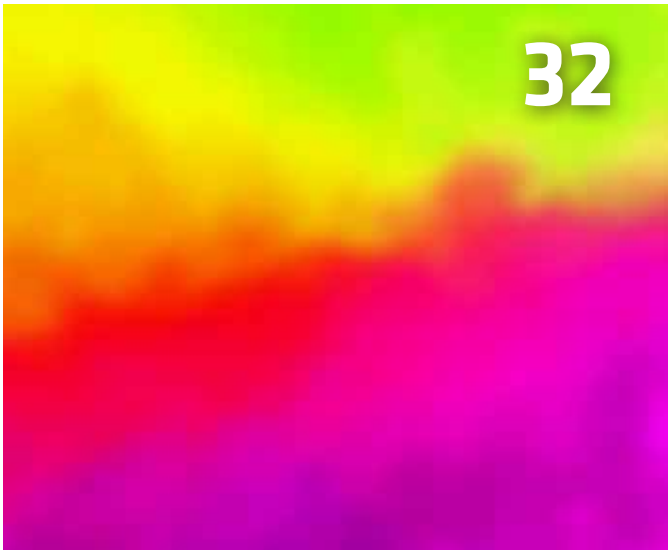

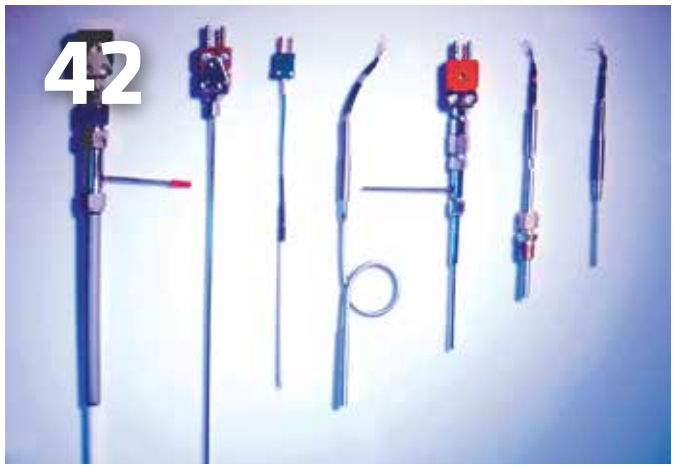

COMPANY PROFILE ///

DELIVERING TEMPERATURE SENSING WITH PINPOINT ACCURACY

BASF Environmental Catalyst and Metal Solutions' (ECMS) innovative pyrometers and thermocouples allow the company to provide the most accurate instrumentation possible for the industry, ensuring more efficient operations.

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FROM THE EDITOR ///

Pyrometry and process control take center stage

The March issue of *Thermal Processing* looks at activities vital to the heat-treat industry, namely pyrometry and process control, and you'll find quite a few articles this month that deal comprehensively with those subjects.

Pyrometry is a subject that is a vital part of making sure equipment performs optimally, and many experts have weighed in with a highly technical approach. Our March feature article about pyrometry, from Sahar Safarloo, Alberto Tapetado, and Carmen Vázquez, takes a deep dive into the experimental validation of the high spatial resolution of a two-color optical fiber pyrometer. Their tests show the potential for quickly measuring temperature gradients in small areas, independent of emissivity, such as in micro-thermography. The article is definitely a heavy lifter, but it offers expertise on a vital subject with laser-like precision.

Process control is also another vital area in making sure equipment maintains its proper temperatures across the board, so when companies decide to upgrade their existing equipment, it's important to make sure the electronics and hardware that monitor those functions are updated as well.

Our cover story, that looks at a tangential area of heat-treating, discusses how the demand for forged parts has spurred the drive to rebuild and automate existing equipment. For both the forging and heat-treat industries, significant automation upgrades are increasingly required for rebuilt models.

Back to the subject of pyrometry, March's company profile features BASF Environmental Catalyst and Metal Solutions (ECMS). The company designs and builds innovative pyrometers and thermocouples that allow it to provide the most accurate instrumentation possible for the industry, which, in turn, ensures more efficient operations.

Proper software is vital when making sure equipment is functioning correctly. In our Q&A, Dante Molle, chief information officer with Aerospace Compliance Software, discusses how ACS is streamlining the process of completing and managing pyrometry certifications, which can include temperature uniformity surveys, system accuracy testing, calibrations, thermocouple tracking, and more.

That's just a taste of what you'll find in this month's issue of *Thermal Processing*.

I also want to take the opportunity to say that if you're looking for a forum to share your expertise, please hit me up with suggestions at the email below so we can continue to make *Thermal Processing* the best heat-treat source it can be.

As always, thanks for reading!

KENNETH CARTER, EDITOR
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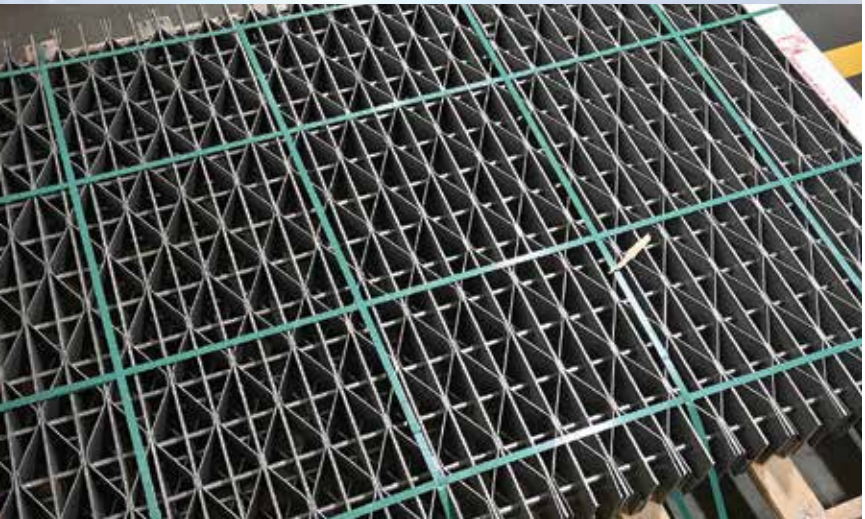

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A recently commissioned Solar Atmospheres vacuum furnace has a working hot zone of 24" x 24" x 72" deep and uses several unique hot zone design features to increase the quench rate. (Courtesy: Solar Atmospheres)

Solar Atmospheres commissions gas quench furnace

Solar Atmospheres in Souderton, Pennsylvania, recently commissioned a new vacuum furnace capable of using high-pressure gas quenching at 20-bar (about 300 PSI) to meet demanding cooling rate specifications for the heat treatment of nickel-based superalloys.

The installation represents an investment of more than $2.5 million in support of the aerospace and power generation markets. The vacuum furnace, manufactured by sister company Solar Manufacturing, has a working hot zone of 24" x 24" x 72" deep and uses several unique hot zone design features to increase the quench rate. The furnace is rated for operation to 2,400°F and temperature uniformity plus/minus 10°F.

"Solar has again raised the bar in the design and capabilities of the gas quench vacuum furnace," said Mike Moyer, Solar's vice president of sales. "The furnace utilizes a 600-HP cooling motor and fan with a creative gas nozzle design to maximize gas flow as it moves through the hot zone and the heat exchanger and back across the workload. For more than 40 years Solar has continuously improved the design of our furnaces to achieve rapid cooling rate while using gas in lieu of oil or water quench."

MORE INFO www.solaratm.com

Aalberts surface technologies makes portfolio changes

Aalberts surface technologies, a leading global provider of specialized thermal processing, surface treatment, and material coating solutions, announced it is making changes to its U.S. portfolio in response to changing market dynamics. Aalberts surface technologies has made investments in its Canton, Ohio, facility, adding austempering capabilities which will provide a logistically favorable option to customers located in the Midwestern, Eastern, and Northeastern U.S. markets. To balance the capacity available in the market with demand, the company will be closing its plant in Fort Smith, Arkansas.

"The expansion of our austempering capabilities in Canton, Ohio, provides current and prospective customers in the area with an opportunity to take advantage of our best-in-class value proposition while not having to absorb added logistical costs to do so," said Steve Wyatt, president of Aalberts surface ¬technologies – HIP | braze | heat treatment. "The decision to exit the austempering market in the South was a difficult one, but the market for austempering in the addressable market for our Fort Smith, Arkansas, plant simply is not sufficient to sustain the operation. We recognize the hardships that this difficult decision may create and will be working with our Fort Smith team to minimize the impact as much as possible, including exploring opportunities at one of the many other Aalberts locations."

The austempering capabilities in Canton, were slated to start up in mid-February and be fully production-ready by the end of March 2024. The decommissioning of the Fort Smith plant was to begin in mid-February, with production expected to cease when Aalberts has completed working with its customers to transition their product, but not later than April 2024.

"We are focused on optimizing our portfolio around the globe; this initiative is about responding to what the market needs and where it is needed," said Oliver Jaeger, CEO of Aalberts surface technologies. "In our business, logistics is a significant percentage of the total cost of our services, therefore, we must constantly be seeking ways to minimize that cost for our customers. We are committed to growing in the U.S. and look forward to partnering with our customers to develop solutions that contribute to our mutual success."

SEND US YOUR NEWS Companies wishing to submit materials for inclusion in Thermal Processing's Update section should contact the editor, Kenneth Carter, at editor@thermalprocessing.com. Releases accompanied by color images will be given first consideration.

Hydrogen-based steelmaking enables a fossil-free value chain from mine to finished steel product. (Courtesy: Tenova)

Aalberts surface technologies has five divisions on three continents and is part of the worldwide leading and globally positioned technology company Aalberts N.V., which has 132 locations worldwide and more than 14,000 employees.

MORE INFO www.aalberts-st.us

LKAB selects ENERGIRON for plant in northern Sweden

The ENERGIRON® technology, jointly developed by Tenova and Danieli, has been chosen by LKAB, an international mining and minerals group that offers sustainable iron ore, minerals, and special products, for the basic engineering of its 100 percent hydrogen-based direct reduced iron (DRI) plant in Gällivare, Sweden. This represents a further step in the application of the technology by the group, as ENERGIRON has already been the key equipment to the full-hydrogen pilot plant in Luleå, Sweden, built by HYBRIT Development AB, a joint venture between LKAB, SSAB, and Vattenfall, and commissioned in 2020.

Results from the HYBRIT pilot plant revealed that the DRI obtained using pure hydrogen as a reducing agent instead of fossil-based reducing gas such as natural gas delivers superior properties and qualities. With a capacity of 1.35 Mtpy of fossil-free DRI, the Gällivare demonstration plant will combine the HYBRIT technology with ENERGIRON technology merging know-how and experience in DRI plants.

Among the characteristics of the new installation, it is notable that an electric process heater — a world first in an industrial DRI plant — will heat the process gas using green electric power. This will reduce carbon emissions down to zero, dramatically increasing the overall energy efficiency of the process. The new DRI plant will use fossil-free electric power from different sources to produce fossil- free sponge iron that will be used by SSAB to make fossil-free steel.

"We're excited to continue our sustainability journey with LKAB in the making of the very first industrial DRI plant that, thanks to our innovative ENERGIRON technology, will produce fossil-free steel using an electric process gas heater," said Stefano Maggiolino, Tenova HYL president & CEO. "With our tireless push for innovation, hydrogen-based iron ore reduction at zero emissions has already become an industrial reality."

The current contract is related to basic engineering services, while future equipment supply and construction are pending waiting for prerequisites like environmental permits and Final Investment Decision (FID).

Tenova, a Techint Group company, is a worldwide partner for sustainable, innovative and reliable solutions in the metals and — also through the well-known TAKRAF and DELKOR brands — in the mining industries. Tenova leverages a workforce of more than 2,300 forward-thinking professionals located in 19 countries across five continents, who design technologies and develop services that help companies reduce costs, save energy, limit environmental impact, and improve working conditions.

MORE INFO www.tenova.com

New electric aluminum aging furnace for ALRO

ALRO, a company in the Vimetco group and listed on the Romanian Stock Exchange, purchased an aluminum aging furnace with electric heating from Seco/Warwick.

ALRO S.A., one of the largest vertically integrated aluminum producers in Europe measured by production capacity, has purchased an aluminum aging furnace with electric heating from Seco/Warwick. The project objective is to increase the output of high and very high added products. This state-of-the-art electric furnace will replace three furnaces powered by natural gas with the aim of streamlining the heat-treatment operations within the ALRO Processed Aluminum Division and represents an important step toward achieving ALRO's goal of becoming a greener producer.

ALRO S.A.'s project objective is to increase the output of high and very high added products. (Courtesy: Seco/Warwick)

The solution has been designed for aging type 2xxx, 6xxx ,and 7xxx aluminum plates with a length of up to 13,000 mm and a width of up to 2,200 mm. They can be arranged in one or two rows. The load will be placed horizontally on loading trays with the maximum capacity of 60 tons net. The furnace will be heated electrically, which will significantly reduce CO_2 gas emissions.

"The challenge of reducing emissions is

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becoming an increasingly important purchasing impulse for customers," said Piotr Skarbiński, vice president of the aluminum process and CAB business segments at Seco/Warwick. "This applies in particular to European producers, because in this region of the world ecological regulations are currently the most restrictive. The aluminum aging furnace, powered by electric heaters, eliminates the emissions problem, hence the growing interest of aluminum producers in such solutions."

Aging furnaces are designed to operate in the temperature range from 80°C to 250°C in accordance with the AMS 2750G standard. The temperature uniformity guarantee throughout the entire load at the level of +/- 3°C was achieved thanks to the use of optimal heat flow inside the furnace using high-performance atmosphere mixers and a system of guides directing the air stream.

ALRO is one of the largest aluminum producers in Europe (in terms of production capacity). The company is organized into two departments, consisting of an aluminum smelter, foundries, and a recycling plant.

"It is an important partner for us, not only because of its huge production scale," said Tomasz Kaczmarczyk, sales manager of the aluminum process and CAB furnaces teams at Seco/Warwick. "We have already completed several orders for new equipment for this customer, including a gas aging furnace and ingot preheating furnace. We have also modernized furnaces for annealing aluminum sheet coils. However, it is interesting that we signed the current contract after a ten-year break, which shows that our solutions perform well in continuous, advanced production, and customers keep coming back even after many years. Good cooperation and partnership have always been a priority for us."

"While we are still making significant efforts to overcome the challenges of the international economic environment, we remain focused on our long-term goals and continue to invest in state-of-the-art technology," said Gheorghe Dobra, ALRO CEO. "The new equipment, provided by Seco/Warwick, will support our program to maximize the value of the products we are manufacturing and will allow us to better serve our customer's requirements. At the same time, the new technology will support our commitment to reduce our environmental footprint."

MORE INFO www.secowarwick.com

Founded in Columbus, Ohio, in 1949, BriskHeat has evolved to serve customers across industries worldwide, providing flexible surface and immersion heating products, controllers, and insulators. (Courtesy: BriskHeat)

BriskHeat celebrates 75 years in industrial heating industry

BriskHeat, a leading provider of flexible surface and immersion heating products, controllers, and insulators, is celebrating its 75th anniversary. Founded in 1949 in Columbus, Ohio, where the company's headquarters remain, BriskHeat has grown to include a global sales network and multiple manufacturing facilities.

"The entire BriskHeat team is celebrating this major milestone," said Mike Thompson, president and chief executive officer, BriskHeat. "It's no small feat for a company to reach its 75th anniversary. We pay tribute to all our customers over the years and our staff members who've given their all to make BriskHeat a leader in the industrial heating space."

In 2018, BriskHeat became part of NIBE Industrier AB, a global group of manufacturing companies with more than 15,000 employees. BriskHeat serves brands across industries, including semiconductor, aviation, aerospace, construction, food processing, laboratory and medical science, marine, mining, oil and gas, plastics, and more.

Highlights of the company's evolution include expanding manufacturing and production to Vietnam and Costa Rica; opening sales offices in Europe, Taiwan, and China; and releasing innovative new products such as the LYNX® temperature control system, ACR hot bonder, vacuum tables, and other out-of-autoclave composite curing equipment.

Founded in 1949 by retired Major General Earnest Briscoe, BriskHeat started as the Briscoe Manufacturing Company. It made airplane wing de-icers for the military, as well as its now famous multi-stranded and serpentine wound knitted and braided heating element. With its superior durability, flexibility, and temperature uniformity, this heating element is still used in most of the company's products today.

Other milestones in BriskHeat's history include:

›› In 1952, BriskHeat moved to Gibbard Avenue in Columbus, Ohio, which served as its primary manufacturing location and corporate headquarters for 64 years until 2016, when it moved to its current location in east Columbus.

›› Over the years, the company expanded its product lines to include the first cloth heating jacket introduced in 1950 and silicone rubber extruded heating tapes and blankets in 1957.

›› From the 1950s through 1981, products were sold under the name "Briskeat." In 1984, the company officially changed its name to BriskHeat.

» BriskHeat received a patent for its grounded heating element in 1999.

» The 1990s saw the rapid rise of semiconductors. With this came the increased need for BriskHeat cloth heating jackets to prevent build-up in gas lines, exhaust lines, and forelines.

» The early 2000s saw the introduction of multiple new products, including IBC/tote tank heaters, gas cylinder heaters, and HSTAT silicone heat tapes

» In 2008, BriskHeat began taking orders online. That same year, it opened a second cloth production facility in Columbus to help support the rapid increase in demand for cloth heating jackets.

» In 2010, BriskHeat opened its Vietnam production facility.

» NIBE Industrier AB acquired BriskHeat in 2018.

» 2023 saw BriskHeat open its Costa Rica production facility.

In 2023, Mike Thompson became the president & CEO of BriskHeat upon the retirement of Domenic Federico, who served in the role for 22 years.

"As for what the next 75 years will hold, our vision is for BriskHeat to be the world's top, one-stop source for all surface heating solutions, temperature controls, and insulating needs," said Thompson. "With our dedicated staff and loyal customers, we look forward to a bright future."

MORE INFO www.briskheat.com

Vac Aero, Vesco collaborate for stronger offerings

Vesco, a company of the Busch Group and a leading service provider in the heat-treatment industry, announced the formalized collaborative agreement with Vac Aero International. Vac Aero is a leading vacuum furnace manufacturer, vacuum heat treating, and coatings service provider to aerospace and high-tech industries worldwide.

The collaboration between Vac Aero International and Vesco is set to combine the unique strengths and expertise of both companies. This venture aims to provide innovative solutions for their customers, enhance service offerings and contribute to the overall advancement and net zero goals of the industry:

» Innovative Synergy: The partnership leverages the collective expertise of Vac Aero International and Vesco to drive service responsiveness and set new benchmarks in the industry.

» Expanded Service Capability: Clients can anticipate a broader spectrum of services, with the combined strengths of both companies leading to an enhanced service portfolio.

» Strategic Vision: Vac Aero International and Vesco share a common vision, marked by excellence, innovation, and customer satisfaction over decades of cooperation.

"We are thrilled to embark on this jour-

ney with Vac Aero International," said Thomas Burke, vice president – business development at Busch Vacuum Solutions. "This collaboration represents a strategic alignment of our strengths, and together, we are poised to make significant contributions to the industry."

"We could not agree more with Thomas and are equally thrilled to partner with Vesco and Busch Vacuum Solutions," said Dave Farmery, president and COO at Vac Aero International. "Together we will enhance our customers' operational performance as well as being able to help drive their overall sustainability initiatives going forward."

Vesco is a renowned heat-treatment service provider privately owned by the Busch Group. Vesco specializes in providing tailored service and product solutions to companies of all sizes in the heat-treatment industry. For more information, please visit www.vacuumengineering.com.

Vac Aero International Inc. is a privately owned Canadian company supplying heat treating and coating services and industrial furnace equipment to the aerospace and high-tech industrial sectors with facilities located in Ontario and Quebec, Canada.

MORE INFO www.vacaero.com
vacuumengineering.com

Insu Teknik invests in Nitrex advanced heat-treat technology

Insu Teknik, a leader in the gas springs sector of the automotive industry, continues to pioneer innovation as a key supplier for aftermarket and OEMs, both in Türkiye and internationally, having successfully implemented a cutting-edge Nitrex system at its facility in Bursa, Türkiye.

As a first-time partner with Nitrex, Insu Teknik has strategically invested in advanced heat-treat technology, focusing on continuous improvement to enhance the quality of gas springs, operational efficiency, and environmental sustainability. Central to their decision was Insu Teknik's commitment to environmentally responsible manufacturing practices, which led them to seek a greener solution.

Commissioned in the last quarter of 2023, the Nitrex system, featuring a large-capacity pit furnace (model NX-1215), combines three key process technologies: Nitreg® controlled nitriding, Nitreg®-C controlled nitrocarburizing, and ONC® in-process post-oxidation. These technologies enhance the surface properties of gas spring rods, notably improving wear and corrosion resistance, and offering considerable operational advantages. The system ensures uniform case depth and precisely managed nitride/nitrocarburizing layer formation, optimizing the mechanical properties of the gas spring rods. It minimizes part distortion — an advantage of operating at lower temperatures compared to salt bath nitrocarburizing — and eliminates the need for post-finishing operations due to the cleaner surface achieved through gas nitrocarburizing, thereby streamlining the manufacturing process. The Nitreg-C technology further increases surface hardness and fatigue resistance, while ONC yields a consistently even oxide layer, enhancing corrosion resistance and the overall aesthetic quality of the final products. Furthermore, the Nitrex system's eco-friendly approach aligns with environmental standards by eliminating the production and disposal of hazardous waste.

İnsu Teknik has invested in a Nitrex system, featuring a large-capacity pit furnace (model NX-1215), combines three key process technologies: Nitreg® controlled nitriding, Nitreg®-C controlled nitrocarburizing, and ONC® in-process post-oxidation. (Courtesy: Nitrex)

"Insu Teknik sought metallurgical consultation for a sustainable and economically viable in-house solution," said Utku Inan, Nitrex's local representative. "Having previously outsourced salt bath nitrocarburizing to a commercial heat treater, Insu Teknik found Nitrex to be the preferred choice due to its environmentally friendly technology and its capability to overcome the challenges associated with salt baths. This investment positions Insu Teknik for heightened control over their production, ensuring improved product quality and consistency."

"The commissioning process was executed seamlessly, marking Insu Teknik's strategic shift towards greater control over their production processes," said Marcin Stoklosa, technical sales manager — EMEA region at Nitrex. "What sets this system apart is its versatility in meeting the specific requirements of various gas spring applications across various industries, including automotive, agriculture, machinery, marine, furniture, medical equipment, and more. This move marks a pivotal moment in Insu Teknik's journey toward sustainable manufacturing and greater customer satisfaction."

MORE INFO www.nitrex.com

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L&L ships large box furnace to castings company

L&L Special Furnace Company recently delivered a large floor-standing box furnace to the heat-treating department of an investment castings supplier.

The furnace will be used as support in the customer's tool and die production along with tempering of finished castings.

The L&L model XLE3436 box furnace has an effective work zone of 34" wide by 22" high by 32" deep. It is equipped with a direct-lift vertical door with a floor switch to activate. The cantilevered vertical door eliminates the need for the upright structure to reduce the overall height of the equipment.

The furnace includes a program control and overtemperature protection. A four-zone SSR control with digital biasing is provided to balance temperature gradients. The XLE3436 also features a paperless chart recorder with six thermocouple inputs, a heavy-duty Inconel sheathed thermocouple, a recirculation fan, and an atmosphere-sealed case for deployment with inert atmospheres.

The L&L model XLE3436 box furnace has an effective work zone of 34" wide by 22" high by 32" deep. (Courtesy: L&L Special Furnace Company)

The inert blanketing gas enables the part to be heat-treated with minimal surface decarb. A stack light indicates the furnace status via an audible and visual indicator light mounted on top of the control.

Additionally, the furnace is equipped with a pyrometry package that has reference control thermocouple ports along with corner locations to record the high and low points within the unit as indicated by the latest temperature uniformity survey.

All L&L models can be designed with various options and be specifically tailored to meet customers' thermal needs. The company also offers furnaces outfitted with pyrometry packages to meet ASM2750.

Options include a variety of control and recorder configurations. A three-day, all-inclusive startup service is provided with each system within the continental United States and Canada. International startup and training service is available by factory quote.

MORE INFO www.llfurnace.com

Evolution of Thermal Care brand within the Piovan Group

While commemorating the 90th anniversary of Piovan Group and its 60th anniversary in the polymer industry, the company has announced a pivotal moment in the ongoing progression of Thermal Care, one of the flagship brands within the group. Piovan Group has launched a new strategic division for industrial and process refrigeration, the result of the integration of the businesses operated by Thermal Care and Aquatech.

The Thermal Care brand now expands globally, facilitated by the integration of the Aquatech business which moves forward under the banner of Thermal Care. Furthermore, the incorporation of "Piovan Group" into the Thermal Care logo not only signifies geographical expansion but also reflects a unified vision for growth and innovation.

With a legacy spanning more than half a century, Thermal Care and Aquatech have solidified themselves as prominent players in industrial process cooling markets by providing high-quality, sustainable equipment and solutions.

Operating primarily out of the United States, near Chicago, Thermal Care has been a leader in the design, manufacturing, sales, and service of top tier heat transfer solutions across various industries — including plastics, food and beverage, and more than 50 other industry segments. Headquartered in Italy, Aquatech has been primarily covering EMEA, Latin America, and Asia Pacific regions with design, sales, and service of similar products, primarily focused on polymers processing. Thermal Care and Aquatech products manufactured in North America, Europe, Asia, and South America will continue to be produced and sold in their respective regions, now under the newly established division.

The new division headed by Lee Sobocinski, current president of Thermal Care Inc., will operate under the Thermal Care brand and will have consolidated sales of approximately 100 million Euro, globally. The creation of the global Thermal Care brand, coupled with the exchange of the institutional knowledge within Piovan Group into this emerging division, will empower the new Thermal Care to provide best-in-class assistance to customers, irrespective of their geographical presence, spanning from preliminary sales engagement to post-sales support.

MORE INFO www.thermalcare.com

Kolene Corporation names Pignotti VP of research

Kolene Corporation promoted of Dr. Louis R. Pignotti to vice president of research and

development, and to an officer of Kolene Corporation, effective January.

Pignotti joined Kolene in September 2012 as a senior research chemist and progressed through the lab to chief chemist in January 2016, where he had remained until his current role as VP of R&D.

"Kolene was founded in 1939, on the basis of unique chemistries and chemical formulations that have served vital and important industry segments globally for nearly 85 years," said Roger Shoemaker, Kolene chairman & CEO. "Kolene's lab and technical capabilities are extremely important to the company's success. Louis has demonstrated he is well qualified to carry on this tradition for Kolene."

In 2006, Pignotti earned his B.S. in chemistry with environmental concentration, from Michigan Technological University, Houghton, Michigan. In 2011, he earned a Ph.D. in inorganic chemistry, also from Michigan Tech.

Dr. Louis Pignotti

Prior to joining Kolene, Pignotti was the manager of research and development at Peninsula Copper Industries, where he developed and patented a new chemical process, while carrying out small scale pilot plant testing at PCI.

"During his time at Kolene, Louis has developed into a technical expert, and a uniquely qualified individual in the molten salt, and metal surface technologies industry," said Kolene president Scott Schilling. "His lab experience and technical expertise has been invaluable to Kolene and is vital to new product development efforts in the future."

While at Kolene, Pignotti has worked to assist in prospective customer development, quality assurance and quality control projects, lab analysis, various environmental regulatory compliance efforts, and new product development. Pignotti is also a named inventor on the Kolene patent for Oxigen-X®. In the role of vice president of research and development, Pignotti will continue to advance Kolene's technology by leading efforts to bring new products and processes to Kolene's customers, along with taking a more active role in company leadership.

MORE INFO www.kolene.com

DENIOS Impact Protection and Barrier Systems offer a comprehensive range of impact protection barriers and bumper protection systems to shield facilities and structures from damage. (Courtesy: DENIOS Impact Protection and Barrier Systems)

DENIOS barrier systems safeguard structures, personnel

DENIOS Impact Protection and Barrier Systems are a simple and intelligent way to avoid accidents and damage to workplace structures, equipment, and material handling tools, while safeguarding employees.

They offer a comprehensive range of impact protection barriers and bumper protection systems to shield facilities and structures from damage during intra-company transport or loading and unloading. Safety barriers are available to protect against high-impact and low-impact collisions maximizing safety and minimizing potential damage. Technologies available include corner and wall protectors, rack protectors, post bollards and bollard covers, polyurethane foam protective bumper guards, retractable tape barrier systems, machinery and rack guarding, I-beam protectors, mobile expanding gates, and more. DENIOS impact protection barriers, traffic safety equipment, and drain equipment are ideal for use in manufacturing plants, process facilities, warehouses, and more.

DENIOS is a world leading manufacturer and supplier of products and services for occupational environmental protection and workplace safety. For nearly four decades they have been supplying legally compliant products, solutions, and custom services for handling hazardous substances. They serve North American customers from a 100,000-square-foot facility in Louisville, Kentucky, which houses engineering, manufacturing, customer service, and administrative support.

MORE INFO www.denios-us.com

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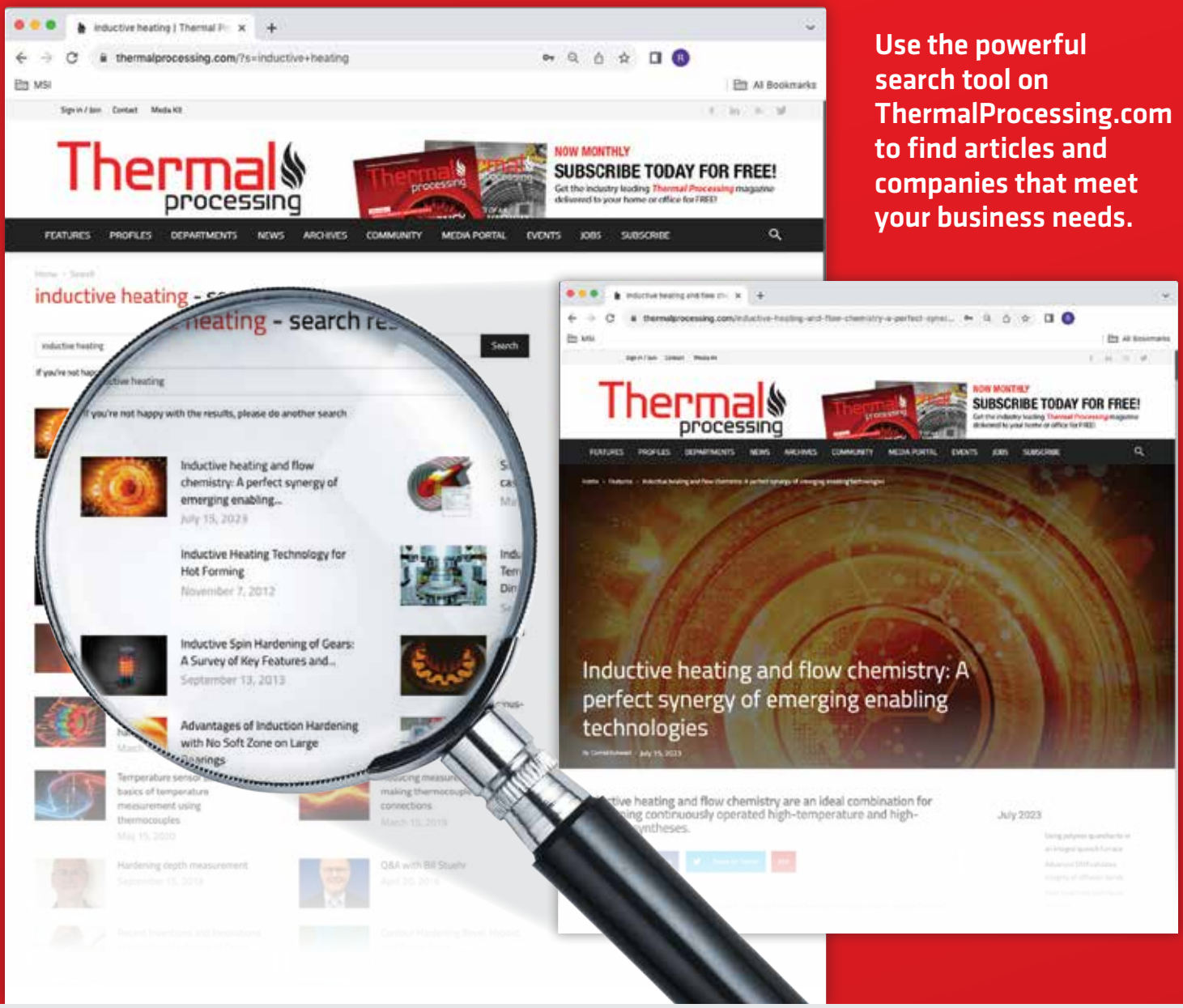

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Tadashi Furuhara to be given IFHTSE medal at World Congress

IFHTSE Medal will be awarded to Prof. Tadashi Furuhara of Tohoku University in Sendai, Japan.

The citation reads: "For his life-time achievement in the physical metallurgy of diffusional and displacive phase transformations in steels and titanium alloys and advanced microstructure characterization with electron microscopy techniques."

The award ceremony will be during the 29th IFHTSE World Congress on September 30, 2024, in Cleveland Ohio.

Tadashi Furuhara

Tadashi Furuhara was born in 1960 in Japan. He received both his bachelor's and master's degrees in engineering from the department of metal science and technology at Kyoto University and his PhD from Carnegie Mellon University in the U.S. From 1989 to 2005, he was employed at Kyoto University. He has been a professor at the Institute of Materials Research (IMR) at Tohoku University in Sendai since 2005. During his career, Prof. Furuhara has served as director of IMR; he is currently director of The Iron Steel Institute of Japan and The Japan Society for Heat Treatment. Furthermore, he is editor of Acta Materialia and Scripta Materialia.

Prof. Furuhara's research achievements concern diffusive and displacive phase transformations in metallic materials, microstructure control by thermochemical processing in ferrous and non-ferrous alloys, as well as shape memory alloys and surface engineering of steels. His academic work from the University of Kyoto and Tohoku University is well-known and well-cited in the discipline of physical metallurgy. He is particularly recognized for his work on variant pairing and variant selection in ferrous martensite and bainite. For his research activities, Prof. Furuhara and his team excel in the application of a suite of electron microscopy and electron diffraction techniques as well as atom probe tomography.

CONFERENCE UPDATES

4th Mediterranean Conference on Heat Treatment and Surface Engineering (MCHTSE 2024)
April 17-19, 2024 I Lecce, Italy

MCHTSE 2024 will be held together with the 5th International Conference on Thermal Process Modeling and Simulation (5th ICTPMS). These two IFHTSE conferences will be in Lecce, Italy.

The conferences aim to provide a forum where engineers, scientists, researchers, and production managers can review and discuss fundamentals, new challenges, recent progress, and emerging topics in the fields of advanced heat treatment and surface engineering technology.

TPMS-5 aims at covering all aspects of modeling and simulation of thermal processes.

›› **More info:** www.aimnet.it/eng/manifestazione.php?id=789&idc=4

2nd Bosphorus International Heat Treatment Symposium
April 25-26, 2024 I Istanbul, Türkiye

BHTS'2024 — 2nd Bosphorus International Heat Treatment Symposium will be at the Halic Congress Center in Istanbul April 25-26, 2024, in cooperation with MISAD — Heat Treatment Industrialists Association and METEM-UCTEA Chamber of Metallurgical and Materials Engineers' Training Center.

With the scope of this symposium, a space will be created where the challenges in advanced heat-treatment technologies, current R&D studies, new developments, and different ideas will be discussed. Within this framework, local, foreign, and international companies are invited that want to exhibit their products, services, and exemplary applications to support them as participants. The symposium is in Turkish and English. Turkish-English simultaneous translation will be provided in all sessions.

›› **More info:** www.bhtsheat.com/en

European Conference on Heat Treatment and Surface Engineering 2024 (and A3TS 50th Congress)
June 5-7, 2024 I Toulouse, France

The ECHT 2024 Conference and the 50th Annual A3TS Congress will take place together in Toulouse, France June 5-7, 2024. The focus will be on processes and technologies for a sustainable future in transport and industry. The conference will deal with all fields of heat treatment and surface engineering: heat treatment of metals (iron and steel, non-ferrous alloys); thermochemical treatment of metals; coat-

The 29th IFHTSE World Congress, a premier global event dedicated to advancing the fields of heat treatment and surface engineering, will be held Sept. 30 to Oct. 3 in Cleveland, Ohio. (Courtesy: Shutterstock)

ings and surface treatments; coatings and surface treatments including dry treatment operations (PVD, CVD, plasma, thermal spraying, etc.); and wet treatment operations (electrochemistry, etc.). Specific sessions will be devoted to the aerospace industry. Additional focus areas include:

- Contribution of innovative heat and thermochemical treatments to EU climate goals.
- Digital technologies in heat treatment and surface engineering industries.
- Coatings made from enhanced materials for electrical and thermal conductivity.
- Surface engineering to address environmental constraints.
- New needs in tribological properties: an open challenge for heat treatment and surface engineering.
- **More info:** echt2024a3ts.sciencesconf.org

29th IFHTSE Congress
September 30-October 3, 2024 | Cleveland, Ohio

The ASM Heat Treating Society (HTS) and the International Federation for Heat Treatment and Surface Engineering (IFHTSE) present the 29th IFHTSE World Congress, a premier global event dedicated to advancing the fields of heat treatment and surface engineering. Co-located with ASM's annual meeting, IMAT 2024, the congress is scheduled for September 30-October 3, 2024 in Cleveland, Ohio.

The 2024 IFHTSE World Congress revolves around the theme "Innovations in Heat Treatment and Surface Engineering for a Sustainable Future." Emphasizing the critical role of these technologies in shaping a sustainable world, the event will explore the latest developments, breakthroughs, and practices that can enhance the efficiency, performance, and environmental impact of heat treatment and surface engineering processes. In addition, traditional heat-treating topics will be offered.

Important dates:

- **Author Notifications of Acceptance:** March 29, 2024.
- **1st Draft of Manuscript Due:** May 17, 2024.
- **Editor Feedback to Authors:** June 14, 2024.
- **Final Manuscripts Due:** June 28, 2024.

- **More info:** www.asminternational.org/ifhtse-congress

SPOTLIGHT ON MEMBERS

University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture

The University of Zagreb (founded in 1669) is the oldest and largest university in southeastern Europe. As a comprehensive public central European university, University of Zagreb offers education and research and in all scientific fields (arts, biomedicine, biotechnology, engineering, humanities, natural sciences, and social sciences) and a broad spectrum of courses at all study levels, from undergraduate to postgraduate. With 29 faculties, three art academies and the University Centre for Croatian Studies, it is the flagship educational institution in the country, a place where more than 7,900 teachers and 72,480 students develop knowledge and acquire skills.

- **More info:** www.unizg.hr

ABOUT IFHTSE

IFHTSE is a federation of organizations not individuals. There are three groups of members: (a) scientific or technical societies and associations; (b) universities and registered research institutes; and (c) companies.

IFHTSE LEADERSHIP

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Prof. Mufu Yan | Harbin Institute of Technology | China

ONLINE www.ifhtse.org | **EMAIL** info@ifhtse.org

MEMBER SPOTLIGHT » Chiz Bros. Refractory & Insulation Specialists

Chiz Bros. provides exceptional customer service and engineering expertise

Chiz Bros. focuses on providing electrically heated ceramic fiber modules, and it can provide a turnkey package of an electric elements system and additional refractory to meet any furnace requirements.

Chiz Bros. is excited to become a member of IHEA this year. Founded in 1968, the company began as a contractor in the steel industry in Pittsburgh, Pennsylvania. Its current focus is ceramic fiber insulation for industrial furnaces, and it specializes in ceramic fiber blanket and board, modules, insulating fire brick, high-temperature gaskets, and engineered drawings. Chiz Bros. make shipments across the country, and 85 percent of the company's products are made in the U.S.

With 35 employees, Chiz Bros. is a family-owned company that provides exceptional customer service and engineering expertise. It serves a multitude of industries, including steel, glass, heat treating, aluminum, power generation, and ceramics. The company provides engineered drawings for its projects, and it maintains a large inventory at its warehouses in Pittsburgh and Detroit for emergency deliveries.

Chiz Bros. prides itself in evolving with the heat-treating industry as customers move toward electrically heated furnaces. The company focuses on providing electrically heated ceramic fiber modules, and it can provide a turnkey package of an electric elements system and

additional refractory to meet any furnace requirements.

Chiz Bros. looks forward to growing as a company and expanding into other cities, but it will continue to ensure that it stays loyal to its family business roots and to always put the customer first.

CONTACT INFO

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›› www.chizbros.com
›› mrhoajr@chizbros.com

MEMBER SPOTLIGHT ›› COMBUSTION 911

COMBUSTION 911 SPECIALIZES IN PARTS FOR COMBUSTION SYSTEMS, INDUSTRIAL BURNERS, AND MORE

Great customer service is going the extra mile as a matter of course. It means real people answering the phone, replying to emails within 24 hours, and engaging on a human level. Giving your customer the opportunity to be the hero, sometimes because you showed them where to find the answer on their own, and maybe sometimes because you knew how to solve the problem from experience.

The goal of providing matchless customer service drives nearly everything Combustion 911 does, and it pays off even when the payoff isn't immediate repeat business. Helping someone out of a jam is fulfilling and builds goodwill equity that your best customers carry for years. People reach out when they have some need, usually related to sourcing products for existing or new equipment, and they are sensitive to lead times and pricing.

When the market suffers due to lead times and discontinued products, Combustion 911 suffers, too. That's why the company has worked hard to build direct relationships with manufacturers who may not have a presence in North America, providing unlooked-for alternative product streams and doing the work to get necessary approvals. These partnerships allow the company to ensure the quality of the products it sells, to maintain direct communication with the manufacturers regarding deliveries and technical support, and to keep prices fair and competitive.

Of course, people contact Combustion 911 for other reasons too, such as installation support or questions regarding the workings of a product they've just received or have owned for years. The company can usually handle these questions quickly and remotely, though it certainly supports and services its products on site when needed. Combustion 911 is always working on new resources to make it easier to size valves according to actual project variables, to visualize manufacturer-suggested installation guidelines and best practices, and to offer easy-to-follow troubleshooting advice.

Positioning itself to best serve its customers means paying attention to changes in emissions requirements, safety standards, and market trends. Therefore, becoming active members of IHEA is an important step for Combustion 911 as it continues to refine its approach.

In the 16 years since it has opened its doors, Combustion 911 has had the opportunity to work with many of the companies currently active in IHEA. Membership is therefore an opportunity to work together in new ways and gain fresh perspectives on issues that affect everyone.

CONTACT INFO

›› Kent, Ohio
›› 330-678-4328
›› combustion911.com

IHEA 2024 CALENDAR OF EVENTS

MARCH 20–24

IHEA 2024 Annual Meeting

Hotel DeSoto | Savannah, Georgia | www.ihea.org/event/AM24

MARCH 28

Sustainability & Decarbonization Webinar Series – Hydrogen Basics

This webinar will present the basics of hydrogen, a general comparison to natural gas as well as its combustion characteristics. Attendees will learn burner and system considerations as they relate to burner design, flame detection, air fuel ratio (stoichiometry), and control/safety components.

APRIL 8–MAY 19

Fundamentals of Industrial Process Heating Online Course

This course is designed to give the student a fundamental understanding of the mechanisms of heat transfer within an industrial furnace and the associated losses and the operation of a heating source either as fuel combustion or electricity.

Course Fees: $775 IHEA members / $950 non-members

APRIL 18

Sustainability & Decarbonization Webinar Series – Making Decisions: Gas vs. Electric

MAY 16

Sustainability & Decarbonization Webinar Series – Increasing Available Heat to Lower CO_2

This webinar will review the proven methods for heat recovery and emissions reduction and their applicability to processes where fuel savings and/or production increases have not previously justified their implementation.

For details on IHEA events, go to www.ihea.org/events

D. SCOTT MACKENZIE, PH.D., FASM
SENIOR RESEARCH SCIENTIST–METALLURGY /// QUAKER HOUGHTON INC.

Oxidation testing clearly showed copper was a very strong catalyst for oxidation of martempering oil. Nickel plating showed a very mild effect and exhibited very little oxidation during the test.

The effect of catalysts on quench oil oxidation

In the last column, I discussed the effect of temperature on the oxidation of a quench oil. As was alluded to in my last column, the oxidation of quench oil is very dependent on the catalyst used.

INTRODUCTION

Quench oils degrade from four primary reasons: oxidation; thermal degradation; contamination; and additive depletion. This is aggravated by residues on parts, washer residues from oil reclaimed from washers, high energy density heater or radiant tubes, and excessive peak temperatures. The addition of robust additive packages prolongs a quenchant life and provides for repeatable quenching.

Oxidation of quench oil is caused by exposure to oxygen. As operating temperatures increase, the kinetics of oxidation approximately double with each 10°C. This is especially true with martempering oils because of their elevated temperature of use.

Thermal degradation is from exposure to temperatures that cause the base oil and additive package to change. This results in the formation of insoluble products of reaction that can cause deposits on parts and sludge the quench tank.

Contamination can be from many sources. Water, dust, scale, and soot are not the direct result of oil degradation but can contribute to other degradation issues. Soot can act as nucleation sites for thermal degradation products and can mimic oxidized oil.

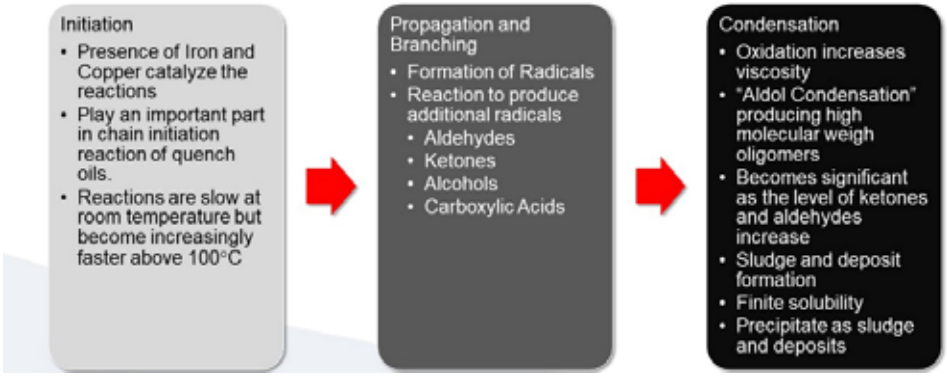

Figure 1: Schematic representation of the progression of oxidation.

Additive depletion is normal and expected. The antioxidants are consumed as part of their function. Antioxidants are replenished as make-up oil is added.

The oxidation mechanism of quenching oils is very complex [1] [2] [3] [4] [5] [6]. The presence of iron and copper catalyzes the reactions and plays an important part in chain initiation reaction. This is schematically shown in Figure 1.

EFFECT OF CATALYST

Often, parts, such as gears, are plated with copper to act as a carburizing "stop-off" to prevent the diffusion of carbon into the part in areas where carburizing is not desired. Copper plating can also be used to protect high-value parts from decarburization of carburizing during neutral hardening. This method is often used for components used in aircraft landing gear. Copper is an effective barrier to carbon diffusion. Copper is also used as a catalyst to accelerate oxidation in testing, such as by ASTM D943 "Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils." [7].

In ASTM D 943, a small test cell, that is controlled for tempera-

Figure 2: Typical equipment used for oxidation testing to ASTM D 943.

ture, is heated in the presence of a copper coil. An example of this equipment is shown in Figure 2.

Testing [8] was conducted according to ASTM D943 "Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils." [7], modified by eliminating the use of water. Standard copper coils were used. To test the effect of different catalysts, the copper coil was plated with nickel. Testing was conducted at 121°C. Oxidation was measured by viscosity (ASTM D445) [8], Total Acid Number (ASTM D664) [9], and by FTIR. Measurements for viscosity and TAN were taken at various intervals. The oil used was a premium martempering oil. The results of the oxidation testing as measured by TAN are shown in Figure 3 and the results of the viscosity testing are shown in Figure 4.

The oxidation testing clearly showed that copper was a very strong catalyst for oxidation of the martempering oil. Nickel plating showed a very mild effect and exhibited very little oxidation during the life of the test. When examined using FTIR (Figure 5), the oil exposed to the copper coil showed extensive oxidation while the oil exposed to the nickel-plated coil showed very little oxidation. The FTIR scans of the new oil and the oil exposed to the nickel coil were practically identical.

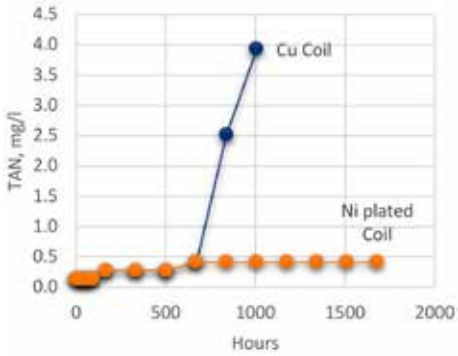

Figure 3: Total Acid Number by ASTM D664 for copper coil and nickel-plated coil.

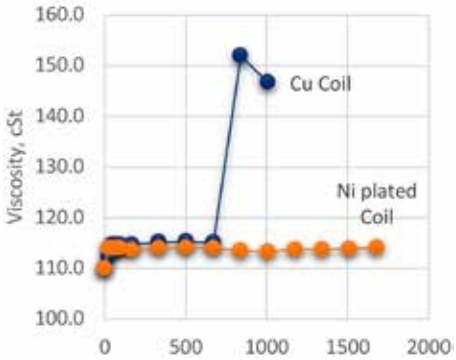

Figure 4: Kinematic viscosity testing per ASTM D445 for the copper coil and nickel-plated coil.

CONCLUSIONS

The oxidation testing clearly showed that copper was a very strong catalyst for oxidation of martempering oil. The use of copper as a local prevention of carburization severely increases the oxidation rate of the oil. Nickel plating showed a very mild effect and exhibited very little oxidation during the life of the test. When examined using FTIR, the oil exposed to the copper coil showed extensive oxidation while the oil exposed to the nickel-plated coil showed very little oxidation. The FTIR scans of the new oil and the oil exposed to the nickel coil were practically identical.

The use of nickel plating for the prevention of carburization has merit in the reduction of oxidation. However, additional testing must be performed to demonstrate that the diffusion of nickel will not change the local composition of the part and change the local hardenability. The use of a copper strike under the nickel plating to improve plating adhesion would help reduce nickel diffusion and provide additional protection from the diffusion of carbon during carburization. Additional investigation is underway to evaluate the effect of nickel plating during high-temperature carburization.

Should you have any comments on this article, or suggestions for further articles, please contact the author or the editor.

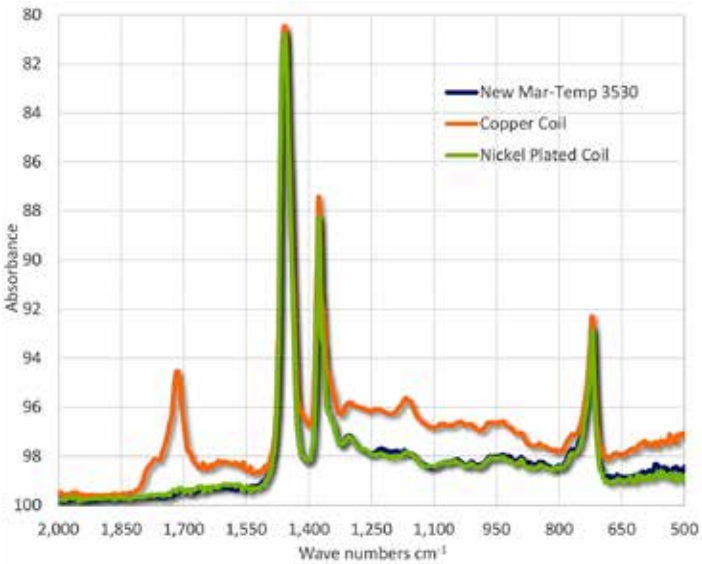

Figure 5: FTIR of new martempering oil compared to the same oil exposed to the copper coil and the nickel-plated coil.

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[10] ASTM, "ASTM D664: Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration," American Society of Testing and Materials International, West Conshohocken, PA.

ABOUT THE AUTHOR

D. Scott MacKenzie, Ph.D., FASM, is senior research scientist-metallurgy at Quaker Houghton. He is the past president of IFHTSE, and a member of the executive council of IFHTSE. For more information, go to www.quakerhoughton.com.

TONY TENAGLIER
QUALITY CONTROL MANAGER ///
HITCHINER MANUFACTURING

The problem isn't more – the problem is learning when to properly do less. Use the cycles of flow to set the proper expectations for the work day.

Achieving consistent quality is a slow, steady process

In a world that asks for more, what we sometimes need is less. I'm currently back in school, working on a Ph.D. in Industrial Organization Psychology to learn how to integrate this concept of flow into the workplace so the people and the processes can get the best out of it.

Flow is comprised of four stages: struggle, release, flow, and recovery. In his book *The Rise of Superman,* Steven Kotler identifies the importance of not only creating conditions for generating *flow* (which can lead to optimal and sometimes peak performance in individuals) but also the need to integrate periods of *release* and *recovery.* So, even though slow and steady might win the race between the tortoise and the hare, the need to take breaks like the rabbit are also best for the long haul.

Imagine reading AMS7250 for the first time. Slow and steady, you read each section and turn each page, moving through sensors, calibrations, system accuracy tests, temperature uniformity surveys, and quality's role in corrective actions. If you were like me when you first read this daunting specification on pyrometry for heat-treat furnaces, you discovered there was a LOT of information to absorb. I certainly *struggled* to even just understand what the acronyms stood for.

Fortunately, in a work day there are breaks such as lunch and even winding down when the shift is done for the day. This isn't to say you should just toss your bags away and off you go to forget about everything from work. An amazing thing about the brain is we really don't forget, and it allows for what is called the *release* phase — allowing for the expectations to dwindle and the dust to settle. Then, the next time you open up AMS2750 and need to implement or perform some of the requirements, it will seem more like second nature. Possibly, it even begins to *flow.*

In his original work, *Flow,* Mihaly Csikszentmihalyi defined flow as optimal experiences that he perceived to be the rare times when all the stars aligned in a world of increasing disorder, which created conditions where humans could find joy in what they were doing. It is at first frustrating when you learn to ride a bike or even drive a car for the first time. You struggle. The stop and go. The challenges of balancing on two wheels. The skill needed to stay upright and peddle forward. How hard to press the brake to ease the car to a stop. Throughout the periods of work and rest, you eventually begin to learn how to ride a bike or drive a car. Similarly, you eventually learn the technical difficulties of AMS2750. And that is why, after a hard day's work, we do need time off — to relax and separate from our work.

Designing flow with an eye to the importance of periods of release and recovery into the employee's potentially stressful days can promote better throughput of the process. It can not only help organizations get more work done and out the door, but due to its inherent nature of flow, it can create intrinsic rewards that last longer than meeting a ship-day requirement.

The point is this: Learning to do less does not mean we sit and do

nothing. It means to be aware that breaks are needed with the same level of attention given to the work that is required. Giving someone AMS2750 for example, with its daunting list of requirements and technical terms, will not be easily digested upon first pass, nor even the second. It takes many iterations and time in between for the elements to land and to learn them. Being more aware of when to properly take breaks and allow moments in between experiences and learning sessions allows someone to better thrive in the work environment.

Where can this further help? As an instructor or boss or coach, knowing the limits of who you are working with will be critical to their overall success. Employees learn at different rates and sometimes in different ways. Some can pick up a specification, read it, and understand quickly how to implement it. Others might understand the SAT when performing it and not getting bogged down as to what correction factor goes where in the calculation. Creating expectations is critical for an employee's success. Teaching someone an SAT one day and then having them perform it the next day allows for all four phases of flow to potentially occur.

Knowledge of this cycle can also help in setting the expectations for the team in mastering something. Knowing you can't give someone AMS2750 the first day they work on the job and have them master it means creating time in the design plan for experience in learning the criteria and then reflecting of it.

Another area to consider "doing less" is in overall expectations. In a manufacturing setting, it can be difficult balancing multiple furnaces with multiple pyrometry requirements in a given shift — heat-treat cycles that need to be set up and run in the furnace; SATs that need to be taken at temperature during a cycle; TUS that needs to be scheduled. Creating situations of too much *struggle* can overwhelm the employee. Instead, having a plan with priorities for the day helps in getting what the company needs done, but also allows the employee to *flow* through the activities.

In this example, maybe a particular production order is overdue and should be handled first. Then the operator can set up the TUS and, while the furnace is coming up to temperature, take the SAT. In this way, there are clear goals, which is an antecedent to flow.

Designing flow with an eye to the importance of periods of release and recovery into the employee's potentially stressful days can promote better throughput of the process. It can not only help organizations get more work done and out the door, but due to its inherent nature of flow, it can create intrinsic rewards that last longer than meeting a ship-day requirement. It creates a desire for the employee to continually want to do that particular work, which is more important so the company can live to ship to the customer another day.

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ISSUE FOCUS ///

PROCESS CONTROL / PYROMETRY

DEMAND FOR FORGED PARTS SPURS DRIVE TO REBUILD, AUTOMATE EQUIPMENT

The high-impact nature of forging takes its toll over time, so parts inevitably need to be replaced, and a rebuild may be the best solution. (Courtesy: Ajax/CECO/Erie Press)

With demand ramping up worldwide, working with an experienced OEM to rebuild equipment is often the fastest, most cost-effective way to increase production.

By DEL WILLIAMS

Today, global demand for rebuilt forging equipment is surging, driven in part by a dramatic rise in the need for military ordnance spurred by Russia's invasion of Ukraine. As in past wars and conflicts, the demand for forged parts often increases as governments seek to replenish depleted stocks of artillery shells, tanks, aircraft parts, and weapons. According to recent news reports, numerous nations have committed billions for new ordnance purchases in 2024.

To meet this demand, forgers are dusting off sometimes decades-old unused or underutilized forging equipment and seeking complete rebuilds from the original equipment manufacturers (OEMs) to ramp up production quickly, even if new forging equipment is ordered and on its way.

For the forging industry, significant automation upgrades are increasingly required for rebuilt models of everything from horizontal forging machines and vertical presses, to hammers, and solid ball die forgers. In doing so, tasks that were once performed manually — such as moving heavy steel rods, pipe, and other stock in and out of equipment — are now automated to improve worker safety.

Now, many of these manual tasks are instead being replaced with the mechanical "hand" of a robot or by integrating servos that can lift, insert, and deposit materials. Even tasks such as automated tooling changes can be completed with the push of a button.

INCREASED PRODUCTIVITY

Not only does this create a safer environment for forging operators, but productivity is increased. By automating forging operations to perform some of the tasks of a human operator, productivity can increase from several hundred pieces per hour to up to 3,000, depending on the type of products being forged.

"Rebuilding is often the fastest, most economical means to get worn or mothballed equipment back into production when purchasing new equipment may not be feasible; as such, it can bridge a gap in production before new equipment can be purchased, manufactured, and delivered," says Justin Wildfire, rebuild engineer, products and part sales, Ajax-CECO-Erie Press (ACE), the largest forging equipment supplier in North America, with more than a century of experience in custom designing and building presses and forming machines.

According to the Forging Industry Association, "Forged components are found in virtually every defense implement, from rifle triggers to nuclear submarine drive shafts. Heavy tanks, missiles, armored personnel carriers, shells, and other heavy artillery are common defense-related applications of forged components."

A forging's versatility of size, shape, and properties also makes it an ideal component in bulkheads, wing roots and spars, engine mounts, brackets, beams, shafts, landing gear cylinders and struts, and wheels in jets, helicopters, piston-engine planes, military aircraft, and spacecraft.

Robust demand for forged components is also expected to increase in the automotive, aerospace, and power generation markets through the end of this decade. According to Grandview Research, the global metal forging market valued at $74.36 billion in 2021 is projected to grow at a compound annual growth rate of 7.7 percent from 2022 to 2030.

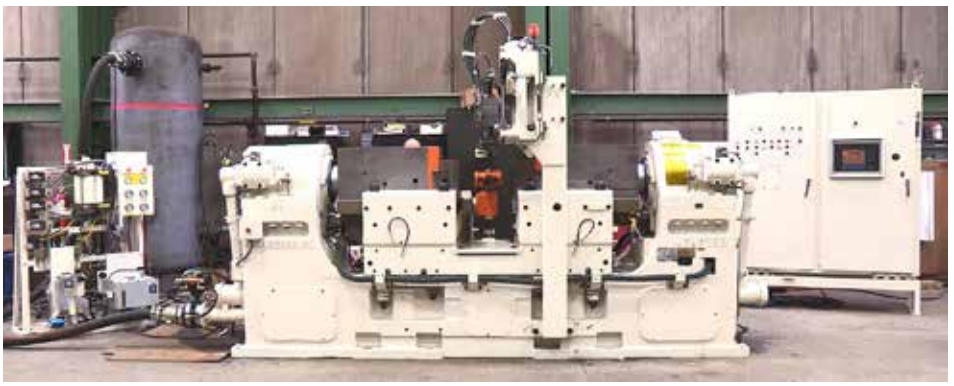
Given the demand, several scenarios could lead manufacturers to rebuild forging equipment instead of purchasing new, according to Wildfire.

It can be advantageous to work with an OEM with the expertise and experience necessary to reliably bring a wide range of systems back to full productivity. (Courtesy: Ajax/CECO/Erie Press)

Rebuilding is reconstructing a machine by removing all its parts and repairing or replacing them with OEM components to return them to manufacturer specifications. This can include replacing high-wear items such as bearings, bushings, seals, and liners and inspecting and repairing the frame.

MORE EFFICIENT AND COST-EFFECTIVE

Rebuilding is often more efficient and cost-effective than purchasing new and is ideal for quickly getting equipment operational again in as little as a few months. Consequently, forgers opt to rebuild aging forg-



As manufacturers consider how to meet the rising production demand for forged parts, rebuilding their equipment with the OEM will often be the fastest and most economical choice. (Courtesy: Ajax/CECO/Erie Press)

To meet increased demand, forgers are seeking complete rebuilds from OEMs to ramp up production quickly. (Courtesy: Ajax/CECO/Erie Press)

ing equipment, which can date back to the 1920s in some instances.

In some instances, the forging equipment may no longer be in use, requiring updating, modifying for new product lines, or servicing to be restored to original specifications. A rebuild can also increase the production capacity of slow, inefficient, or unreliable equipment.

According to Wildfire, the high-impact nature of forging eventually takes its toll over time. When this occurs, parts will inevitably need to be replaced, and a rebuild may be the best solution to extend the life of the forging equipment.

At this point, the choice is to contact the OEM to rebuild the equipment or contract with a third-party rebuilder. The decision is significant, given the need for a complete, dependable rebuild that will perform as expected for many years.

Rebuilders often use a reverse-engineering process to create their parts or have them machined at local CNC shops. Although this approach may work in the short term to "get the equipment up and running," it ignores the long-term view.

Even rebuilders with experience working on various other types of equipment, such as stamping presses or injecting molding machines, may only partially appreciate the forces exerted during the forging operation.

According to Wildfire, critical engineering design data is lost when an independent rebuilder reverse engineers a part, resulting in inferior part construction and premature wear or component failure.

"Often they are rebuilding a machine without truly understanding the original design intent or the loads that will be placed on the parts and equipment," he said.

Without the benefit of the original design specifications, there is the risk of a wrong or sub-optimal part being used in the rebuild. Given the loads placed on a forger, even minor material changes can significantly affect equipment longevity.

Consider that forging equipment has to take the highest impact and accept the highest pressure of any metal-forming equipment. Simple aspects of a design, like the size and placement of a corner radius, can affect the longevity of a component.

COSTLY SHORTCUTS

There is also the risk of working with a rebuilder who takes shortcuts. A conscientious rebuilder will try to reverse engineer how the forging equipment was built, which may lead them to contact the OEM to source the correct part and access engineering drawings. However, some shops will apply a fresh coat of paint and not do all the work needed.

An incomplete or incorrect rebuild can be very costly to a manufacturer. Forging performance may be sub-optimal, the forging equipment may operate less efficiently, and the life of the equipment may be shortened. Often, there is no warranty offered on the rebuild. Notably, there can also be operator safety risks and OSHA compliance issues.

Instead, as an alternative, it can be advantageous to work with the OEM for an equipment rebuild. The OEM has the original design specifications, critical materials, and clearance specifications to jump on rebuilds and quickly finish the work. A vast range of information is required for a quality rebuild, such as critical data on high-wear parts, the material grade of the steel, the heat-treating process used, and the required clearances used in the engineering of that forger.

"If a 60-year-old forging machine had a secondary heat-treat surface coating as part of the original design specification that wore off over the years, it would not be apparent to a third-party rebuilder," Wildfire said. "Not adding a replacement surface coating during a rebuild could compromise longevity. However, the OEM keeps documentation on all modifications, which will be reviewed when replacing parts."

With large spare part inventories, choosing an OEM can reduce service times compared to going to a rebuilder, who would first need to purchase a piece of steel and then machine it. The parts and the rebuild are also backed with a warranty from the OEM.

AUTOMATION UPGRADES ON REBUILT EQUIPMENT

Today, the vast majority of project requests involve some aspect of automation. Many customers have, or acquire, an older model of equipment and ask for it to be rebuilt or remanufactured while adding automation upgrades.

Most of the automation requests are for control consoles or some type of material handling and conveying equipment to bring the steel into the machine, move it around as needed for heating and forging, then finally deposit the finished item into a bin when completed.

In the most advanced examples, entire forging line "cells" can be created that include sophisticated communications that report production rates and machine performance back to company networks.

It can be advantageous to work with the OEM for an equipment rebuild. The OEM has the original design specifications, critical materials, and clearance specifications to jump on rebuilds and quickly finish the work.

APPROACHING A REBUILD

Rebuilds can be approached in several different ways. The forging equipment can be sent to the OEM for rebuilding; the OEM can send repair personnel to the manufacturer's facility to rebuild equipment on-site, or the OEM can supervise a rebuild by maintenance staff. This allows the in-house staff to ask questions and better understand the operation of the equipment they are maintaining.

According to Wildfire, the OEM will typically perform a quick initial assessment of the forging equipment to determine how "true" it is if it is running. This involves measuring squareness and parallelism and checking for cracks and failure points. Afterward, the scope and timeline of the rebuild can be jointly determined by the OEM and the customer based on their requirements and priorities.

Since a manufacturer can have various types of forging equipment that need rebuilding, it can be advantageous to work with an OEM with the expertise and experience necessary to reliably bring a wide range of systems back to full productivity.

ACE, for example, has spent the past two decades acquiring established forging equipment brands and can now service, rebuild, or refurbish forging machines from Ajax, Chambersburg (CECO), Erie Press, and LNF as the OEM. In addition, it similarly services all other brand-name forging equipment.

"The full range of forging equipment can be rebuilt by ACE, whether hammers, mechanical presses, hydraulic presses, or stretch forming equipment," Wildfire said.

On a recent rebuild, Wildfire reviewed the engineering drawings of a hammer originally designed by Erie Press in 1927. The hammer was still in production, and the user sought to rebuild its top-end cylinder with some seals and rings.

"We provided engineering assistance to determine which parts needed to be replaced," he said. "The serial number led us to a set of prints developed around 1927. And we have worked on older machines than this."

ACE also recently rebuilt an Erie Press hydraulic sizing press and a Bliss mechanical press for the government. ACE is rebuilding several vertical hydraulic press lines for the same facility that will be used to manufacture artillery shell casings.

As defense contractors and other manufacturers consider how to meet the rising production demand for forged parts, rebuilding their equipment with the OEM will often be the fastest and most economical choice.

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EXPERIMENTAL VALIDATION OF HIGH-SPATIAL RESOLUTION OF TWO-COLOR OPTICAL FIBER PYROMETER

Tests show the potential for quickly measuring temperature gradients in small areas, independent of emissivity, such as in micro-thermography.

By SAHAR SAFARLOO, ALBERTO TAPETADO, and CARMEN VÁZQUEZ

Taking non-contact temperature measurements in narrow areas or confined spaces of non-uniform surfaces requires high spatial resolution and independence of emissivity uncertainties that conventional cameras can hardly provide. Two-color optical fiber (OF) pyrometers based on standard single-mode (SMF) and multi-mode optical fibers (MMF) with a small core diameter and low numerical aperture in combination with associated commercially available components can provide a spatial resolution in the micrometer range, independent of the material's emissivity. Our experiment involved using a patterned microheater to generate temperatures of approximately 340°C on objects with a diameter of 0.25 mm. We measured these temperatures using two-color optical fiber pyrometers at a 1 kHz sampling rate, which were linearized in the range of 250 to 500°C. We compared the results with those obtained using an industrial infrared camera. The tests show the potential of our technique for quickly measuring temperature gradients in small areas, independent of emissivity, such as in micro-thermography. We also report simulations and experiments, showing that the optical power gathered via each channel of the SMF and MMF pyrometers from hot objects of 250 µm is independent of distance until the OF light spot becomes larger than the diameter of the object at 0.9 mm and 0.4 mm, respectively.

1 INTRODUCTION

Temperature measurements are crucial for studies of heat generation and transfer processes in a variety of engineering systems. Many of these systems, including microscale engineering systems, have dimensions of only a few micrometers or even tens of nanometers [1]. It has been shown that temperature measurements in earthquake physics [2], materials processes [3], diamond cutting [4], and hypersonic vehicles [5] also need to have a spatial resolution in the order of micrometers. Without a high spatial resolution and fast temperature measurement techniques, it is impossible to conduct experimental studies of the microscale thermal processes that occur in these systems.

Generally, temperature measurement technologies can be grouped into contact measurements, including thermocouples and resistance thermometers, and non-contact techniques, which include infrared (IR) cameras, pyrometers, and micro-Raman thermometers [6].

In the case of contact sensors, placing them in hard-to-reach measuring areas is challenging [7]. Moreover, thermocouple temperature measurements are significantly influenced by the ambient temperature and the length of the sensor [7,8], in addition to the fact that they only measure average temperatures across the entire length of the sensor and do not capture localized maximum temperatures [9].

The IR camera is a non-contact technology that has been applied to a wide range of applications, such as detecting the temperature of the side of a tool's face during metallurgical processes [10], metal additive manufacturing [11], and nuclear fusion [12]. However, as mentioned in [13], emissivity uncertainty has a negative impact on its accuracy. The minimum measurable spot size on IR cameras is limited by its field of view and depends on the distance, reaching roughly 1 mm. This feature can be enhanced to 5-10 µm using an additional close-up lens at a higher cost [13,14]. As mentioned, an important disadvantage of the IR camera is that measurement uncertainty depends on the object's emissivity, which can be lightly compensated at certain temperature ranges by performing regular calibrations for each kind of material and measuring condition [15].

On the other hand, micro-Raman thermography is commonly used in microelectronics to measure device temperatures. Since a laser beam is used to excite the measuring zone in micro-Raman thermography, the spatial resolution is dependent on the laser beam spot and is typically in the sub-micrometer range [16]. However, the acquisition time for this measuring technique is long and might vary depending on the material being studied from a few seconds to several minutes [17].

Compared to the methods mentioned earlier for temperature sensing, the two-color optical fiber pyrometer not only has the advantages of a fast response [18], highly localized temperature measurement [19], and measurement accuracy [20], but it can also be used in wet conditions [6] and provides fast and localized measurements, for example in the machining of metals [21]. This technique can integrate a self-reference method by using two wavelength bands, such as in [22], allowing an absolute temperature measurement to be obtained without knowing the material's emissivity [23]. It is achieved by choosing bands that are far enough apart to enable filtering and lower measurement errors, yet close enough together to avoid the emissivity effect of the material [18,19]. The spatial resolution of the pyrometer is dependent on the optical fiber employed and the distance between the optical fiber and the object being measured and is limited by the diffraction limit of light. In the literature, various optical fibers have been proposed. These pyrometers typically employ optical fibers with core sizes ranging from 280 µm [24] to 1 mm [23]. The utilization of adjacent channel bands as suggested in [18,19] facilitated the deployment of indistinguishable photodetectors across both channels. The aforementioned approach, in combination with a demultiplexing technique that incurs minimal insertion loss, enabled the utilization of optical fibers possessing core diameters as small as 62.5 µm. A standard single-mode fiber was used in [20] for the first time and could theoretically achieve a spatial resolution as small as 16 µm for a target surface at 25 µm [25]. Table 1 provides information on the estimated diameter of the smallest spot size that can be measured using different pyrometers. However, it is important to note that none of the authors of the studies mentioned earlier has conducted any actual measurements to verify the spatial resolution capabilities of these systems.

In this work, the authors have tested, for the first time, the high spatial resolution of optical fiber pyrometers using single-mode and multi-mode standard fibers with a patterned heated sample using

the same conditioning and acquisition system as that in [20] and compared them with the results of a commercial IR camera. We have also proved the relationship between distance and the spatial resolution of the pyrometer via experiments and simulations.

2 THEORETICAL BACKGROUND AND MODELING

All physical objects emit electromagnetic radiation in every direction at a certain temperature (T). The quantity of this radiation, called spectral radiance (L), is the basis of pyrometry. Planck's law can be used to estimate the radiance that is emitted by objects, as follows:

$$L(\lambda,T)=\frac{C_1\times\varepsilon(\lambda,T)}{\lambda^5\times\left(e^{\frac{C_2}{\lambda T}}-1\right)} \quad \text{Equation 1}$$

where ε is the emissivity of the measured object, and C_1 and C_2 are Planck's radiation constants, with values of $1.19\times10^{8}\ \ W\cdot Sr^{-1}\cdot\mu m^{4}\cdot m^{-2}$ and 1.44×10^{4} μm·K, respectively.

The target's radiance captured with a two-color optical fiber pyrometer is separated into two wavelength bands. The acceptance cone of the optical fiber, which is determined by the numerical aperture (NA) of the fiber and the distance from the target surface, serves as the limit for the spectral radiance measured in optical fiber pyrometers. The NA depends on the refractive indices of fiber cladding and core. For a circular target whose center is aligned with the axis of the optical fiber, see Figure 1, and whose placement is perpendicular to the optical fiber, the measured current signal, I_D, of the photodetector for each wavelength band is given by [18]:

$$I_D(T)=\int_{\lambda=\lambda_A}^{\lambda_B}R(\lambda)\times IL(\lambda)\times\alpha(\lambda)\cdot\int_{S_T}\int_{A}L(\lambda,T)\times dA\times dS_o\times d\lambda \quad \text{Equation 2}$$

where λ_A and λ_B are the shortest and longest wavelengths of each wavelength band, respectively, R is the photodetector responsivity, IL is the insertion loss of the filter, α is the fiber attenuation coefficient, and dA and dS_o are the differential elements of the solid angle and the target surface, respectively.

By integrating the radiation emitted by each dS_o of an object of radius r_T with the cone surface projected by the fiber NA, the power acquired by the optical fiber is determined. The maximum acceptance cone angle, β_{max}, is given by:

$$\beta_{max}=\sin^{-1}\left(\frac{NA}{n_0}\right) \quad \text{Equation 3}$$

where n_0 is the refractive index of the medium between the fiber end and the target surface.

The derivation of the equations used to consider the effect of the object size on the spectral radiance is described in [33], including different cases under analysis with the integration limits as a complement to the analysis provided in [34]. Considering the transimpedance amplifier of the detector, the output voltage (V_D), see [20], is given by:

Fiber Diameter	Temperature Range	Calculated Spatial Resolution at 0.2 mm	Measured Spatial Resolution [1]	Ref.
Silica fiber, d_{core} = 62.5 μm	2500–10,000 K	175 μm	–	[26]
F-doped fused silica fiber d_{fiber} = 330 μm	Up to 1200 °C	>330 μm	–	[27]
chalcogenide glass fiber, d_{fiber} = 400 μm	180–250 °C	>400 μm	–	[28]
Quartz fiber, d_{fiber} = 400 μm	300–1700 °C	>400 μm	–	[6]
Silica fiber, d_{core} = 9 μm	300–1200 °C	65 μm	–	[20]
Quartz optical fiber: d_{core} = 1 mm	200–1200 °C	1088 μm	–	[23]
Fluoride glass fiber d_{core} = 450 μm, d_{clad} = 500 μm	500–1000 °C	531 μm	–	[29]
Silica fiber: d_{core} = 100 μm, d_{clad} = 140 μm	900–1100 °C	188 μm	–	[30]
Pure silica core and fluorine-doped silica cladding: d_{fiber} = 400 μm		488 μm		[31]
Not mentioned	200–1200 °C	400μm	–	[25]
Sapphire fiber, d_{fiber} = 390μm	1000–1700 °C	>390μm	–	[32]
silica fiber d_{clad} = 125μm: d_{core} = 9 μm (NA = 0.14) d_{core} = 62.5 μm (NA = 0.275)	300–1200 °C	65, 175 μm	≤250μm [2]	This work

Table 1: Comparison between the spatial resolution of different two-color optical fiber pyrometers found in literature and this work.

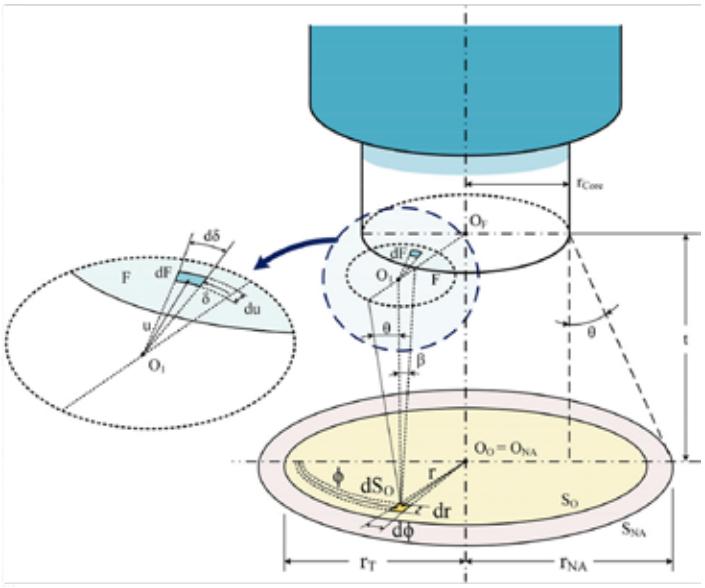

Figure 1: Acceptance cone of the pyrometer, target surface, and integration variables; see [27].

$$,T)=G\times I_D(\lambda,T)+V_{noise} \quad \text{Equation 4}$$

where V_{noise} is a factor that accounts for shot, thermal, and dark noises, as well as the offset voltage at the detector's output, and G is the amplifier's transimpedance gain.

If the chosen wavelength channels of a two-color optical fiber

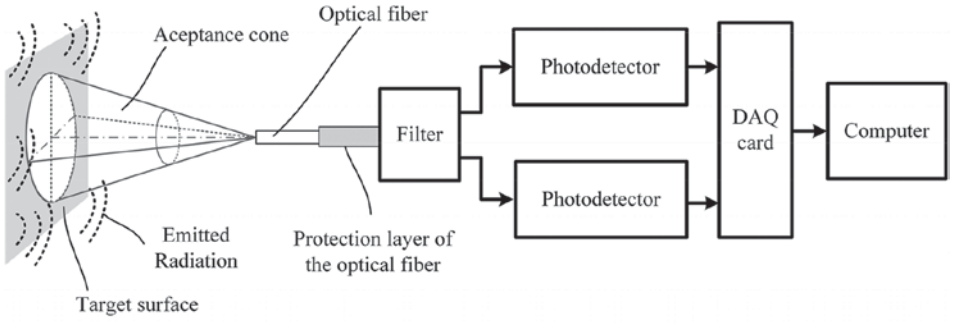

Figure 2: Experimental two-color optical fiber pyrometer set-up [20].

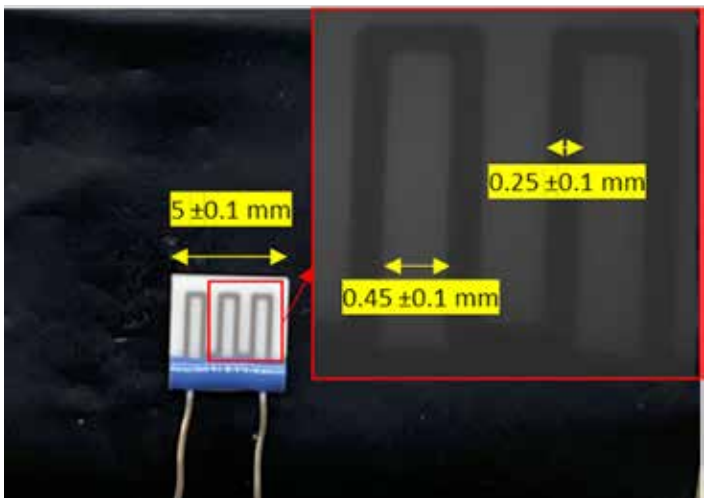

Figure 3: The commercial microheater and its pattern, which was acquired using an optical microscope at 100× zoom.

Parameter	Value
Total connector loss, dB	0.6
Fiber attenuation (α) at 1310 nm, dB	0.58
Fiber attenuation (α) at 1550 nm, dB	0.28
Conversion factor at 1310 nm, V/W	9×10^8
Conversion factor at 1550 nm, V/W	8×10^8
Voltage noise for photodetector 1, V	0.013
Voltage noise for photodetector 2, V	0.0115
Distance between target and fiber end, mm	0.2

Table 2: Simulation parameters used for the theoretical calculations of SMF.

pyrometer are close enough to one another, the surface's emissivity can be discarded. The measuring area (S_{NA}) of the pyrometer, see Figure 1, depends on its acceptance angle (Θ_{max}) and the distance (t) between the fiber and the target surface, as follows:

$$\left(t \times \tan\theta_{max} + \frac{d_{core}}{2}\right)^2 \times \pi \qquad \text{Equation 5}$$

The spatial resolution is defined as the diameter of the light spot calculated using Equation 5.

3 EXPERIMENTAL SET-UP

Figure 2 depicts the pyrometer set-up, which is based on that in a previous study [20]. The radiation gathered by the acceptance cone of the fiber was divided into two spectral bands with central wavelengths at around 1,310 and 1,550 nm by a low-insertion-loss optical filter. Two InGaAs photodetectors (PD) with transimpedance amplifiers that operate in the 800-1,700 nm spectral range were used. They transform the optical radiation into an electrical signal using high gain (HG) for weak optical powers and low gain (LG) for stronger optical signals. Then, a PC-connected data acquisition card (DAQ) captured the electrical signal. The DAQ output voltage range was from zero to either 1 V or 10 V. The sampling rate was fixed at 1 kHz for both wavelength bands. The pyrometer can measure temperatures up to 600°C using MMF and up to 1,200°C using SMF.

Two different types of standard optical fibers were employed in this work:

- A multi-mode optical fiber (MMF) OM1 with core/cladding diameters of 62.5/125 µm and an NA of 0.275.
- A single-mode optical fiber (SMF) G.652 with core/cladding diameters of 9/125 µm and an NA of 0.14.

A dry block calibrator (Jupiter 650, Isotech) with a black body (an emissivity of 0.99) was used for the measurements. The control unit ensures a maximum temperature stability and uncertainty of ±0.03 and ±0.17°C, respectively. Calibration was carried out in 25°C increments in a temperature range from 100 to 600°C. A calibrated metallic holder was used to guarantee the position of the fiber inside the furnace and place it at a distance of 0.2 mm from the black body surface. With a sampling rate of 1 kHz and 1 kS per temperature, the DAQ was set up to measure both wavelength channels. From the recorded samples, the average output voltage and standard deviation were determined for each temperature and wavelength channel.

We employed a commercial microheater with the dimensions shown in Figure 3 to check the real spatial resolution. The gray lines of the microheater were heated, which are positive temperature coefficient resistors, by applying a voltage of 5 V. White sections (which are made of Al_2O_3) were then heated via heat transfer processes, and therefore, have a lower temperature compared to those of the gray lines. In order to distinguish this temperature difference, a temperature sensor should be as small as 0.25 mm.

4 RESULTS AND DISCUSSION

4.1 Calibration

As described in the previous section, the experiments were conducted using a dry block calibrator and a black body with the pyrometer in HG configuration. To adjust the mathematical formulas for the properties of the various pyrometer elements, different approximations and assumptions were taken into account during the theoretical calculations characterizing the pyrometer response, such as in [20]. Table 2 provides an overview of the factors that were taken into consideration when theoretical analysis of all the optoelectronic components for SMF was performed. We used a typical value of 0.3 dB for each connector to calculate the total connector loss. The optical filter's insertion loss and the fiber's attenuation were chosen as the mean value of the selected channel band. The transimpedance amplifier gain and photodetector responsiveness were both included in the conversion factor. This value depends on the conditioning circuit and was obtained in this work by conducting experimental methods, launching known optical power into the photodiodes, and measuring the output voltage with the pyrometer system. Experiments were also used to obtain the detector voltage noise. All calculations were performed with the Symbolic Math Toolbox of MATLAB.

Figure 4 shows the experimental and theoretical calibration curves

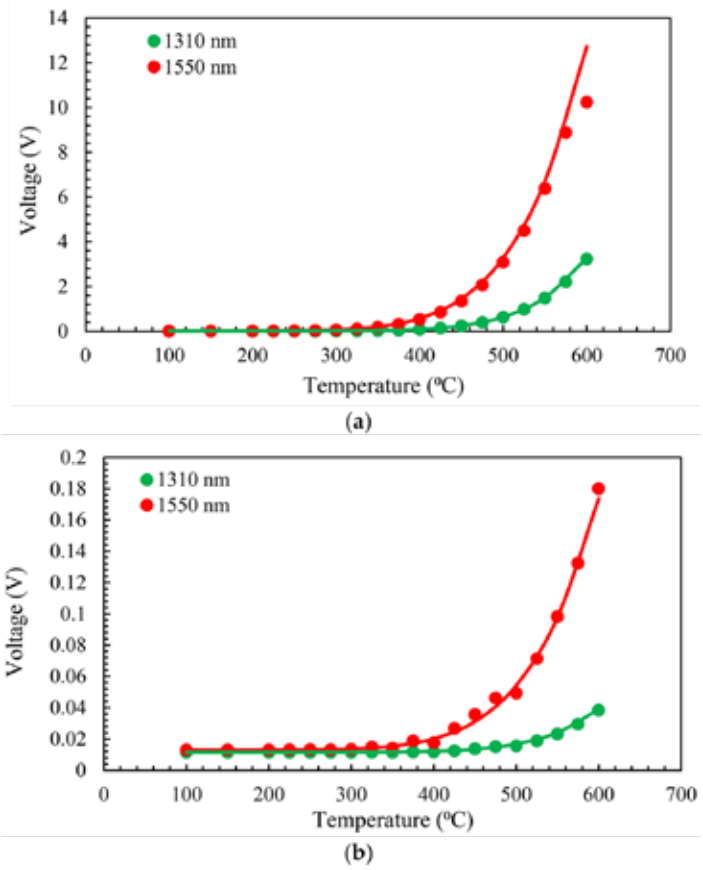

Figure 4: Experimental (dots) using the black body in the dry block calibrator and theoretical analysis (lines) results obtained for the pyrometer: (a) MMF; (b) SMF.

for MMF and SMF configurations. The experimental results and the simulations match very well. For MMF, the voltage collected in the channel at 1,550 nm is saturated for temperatures above 600°C as it reaches the maximum voltage readable by the DAQ (10 V). This is the reason that we ensure there was a difference between the theoretical and experimental values at this point. The dynamic range of the pyrometer increases by changing the gain switch of the photodetectors from the HG condition to the LG condition. However, for this study, we used the HG configuration to take lower temperature measurements.

In order to eliminate the effect of emissivity, the two-color optical fiber pyrometer can employ the voltage ratio of the measuring channels (in our case, 1,310/1,550) at each calibration point. The aforementioned ratio was obtained for each temperature, subsequent to the deduction of the noise voltage from the signals in each channel. Figure 5 illustrates this ratio for both fibers in their linear range, which refers to the range in which there is no influence of DAQ saturation, and a large enough signal is present after noise reduction. The lines depicted in Figure 5 signify the linear approximation interpolated from the experimental data. These lines indicate that within the temperature range provided, the sensitivities of the pyrometer for MMF and SMF are 0.0005 and 0.0004°C^{-1}, respectively. We used this linear approximation to calculate the temperature in the following experiments. In addition, the relative temperature error ranges from 7% to 1.6% from 275°C to 500°C, with it being mostly below

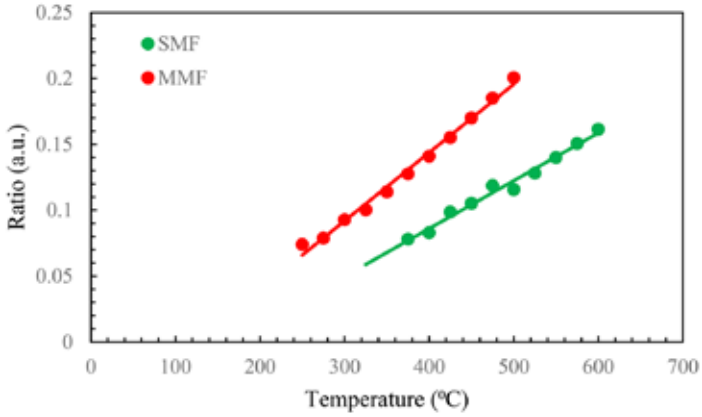

Figure 5: Experimental (dots) ratio and its linear approximation (lines) for SMF and MMF pyrometers.

2%. Meanwhile, for the SMF configuration, they are always below 4% in the measuring range.

4.2 Relationship between Distance and Spatial Resolution of the Pyrometer

In this section, we aimed to investigate the effect of the distance between the target and fiber end on the measured optical power. To achieve this, we employed the commercial microheater shown in Figure 3 and fixed it on a holder, as shown in Figure 6. The plastic jacket of the fiber was peeled and was 5 cm in size, and the fiber end was precisely cut using a high-precision fiber cleaver. The fiber end was positioned in front of the microheater at a distance of 0.05 mm from the center of a gray line of the microheater using a 3-axis positioner (Thorlabs Mitutoyo 150-801 ME). This positioner had a microcontroller with a 25 mm travel range and engraved graduations every 0.01 mm (see Figure 6). To measure the effect of the distance, we gradually increased the distance between the fiber end and the microheater with steps of 0.05 mm using the microcontroller. At each step, the optical power was measured to determine the effect of the distance on the measured power.

For the simulation, we used the model described in [33]. Considering an object size of 250 µm, we used the same pyrometer parameters as we did in the previous section, at 340°C, and swept the distance from 0.05 to 1.2 mm with a step of 0.05 mm. Figure 7 illustrates the results of experiments and simulations for both fibers and in channel at 1550 nm.

According to the theory, the optical power is at its maximum value and is independent of distance until the diameter of the light spot

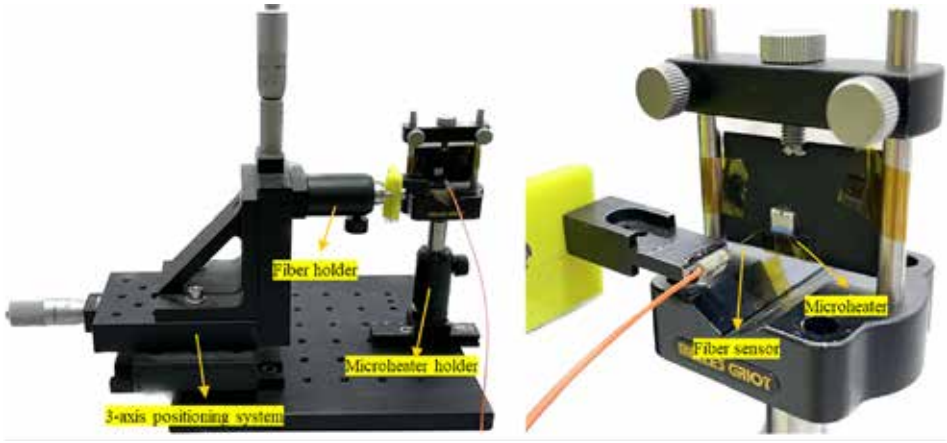

Figure 6: The experimental set-up with fiber and microheater holders and the positioning system.

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(calculated from Equation 5) becomes larger than the diameter of the object. This is the reason for the flat part of the graphs. The optical power decreases drastically as soon as the light spot exceeds the size of the object. The reason is that a portion of the measuring area that is outside the object does not contain emitted radiations. In our experiment, this process allowed us to collect data from the surrounding media, which is the white part of the microheater. Consequently, the total optical power is a combination of radiations from both the gray and white areas, and the resulting measured temperature is a weighted average with less accuracy that depends on the emissivity and real temperatures in these zones. In the simulations in which we only consider a single finite hot object, there is a less dramatic drop in the experiments compared to that in the simulations, which is also evidence of the lower temperatures in white regions. Nevertheless, the experimental graphs begin to show a decline in voltage at the same distance as that in the simulation results in both MMF and SMF.

4.3 Testing the Spatial Resolution with a Patterned-Heated Sample

In this section, we used the microheater to measure the sample's temperature with the optical fiber pyrometer and compared the results with the temperatures measured with a commercial thermal camera (FLIR Ax35 f = 9 mm with SC kit) that has a resolution and temperature range of 320×256 and from minus-40°C to 550 °C, respectively. The camera also has a thermal sensitivity of <0.05°C at 30°C and a precision of ±5°C or ±5% for reading. For the pyrometer tests, we positioned the fiber optic end right before the first gray line on the left side of the microheater at a distance of 0.2 mm, as shown in Figure 6. At this distance, the spot diameters of SMF and MMF are equal to 0.065 and 0.175 mm, respectively, which are both smaller than the width of the gray lines (0.25 mm). Then, we moved the fiber to the right with steps of 0.1 mm using the microcontroller and measured the temperature at each stage.

Figure 8a shows the measured voltage by the MMF pyrometer versus position. The signal shows maximums and minimums (in both channels) following the microheater pattern process and a lower voltage level at the 1,310 nm channel, which is as expected. Figure 8b shows the measured signal for the SMF pyrometer. In this case, the signal at the 1,550 nm channel exhibits distinct peaks and troughs, the channel at 1,310 nm has also similar features but in many measuring points, and the noise distorts the signal. Some of the reliable data are in the two positions highlighted in green, as they exhibit adequate power in both channels.

The measured signals shown in Figure 8 were converted to temperature using the ratio value and compared with the calibration ratio from Figure 5. The results are shown in Figure 9a. In the case of SMF, we calculated the temperature only for two positions with the highest temperature, as in many other positions, the signal in channel 1,310 nm was mostly dominated by noise and data that were not reliable. To address this issue, SMF can be used without a filter by using a single-color pyrometer and by gathering radiation across the entire wavelength range. However, to enable the translation of the signal to temperature in this scenario, it is crucial to have knowledge of emissivity. According to these results, the pyrometer is capable of distinguishing between high-temperature and low-temperature zones and represented a temperature pattern with the same characteristics as the microheater. The spot area for MMF is d = 0.175 mm, and the measuring step is 0.1 mm; so, the spot area is entirely within the gray lines in at least one point and within the white areas in at least two points, and the temperature can be accurately determined for these positions. However, for positions where radiation is collected from both the white and gray areas, the temperature is a weighted aver-

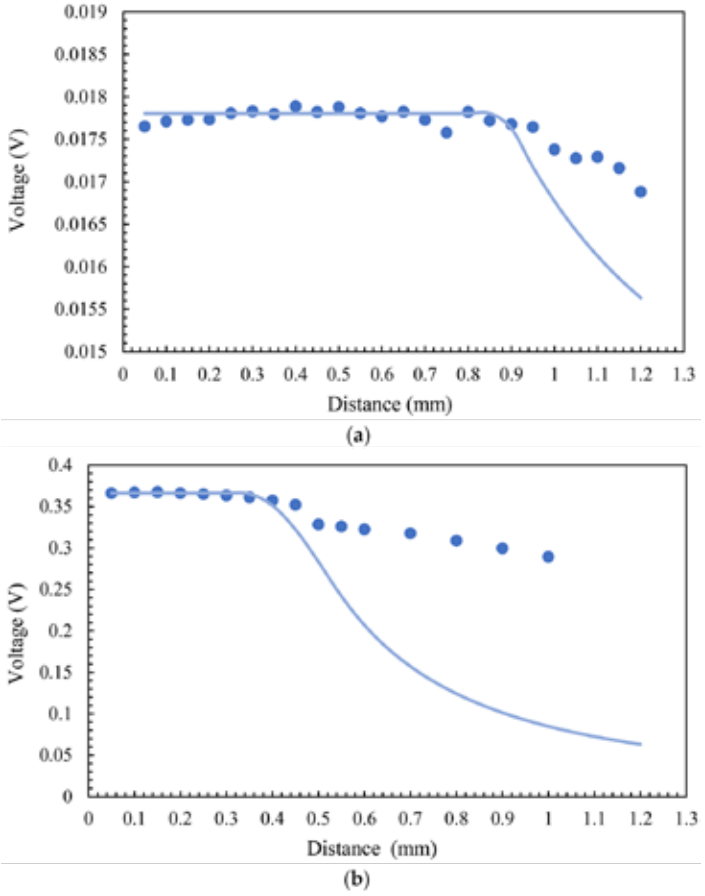

Figure 7: Experimental (dots) and theoretical (lines) voltage in channel 1,550 nm vs. distance from an object with a diameter of 0.25 mm for (a) SMF, and (b) MMF.

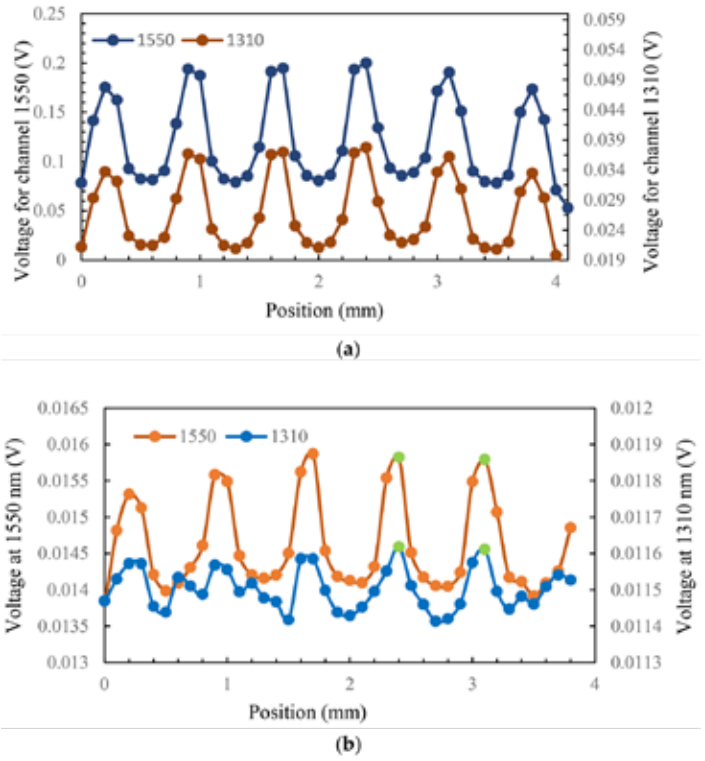

Figure 8: Measured voltage signal at both channels versus position conducted with pyrometer: (a) MMF; (b) SMF, green dots show data with negligible effect of noise in both channels.

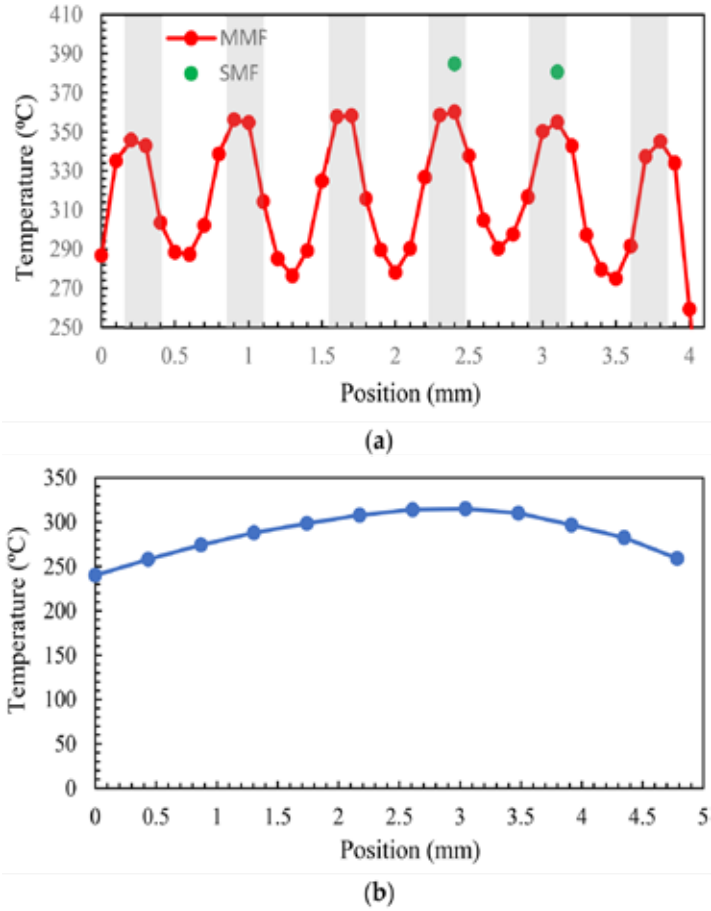

Figure 9: Temperature measurements with the micrometer in different positions with: (a) high spatial resolution optical fiber pyrometer; (b) thermal camera. Shadow lines show the microheater pattern.

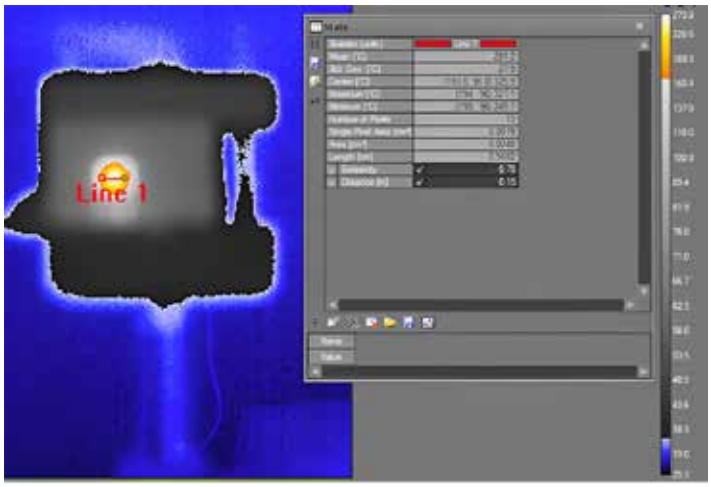

Figure 10: Temperature measurement of the micrometer obtained with the thermal camera.

age. SMF measures higher temperatures at the peaks, which could be due to its better spatial resolution that ensures the measuring area is completely inside the gray line at those points and that the measured temperature is not a weighted value.

After conducting tests with the pyrometer, we positioned the thermal camera at a distance of 15 cm away from the microheater, which is the shortest distance that can provide a proper focus. At this distance, the length of each pixel is 0.435 mm, which is bigger than the width of each gray line. Nonetheless, the manufacturer indicated that a single pixel measurement may be inaccurate for various reasons (thermal camera can develop bad pixels; solar or object reflections can cause a false high reading, and distortion in optical systems can affect measurements) and recommended covering the hot area with at least 3×3 pixels. A measurement cursor in the software of the camera consists of 3×3 pixels, which results in a length of 1.3 mm for each measuring point. On the other hand, the camera software requires the input of emissivity; however, the emissivity of gray parts is unknown. We used the typical value of emissivity for Al_2O_3, the constructive material of the microheater in white parts, which is 0.75.

Figure 10 shows the thermal camera image of the microheater. Line 1, with a length of 5.6 mm, is depicted in the image, showing the width of the microheater in the center. Then, we moved a measurement cursor in steps of 1 pixel (0.435 mm) from the line's left point to its right point. The results are shown in Figure 9b. Since the width of each measuring zone is 3×0.435 mm, the result shows an average temperature in all the positions, and it is not possible to see the thermal pattern such as in the case of pyrometer measurement. The reason for having lower temperatures at the ending points is that, at these points, the camera captures the average between the microheater and its background, which has a much lower temperature.

If we take the two maximum points that are almost in the middle as representatives of temperature in the microheater and not those in the background, the average temperature according to the thermal camera would be 311°C. The average temperature of all points with accurate measurement in the microheater, according to the optical fiber pyrometer with MMF configuration, is equal to 314°C. With the exception of having very localized measurements without the need to be aware of emissivity in the case of the pyrometer, the results are comparable.

5 CONCLUSIONS

We report temperature measurements with micrometer spatial resolution, independent of material emissivity, and at a 1 kHz sampling rate using two-color optical fiber pyrometers based on standard single-mode (SMF) and multi-mode optical fibers (MMF) with small core diameter and low numerical aperture in combination with associated commercially available components. For a target surface at a distance of 0.2 mm, the pyrometer has spatial resolutions of 65 and 175 µm for SMF and MMF, respectively. The experiments with a patterned microheater show that the pyrometer resolved spatial resolutions of about 100 µm and was limited by the experimental setup. Meanwhile, a thermal camera with 320×256 resolution cannot resolve the 700 µm periodic temperature pattern and requires knowledge of the target's emissivity. The two-color optical fiber pyrometer has the potential of quickly measuring temperature gradients in small areas, independent of emissivity, such as in micro-thermography, or in difficult-to-access areas, such as in machining processes. However, the two-color pyrometer is limited in its ability to measure temperatures below 250°C in the MMF configuration and below about 325°C in the SMF configuration and cannot provide a 2D map of temperature from a single measurement. We show that optical powers gathered by each channel of SMF and MMF pyrometers from hot objects of 250 µm are independent of distance until the diameter of the light spot becomes larger than the diameter of the object, at 0.9 mm and 0.4 mm, respectively, via simulations and experiments.

AUTHOR CONTRIBUTIONS

S.S. analyzed the state-of-the-art data, performed the tests, and was the main contributor who wrote the paper; A.T. produced some figures, ran simulations, calculated errors, and revised the paper; C.V. led the team, proposed the idea, the tests, and study cases, and revised the paper. All authors have read and agreed to the published

version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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COMPANY PROFILE ///

BASF ENVIRONMENTAL CATALYST AND METAL SOLUTIONS (ECMS)

DELIVERING TEMPERATURE SENSING WITH PINPOINT ACCURACY

BASF ECMS thermocouples for the heat treat industry. (Courtesy: BASF ECMS)

BASF Environmental Catalyst and Metal Solutions' (ECMS) innovative pyrometers and thermocouples allow the company to provide the most accurate instrumentation possible for the industry, ensuring more efficient operations.

By KENNETH CARTER, Thermal Processing editor

To perform a proper heat treatment, technicians must ensure that the oven or furnace is operating at the correct temperature.

To that end, BASF Environmental Catalyst and Metal Solutions' (ECMS) temperature sensing business manufactures top-of-the-line pyrometers, thermocouples, and other products that help its customers achieve those optimum temperatures.

"The EXACTUS® pyrometer was originally developed for semiconductor applications because of its characteristics specifically being so accurate, with such a large dynamic range and great long-term stability," said John Grossi, technical sales manager for industrial products at ECMS. "There's only a 0.1-degree C per year drift on this particular unit. It really lends itself to semiconductor applications."

ECMS deals with very high-temperature applications for precious metals, according to Grossi.

"Our biggest application was in glass," he said. "Because of the properties of precious metals and the accuracy of precious metals, it lent itself very well for molten-glass applications. Originally, we looked at the pyrometer and those types of applications, and then we just kept on expanding the industrial base — heat treating being one of them. We feel the accuracy and its low drift lends itself to a lot of applications in the heat-treating industry."

ENSURING ACCURACY

A company being able to keep product runs stable is necessary to ensure accuracy, according to Patrick Sprinkle, plant manager for the Portland, Oregon, site focusing on the optical pyrometer product line.

"The end customer has to outfit their furnaces where they do some of the treating for the application, and so there are multiple units of ours looking at different zones, and they then leverage that information into their overall system," he said.

ECMS's innovative sensors allow the company to provide the most accurate instrumentation possible for the industry so their operations can run better, according to James Peterson, general manager of ECMS's temperature sensing business.

And that means, according to Grossi, creating more and more precise sensors to meet an evolving industry.

"As instrumentation got more precise — especially data acquisitions — the industry needed actual equipment that could provide more precise measurements," he said. "For us, specifically now, we find that the trend is people want to minimize downtime as much as possible. We really feel that our pyrometer can help customers with that specific application and help them reduce downtime and get them more productivity."

ACCURATE INSTRUMENTATION

Meeting those goals boils down to a few aspects, according to Grossi. One is accuracy and stability, which means a company doesn't have to perform a recalibration every year.

"I think that helps them significantly," he said.

The other aspect is that ECMS offers very accurate instrumentation vs. its competition, according to Grossi.

Heat monitoring with EXACTUS® in a rolling mill reheat process. (Courtesy: BASF ECMS)

"When they're looking at precise monitoring of their product, we feel that we're the best in the industry," he said.

NIST APPROVED

And Peterson said those aren't just empty words.

"The reason we feel that we're the most accurate is because the industry bodies also agree with us," he said. "The NIST (National Institute of Science and Technology) uses our instruments for their calibration purposes."

An EXACTUS® pyrometer used for furnace temperature measurement. (Courtesy: BASF ECMS)

The NIST is where everyone sends their products to be calibrated if they want to be recognized, according to John Dowell, product development manager for the EXACTUS Optical thermometers.

WORKING WITH CUSTOMERS

High-quality products don't mean much if you can't get them to the customers who will benefit from them the most, so that is where ECMS's sales team comes in, according to Grossi.

"You have the first dialogue on what specifically the application is, and what their measurement problem is, but then we have the expertise from John Dowell and Patrick Sprinkle," he said. "We'll literally pick up our suitcases and go visit the customer at their site to look at their process."

To aid in that, Grossi said the company has close to 200 years of combined expertise in a variety of vital applications.

"I feel that our real strength is in those high-temperature applications, especially when you're lending it to high-temperature heat treating or hipping," he said. "That's where we really bring our expertise to the table. We don't normally deal with very low-temperature applications, but in these high-temperature applications, by far, we're the industry experts."

Sprinkle agreed with Grossi.

"I think that sums it up really well," he said. "Our temperature range is typically something like 400 Celsius up to about 3,000 Celsius, just for some perspective there. We're not exactly looking at molten chocolate here. Just to give you an idea, one instrument has a very large dynamic range vs. other instruments in the field. I think for some other instruments to cover that dynamic, that range, you would almost need two of their pyrometers vs. one of ours."

And although ECMS's pyrometers can monitor lower temperatures, Peterson said the equipment is better suited for higher temperatures.

"We do go to lower temperatures, but what happens is the lower in temperature you go, the lower the max is," he said. "Most of the time in heat treating, you care about hot temperatures, not low stuff. There are applications where we can go down to nearly room temperature, but that's an aside, just letting you know that there is a breadth of product, but we're focusing on — or at least talking about — the higher temp applications."

IMPRESSIVE HISTORY

BASF has been around for decades, so it stands to reason the company has a few products that it is proud of, but none so much as the catalytic converter, according to Peterson.

"We invented the catalytic converter, and we offer full loop recycling," he said. "Along with the catalytic converter and full loop recycling, one of the things that most people don't realize is that

it's a very good sustainability story when you think about the billions of pounds of pollutants that product alone has cleaned up from the atmosphere in tailpipe emissions."

What ECMS does was part of an acquisition in 2006, when BASF purchased the Engelhard Corporation, according to Sprinkle. This company was part of the mobile emission catalytic converter invention, as well as the refinement of platinum-group metals and chemical process catalysts. Today, ECMS is comprised of two businesses — precious metal services and recycling and mobile emissions catalysts.

"And our business, which is involved around temperature sensing and part of precious metal services and recycling," he said.

FUTURE PLANS

Being environmentally conscious has been a part of who ECMS is for a long time, so as the company looks to the future, Peterson said he expects that aspect of ECMS to continue.

"From my perspective, I think the industry, like a lot of industries, is going to focus on: How do they reduce their carbon footprint? And how do they accomplish the same heat-treating goals while minimizing their energy consumption — minimizing maybe the temperatures that they have to operate in? Is there a different way to achieve that?" he said. "Our piece in that is, as they push the envelope in terms of how they operate their facilities, our instrumentation will allow them and enable them to at least be able to have tighter process controls. Our small part of that is going to be on the instrumentation part of it."

Being able to reduce the need for precious metals will be a part of that, according to Dowell.

"As you get into more exotic materials and you're pushing the envelope with even higher and higher temperatures, that's where we can lend — both pyrometry-wise and thermocouple-wise — our expertise to achieve more accurate and better temperature measurement readings," he said. "That's our game. We measure high temperatures very accurately."

"From my perspective, I think the industry, like a lot of industries, is going to focus on: How do they reduce their carbon footprint? And how do they accomplish the same heat-treating goals while minimizing their energy consumption — minimizing maybe the temperatures that they have to operate in? Is there a different way to achieve that?"

An EXACTUS® pyrometer used in the semiconductor industry. (Courtesy: BASF ECMS)

REDUCING THE NEED FOR PRECIOUS METALS

And that's important from the thermocouple side, where ECMS has made significant strides in helping customers reduce the amount of precious metals needed.

"A lot of our customers are trying to make a high-temperature thermocouple with less precious metal, and yet still achieve the longevity and the accuracy that they require," he said. "We believe ECMS is ahead of our competitors technology-wise. We have proprietary materials that help our customers achieve that goal, by reducing the precious metal while maintaining the overall life and the accuracy of the thermocouple."

Because of that and more, Sprinkle said he expects ECMS's temperature-range accuracy to continue to shine.

"We've found that in the semiconductor sector — and we believe it to be true in other applications as well — that when this technology was first implemented, it was way ahead of its time," he said. "We've really seen a huge uptick in our sales and growth in the last few years as a result of people finally being able to make full use of it. We expect to see that in other applications as well."

MORE INFO catalysts.basf.com/industries/temperature-sensors

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DANTE MOLLE /// CHIEF INFORMATION OFFICER /// AEROSPACE COMPLIANCE SOFTWARE

"Offering a wide range of specifications allows a heat treater to be able to customize the tests conducted using ACS to their individual needs."

What does Aerospace Compliance Software (ACS) do for the heat-treat industry?

The goal of ACS is to streamline the process of completing and managing your pyrometry certifications — temperature uniformity survey, system accuracy testing, calibrations, thermocouple tracking, etc. It can provide near instant certifications while error-checking the certifications. This provides instant feedback for the heat treaters so they are able to proceed using their equipment with confidence or be able to more quickly address problems that the pyrometry testing may have found.

Why is pyrometry software important to the heat-treat industry?

A majority of NADCAP audit findings arises from pyrometry. A software that can automatically generate reports to the specifications that are being used can ensure that all parts of the specification are being followed, keeping equipment in compliance. Pyrometry software also allows for faster certification generation. Rather than having to record data manually or sift through hours of temperature data to determine if a uniformity survey passes, feeding the data to a software can cut down on hours of work for employees.

Why is it important to offer a wide range of specifications?

Offering a wide range of specifications allows a heat treater to be able to customize the tests conducted using ACS to their individual needs, so, not only is someone testing to an aerospace specification like AMS-2750F, but they can also test to an automotive spec like CQI-9. Additionally, users are able to test to multiple specifications simultaneously, keeping them in compliance with multiple ones. Not only are users able to test to a variety of widely used specifications, but they are able to enter their own internal specifications or procedures that may not be covered already or to tighten the requirements of something already available. If any widely available specifications are needed that are not already in the software, the ACS development team is more than happy to add additional ones upon request.

As specifications are updated, how does your software respond?

The ACS development teams works diligently to update and add specifications to the software as revisions are published or new specifications become available. Once the new specifications are in the system, they are immediately available for testing. ACS will adapt all its calculations to the new specifications once they are selected for testing.

How can ACS integrate into a heat treater's existing operations?

ACS can easily be set up in an existing facility to streamline their pyrometry processes. Once a heat treater's equipment is entered into

ACS, tests can be conducted immediately. The ACS dashboard is easy to navigate and gives a broad overview of testing that is needed on equipment. No special hardware is needed to use ACS — the software is built to run in most web browsers as well as a PWA program on a device, so you are not restricted to Windows/iOS/Android. The cloud-based nature of ACS allows for a technician to be out on the shop floor entering data in real-time, and, once the data is submitted, the quality department will have instant access to the certifications. Data is also able to be processed without an active internet connection using ACS's built-in offline mode. When a certification is entered offline on a device, once an active internet connection is re-established, pending certifications will be uploaded to the cloud and available to everyone.

What kind of training is needed to implement the software?

Minimal training is necessary to use the software. ACS does make a reliance on a working knowledge of the equipment used in your facility, though. Accurately encompassing the information within your facility that pertains to pyrometry is critical — processing equipment and instrument details and their relation to each other, required supplemental details, testing equipment, etc. Once the required information is in the system, data entry is streamlined for ease of use. ACS offers a knowledge base for quick reference when a user needs guidance, a highly responsive help desk for any complex issues or unique questions, and online and in-person training are also available upon request to aid in setup and to instill confidence with the use of the system.

MORE INFO www.atp-cal.com/acs

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