Technologies and Processes for the Advancement of Materials

Thermal processing

ISSUE FOCUS ///

MEDICAL APPLICATIONS / THERMOCOUPLES

GOING VIRAL

OUTSIDE-THE-BOX RESEARCH INTO RE-USING N95 MASKS

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DEPARTMENTS ///

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A timely issue for challenging times

In these challenging times, it's important that we all try to maintain some sense of normalcy amid the social distancing and mask wearing.

That's why we at *Thermal Processing* want to make sure you're staying informed about what's going on in the industry, even when you're stuck at home in never-ending conference calls on Zoom.

When we were planning out the Focus topics for 2020, we wanted to add a topic on medical applications.

Little did we know how coincidental that would become as the Coronavirus pandemic slowly moved across the globe during the first few months of the year.

While searching for an appropriate article to serve as an inaugural launch of this new focus topic for *Thermal Processing*, I was sent an intriguing news release from Thermal Product Solutions describing how the company had teamed up with a medical research hospital in hopes of using its Gruenberg ovens to disinfect masks for re-use. It was a fascinating project that I immediately wanted to know more about.

Within a few days, I was talking to key players on both sides of the research equation about what was involved in testing the masks. The end results have been very promising. Be sure to check out the article. Hopefully, by the time *Thermal Processing* officially prints, even more progress will have been made on this potential new weapon against COVID-19.

In addition to medical applications, this month's issue also tackles thermocouples (which also had a small part to play in the mask-disinfection tests).

In this month's second feature article, Acromag's Bruce Cybert looks at the basics of temperature measurement using thermocouples.

In addition to these features, be sure to check out our monthly columnists as they tackle a variety of subjects vital to heat treating.

I hope you enjoy this month's content, and if you'd like to contribute to a future issue, please don't hesitate to contact me. I'm always on the lookout for expert advice that furthers the advancement of the heat-treat industry.

Yes, May is finally here. And even though "normal" is on vacation for the time being, summer is still right around the corner.

So, grab our latest issue and take it to the deck. It may not keep you cool, but the information inside certainly is. And besides, haven't you made it to the end of Netflix by now?

As always, thanks for reading!

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A medical waste incinerator will not only eliminate the virus on waste but also reduce the amount of waste by up to 99 percent. (Courtesy: Baker Furnace)

Baker Furnace has idea for infectious COVID-19 waste

Baker Furnace, a leading supplier of pollution control equipment, announced an incineration solution for infectious medical waste. As more and more people are treated for COVID-19, the amount of infectious waste produced will continue to increase. Baker Furnace manufactures medical waste incinerators that use temperatures in excess of 1,000° C to eliminate infectious pathogens and reduce waste.

According to preliminary data, the COVID-19 virus survives longer outside the body than the common flu. The medical waste that hosts these pathogens will need to be treated at help centers and hospitals across the world. For example, medical personnel are using N95 masks throughout their shifts. These N95 masks may contain the COVID-19 virus and will need to be disposed of properly to eliminate the potential of infecting others. The sheer number of N95 masks and other PPE that are being used and disposed of creates a waste issue at medical facilities. If this waste is simply sterilized and taken to a landfill instead of incinerating, the environmental impact will be significant.

Medical waste incinerators provide an effective, environmentally friendly solution to the impending medical waste crisis. Baker Furnace specializes in pollution control equipment including waste incinerators that are used on pathological and infectious medical waste. These incinerators effectively destroy COVID-19 along with other virus by using a thermal oxidation process and heating the medical waste to extreme temperatures in excess of 1,000°C.

Baker Furnace's medical waste incineration systems are designed in configurations that allow for them to be transported from site to site and only require an electric and gas connection. This provides facilities with the option to maximize their usage and waste reduction. A medical waste incinerator will not only eliminate the virus on waste but also reduce the amount of waste by up to 99 percent. This secondary benefit is important to consider because it minimizes the increase in landfill waste due to this pandemic and provides a cost savings to facilities on waste disposal services.

"Autoclaves can use steam to sterilize medical waste but there is no reduction of waste. Our systems can be designed to process a few pounds of waste to thousands of pounds of waste. As medical waste increases during this pandemic, it is important to limit the environmental impact and minimize additional landfill waste," said Greg Jennings, president and CEO.

Baker Furnace, Inc. has been designing, engineering, and manufacturing industrial ovens, pollution control equipment and other heating equipment since 1980. Their custom and standard equipment are used for a multitude of applications including heat treating, finishing, drying, and curing. Many of the industries they serve require specific temperature uniformity and equipment performance documentation. Their experienced engineering team can meet even the most stringent standards for their customers' equipment.

MORE INFO www.bakerfurnace.com

Gasbarre delivers custom batch tempering furnace

Gasbarre Thermal Processing Systems recently delivered a custom-built batch tempering furnace to a commercial heat-

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.

Gasbarre Thermal Processing Systems recently delivered a custom-built batch tempering furnace to a commercial heat-treating company in the aerospace industry. (Courtesy: Gasbarre Thermal Processing Systems)

treating company located in the heart of the aerospace industry on the West Coast of the United States. With a working load size of 168 inches wide, 48 inches deep, and 48 inches tall, coupled with a max load weight of 10,000 pounds, the furnace can accommodate a number of differently sized parts within its market. The gas-fired air furnace passes survey at +/- 10 over a temperature range of 850 to 1,350 per AMS2750E. At the customer's request, the electrical controls are UL-approved and include the latest in Eurotherm brand temperature controlling instrumentation. Gasbarre was chosen as the provider of this equipment because of its ability to provide key custom sizing at the desired temperature uniformity and proven performance from prior equipment purchases.

With locations in Plymouth, Michigan; Cranston, Rhode Island; and St. Marys, Pennsylvania; Gasbarre Thermal Processing Systems has been designing, manufacturing, and servicing a full line of industrial thermal processing equipment for nearly 50 years. Gasbarre's product offering includes both batch and continuous heat-processing equipment, and specializes in temper, tip up, mesh belt, box, car bottom, pit, and vacuum furnaces as well as a full line of replacement parts and auxiliary equipment which consists of atmosphere generators, quench tanks, and charge cars. Gasbarre's equipment is designed for the customer's process by experienced engineers and metallurgists who understand the requirements.

MORE INFO www.gasbarre.com

Tenova reorganizing its businesses, governance

Tenova, a Techint Group company specialized in innovative solutions for the metals and mining industries, has decided to reorganize its businesses and review its governance structures accordingly. The changes are intended to steady Tenova around the two businesses in which the company operates – metals and mining – so as to better focus on each's specific priorities, market approach, and global presence.

In the context of this reorganization, the role of Tenova CEO has been assigned to Roberto Pancaldi, previously CEO of the metals division, while Andrea Lovato, the former Tenova CEO, will assume the role of TAKRAF CEO. Tenova and TAKRAF are indeed two strong brands that will continue to be a leader in their respective markets.

"The extraordinary situation caused by the outbreak of COVID-19 at a global level has accelerated the rethinking of our business model and the definition of a new structure to better fit the complexity of the current business scenario, with a leaner structure and a clearer definition of roles," Lovato said.

This change will leave more autonomy to the respective CEOs in developing their businesses and in building their long-term sustainability while they concentrate on short-term consolidation and continuity.

"I am sure that this reorganization will help us to better focus our strategy and result in our steel and metals market offering being more solid," said Pancaldi.

Tenova, a Techint Group company, is a worldwide partner for innovative, reliable, and sustainable solutions in metals and mining. Leveraging a workforce of more than 2,500 forward-thinking professionals located in 19 countries across five continents, Tenova designs technologies and develops services that help companies reduce costs, save energy, limit environmental impact and improve working conditions.

MORE INFO www.tenova.com

Tenova CEO Roberto Pancaldi

The new QC Toolholders include cutting heads for general ISO turning, MDT, threading, and parting-off. (Courtesy: Seco Tools)

Seco QC introduces modular toolholder system

Seco Tools has introduced a modular toolholder system for manufacturers seeking to improve their productivity with Swiss-style machining.

The system enables fast, easy, and repeatable insert indexing and tool changes outside of tight machine work spaces. The QC (Quick-Change) toolholders also feature Seco Jetstream Tooling® and Jetstream Tooling® Duo technology for optimal chip control, high-quality surface finishes and extended tool life.

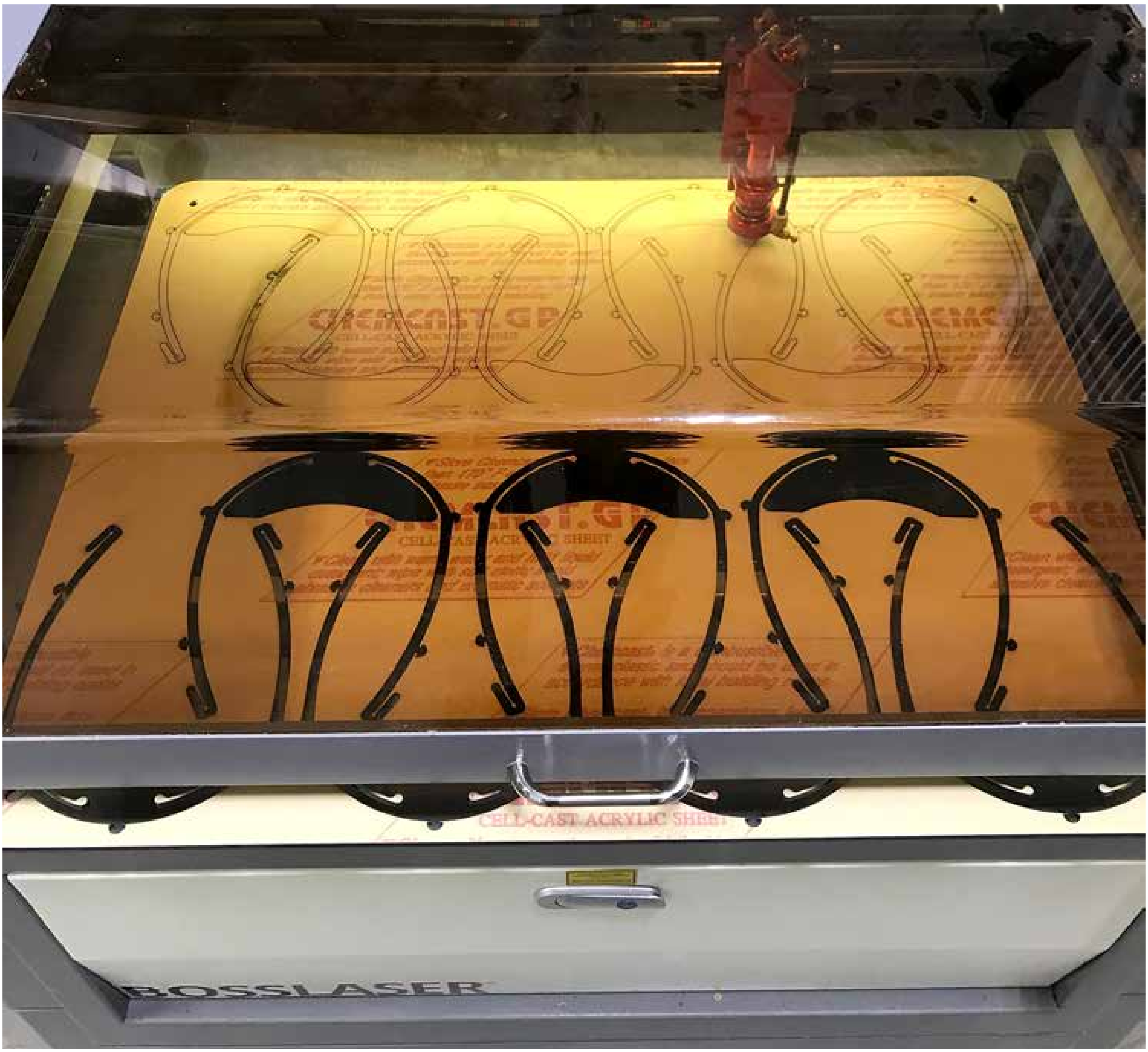
For ease of use, the Seco QC Modular Toolholder allows users to remove both cutting heads and inserts as a single assembly, quickly index them, and reinstall. Manufacturers may also use this system to exchange cutting heads and inserts with a second set for even greater efficiency. The QC cutting head also features double carbide pins for accurate, consistent and secure insert mounting and indexing.

Seco Jetstream Tooling® technology precisely directs high-pressure coolant through the QC Toolholder to the cutting zone. Seco Jetstream Tooling® Duo, available on a selection of cutting heads, adds a second coolant channel to the underside of the holder. The second coolant channel can be switched off if needed for even more versatile machining.

The new QC Toolholders include cutting heads for general ISO turning, MDT, threading, and parting-off. Shanks are available in metric sizes of 10 mm, 12 mm, and 16 mm, and inch sizes of 0.375", 0.500", and 0.625".

MORE INFO www.secotools.com

IHEA member Alabama Power (Southern Company) provides support during pandemic



Alabama Power's Technology Applications Center uses lasers to cut the acrylic for face shields.

A print shop laser cuts face shields. About 100 a day can be produced this way.

Assembled face shields. The one on the right is 3D printed.

The team at Alabama Power's Technology Applications Center (TAC) recently turned their focus from keeping the lights on to helping save lives. Through a partnership with the Alabama Productivity Center at The University of Alabama and UAB's School of Engineering, they are meeting the needs of local medical workers.

Ordinarily, Alabama Power's TAC facility serves as a demonstration and test facility that investigates ways to reduce production costs, improve energy efficiency and productivity while addressing environmental concerns. Lately, their attention on this new project means a different type of service for their customers.

Acrylic headbands.

"I look at it from our group's perspective; we are helping our customers," said Scott Bishop, team lead at Alabama Power and IHEA's current president. "In this case, our customer is the hospital's staff. We are still helping our customers, just in a different way."

Medical personnel across the country are in dire need of personal protective equipment (PPE) to continue the fight against COVID-19. While traditional supply chains are struggling to keep up, technology is helping fill the gaps for PPE.

When Bishop got word that 3D printers were needed to make headbands for face shields for medical staff at the University of Alabama at Birmingham, he rallied a small crew within his company to produce the needed equipment.

In addition to 3D printing headbands, the project evolved into making full face shields when Bishop realized they could use the TAC's laser cutting capabilities to cut acrylic for the face shields that would last longer, producing approximately 100 per day. Knowing that the most contaminated part of the body is the face, the shields play an essential role in keeping healthcare workers safe when dealing with infectious deceases. Using the laser-cut acrylic face shields will go a long way during the COVID-19 crisis.

Countless people have stepped up in support of their communities and the nation during this unprecedented emergency, and IHEA is proud to recognize the team at Alabama Power and their partners for making a difference. Using their internal network to support an idea created hope for so many.

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

Cleanliness and oxygen are important controlling factors to minimize the occurrence of bacteria in the quench tank, as well as avoiding corrosion problems.

Troubleshooting induction hardening problems: Part 2

Last month, I began a two-part article about troubleshooting induction hardening problems and discussed possible corrections. This month, I will discuss biological and odor problems, and corrosion issues.

Induction hardening is a unique method used to harden steels. The process uses a power supply, RF generator, induction coil, and quenching mechanism (spray or immersion) to yield a high surface hardness and advantageous residual surface stresses.

There are many problems that can occur in induction hardening that can have nothing to do with the power supply, RF generator, or coil. These are process-related issues that can be traced back to improper or inadequate process control.

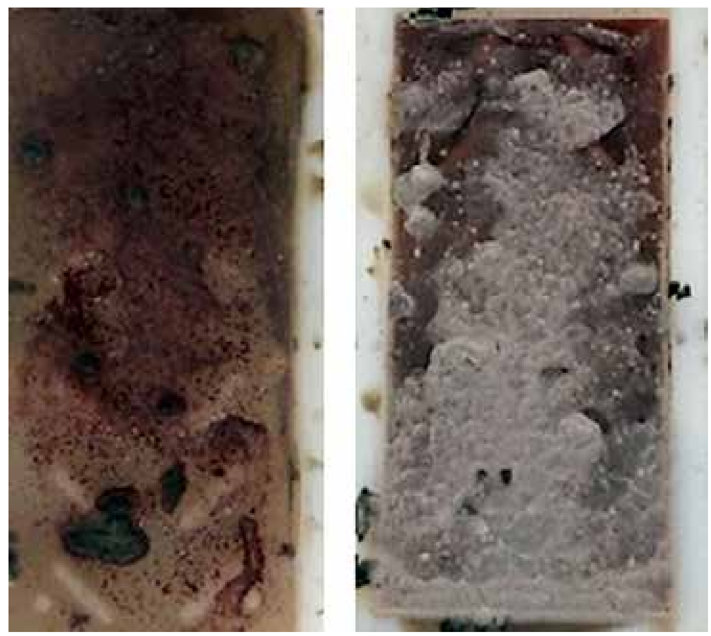


Figure 1: Extreme example of bacteria, left, and fungi growing on a dip slide that was exposed to a quench fluid and allowed to incubate for 24 hours.

BIOLOGICAL AND ODOR PROBLEMS

Biological issues such as bacteria and fungi can be a major issue in induction hardening. Bacteria and fungi are floating in the air. When they land in a moist place they tend to grow. Fungus tends to grow at difficult to reach places where there is little motion of the fluid. Oftentimes this is at the waterline of the quench tank. Bacteria likes to grow in stagnant, oxygen-depleted, food-rich locations. Scale and other debris are wonderful food for anaerobic bacteria found in the typical quench tank. Bacteria and fungi can change the cooling curve of the polymer. This is done by either degradation of the polymer, or by other mechanisms [1]. In addition to changes to the cooling curve of the quenchant, they can produce very unpleasant odors – such as a rotten egg smell, or a badly mildewed locker room. Figure 1 shows an extreme example of bacteria and fungi grown on a dip slide after 24 hours. Additionally, the presence of bacteria and fungi lower the pH, which can increase problems with corrosion or rusting.

Figure 2: Quench tanks collect everything. They should not be used as part washers. Skimmers and similar equipment should be inspected and used.

Cleanliness and oxygen are important controlling factors to minimize the occurrence of bacteria. Keeping the quenchant moving will minimize the occurrence of bacteria. Motion of the quenchant will also entrain air, which helps minimize bacteria. However, excessive agitation can result in splashing. This splashing can settle on difficult-to-reach locations where fungus can grow.

Contamination from outside sources is often a prime driver for bacteria and fungus growth in a polymer quench tank. Machining coolants are often not cleaned from parts prior to induction hardening. They often contain large quantities of swarf, bacteria, and fungi. This is bad practice. Quench tanks are not parts washers — they collect everything (Figure 2). Make sure that skimmers, agitators, and associated equipment is working properly. Coolant should be removed from parts by proper cleaning and rinsing prior to induction hardening. For instance, if a part contains just 5 ml of coolant (one teaspoon), and there are 3,000 parts produced per day, this means that 15 liters of contaminant are dragged into the typical 500-liter quench tank per day. It doesn't take long before the quench tank containing only water and polymer becomes a coolant contaminated mess (Figure 3).

To control biological contamination, biocides are often used to

Figure 3: Samples taken from a badly contaminated polymer quenchant solution used for hardening critical suspension components.

Contamination from outside sources is often a prime driver for bacteria and fungus growth in a polymer quench tank. Machining coolants are often not cleaned from parts prior to induction hardening. They often contain large quantities of swarf, bacteria, and fungi. This is bad practice. Quench tanks are not parts washers — they collect everything.

kill bacteria and fungi [2]. These biocides are used to control and kill unwanted microorganisms. Not only do biocides kill pathogens, they also kill non-pathogens. This means that they can be dangerous to humans. Only tiny amounts are necessary to kill the bacteria and fungi present. For a typical 500-liter quench tank, only 1.25 fluid ounces are required to kill the bacteria and fungi. Biocides are severe skin irritants and corrosive to eyes. They may also cause burning of the skin and cause skin sensitization (contact dermatitis) [3]. Proper personal protection equipment, including face shields, goggles, rubber gloves, protective suits, and other PPE are necessary to prevent personnel injury. Not only are biocides hazardous, they are also very expensive.

Biocides only last for 2 to 4 weeks depending on the contamination, and the number of new bacteria and fungi brought into the system. Constant dosage of new biocide may initially keep bacteria and fungi low, but eventually, resistant bacteria and fungi will be created. Generally, anything that the heat treater can do to avoid using biocides is a good idea.

Alternatively, one can use specially developed bio-resistant polymer quenchants. These quenchants are specially formulated to be resistant to biologicals, and not create the odors associated with biologicals. A limited or specialized biocide may be present, depending on the quenchant. These quenchant will minimize the use of biocides and be damage tolerant to contamination.

CORROSION ISSUES

Corrosion issues can be the result of a depletion of corrosion inhibitors, or biological contamination. It can be the result of improper washing and rinsing of the parts after induction heat treatment.

Most polymer quenchants have both ferrous and non-ferrous corrosion inhibitors. They serve several purposes. The first is to protect the machine. Most induction hardening equipment uses a variety of different materials – copper, aluminum, steel, etc. This is wetted by the quenchant and so galvanic corrosion is a real problem to be overcome. Stray currents and improperly grounded equipment can make corrosion issues worse. Secondly, the hardened part needs short time corrosion protection.

Corrosion from chlorides can be a real problem. Most tap waters contain nominal amounts of chloride as part of water treatment facilities by cities. If a well is used, the chloride level in the water can peak in April and May due to the infiltration of chlorides from road salt. As equipment is used, water evaporates. The inorganic load in the equipment does not evaporate but builds concentration. Once this concentration exceeds some chloride value, corrosion in the form of flash rusting can occur. This value of chloride varies by customer and practice. A concentration greater than 25-50 ppm chloride is considered the threshold for corrosion.

If corrosion is an issue, the supplier may be able to supply an additive package to enhance the corrosion protection of the quenchant. Additionally, washing (and rinsing) any residual polymer from the part is recommended. If the parts are not properly washed (and rinsed), or if the parts are not washed at all, there will be residual polymer and water film remaining on the part. During tempering, water will be driven off, and will concentrate any residual chlorides and will become a source for flash rusting. Washer residues from alkaline cleaners can also be a source for corrosion. It is extremely important that parts are properly rinsed to avoid residues that can cause corrosion to the active hardened surface.

CONCLUSION

In this article we have tried to provide an understanding of the potential for problems during induction hardening, and to provide the user with some possible corrective actions. Many of the issues in induction hardening can be directly related to the amount of contamination in the quench system, and improper or inadequate cleaning.

Should you have any questions regarding this article, or have suggestions for new articles, please contact the editor or the author.

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JASON SCHULZE
METALLURGICAL ENGINEER /// CONRAD KACSIK

Factors such as environment, temperature, and damage should be considered when buying or using thermocouples.

Understanding the technology is key to proper use

I teach pyrometry courses throughout the year and, when I do, I include a thermocouple tutorial video from YouTube. In this video the function of thermocouples is discussed, and examples shown. I have always thought that this video gave good examples, although a friend of mine who was attending one of my courses was nice enough to tell me that he felt the video was, well, let's just say "corny" for lack of a better term. He and I then discussed different ways I could present the technical workings of thermocouples. As he said, "thermocouples are simple; dissimilar wire emits an EMF signal which is then turned to temperature." While he is generally correct, there are details in between that thermocouple users may find valuable or at the very least interesting.

Thermocouple type and usage tends to receive quite a bit of attention. In this article, we will examine the history, basic function, and requirements of thermocouples used in thermal processing.

HISTORY

Typical historic accounts of thermocouple technology begin with Thomas Johann Seebeck's accidental discovery of the thermocouple in 1821. There is a back story that helps support Seebeck's involvement and eventual, albeit accidental, discovery.

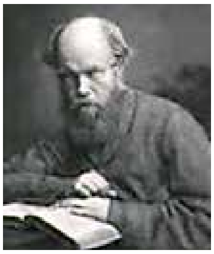
Seebeck, born in Estonia on April 9, 1770, was the son of a wealthy merchant who left home at 17 to study medicine in Berlin. Seebeck was financially independent due to his father's wealth and had an attraction to natural science. Because of this he eventually changed his focus to private research, where he worked on optics. Arriving in Nuremberg in 1810, he met and was the guest of Hans Christian Ørsted, who was a physicist and is responsible for discovering the connection between electricity and magnetism (Ørsted's law). This connection once again changed Seebeck's focus from optics to electromagnetism. It was 1821 when Seebeck announced his discovery of the thermocouple. Once announced, Seebeck's experiments were repeated throughout Europe is several areas of research, cementing thermocouple technology.

While Seebeck is credited with the discovery, thermocouple technology as it exists today owes homage to several other scientists. Professor P.G. Tait of Edinburgh University performed several tests in an attempt to establish thermo-electric diagrams. He concluded that thermocouple technology is based on electromotive force (EMF) which is a parabolic function of an absolute temperature. Tait also stated that

Rhodium-Platinum thermocouple wire.

Hans Christian Ørsted

Thomas Johann Seebeck



Professor P.G. Tait

the slightest impurities in the metals will severely change the accuracy of the readings.

Of course, there were American contributions as well. Dr. Carl Barus was researching high temperature measurement and attempted his study with multiple allows of platinum-iridium.

The first available temperature measurement device shows up in a Cambridge Instrument Company catalogue from 1898, although it was not available until 1902 once a large enough collection of platinum and rhodium-platinum were obtained from Johnson Matthey.

There are several other scientists I have not mentioned who also had an influence on current thermocouple technology.

THERMOCOUPLE TECHNOLOGY

Let's start with the definition of a thermocouple. ASM Materials Engineering Dictionary:

"A device for measuring temperatures, consisting of lengths of two dissimilar metals or alloys that are electrically joined at one end and connected to a voltage measuring instrument at the other end. When one junction is hotter than the other, a thermal electromotive force is produced that is roughly proportional to the difference in temperature between the hot and cold junctions." [1]

While this definition is much more detailed than that of other publications, it underlines the basic principles of a thermocouple.

Each thermocouple has two dissimilar wires which produce a voltage in the microvolt range (Figure 1). Due to being a microvolt, the wire must produce enough voltage to produce an accurate reading. Each one of the wires, being different alloys, has an electric potential gradient in line with the temperature gradient of each wire. The thermoelectric EMF is different in specific alloys for the same temperature and it is this difference

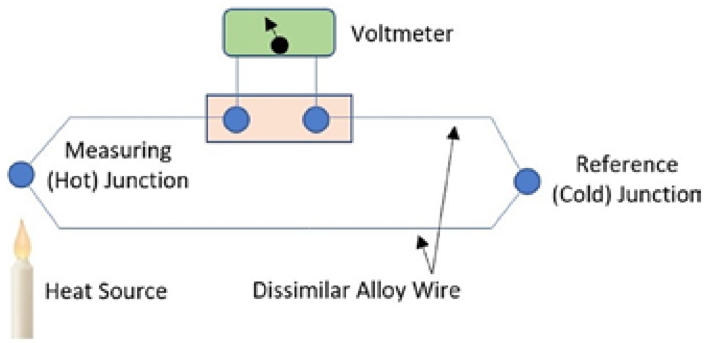


Figure 1: Each thermocouple has two dissimilar wires that produce a voltage in the microvolt range.

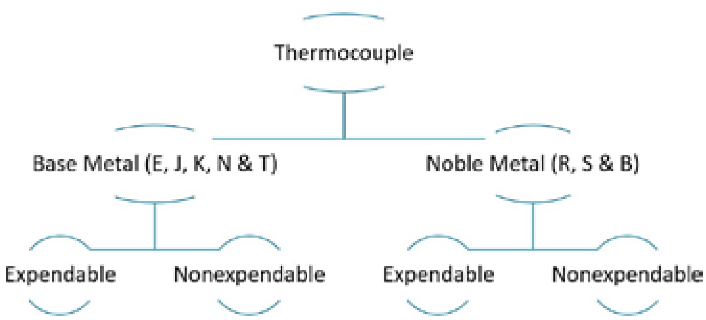


Figure 2: Expendable thermocouples can generally be those covered in fabric or plastic-covered wire, and nonexpendable thermocouples are all others.

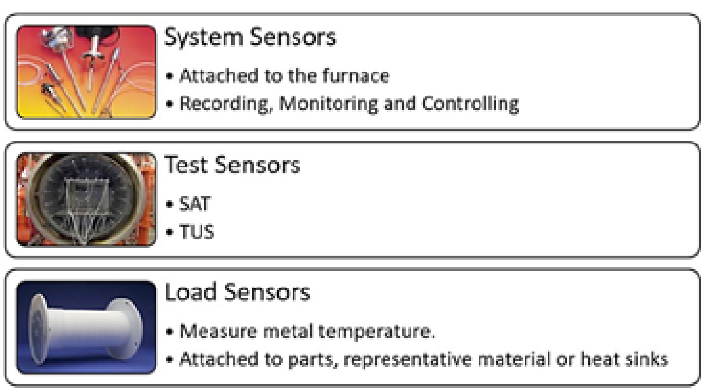


Figure 3: Typical use of thermocouples within thermal processing will align with 3 categories: system sensors, test sensors, and load sensors.

Thermocouple temperature limitations are governed by the type (alloy combination) of the thermocouple. Each thermocouple type has its advantages and disadvantages.

that allows thermocouples to be used to measure metal temperature.

Each wire that makes up the thermocouple is a different metal/alloy. As an example, type K thermocouple is an alloy called chromel (90% Ni & 10%Cr) on the positive leg and an alloy called alumel (95% Ni, 2%Mn, and 2%Al) on the negative leg. For type K thermocouples, the negative leg is magnetic, making it a bit easier to assemble thermocouples to the appropriate plugs before use. Thermocouples are then separated into base metal and noble metal. Noble metal thermocouples are those containing precious or noble metals, such as Type R and S. It is then that thermocouples can be separated into the expendable or nonexpendable categories (Figure 2). What governs the appropriate category is the type of insulation the thermocouple is purchased with. Put simply, expendable thermocouples can generally be those covered in fabric or plastic-covered wire, and nonexpendable thermocouples are all others. Thermocouple usage limitations are typically defined by expendable and nonexpendable categories although industry specifications differ, and each user should be aware of the applicable specification limitations.

THERMOCOUPLE LIMITATIONS

Thermocouple temperature limitations are governed by the type (alloy combination) of the thermocouple. In keeping with our example, type K has a range of -328°F to 2,282°F, although most users do not use type K thermocouples below ambient as other thermocouple types (i.e. type T) are better suited for negative/lower temperatures due to their accuracy.

Each thermocouple type has its advantages and disadvantages. Type K is suitable for oxidizing atmospheres in higher temperature ranges, provides a more mechanically and thermally rugged unit than platinum, rhodium-platinum, and longer life than iron. A disadvantage of type K is it is especially vulnerable in reducing atmospheres, requiring substantial protection when used in such atmospheres.

Typical use of thermocouples within thermal processing will align with three categories: system sensors, test sensors, and load sensors (Figure 3). Again, each prime/industry specification may have its own nomenclature for these categories, but in general, these are the three categories of use. Within thermal processing equipment, these categories of thermocouples may be different types depending on the instrumentation type configuration. As an example, a vacuum furnace may have a type S control and overtemperature thermocouple, while the load and test thermocouples are type K.

Thermocouple suppliers can typically help users identify what type of thermocouple will be best to use on their specific process and will be based on temperature and heating environment, as well as heat cycles.

SUMMARY

Understanding thermocouple technology is essential to proper thermocouple use. Consideration of the environment, temperature, and temperature cycling, as well as physical damage, should be considered when using thermocouples, or purchasing thermocouples.

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ISSUE FOCUS ///

MEDICAL APPLICATIONS / THERMOCOUPLES

Gruenberg truck-in sterilizer. (Courtesy: TPS)

GOING VIRAL
WITH OUTSIDE-THE-BOX THINKING

In an effort to keep medical facilities supplied with protective gear in the fight against COVID-19, Thermal Product Solutions has teamed with a New York research hospital to use its Gruenberg dry heat sterilizers to disinfect used equipment.

By KENNETH CARTER, Thermal Processing editor

With the COVID-19 pandemic still raging across the country and the world, the need for personal protective equipment for medical professionals has pushed the production and distribution of this literal life-saving necessity to their limits.

Given the ongoing challenge of demand exceeding production, Thermal Product Solutions (TPS) has been working with health professionals to use the company's Gruenberg product line for dry heat sterilization to treat PPE and N95 masks for re-use. The Gruenberg sterilizers use convection airflow and dry heat for the process.

In order to evaluate the impact of dry heat treatment on 3M respirator masks, TPS teamed with Stony Brook Medicine, Long Island's premier academic medical center.

So far, the results have been extremely promising.

THE EXPERIMENT BEGINS

Using a Gruenberg sterilizer to disinfect PPE was part of an initiative started by Stony Brook University's Dr. Kenneth R. Shroyer. The Gruenberg dry heat sterilizer was recently installed in a lab animal cage wash facility and had just started acceptance testing within the hospital when the researchers reached out to Robert Davis with TPS's representative, Process Control Solutions, to help refine their process.

"We were waiting for this large VHP equipment to come from Battelle Memorial, which it ultimately did arrive," said Glen Itzkowitz, Associate Dean for Facilities and Operations at Stony Brook. "Prior to the installation of the Battelle vaporized hydrogen peroxide system, there was an effort on the ground to try to disinfect model 1860 masks, a rigid frame N95 mask, by heat."

VHP, or vaporized hydrogen peroxide, is a recently approved method for sterilizing some pieces of PPE for reuse.

First efforts to sterilize the masks and PPE using traditional autoclaving methods were unsuccessful, which is where TPS's Davis entered the picture.

"They were having some questions about their cycles that we had already validated for their laboratory, and they called me to ask some follow-up questions," Davis said. "Then they started to say that they had been sterilizing N95 masks in their dry heat sterilizer but had some questions and needed some additional validation help."

AUTOCLAVE DILEMMA

Hospitals typically use an autoclave to sterilize equipment using steam heated to 121°C, which is why that initial temperature was used for the dry heat test, according to Davis.

The problem with using an autoclave for PPE and N95 mask sterilization is that the autoclave process distorts the masks and causes problems with fitting.

"The fit test fails," Davis said. "The fit test includes how it fits around your face and seals, but it also looks at the filtration efficiency of the mask."

Gruenberg tabletop sterilizer. (Courtesy: TPS)

With autoclave attempts not working and with Stony Brook still waiting on the VHP equipment, Itzkowitz said Plan B was to try the new Gruenberg dry heat sterilizer in the facility's Medical and Research Translational Science Building (MART). Stony Brook first learned about dry heat sterilization from the Dana Farber Cancer Center, where it is used in its lab animal facility.

"They use quite a bit of this technology," he said. "The concept was good for us because this was in a cancer center research building as well. So, we had this brand new TPS Gruenberg dry heat sterilizer that was installed, and we were in the process of just starting to validate it for lab animal work when we shut down due to COVID-19. We basically put our research programs on a 10,000-foot holding pattern."

That's when Stony Brook's dry heat sterilizer came into play, according to Davis.

PERFORMING TESTS

With significant scientific input from two pre-doctoral students from Dr. Shroyer's lab, Stony Brook successfully completed a series of rigorous tests. Initially, three tests were performed on 3M 1860 and 1870 masks. For safety's sake, actual COVID-19 wasn't used in the tests.

A lot is known about Coronaviruses in general, and although COVID-19 is a strain of Corona, the thermal destructive range of COVID-19 has yet to be verified, according to Itzkowitz.

"Coronavirus has been in the veterinarian community as a canine health concern for a long time," he said. "Someone's going to eventually publish a thermal destruction number for dry heat disinfection of SARS CoV2/COVID-19 Novel Coronavirus."

In one of the tests, masks were inoculated with surrogate bacterial markers, placed in a lightweight paper bag, and sterilized in the Gruenberg dry heat sterilizer at 100°C for 30 minutes, according to Davis. The masks were cultured after dry heat disinfection and were found to have no presence of inoculated bacteria.

ASSISTANCE FROM TPS

During the testing, one of the main assists from TPS was to install temperature probes to aid in the process, according to Itzkowitz.

"We got really good information about where the cooler spots and the hotter spots were in the dry heat sterilizer, so we could ensure that we were truly creating an apples-to-apples test," he said. "That was invaluable learning to us. Now that we understood that, we went back and started adjusting the recipes accordingly."

There is a certain temperature and a certain time at temperature that is required, according to Jeff Kent, director of sales for TPS.

"Depending upon how dense the product is loaded and depending upon what the actual product is, that's all going to affect the heat-up time," he said. "So even if you're destroying the same pathogen, you can have a wide variety of total cycle times."

Even with those variables, during the testing, Stony Brook proved the PPE could be treated at 100°C, which should be sufficient to disinfect COVID-19, according to Kent.

The reason Stony Brook initially chose 121°C is it's the temperature that autoclaves use, according to Davis.

"Subsequent to that, there was a little bit of information out there saying these masks could be sterilized effectively at lower temperatures," he said. "Then they did a more extensive follow-up test showing that these could be treated at 100°C, and that's the data that they ultimately put out to some pathology associations."

SURPRISING RESULTS

After some discussion, Stony Brook conducted another round of tests, specifically on the model 1860 masks, according to Davis. Masks were placed in light weight brown paper bags, labeled for single blind quantitative testing, and incubated for 30 minutes at 100˚C. Fit tests were performed after one cycle and again after four total cycles of heat treatment using a respirator fit tester to measure the 300 nm particle concentration outside and inside the mask to calculate fit factor to OSHA (US)-compliant fit test methods. It was concluded that the dry heat treatment at 100˚C could be used to enable re-use of either model 1860 or 1870 N95 masks. The final test scores show the sterilized masks could be re-used through quantitative testing, according to Itzkowitz.

"What we believe is that at temperatures below the thermally destructive threshold of the mask itself, we could probably dry heat treat these masks many more times than we did," he said. "These temperatures did not structurally degrade the masks or negatively impact their integrity to filter air, as based on the data of the quantitative fit testing — which is great."

Theoretically, according to Itzkowitz, for a small community medical center or nursing home facing COVID-19 with a limited supply of PPE — for instance 1,000 N95s — and having a solid PPE conservation/recycling program in place, the same facility would now have the equivalent of 4,000 masks.

Itzkowitz further broke down what those results might mean.

"Nurse Jones can write 'Nurse Jones' with a Sharpie on her mask and write 'Nurse Jones' on a brown paper bag, bring it to a dry heat sterilizer and run that mask time and time again at a 100°C for 30 minutes and keep reusing a disinfected mask," he said. "But it's got to be a 3M 1860 or 1870 mask because that's what we tested."

LIMITED TO 3M MASKS

As of now, tests have only been conducted on 3M N95 masks, so Davis said he is unsure if the results could be extrapolated to other brands, so more tests will need to be conducted.

But with the voracious need for PPE, the use of the Gruenberg products for sterilization is a path TPS is diligently pursuing in order to get FDA approval as quickly as possible, according to Kent.

"We're looking for additional institutions and hospitals to do testing to gather more information and to help collect the validating data that can be presented to the FDA," he said. "If we can standardize on a couple different sizes based on what we feel that the market might want to accept, then it can move through quicker."

THE GRUENBERG STERILIZER: TWO CONFIGURATIONS

Currently, there are two configurations for the Gruenberg sterilizer: A small tabletop model with a capacity starting at 1.25 cubic feet and a large truck-in model offering 1,000 cubic feet of sterilization capacity. The larger truck-in unit is estimated to have the capacity to sterilize 15,000 to 18,000 masks a day based on a cycle time of about an hour, according to Kent.

Gruenberg's smaller dry heat sterilizers feature a design where the process chamber is sealed throughout the entire cycle, containing any airborne particulates and sterilizing them. Larger chamber systems are easily customized, feature intake and exhaust HEPA filters, and offer several door seal options for additional safety measures.

There is HEPA filtration on the intake and the exhaust to ensure that anything that would become airborne in the oven during the process stays there, according to Davis.

"That's also there so we're not introducing any pathogens by drawing the air in," he said. "Typically, the air is drawn in from some type of an interstitial space. So, we want to make sure the air we're bringing in is clean."

The sterilizers also use a controller that's easy to program and run a cycle, according to Davis.

"The operating costs of a dry heat sterilizer are much lower than a steam sterilizer," he said.

DRY HEAT VS. VHP

But since it's been proven that steam sterilization is ineffective for PPE, Davis suggested it be compared to another method that is available: the use of VHP — vaporized hydrogen peroxide.

"A company called Battelle in Ohio just commercialized and got the FDA to approve a process where they put masks in a shipping container, that door is sealed — it's a custom door that they put on

The dry heat sterilization process could become a valuable tool in smaller sub-acute care settings where PPE is going to become an issue and where there are going to be a lot of sick people discharged from hospitals to nursing homes.

With the voracious need for PPE, the use of the Gruenberg products for sterilization of N95 masks is a path TPS is diligently pursuing in order to get FDA approval as quickly as possible. (Courtesy: Shutterstock)

it — and they inject vaporized hydrogen peroxide into the shipping container with all these masks hanging in there," he said. "They circulate it for a period of time, and then they have to exhaust it to recover the vaporized hydrogen peroxide, because vaporized hydrogen peroxide is extremely hazardous and deadly to people in any kind of concentration form."

The cycle time is long, and the process is acutely hazardous, according to Davis. And the hydrogen peroxide is expensive.

"And obviously these machines are fairly large," he said. "It's a 20-foot shipping container that they use."

POTENTIAL VHP PROBLEMS

Another issue that may come up with the VHP technology is that it is not clear if it provides full-thickness disinfection of the N95 or only sterilizes the surface of the PPE, according to Itzkowitz.

"One of the concerns was if a mask is makeup or cosmetic-product contaminated and you are going to recycle that mask, the makeup might block vaporized hydrogen peroxide and protect viral particles from being exposed to the VHP molecules," he said. "But we know in thermal destruction, that's not an issue because the whole mask is heated up. So, we took masks, we painted the inside of them, especially around the edges, with lipstick and with moisturizers and with all kinds of makeup. We did another quantitative fit test on four of them after we soaked them at a 100°C for 30 minutes, and they all passed. I'm a big believer in VHP. It's an amazing technology for cleaning stuff that's living on the surface. If you want a 6-Log kill of something biological on a surface of something else, expose it to VHP for a prescribed amount of time. If it's living, it won't be after the VHP chews on it. VHP is great on stuff that's non-autoclaveable or cannot be put into a sterilizer of any sort because it's too big or that process is destructive to that surface."

A 6-Log kill using VHP means that exposed biological material has been rendered 99.9999 percent dead.

The perfect situation that Itzkowitz said he would like to see is where both VHP and dry-heat sterilization could be used in tandem.

"What we don't know is if a virus particle became embedded deeper into the matrix of the mask fibers itself, could VHP attain a 6-Log kill? That is where we don't know if the VHP could not adequately penetrate to disinfect the deepest parts of the mask," he said. "It can't kill what it can't touch. Think about the makeup in this example as well."

But thermal destruction is a different story, according to Itzkowitz.

"In an ideal world, if a facility had the ability to both surface decontaminate with VHP and take those same masks and put them into a dry heat sterilizer, you're getting a 6-Log kill by chemical disinfection through the VHP and a 6-Log kill through heat destruction," he said.

GRUENBERG ADVANTAGES

Installation of a Gruenberg sterilizer is much less complicated than other methods because mainly all that's needed is a power source, according to Kent.

"Our process requires electricity and an exhaust," he said. "We also have developed a different system that is a sealed-chamber system, which just requires electricity. These are smaller systems that are very efficient to run with a very fast cycle and typically would be deployed at point-of-use rather than in a parking lot or in the back of a hospital."

Itzkowitz believes the dry heat sterilization process could become a valuable tool in smaller sub-acute care settings where PPE is going to become an issue and where there are going to be a lot of sick people discharged from hospitals to nursing homes.

"How do you protect the staff in those hospitals with probably a much more limited supply chain of PPE than we have here at a big academic medical center?" he said. "But at low temperatures in brown paper bags, you could put this stuff in an oven at 212 degrees (F) for 30 minutes and be destructive to Coronavirus, we believe. But again, COVID-19 is still a wild card."

DEPLOYMENT TIMELINE

Once TPS gains FDA approval of the Gruenberg sterilizer to be implemented for PPE re-use, the smaller products could be deployed immediately, according to Davis.

"The larger products would be a built-to-order scenario, and we could be making deliveries from probably as soon as 16 weeks after receipt of order," he said.

However, there is hope that could be fast tracked if needed, according to Kent.

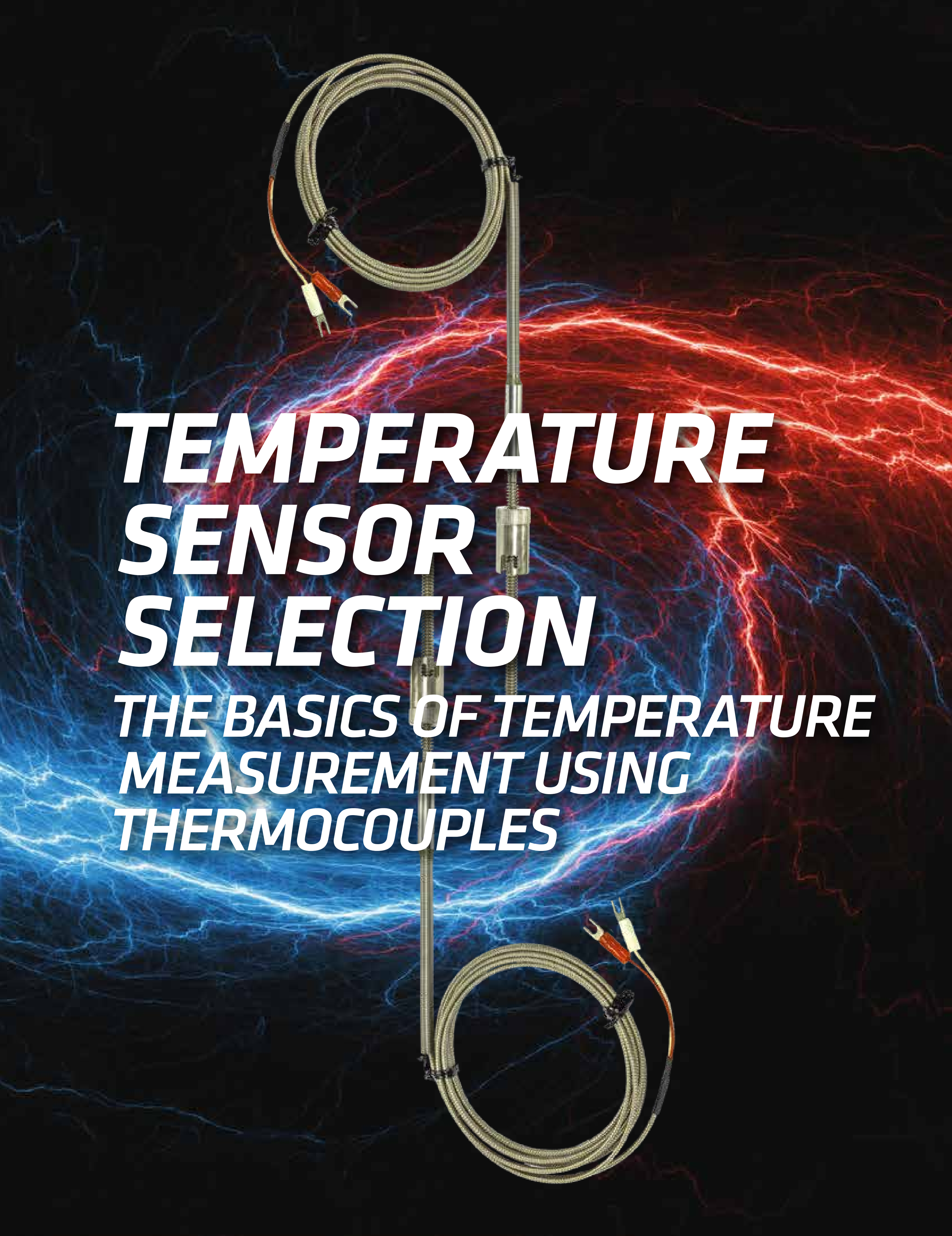
"We've been talking about trying to reduce that to be a little bit more aggressive, especially if we get a little bit more information," he said. "We will have to work with some of the key players in the market to see whether or not we can whittle it down to a small handful of standard sizes compared to very often these larger ones that are engineered to order. A lot of the customization is because the sterilizers are being put into very small areas that have existing infrastructure in place."

But Kent said standardization challenges will be met as work on the sterilization method progresses.

"I think one of the keys that we've seen in the past for Gruenberg, as well as some of the other brands that we have under the Thermal Product Solutions umbrella, is that standardization has a lot of benefits, including lowering costs and decreasing lead times and improving quality as well," he said.

Davis said there are methods in place that might could expedite the equipment to areas hardest hit and in the greatest need.

"We have equipment available — meaning truck-in dry heat sterilizers available for deployment right away," he said. "We also have the smaller, sealed system dry heat sterilizers available for deployment right away as well. And TPS and our company have people that would be able to support getting those installed and up and running, while also working with those parties to make sure the processes are validated and that we're helping make sure that those masks are safe for use when they come out."



TEMPERATURE SENSOR SELECTION

THE BASICS OF TEMPERATURE MEASUREMENT USING THERMOCOUPLES

When choosing a temperature sensor for an application, consideration must be given to sensor material type, the application temperature range, the relative sensitivity of the sensor, the limitations of its insulation material, and its reaction with the measurement environment.

By BRUCE CYBURT

You are probably somewhat familiar with the thermocouple, or you wouldn't be reading this article. But there are important points about thermocouples that must be understood and that will help you to make an informed selection between sensor types and avoid potential problems in your application.

First, we need to clear up a common misconception about how thermocouples work. You may have been told something like "a thermocouple produces a small voltage created by the junction of two dissimilar metals." This simplification of the thermocouple is at best only half true and very misleading. The reality is that it is the temperature difference between one end of a conductor and the other end that produces the small electromotive force (emf), or charge imbalance, that leads us to the temperature difference across the conductor.

OK, simple enough, but how do you actually measure this emf in order to discern its relationship to temperature?

The "emf" or electromotive force refers to a propensity level, or potential for current flow as a result of the charge separation in the conductor. We refer to this propensity for current flow between two points as its potential difference, and we measure this difference of potential in volts. But in order to actually measure the emf or voltage difference, we need two points of contact. That is, we must complete the circuit by adding a return electrical path. If we simply choose to use the same metal as a return path, the temperature difference between the ends of your original conductor would simply create an equal and opposite EMF in the return path that would result in a net EMF of zero — not very useful for measuring temperature. This relationship is expressed by the "Law of Homogeneous Material" as follows (see Wikipedia.org):

A thermoelectric current cannot be sustained in a circuit composed of a single homogeneous material by the application of heat alone, and regardless of how the material may vary in cross-section. That is, temperature changes in the wiring between input and output will not affect the output voltage, provided all wires are made of the same material as the thermocouple. No current flows in the circuit made of a single metal by the application of heat alone.

Different conductive metals will produce different levels of emf or charge separation relative to the thermal gradient across the metal. Thomas Seebeck discovered this principle in 1822 and it is known today as the "Seebeck Effect." Thus, we can apply the "Seebeck Effect" and make it useful for measuring temperature by using a different metal for our return path, and then relating the differences in charge separation between the two metals to the temperature between the ends. We join these metals at the start of our return path by forming a junction between them — that is, the junction simply joins our circuit and is not the source of the emf, as is often inferred by the traditional definition of a thermocouple.

Now, at the other end of our closed thermocouple circuit, we can measure a voltage between the two wires that will be proportional to the temperature between the ends. By the Law of Homogeneous Materials expressed earlier, the thermocouple wires can each pass into and out of cold areas along their path without the measuring instrument detecting the temperature changes along the path because the emf created as the continuous wire enters and leaves an area will sum to zero and have no net effect on our final measurement.

We still have a conceptual problem though — how do we measure the voltage at the open end of our thermocouple without introducing additional "thermocouple" voltages into our measurement system? That is, the connection points of the T/C to the measurement system (which is typically copper) will itself act as a thermocouple. It turns out that the effect of these additional thermocouples on our measurement system can be minimized by simply making sure the connections are at the same temperature. This principle is expressed by "The Law of Intermediate Materials" as follows (see Wikipedia.org):

The algebraic sum of the thermoelectric emfs in a circuit composed of any number of dissimilar materials is zero if all of the junctions (normally at the cold junction) are maintained at a uniform temperature. Thus, if a third metal is inserted in either or both wires while making our cold junction connections, then as long as the two new junctions are at the same temperature, there will be no net voltage contribution generated by the new metal in our measurement system.

So, our ability to overlook these unintended thermocouples in our measurement will depend on how well we can maintain both cold junction connections at the same temperature. This is often easier said than done, and small thermal gradients will usually occur, often as a result of the self-heating of components across the circuit board. Other thermal gradients can be driven by heat generated from adjacent circuits, nearby power supplies, or via variable wind currents or cooling fans in the system. For any thermocouple transmitter, special care must be taken to minimize these sources of error.

A third law for thermocouples that helps us combine emfs algebraically is "The Law of Successive or Intermediate Temperatures" stated as follows (see Wikipedia.org):

If two dissimilar homogeneous materials produce thermal emf1 when the junctions are at T1 and T2, and produce thermal emf2 when the junctions are at T2 and T3, then the emf generated when the junctions are at T1 and T3 will be emf1 + emf2, provided T1<T2<T3.

Still, our measurement of the open-end voltage across our thermocouple only relates the thermoelectric voltage to the difference in temperature between both ends. That is, we need to know the temperature of the cold junction at one end in order to extract the sensed temperature from the other end (hot junction). Ideally, if both connections made at the measuring end were at 0°C, their thermoelectric

Table 1: Common thermocouple types and their applications.

ANSI TYPE	JUNCTION MATERIALS	TYPICAL USEFUL MEASURE RANGE	NOMINAL SENSITIVITY	Atmospheric Media[1] I	R	O	V
K[2]	Chromel (Nickel & Chromium) – Alumel (Nickel & Aluminum)	-184°C to 1260°C	39uV/°C	Yes	No	Yes	No
	Most common general purpose type with a wide temperature range and lowest cost. Good for high temperatures with good corrosion resistance. Positive lead is non-magnetic, while the negative lead is magnetic. Good for clean oxidizing atmospheres but vulnerable to sulfur attack and should be kept from sulfurous atmospheres.						
J	Iron – Constantan	0°C to 760°C	55uV/°C	Yes	Yes	Yes	Yes
	Second-most common type but limited in range. Good for general purpose dry applications where moisture is not present. Positive iron wire is magnetic, while negative wire is non-magnetic. Lower service life due to fine wire size and rapid oxidation of iron wire at temperatures above 540°C, not recommended for sulfurous atmospheres above 540°C. Ok for use in vacuum, air, and reducing or oxidizing atmospheres up to 760° and in the heavier gage sizes. Limited sub-zero use due to rusting and embrittlement of the iron wire. Should not be used above 760°C due to an abrupt magnetic transformation at the Curie point of iron (~770°C) which changes its characteristic and can cause permanent de-calibration.						
E	Chromel (Nickel & Chromium) – Constantan	0°C to 982°C	76uV/°C	Yes	No	Yes	No
	Non-magnetic with highest output voltage offering the best sensitivity and suitable for cryogenic use. Recommended for use up to 900°C in oxidizing or inert atmospheres. Vulnerable to sulfur attack and should be kept from sulfurous atmospheres.						
T	Copper – Constantan	-184°C to 400°C	45uV/°C	Yes	Yes	Yes	Yes
	Corrosion resistant from moisture and condensation and has high stability at low temperatures. Limits of error guaranteed for cryogenic temperatures and good for wet applications. Useful service in oxidizing, inert, or reducing atmospheres, or in a vacuum. Non-magnetic, useful up to about 370°C, very stable, and moisture resistant in air, appropriate for use down to -200°C.						
N	Nicrosil – Nisil	0°C to 1100°C	10.4uV/°C	Yes	Yes	Yes	Yes
	High stability and resistance to high temperature oxidation makes type N a lower cost alternative to B, R, and S types for some applications. Very accurate and reliable at high temperatures. Good for oxidizing, inert, or dry reducing atmospheres. Vulnerable to sulfur attack and should be kept from sulfur containing atmospheres.						
C*	Tungsten (5%)/Rhenium – Tungsten (26%)/Rhenium	0°C to 2300°C	16uV/°C	Yes	No	No	Yes
	Recommended for high-temperature use in vacuum furnaces, high-purity hydrogen, or high-purity inert atmospheres. Must never be used in the presence of oxygen at temperatures above 260°C. Very poor oxidation resistance. *Not an ANSI type.						
T/C types B, R, and S follow and are the most stable T/C types due to their low sensitivity (≤10uV/°C). T/C's with low sensitivity have lower resolution, are more expensive, and are typically only used for high temperatures.							
B	Platinum (6%)/Rhodium – Platinum (30%)/Rhodium	38°C to 1800°C	7.7uV/°C	Yes	No	Yes	Yes
	Least sensitive with lowest output voltage. For very high temperature applications. Always protected by high-purity ceramic. Because this type gives the same output at 0°C and 42°C, it is useless below 50°C. Useful in inert or oxidizing atmospheres, or for short periods of time in a vacuum. Easily contaminated and must be protected from reducing atmospheres and contaminating vapors.						
R	Platinum (13%)/Rhodium-Platinum	0°C to 1593°C	6uV/°C	Yes	No	Yes	Yes
	High temperature use. Usually with a ceramic sheath. Popular in UK. Useful in inert or oxidizing atmospheres, or short periods of time in a vacuum. Easily contaminated and must be protected from reducing atmospheres and contaminating vapors.						
S	Platinum (10%)/Rhodium – Platinum	0°C to 1538°C	10.4uV/°C	Yes	No	Yes	Yes
	Widest useful temperature range, but low sensitivity and high cost make it unsuitable for general purpose applications. Usually has a ceramic sheath. Useful in inert or oxidizing atmospheres, or short periods of time in a vacuum. Easily contaminated and must be protected from reducing atmospheres and contaminating vapors. Because of its high stability, type S is used as the standard for calibrating the melting point of Gold.						

NOTES

1. From Table 1, the "I" designation refers to applications in Inert atmospheres, "R" refers to Reducing atmospheres, "O" refers to Oxidizing atmospheres, and "V" refers to operation in a vacuum. See below for a brief explanation of these environmental conditions.

2. The Type K thermocouples use the magnetic material Nickel. Magnetic materials will exhibit a step change in their output once they reach their Curie point, which for a Type K occurs at approximately 354°C. The Curie point refers to the temperature where a ferromagnetic material becomes paramagnetic when heated. For example, a magnet will lose its magnetism if heated above the Curie temperature. This is a reversible change on cooling for Nickel. Some Curie points for different materials are as follows: Iron (Fe) above 770°C, Cobalt (Co) above 1130°C, Nickel (Ni) above 358°C, and Iron Oxide (Fe_2O_3) above 622°C.

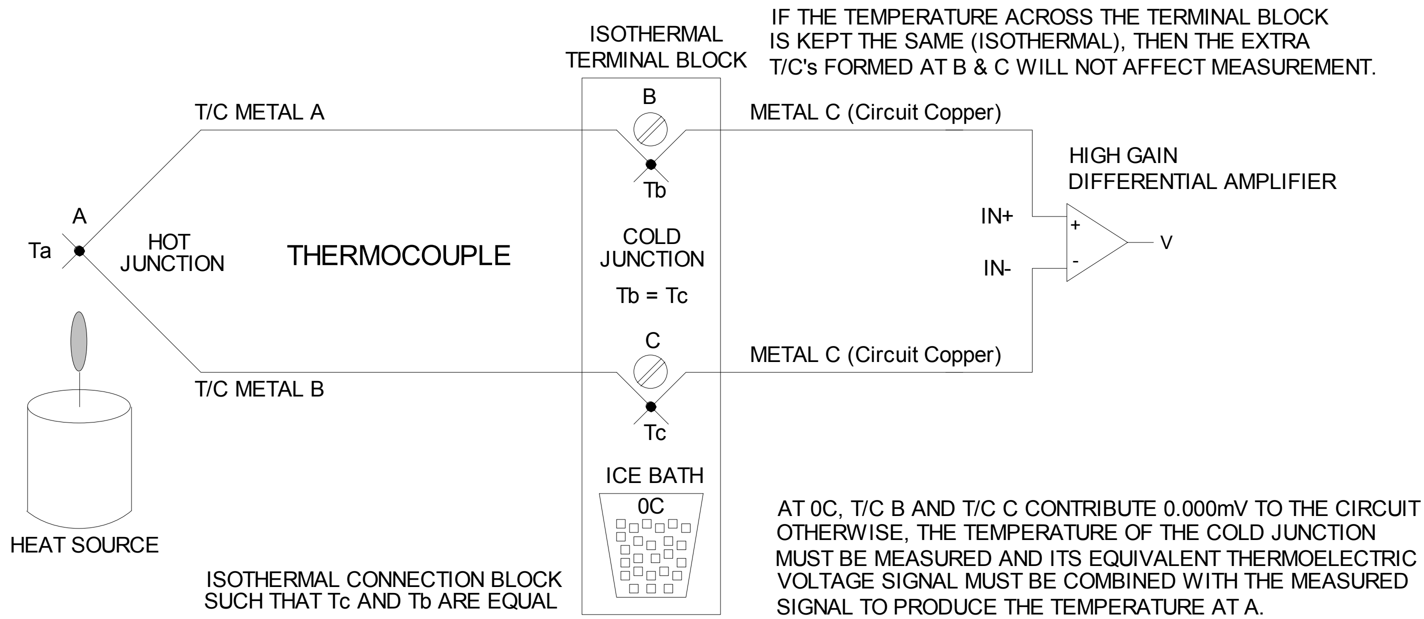


Figure 1: A simplified thermocouple measuring circuit.

equivalent voltage contributions to our measurement would be 0mV, and we could easily determine the sensed temperature directly from our measured voltage. Since this can't be easily assured, the actual temperature of the cold junction connection point is usually measured separately. Then the measured T/C signal can be compensated for the thermoelectric contribution of the connection point or "cold junction," and we can extract the actual temperature of the remote end of our thermocouple by a mathematical combination of either the measured temperature or its thermoelectric equivalent voltage. See Figure 1.

Although we could form a thermocouple by joining any two dissimilar conductors, a number of standard thermocouple types are available that use specific metals combined to produce larger predictable output voltages with respect to their thermal gradients. The most common types are listed in Table 1.

NOTES (TABLE 1)

› **1.** From Table 1, the "I" designation refers to applications in Inert atmospheres, "R" refers to Reducing atmospheres, "O" refers to Oxidizing atmospheres, and "V" refers to operation in a vacuum.

› **2.** The Type K thermocouples use the magnetic material nickel. Magnetic materials will exhibit a step change in their output once they reach their Curie point, which for a Type K occurs at approximately 354°C. The Curie point refers to the temperature where a ferromagnetic material becomes paramagnetic when heated. For example, a magnet will lose its magnetism if heated above the Curie temperature. This is a reversible change on cooling for Nickel. Some Curie points for different materials are as follows: iron (Fe) above 770°C, cobalt (Co) above 1,130°C, nickel (Ni) above 358°C, and iron oxide (Fe2O3) above 622°C.

From Table 1, we see that the selection of a specific T/C type will be guided by the useful measurement range of the sensor, its sensitivity, its material, and its operating environment. Sensor cost may also play a role in this decision as certain types are more expensive than others — for example, the platinum-based sensor types are generally more expensive by virtue of their platinum content.

Because materials used at extreme temperatures can be permanently altered by their application environment, you must also consider the atmospheric conditions of their application as noted in Table 1.

An "inert atmosphere" refers to an environment of a gaseous mixture that contains little or no oxygen and primarily consists of non-reactive gases or gases that have a high threshold before they react. Nitrogen, argon, helium, and carbon dioxide are common components of inert gas mixtures.

A reducing or "reduction atmosphere" refers to an environment in which oxidation is prevented by the removal of oxygen and other oxidizing gases or vapors. This usually refers to environments containing nitrogen or hydrogen gas. For example, it is often imposed in annealing ovens to relax metal stresses and prevent metal corrosion.

Nitrogen is also used in some electronic soldering ovens to improve the performance and/or appearance of the solder joint.

An "oxidizing atmosphere" is a gaseous environment in which the oxidation of solids readily occurs due to the presence of excess oxygen. Contrast this to the reducing atmosphere described earlier in which the available oxygen is reduced or eliminated. Many combustion processes will use oxidizing atmospheres. Many substances oxidize rapidly when heated sufficiently in the presence of free oxygen. The oxidation that results refers to the transformation that occurs when portions of compounds and molecules break free from the material allowing the free oxygen to attach to the remaining material and form oxides. For example, it is commonly used inside kilns for firing pottery in order to drive materials to convert to their oxide forms, or to control material color. When copper carbonate is fired, the carbon detaches and burns off as the copper-carbon bond is broken, the available oxygen rushes in to attach to the copper, forming a copper oxide.

A "vacuum atmosphere" refers to an environment or volume of space that has been evacuated of free matter, such that its gaseous pressure is much less than the surrounding atmospheric pressure. Note that a perfect vacuum is not practically achievable as atoms and particles are always present in the atmosphere, but the quality of a vacuum environment would refer to how well it approaches a perfect vacuum, as indicated by how low its environmental pressure is relative to atmospheric pressure.

The maximum temperatures of any thermocouple type are generally limited by the type of insulation used.

POINTS OF CONSIDERATION WHEN USING THERMOCOUPLES TO MEASURE TEMPERATURE

Since accuracy will ultimately play a significant role in selecting a

TYPE	CLASS	TEMPERATURE RANGE	FIXED TOLERANCE	CALCULATED TOLERANCE AT T°C
K	1	t = -40°C to +1000°C	± 1.5°C	± 0.004 * t°C
&	2	t = -40°C to +1200°C	± 2.5°C	± 0.0075 * t°C
N	3	t = -200°C to +40°C	± 2.5°C	± 0.015 * t°C
J	1	t = -40°C to +750°C	± 1.5°C	± 0.004 * t°C
	2	t = -40°C to +750°C	± 2.5°C	± 0.0075 * t°C
	3	NA	NA	NA
E	1	t = -40°C to +800°C	± 1.5°C	± 0.004 * t°C
	2	t = -40°C to +900°C	± 2.5°C	± 0.0075 * t°C
	3	t = -200°C to +40°C	± 2.5°C	± 0.015 * t°C
T	1	t = -40°C to +350°C	± 0.5°C	± 0.004 * t°C
	2	t = -40°C to +350°C	± 1.0°C	± 0.0075 * t°C
	3	t = -200°C to +40°C	± 1.0°C	± 0.015 * t°C
B	1	NA	NA	NA
	2	t = +600°C to +1700°C	± 1.5°C	± 0.0025 * t°C
	3	t = +600°C to +1700°C	± 4.0°C	± 0.005 * t°C
R	1	t = 0°C to +1600°C	± 1.0°C	± [1 + 0.003 * (t°C-1100°C)
&	2	t = 0°C to +1600°C	± 1.5°C	± 0.0025 * t°C
S	3	NA	NA	NA

Table 2: IEC 584-2 standard thermocouple tolerances.

sensor type, we should be familiar with potential sources of error when making temperature measurements with thermocouples. Some of these considerations may steer us from one T/C type to another, or perhaps to another sensor type, like RTD for example.

T/C Sensor Inaccuracy

Some manufacturers of thermocouple sensors may have their own accuracy designations different from the standard designation described in Table 2, and those should always be consulted first, as they sometimes offer better than standard performance. But by the IEC 584-2 standard, thermocouple sensors are divided into three accuracy classes: Class 1, Class 2, and Class 3. By this standard, two tolerance values apply for a given temperature and thermocouple type: a fixed value and a calculated value based on the sensor temperature. The larger of these two values is normally taken as the sensor tolerance (note that Type C has been excluded below as it is not an ANSI type designation).

T/C Sensor Non-Linearity

The non-linearity of the thermocouple output itself can vary up to several percent or more over the full temperature range of a T/C type. The mathematical relationship between sensor temperature and output voltage is modeled via a complex polynomial to the 5th through 9th order depending on the T/C type. Some transmitters will take special measures to adjust their output response for these non-linearities and make their outputs linear with the input temperature range. Other applications are not concerned with linearizing the transmitter's output response relative to the sensor temperature, and their response will instead be linear with the thermoelectric voltage signal of the sensor. In many cases, a given thermocouple will be nearly linear over a smaller range of its application temperature, and some non-linearity will be acceptable without applying special linearizing methods.

Likewise, some low-cost transmitters will use analog methods to shift the output to adjust for this non-linearity, and this generally works best over smaller or truncated portions of the sensor range. Some modern digital instruments will actually store thermoelectric breakpoint tables in memory to accomplish multi-segment linearization of a T/C range and return the corresponding temperature for a given voltage measurement.

Depending on your application, the lack of linearization can be a significant source of error if you fail to account for it.

T/C Sensor Sensitivity

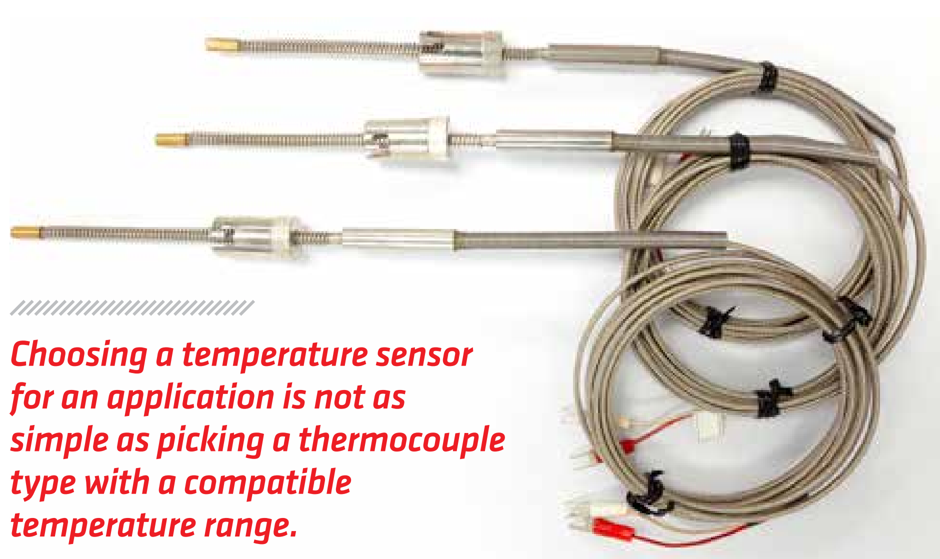
As mentioned earlier, we noted that any conductor subject to a thermal gradient along a dimension will generate a voltage difference along that same path, and this is known as the Seebeck effect. Different materials will exhibit different magnitudes of thermal emf related to the difference in temperature. Combining two different materials and joining them at one end allows us to complete a circuit, build the thermocouple, and actually measure the relative voltage. The relative sensitivity of the thermocouple refers to its Seebeck coefficient, which is simply a measure of its incremental change in thermocouple voltage corresponding to an incremental change in temperature (i.e. dV/dT in mV/°C or uV/°C). This is essentially the slope of the thermocouple function (voltage versus temperature) at a selected temperature. It's important to note that just as a thermocouple varies its linearity over temperature, its relative sensitivity is also temperature dependent. That is, some thermocouples will be more or less sensitive for smaller portions of their application temperature range. Table 1 gave a nominal sensitivity figure for the thermocouple over its entire application range to help differentiate the thermocouples by sensitivity, but over smaller ranges, this figure can vary considerably. T/Cs that have lower sensitivity will have lower resolution. These are generally used at higher temperatures where the need to resolve a given temperature to a high degree of accuracy is not a requirement. Likewise, if you need to resolve temperature to a fraction of a degree, you would select a T/C with higher sensitivity and a corresponding higher resolution.

Sensor Drift, Aging, and De-Calibration

Drift or de-calibration of a thermocouple sensor refers to the process in which the metallurgy of the thermocouple wire has been altered as a result of its exposure to temperature extremes, usually for prolonged periods of time. It may also occur inadvertently by failing to consider the “entire” operating range of a sensor application including its over-range and under-range or fault conditions. Drift usually occurs as a result of the diffusion of atmospheric particles into the metal at extreme temperatures. But it can also occur due to the diffusion of impurities and chemicals from a thermocouple’s insulation or protective sheath into the T/C wire at temperature extremes. It is always good policy to check the specifications of the thermocouple or probe insulation, as it usually limits the effective operating ambient of the thermocouple itself.

Choice of Extension Wire

For thermocouples that must pass over a long distance, thermocouple extension cable is often used. Extension cables are generally used to lower the total cost of the sensor and will use similar materials to the thermocouple itself or materials better suited for the intervening environment. The important thing to remember about the use of an extension cable is that its thermoelectric behavior sometimes only approximates that of the thermocouple, and it will usually limit the applicable range of the thermocouple by virtue of its insulation. Be cognizant of the extension wire used in an application and its limitations, as it can be an increasing source of error if applied improperly with respect to temperature and environment. Note that for base metal thermocouples (J, K, N, E, and T), the extension wire conductor is the same composition as the corresponding thermocouple and will exhibit the same thermoelectric properties as the thermocouple itself. However, for noble metal thermocouples (R, S, and B), the wire is usually a different alloy that will only approximate the noble metal thermoelectric properties but over a more limited range.



Choosing a temperature sensor for an application is not as simple as picking a thermocouple type with a compatible temperature range.

The conductor material is different because the noble metals contain platinum, which would be very expensive to use as extension wire. Use of a different material is often not a problem, as these T/C types are generally used at higher temperatures and have a lower resolution, such that the small error contribution of using a different but similar extension wire is less significant. In all cases, the maximum application temperature will be limited by the type of insulation used by the extension wire and this is an important factor in selecting the proper extension wire for a given application.

Response Time

The response time refers to the time interval between the application of a sudden change in temperature to a sensor and its corresponding change in output. This change is frequently defined as the time it takes for the sensor to reach 63.2 percent of its final value. A rapid response time or shorter time constant helps to reduce error in systems that encounter rapid changes in temperature. It is dependent on several parameters, such as T/C dimensions (wire size), construction, tip configuration, and the medium to which it makes contact. For example, if a thermocouple penetrates a medium with high thermal capacity and rapid heat transfer, the effective response time would approach that of the thermocouple itself (its intrinsic response time). But if the thermal properties of the medium are poor, still air for example, the response time can be 100 times greater. For an insulated or ungrounded thermocouple, response time can vary from a fraction of a second (small diameter) to several seconds (large diameter). For non-insulated or grounded thermocouples, the typical time varies from a small fraction of a second (small diameter) to a few seconds (large diameter). In general, thermocouple temperature sensors have the fastest response times, especially when compared to RTD sensors. It is generally their small point of contact and low thermal mass that gives them a faster response time. But similar to an RTD, the response time of a thermocouple measurement will also depend on its insulation. That is, you can specify a grounded (non-insulated) or ungrounded (insulated) thermocouple. A grounded thermocouple junction puts the material junction in direct contact with the surrounding case metal, which gives it a faster response time. But the grounded tip is also more prone to noise pickup and may increase measurement error, in particular when wired to non-isolated measuring instruments. You should tend to use an ungrounded (insulated) sensor to avoid these issues, but only when sensor isolation and response time are not over-riding issues for your application. If your application absolutely requires a fast response time, you will probably need a grounded tip and will have to take other measures to combat noise pickup or isolate your signal, such as selecting a compatible isolated transmitter.

Cold Junction Compensation

Near room temperature, the major source of error for any thermocouple sensor is that which is attributed to cold junction compensation (CJC). Because thermocouples only measure the difference in temperature between two points and not the absolute temperature of the sensor, we must apply cold junction compensation (also reference junction compensation) in order to directly relate the measured voltage to the sensor temperature. Realistically, our temperature measurement can only be as accurate as our method of cold junction compensation. This compensation contributes significant error to our measurement and, in order to minimize cold junction error, the measurement cold junction circuit has to accomplish two things very well:

› The connection points to the thermocouple must be kept at the same temperature, or “isothermal.” Any temperature gradient from one point to the other will be a source of error (Recall the Law of Intermediate Materials explored earlier).

› The actual temperature of the connection points must be measured accurately, or at least as accurately as the thermocouple itself. The response time of the CJC sensor can also be a factor in maintaining accuracy, in particular for systems that require a fast response time but may have unstable cold-junction ambient.

While our thermocouple allows us to make precise differential temperature measurements, we need to make sure that the pair of terminals that connect to the T/C and comprise our cold junction are at the same temperature or "isothermal" with one another. Not doing so would introduce an errant T/C voltage into our measurement. We also have to make sure that the cold junction has enough thermal mass so that it will not change temperature over the time it takes for us take the two measurements necessary to convert the T/C signal into the actual temperature at the remote end.

Connection Problems

Potential measurement error is often a result of poor connections, which drive unintended thermoelectric voltage contributions to our measurement voltage. If you need to increase the length of thermocouple wires, you must use the correct type of T/C extension cable for the thermocouple. Substitution of any other type will add errant thermocouple junctions to our measurement system. If terminals are used to connect the wires, then you must additionally select connectors made up of the same material type, unless you can ensure that the connections are kept at the same temperature. You also need to observe the proper polarity when making connections.

Other connection problems arise when an incompatible material type is used for a given environment, or where extension wire has been mismatched to the sensor or its environment. For example, thermocouples that use iron as a material will be subject to corrosion that may impede continuity, particularly in wet environments.

Thermal Shunting and Immersion Error

All thermocouples have some mass, and heating this mass will absorb some energy that will ultimately affect the temperature you are trying to measure. In some applications, the T/C wire will act like a heatsink at the point of measurement, and that can result in significant measurement error. The use of thin T/C wires helps minimize this effect in many applications. For example, consider a thermocouple immersed in a small vial of liquid to monitor its temperature. Heat energy may travel up the T/C wire and dissipate to the atmosphere reducing the temperature of the liquid around the wires. Or, if the thermocouple is not sufficiently inserted into the liquid, the cooler ambient air surrounding the wires may actually conduct along the wire and cool the junction to a different temperature than the liquid itself. The use of thinner wires would cause a steeper thermal gradient along the wire at the junction between the ambient air and the liquid itself. However, thin wires have a higher resistance, and this can drive other errors. It may be better to use shorter thin T/C wires connected to much thicker thermocouple extension wires in order to alleviate the resistance effect for some applications.

Lead Resistance

To minimize the effects of thermal shunting and to improve response time, thin T/C wire is generally used. The use of thin wire is also at least partially driven by the type of wire that is more expensive, in particular for the platinum-based, noble metal types R, S, and B. But the downside to using thin wire in some systems is that it increases the sensor resistance making it more sensitive to noise, and potential IR errors driven by the measuring instrument. Care should be taken to ensure that the loop resistance of a wired thermocouple be kept low, and a general rule of thumb is to keep it below 350Ω to avoid excess error and below 100Ω would be better.

Noise

The thermocouple output voltage is a small signal that is prone to errant noise pickup. Likewise, the fine leads are made from other materials than copper and have a higher resistance, making them more sensitive to noise pickup, in particular AC-coupled noise. Further, the high gain that generally operates on these small signals further amplifies this noise. Other sources of thermal noise result from unstable ambient temperatures at the cold junction. The generally fast response time of the thermocouple exhibits this noise at the output as the cold junction generally tracks the junction temperature much slower than the T/C sensor itself, usually as a result of its larger thermal mass and the sensor used to measure its temperature. Noise can usually be minimized by twisting the wires together to make sure that both leads pick up the same signal (i.e. common mode noise is rejected).

Likewise, minimize the length or loop area where the cables part to make a connection to the instrument. Route T/C wires defensively, keeping them from combining with power wires. Operation in noisy environments or nearby electric motors may benefit from the use of screened extension cable. If noise pickup is suspected, simply switch off suspect equipment and observe if the reading changes.

Common-Mode Voltage

Although the thermocouple signals are small, much larger voltages may exist at the instrument itself due to the presence of common-mode voltages driven by inductive pickup along the sensor wire or via multiple earth-ground connections in the system. Inductive pickup is commonly a problem when using a thermocouple to sense the temperature of a motor winding or power transformer. Multiple earth grounds may be inadvertent, perhaps when using a non-insulated or grounded thermocouple to measure the temperature of a hot water pipe. In this instance, any poor connections to earth ground may drive a few volts of difference between the pipe and measuring instrument. The use of high-quality, high-gain, differential instrument amplifiers will generally reject this noise as it is common to both input leads, but only as long as the voltages remain within the common-mode input range of the instrument amplifier (usually limited to ±3V to ±5V by the internal DC voltage rail of the instrument). As noted with errant noise earlier, it usually helps to twist the wires together to make sure that both leads pick up the same signal (i.e. common mode noise is rejected by the amplifier). Also keep the length short or the loop area small where the cable conductors part to make a connection to the instrument.

By now you should realize that choosing a temperature sensor for an application is not as simple as picking a thermocouple type with a compatible temperature range. You must consider the sensor material type, the application temperature range, the relative sensitivity of the sensor, the limitations of its insulation material, and its reaction with the measurement environment. You must also be aware of the inherent limitations of the thermocouple and potential error sources in its application.

ABOUT THE AUTHOR

Bruce Cyburt is a senior product engineer at Acromag, Inc. He has 30-plus years of experience developing temperature transmitters and signal conditioners. He holds a BS in Electrical Engineering from Lawrence Technological University. Learn more at www.acromag.com.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Thermal processing

APPLYING ADVANCED TECHNOLOGY TO THE MANUFACTURING PROCESS

An SSi customer does a furnace uniformity survey using the SSI SDS 8020 survey box. (Courtesy: Super Systems)

Since it opened its doors in 1995, Super Systems Incorporated has worked to make heat treaters more efficient using today's technology.

By KENNETH CARTER, Thermal Processing editor

It might be a cliché, but the path to a successful business can often be summed up in six words: Be good at what you know.

For Super Systems Incorporated, that expertise is evident in how it has become a prime player in thermal processing.

"With our specific focus on the heat-treat industry only, it allows us a great deal of strength and expertise in that area for the technology we provide," said Stephen Thompson, president of Super Systems.

By focusing only on the thermal processing market, which includes heat treat, atmosphere, vacuum, nitriding, and ferritic nitrocarburizing, Super Systems is able to offer its customers consistent quality products and services, according to Thompson.

Super Systems Inc. (SSi) was established in 1995 as a supplier to the thermal processing industry with a focus on sensor and control technology for protective atmospheres. The company was founded by Bill Thompson, who has a long history of servicing the heat-treating industry. Today, under the direction of Stephen Thompson, SSi provides a wide variety of products and services for the industry worldwide.

"Something unique to us is we only sell to the heat-treat market, and with this focus, we provide more solutions to the same customers, building our relationships, which are key in the growth of our company," Thompson said. "It's not just one sale; it's a beginning of a long-term relationship."

SSi's philosophy for innovation and customer service is simple: *They listen*. According to Thompson, whether they are serving a customer who needs technology to maximize efficiency and deliver the highest quality services, or investing back into their Research & Development (R&D) team and challenging them to deliver innovative technology to the heat-treating industry, customer focus and innovation have always set them apart.

"Many of our customers believe our products have provided them with a foundation for intelligent heat treating, gaining and maintaining the competitive edge they need," he said.

ISO9000 ACCREDITATION

"We are focused on our quality systems, which has allowed us structured growth in the organization," Thompson said. "We use the quality standards to provide a foundation for continuous improvement in all areas of our business."

SSI's products include probes, controllers, software, analyzers, gas flow meters, and installation and engineering services covering all facets of heat treating. Super Systems is ISO 9001:2015 certified and ISO/IEC 17025 certified for the calibration of dew point, infrared analyzers, and temperature instrumentation. SSi participates in many industry forums as well, such as ASM Heat Treating Society, AMEC and Nadcap, and the company is a proud member of the Metal Treating Institute and IHEA, according to Thompson.

TECHNOLOGY AND SOFTWARE

"As a technology company, we develop software for multiple applications focusing on productivity, repeatability, and quality. Almost all of our products are complemented with software providing ease of use and accessibility," Thompson said. "From configuration tools, backup utilities, mobile applications, and complete SCADA system, our software provides tools to enable heat treaters to do their jobs better and more efficiently."

Data provides access to many key performance indicators that can be critical to the shop floor operating efficiently, according to Thompson. "A heat-treat shop or department can easily capture 1 million data points in a day, and that data can be used to show compliance and, better yet, provide valuable information looking forward," he said. "Both maintenance and operations can really see how to create efficiencies, predict compliance, and anticipate downtime with predictive maintenance."

"Something unique to us is we only sell to the heat-treat market, and with this focus, we provide more solutions to the same customers, building our relationships, which are key in the growth of our company."

Having the ability to see the operational efficiency of the equipment and staff helps in making better decisions on capital investments, training, and maintenance, according to Thompson.

SSi develops hardware with methodical process and procedures. It focuses on a good user experience, producing a technically sound product that addresses a specific need in the industry.

"Our instrumentation and controllers are built around addressing a customer need," Thompson said. "This could be addressing an industry standard, a unique application that involves algorithms not readily available from other products, and most importantly, something that customers find valuable."

CUSTOMER SATISFACTION

But you can't have great products without treating customers right from the get go.

"We have established a worldwide footprint that gives us an opportunity to support heat treaters around the globe," Thompson said. "Our team takes a lot of pride in helping heat treaters with everyday problems. Sometimes those problems are future investments in technology to address controls or SCADA, and sometimes those questions are customers looking for support on metallurgical results they have been getting. We have a team to address the customer needs."

With thousands of furnaces and ovens using SSi products, it is

A variety of SSi products.
(Courtesy: Super Systems)

important to have a sound process in place for getting resolution, according to Thompson. SSi has a support system in place that tracks incoming support calls with an escalation process to address potentially critical issues.

"Our engineering team has a methodical approach to ensuring our systems are supportable by all our staff," he said. "With updated electrical drawings, well documented code with strict standards, we can easily support our install base both onsite and remotely."

The end goal is the ability to provide the necessary support a customer needs.

In addition to Super Systems' global footprint, Thompson is quick to point out the company's excellent worker retention. "We are proud of our team and the years of service accumulated," he said.

THE FUTURE OF SUPER SYSTEMS

From a glance at the past to an eye on the future, as Super Systems enters the next phase of what's cooking in the heat-treat industry, Thompson has a few prognostications as he looks into his crystal ball.

"Future demands for us will remain the same, innovating products to meet and exceed our customers' expectations," he said. "Automation, big data, and tighter heat-treat tolerances are all areas that we will integrate into our products. With a market place that will see changes in our future, we will continue to lead the technology trends in industry and plan on continue to work with commercial and captive heat treaters worldwide in delivering quality heat-treated products."

This article first appeared in the January 2019 issue of *Thermal Processing* magazine.

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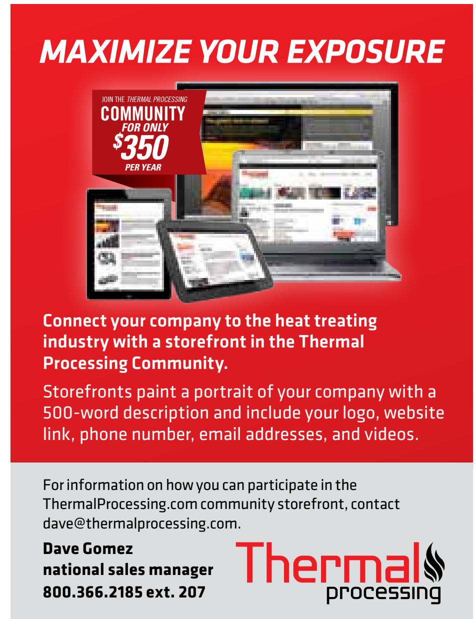

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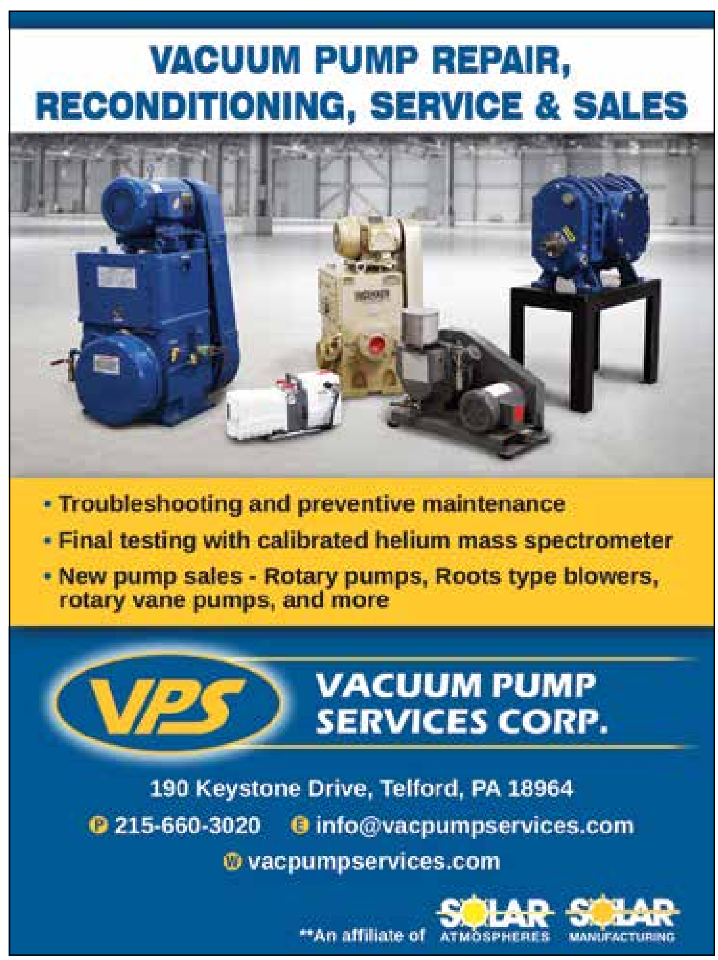

DAVID WOLFF /// REGIONAL SALES MANAGER /// NEL HYDROGEN

"What's important to users is the hydrogen generator makes hydrogen at the same rate that they're using it, eliminating hydrogen storage."

What's a typical day like for you at Nel Hydrogen?

I'm in field sales and work with customers to make sure their process needs that involve hydrogen for atmospheres are met.

Why is hydrogen important to some heat-treat processes?

Hydrogen is a reducing gas, which means that it prevents, and to some degree, reverses oxidation. Hydrogen cleans up the part surface, which is particularly important for sintering applications because it enables parts to be successfully sintered to achieve desired density.

What are some of the challenges when using hydrogen?

Hydrogen is a flammable gas, so it's got all of the challenges associated with all other flammable gases, and hydrogen also has a few characteristics that make it trickier to work with. One, hydrogen (like helium) is one of the smallest molecules. As such, hydrogen and helium are both used as leak detection agents, and what that means is that hydrogen will leak through the smallest possible opening.

Therefore, it is extremely important for users of hydrogen to constantly maintain their piping system to make sure they don't have any leaks. In fact, unlike natural gas, you can't send hydrogen through plastic tubing, because it'll go right through.

Another consideration is, unlike natural gas, hydrogen cannot be odorized, because the odorant would interfere with the chemical uses of hydrogen — such as atmospheres. So, hydrogen is odorless, and so you must use detectors to determine if you have a hydrogen leak.

A third challenge with hydrogen is that it has a very wide flammability range. For example, we think of gasoline as being highly flammable, but gasoline has a fairly narrow mixture in air that will actually burn — if the blend is too rich or too lean, the gasoline simply won't ignite. Hydrogen has the widest flammability range of any gas, so it's flammable from 4 percent to 75 percent in air, which means that if you have a leak of hydrogen, it'll almost surely burn.

Finally, hydrogen has an enormous amount of chemical energy. A cylinder of hydrogen, which holds about 250 cubic feet, has the chemical energy of 35 pounds of TNT. So, you want to be very careful about having hydrogen leak and collect.

How do Nel's on-site generators create hydrogen?

We create hydrogen by electrolyzing water. We run an electrical charge through water, and we collect the hydrogen and provide it to the customer as a pressurized, pure, dry hydrogen stream.

One of the advantages of Nel's PEM electrolysis technology is that the hydrogen is very pure, and purity is not dependent on elaborate secondary purification steps. The only processing we do to that hydrogen once it's created is we dry it. No additional purification is necessary to provide 99.9995-plus percent pure, dry, pressurized hydrogen. What's important to users is the hydrogen generator makes hydrogen at the exact same rate that they're using it.

What are the advantages of the on-site hydrogen generator?

One advantage is the ease of permitting. Because hydrogen is so flammable and has such high-energy content, local fire departments are always very leery and very prescriptive about customers' storing hydrogen. When customers use hydrogen generation, it eliminates hydrogen storage, so many customers find that it is far easier to permit a facility using hydrogen generation than it is to permit a facility using liquid or gaseous stored hydrogen.

A second advantage is that we make very pure hydrogen at the same cost as industrial-grade hydrogen. Hydrogen comes in different grades, and certain processes benefit by additional hydrogen purity. If your process benefits from increased purity, you'll save by getting near semi-grade hydrogen for the cost of industrial grade hydrogen.

Because of the characteristics of hydrogen, if your setting requires you to keep your hydrogen indoors, then you need to build a gas room, which can be very expensive. Hydrogen generation makes it unnecessary to use a gas room, because our equipment is UL-compliant and therefore can go into a normal (unclassified) space.

We generally save people money on the overall cost of supply. If they look at their facility and compliance costs, the cost of hydrogen, and the cost of rental of cylinders or tanks, then they'll save money on the total cost of ownership.

Many people doing thermal processing in metallurgy don't store hydrogen. Instead, they use dissociated ammonia. When they dissociate ammonia, they make an atmosphere, which consists of hydrogen and nitrogen. Dissociated ammonia has been a very popular atmosphere because it's inexpensive to generate. And ammonia, unlike hydrogen, generally doesn't explode, but ammonia has its own challenges to deal with because it's toxic, and it has a very distinctive and powerful odor. Ammonia is a highly regulated hazardous material. A significant part of our business is helping people replace stored ammonia used with a dissociator with generated, zero-inventory hydrogen blended with stored or generated nitrogen.

MORE INFO www.nelhydrogen.com

This first appeared in the August 2019 issue of *Thermal Processing* magazine.