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COMPANY PROFILE ///

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COMBUSTION OPTIMIZATION IN GAS BURNERS OF REVERBERATORY FURNACES DURING NICKEL-ALLOY MELTING

Burners are an essential part of a furnace, and it is necessary to optimize them based on combustion processes to find the ideal balance when mixing the fuel with the air to ensure complete combustion and, therefore, a desired temperature in the required time.

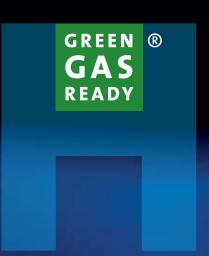




COMPANY PROFILE ///

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VOLUME 11 / NUMBER 2

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- >> 2021 was a year of awards for Seco/Warwick.
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JEFF MARSHALL

VP AND GENERAL MANAGER /// METALLURGICAL HIGH VACUUM CORP

RESOURCES ///

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International Federation for **Heat Treatment (IFHTSE)**



The international association whose primary interest is heat treatment and surface engineering shares news of its activities IFHTSE to promote collaboration

on issues affecting the industry.

Industrial Heating Equipment Association (IHEA)



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FROM THE EDITOR ///



Is it February already?

t looks like 2022 is moving at a brisk pace to match the brisk weather.

I hope you feel, as I do, that the world is continuing to move toward a normal pace once again. That should elicit a collective "sigh" from everyone.

To help push that return to normal, this month's *Thermal Processing* is packed with expert advice as well as insider knowledge and know-how from some of the best the heat-treating world has to offer.

In our Focus section, we take a deep dive with articles discussing burners and combustion as well as a look at new and exciting insulating materials being developed.

Our cover article from Dr. Neil Canter takes an in-depth look at heat-transfer fluids. In the article, Canter talks with nine key industry experts on how heat-transfer fluids perform important functions in industrial applications and how they are taking on a prominent role in electric vehicles.

On the subject of burners and combustions, experts with the Department of Automation of Technological Processes and Production in St. Petersburg, Russia, share their insights on the importance of combustion optimization in the gas burners of reverberatory furnaces during the melting of nickel alloys.

Our columnists are also offering up some solid advice as well:

- >> In Hot Seat, Scott MacKenzie talks about the sampling of quench oil for proactive maintenance.
- >> In Metal Urgency, Justin Sims looks at how a material's conduction limits the significance of convective heat transfer.
- >> And in Quality Counts, past columnist Jim Oakes, president of Super Systems Inc., returns to discuss how the advancements in technology and computing power provide the foundation for better and automated decision making in the heat-treat community.

With all that in mind, I hope you enjoy this issue of *Thermal Processing* and find it informative and timely.

And one last thing: Please remember that I'm always looking for fresh, informative articles to share with our readers. Hit me up if you're interested in having your work published.

And, as always, thanks for reading!

KENNETH CARTER, EDITOR editor@thermalprocessing.com

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UPDATE /// HEAT TREATING INDUSTRY NEWS



Tenova Pyromet designs and supplies high-capacity AC and DC furnaces and complete smelting plants for production of ferroalloys, base metals, slag cleaning, and refining. (Courtesy: Tenova)

Sibanye-Stillwater selects Tenova Pyromet for upgrade

Tenova Pyromet, a Tenova company specializing in the design and supply of submerged arc furnace technology for the metals industry, has been selected by Sibanye-Stillwater* as their technology partner for the upgrade of their largest PGM (Platinum Group Metals) smelting furnace.

Sibanye-Stillwater awarded a feasibility study in November 2020 to Tenova Pyromet to develop the upfront engineering and budget estimate for the upgrade of the crucible of their Furnace No. 1 at Marikana, North West Province, South Africa. Subsequently, in July 2021, Tenova Pyromet was awarded the contract for the detail design, supply, and construction of the furnace crucible upgrade. The detail engineering and pro-

curement phase is well under way, and the construction phase is due to start during the second quarter of 2022.

Sibanye-Stillwater's main objectives with the furnace upgrade are to further improve reliability, campaign life, and availability in the long run.

Bennie du Toit, Sibanye-Stillwater vice president smelting, said, "We selected Tenova Pyromet for the Furnace No. 1 upgrade based on their innovative technical offering as well as our positive experience with Furnace No. 2, which has been reliable and stable for almost a decade." Furnace No. 2 was designed, supplied, and constructed by Tenova Pyromet and started up in 2012.

Tenova Pyromet's innovative composite graphite-copper sidewall coolers will be employed in the upgraded furnace sidewall. The design represents the next iteration of the reliable copper plate cooler design used on Furnace No. 2 combined with Tenova Pyromet's composite graphite-copper Maxicool® high-intensity coolers, successfully in operation on another PGM smelter. Tenova developed a patent that covers the use of graphite in combination with copper cooling to prevent the sulphide corrosion of the copper cooling elements in a furnace sidewall. The use of graphite helps to protect the copper cooler from the corrosion caused by free sulphur present in the furnace sidewall adjacent to the concentrate feed layer.

"Tenova Pyromet is honored to be selected by Sibanye-Stillwater and it is a privilege to continue our relationship with their highly competent smelter team. They continually challenge us to improve our technology and products," said Hugo Joubert, Tenova Pyromet manager for base metals and copper products.

To date, Tenova Pyromet has designed and supplied eight circular PGM smelting furnaces in South Africa.

Tenova Pyromet is a leading company in the design and supply of high-capacity AC and DC furnaces and complete smelting plants for production of ferroalloys, base metals, slag cleaning, and refining. Tenova Pyromet also designs and supplies equipment for material handling and pretreatment; alloy conversion and refining; granulation of metal, matte, and slag; furnace off-gas fume collection and treatment; and treatment of hazardous dusts and waste.

MORE INFO www.tenova.com

Snam, Tenova unite to decarbonize metals industry

Snam, Europe's largest energy infrastructure operator, and Tenova, leading developer and provider of sustainable solutions for the green transition of the metals industry, committed to conducting joint strategic studies and market analysis to implement specific infrastructure and metals production sys-



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.

tems by using green hydrogen in an agreement to foster the decarbonization of the metals sector in Italy and abroad.

The aim is to bring integrated, turnkey commercial solutions tested in industrial plants to implement a substantial reduction of ${\rm CO_2}$ and ${\rm NO_x}$ emissions in the metals production process — from melting to processing of half-processed products.

"Through this agreement, we further develop our network of partners and projects to introduce green hydrogen into the relevant productive processes of the metals industry. Hydrogen is essential to cut emissions from the production of steel and other metals, as well as from all hard-to-abate sectors such as cement, ceramic, chemistry, and refining. Snam is willing to contribute through its technologies and know-how by enabling, as fast as possible, the hydrogen transition of such crucial commodity chains for the Italian economy," said Cosma Panzacchi, EVP Hydrogen at Snam.

Snam will provide its expertise in hydrogen technologies as well as transport, whereas Tenova will contribute through its knowhow in this sector, more specifically in combustion systems for reheating and heating treatment, and in electric arc furnaces. The collaboration between the two companies



The two companies will work together over the next three years to design integrated solutions based on the use of green hydrogen. (Courtesy: Tenova)

will develop through specific tests in the laboratory under construction at Tenova's headquarters (in Castellanza, Varese), and through installations and production tests on industrial sites. "Everyone talks about green hydrogen, but the reality is that its supply and use are still limited, and, at the same time, pressures to mitigate climate change are getting stronger. For this reason, we are





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UPDATE /// HEAT TREATING INDUSTRY NEWS

developing a ready-to-use solution for our customers, directly at their production sites. The expertise of Snam and Tenova is complementary, and together we are ready to face the challenge of decarbonization, on which Tenova has been working for years thanks to solutions that make us the ideal technological partners to improve environmental performances without compromising the economic ones," said Roberto Pancaldi, Tenova CEO.

Tenova's combustion systems, a key part of the agreement with Snam, represent an innovative solution and unique on the market. First, they enable CO_2 emissions reduction in a scalable and flexible fashion — once installed, these systems can work through a blend of natural gas and hydrogen in variable percentages, up to 100 percent of hydrogen, whereby maintaining emissions well below the most restrictive limits. Furthermore, they can be integrated with advanced 4.0 technologies, offering significant advantages in terms of management and maintenance, thanks to Tenova's digital infrastructure.

Through its know-how on hydrogen technologies and transportation, Snam will be able to secure an optimized integration across the entire value chain, thus meeting this industry's needs.

MORE INFO www.snam.it www.tenova.com

Solar Atmospheres adds furnace to reclaim titanium

Solar Atmospheres Souderton, Pennsylvania, facility commissioned a new high-production vacuum furnace, doubling hydriding and de-hydriding capacity in the reclamation process of high-value titanium and tantalum materials.

For decades, Solar Atmospheres has been a globally-recognized leader and innovator in the process of reclaiming titanium and tantalum materials through vacuum heattreatment solutions.

The installation incorporates Solar Manufacturing's latest and most advanced vacuum furnace technology, aimed at safety and efficiency. The qualified working zone



The vacuum furnace installation incorporates Solar Manufacturing's latest and most advanced vacuum furnace technology, aimed at safety and efficiency. (Courtesy: Solar Atmospheres)

is 48" x 48" x 72" with a weight capacity of up to 7,500 pounds per batch.

MORE INFO www.solaratm.com

2021 was a year of awards for Seco/Warwick

In 2021, Seco/Warwick — a global leader of metal heat-treatment technology – received six awards: the titles "Reliable Employer of the Year," "Innovation Leader," and "Business Leader;" an international award for the Best Economic Expansion on the North-American Market as well as "Safety Laurel," and the title "Employer – Creator of Safe Jobs."

The awards reflect the values fostered by Seco/Warwick: safety and stability, innovation, reliability, partnership, and credibility.

Over the decades, Seco/Warwick received several dozen awards, distinguishing them among other companies by constantly reaching for more, developing, and striving to achieve their goals. The companies of the Group develop steadily and sustainably, regularly improving their results.

"2021 was unique for Seco/Warwick. It was the 30th anniversary of the Polish business, we organized the largest global online event for the metal heat-treatment industry, and the number of orders and deliveries grew significantly. But during that demanding time of high activity, we stayed true to our values. These include innovation, partnership, safety, stability, reliability, and credibility. Our shared efforts were reflected by the multitude of awards which also prove that these values are rooted in our DNA," said S awomir Wo niak, CEO of Seco/Warwick Group.

"The idea of innovation is represented by the Innovation Leader award which we have received for the fourth time. Our reliability was recognized with the 'Business Leader' prize, 'Partnership' is confirmed with the award for the Best Economic Expansion on the North American Market, whereas the 'Reliable Employer' title underlines our credibility. On top of that, we received two awards for the observance of strict OHS standards and care for the employees - 'Safety Laurel' and 'Employer - Creator of Safe Jobs' title. These awards testify to our values of safety and stability. We are extremely glad to have been recognized in all five areas that are the key to our development and the development of our partners," said Katarzyna Sawka, Marketing VP, Seco/Warwick Group.

The values important for Seco/Warwick are universal. Innovation means action leading to the development of new or better products, processes, technologies, or organiza-

tions. In Seco/Warwick, innovation is visible in its approach, thinking, and performance, anywhere in the world, at any workplace and in any operation.

Partnership for the Group means that it honors the mutual obligations of the parties, founded on respect and responsibility, where feedback is highly important. This enables the company to ensure the safety and stability of reliable products delivered as well as maintaining perfect and safe working conditions. Reliability in turn is the key feature when metal heat treatment comes to mind. It is understood as not only the trouble-free operation of equipment, but also as the reliability of a team that always uses all its capabilities. This allows Seco/Warwick to be a reliable and credible company in any business relationship.

Last year, for the second time, Seco/Warwick was awarded the title "Reliable Employer of the Year." This title goes to the best employers in Poland. For this company from Świebodzin, the key to success lies in



In 2021, Seco/Warwick – a global leader of metal heat-treatment technology – received six awards. (Courtesy: Seco/Warwick)

a well-formulated and consistently implemented development strategy.

In August, at one of the most important events for the USA-Central and Eastern Europe economic cooperation "USA-Central Eastern Europe Investment Summit & Awards," Sławomir Woźniak, CEO of the Seco/Warwick Group received the award in the category for "Most Successful Expansion."

"The award for the Most Successful





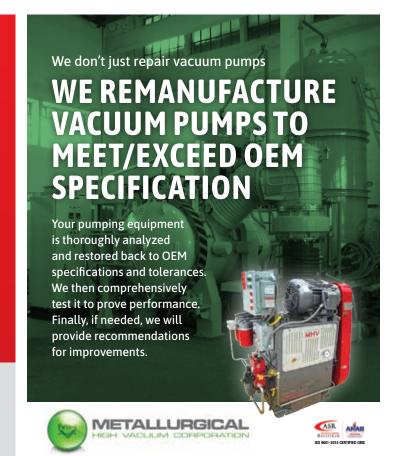
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UPDATE /// HEAT TREATING INDUSTRY NEWS

A Solar Atmospheres retrofitted vacuum furnace has been in production for over a month and has produced multiple high temperature sintering cycles. (Courtesy: Solar Atmospheres of Western PA)



Expansion at the 'USA-Central Eastern Europe Investment Summit & Awards' makes us incredibly happy. It shows that we have chosen the right path to grow," said Woźniak. "The U.S. market is a key sales area, hence the presence of our three subsidiaries, SVT, SWC, and Retech. We have set our sights on this region in particular, and our furnaces operate in major U.S. companies in such strategic branches as defense, aviation, and automotive. Our current order book indicates that the share in the North American market will grow significantly this year, and will reach over 30 percent in subsequent periods."

Seco/Warwick is a company with a hundred years of history renowned for implementing innovative products that have revolutionized the metal heat-treatment industry. The company holds more than 60 patents which allow it to propose breakthrough solutions to its worldwide customers. From the very beginning, the philosophy of the company was founded on the development of products and technologies to meet the needs and expectations of customers or, to be more precise, to define and create together technological game changers for the heat treatment industry. However, this could not have been possible without the engagement of its employees. Andrzej Zawistowski, one of the founders of the company, said, "Seco/ Warwick owes their strength to the people."

Last year, Seco/Warwick received the

Business Leader title yet again. This is a significant local award that proves that the company is connected with its origins, its roots, credibility, and identity. "Business Leader of Lubuskie" is a prestigious contest in the Lubuskie region. The awards chapter recognizes the best companies in Western Poland who conduct their business in a transparent and honest manner and their success is a regional trademark.

The last two awards — "Safety Laurel" and "Employer — Creator of Safe Jobs" title — are the effect of the great job done by the company's OHS team. Procedural awareness and care for employees — the most important element of a company as a whole — are the grounds for running a production business.

"We ended the year with six titles which perfectly reflect the Group's DNA. What is particularly important for us is that we can say that these are not just empty words, they are really the pillars of Seco/Warwick operations. It is nice to receive honorable titles and awards, but this is not really our goal. We will continue the development of all the organizations within the Group. Development that is stable, safe, and credible. Development which puts partnership first — with our employees, suppliers, and customers. Finally, development that makes it possible to create reliable and innovative equipment," Sawka said.

MORE INFO www.secowarwick.com

Solar results with new sintering furnace are impressive

Solar Atmospheres of Western PA has found good results with a retrofitted vacuum furnace for use in a new metal injection molding (MIM) and additive manufacturing (AM) binder removal technology application.

In 2021, the company announced the retrofit of the vacuum furnace. The goal was to build a vacuum sintering furnace with a new innovative hot zone and pumping technology that would minimize and target the deposit of detrimental binders evaporating out of MIM and AM parts. The furnace has now been in production for over a month and has produced multiple high temperature sintering cycles and the results are impressive.

The hot zone, after repeated 2,400°F sintering cycles, remains immaculately clean. The problematic binders coalesced exactly where they were targeted to consolidate — within a separate heated pumping port while keeping the primary pump and booster uncontaminated. Most importantly, the customer reported that their sintered parts processed in this new furnace never looked better. The MIM parts were extremely bright and met their critical density and

dimensional requirements.

The anticipated maintenance savings on this dedicated furnace versus processing sintering and AM work with binders in a traditional vacuum furnace will be considerable. Processing this job in a conventional vacuum furnace required a scheduled monthly shutdown. Solar's maintenance team had to extract the hot zone, replace the ceramics, clean or replace the power feed through terminals, scrape the cold walls, clean the diffusion pumps, and scour all the pumping system pipes. The added labor and material costs coupled with the lost production time and degradation on the life of the hot zone cost the company more than \$180,000 per year. The projected maintenance costs on this newly designed sintering furnace will be \$10,000 per year.

Bob Hill, president of Solar Atmospheres of Western PA, said, "Knowing the effects of what MIM and certain AM processing had done to our equipment in the past, Bill Jones and the engineers at Solar Manufacturing developed an innovative solution for us. Having this newly designed vacuum furnace will be an asset for our future in MIM and AM processing."

MORE INFO www.solaratm.com

International PM launches conference programs

The North American conference on powder metallurgy (PM) and particulate materials has launched its 2022 conference program for PowderMet2022: International Conference on Powder Metallurgy & Particulate Materials. It will be co-located with AMPM2022: Additive Manufacturing with Powder Metallurgy Conference. The conference features more than 200 technical presentations from worldwide indus-

try experts presenting on PM, particulate materials, and metal additive manufacturing (AM) at the Hyatt Regency in Portland, Oregon, June 12–15, 2022.

In addition to PowderMet's high-level technical programming, the conference features the PM industry's largest tradeshow devoted exclusively to powder metallurgy, particulate materials, and metal additive manufacturing. With more than 100 booths, this international marketplace will present leading companies featuring the latest PM and metal AM equipment, powders, products, and services. Industry networking events such as the popular PM Evening Alehouse provide the best opportunity to meet industry suppliers all together in one place.

PowderMet2022 and AMPM2022 are sponsored by the Metal Powder Industries Federation and APMI International.

MORE INFO www.powdermet2022.org www.ampm2022.org

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INTERNATIONAL FEDERATION OF HEAT TREATMENT AND SURFACE ENGINEERING



A letter from IFHTSE's outgoing president



The 11th International Conference on Residual Stresses, just one of the many IFHTSE conferences in 2022, will be held in Nancy, France, in March.

Dear Colleagues and Friends:

Now 2021 has come to its end, it is time for a look back on the past two years, which were my time as IFHTSE president. Although



they were heavily impacted by the Corona pandemic, it has been a pleasure to see in this second year 2021 that some conferences have still been able to take place thanks to digital solutions. Others had to be re-planned and moved forward in time.

Despite the new possibilities provided by the digital format, my hope is that 2022 will be the year when we all can travel and meet in person again. Please have a look at the pro-

gram for forthcoming conferences. We have a lot to look forward to.

I thank all IFHTSE officials and friends for their support during my presidency and wish the next IFHTSE President, Prof. Masahiro Okumiya, a successful work in a more prosperous environment.

Yours sincerely,



Eva TroellPresident of IFHTSE (2020–2021)

UPCOMING EVENTS

ICRS 11 – 11th International Conference on Residual Stresses March 27–30 | Nancy, France

The 11th International Conference on Residual Stresses is intended as a continuation of the successful series initiated in Garmisch-Partenkirchen (Germany, 1986) and continued in Nancy (France, 1988), Tokushima (Japan, 1991), Baltimore, Maryland (U.S., 1994), Linkoping (Sweden, 1997), Oxford (U.K., 2000), Xi'an (China, 2004), Denver, Colorado (U.S., 2008), Garmisch-Partenkirchen (Germany, 2012), and Sydney (Australia, 2016).

The conference provides a key forum for scientists, students, and engineers interested in the prediction, evaluation, control, and application of residual stresses. Equal emphasis is given to the measurement, modeling, and utilization of residual stress/strain data.

Details at sf2m.fr/events/icrs-11.

POSTER AWARDS TO BE GIVEN AT 27TH IFHTSE CONGRESS, SALZBURG

An excellent opportunity for authors of posters to have their work acknowledged: Poster Awards will be given at the 27th IFHTSE Congress September 5-8, 2022, in Salzburg, Austria. These Poster Awards are sponsored by Burgdorf KG in Stuttgart, Germany and

Fluxtrol, Inc., in Auburn Hills, Michigan, U.S.

These awards are open to authors of all ages. Posters are a valued communication form of their own and equally important as oral presentations.

Burgdorf (www.bongroup.de/en) is a manufacturer of products for steel hardening and quenching processes, and Fluxtrol (fluxtrol. com) provides induction heating solutions using proprietary magnetic materials, scientific knowledge, and engineering experience. Fluxtrol has been an IFHTSE member since 2018.

SPOTLIGHT ON MEMBERS

IFHTSE is a federation of organizations not individuals. There are three groups of members: scientific or technical societies and associations; universities and registered research institutes; and companies. In this segment, we will highlight our members.



Chinese Heat Treatment Society

The Chinese Heat Treatment Society was established October 25, 1963, and became a member of the International Federation for Heat Treatment and Surface Engineering (IFHTSE) in 1981. It is a national academic organization of heat-treatment science and technology workers under the leadership of the China Association for Science and Technology and the China Mechanical Engineering Society with more than 400 group members and nearly 1,000 individual members.

CHTS publishes several well respected heat treating journals including Jinshu Rechuli (Heat Treatment of Metals) and Journal of Materials Heat Treatment.

IFHTSE 2022 EVENTS

MARCH 27-30, 2022

ICRS 11 - 11th International Conference on Residual Stresses

Nancy, France | sf2m.fr/events/icrs-11

APRIL 25-27, 2022

12th Tooling Conference & Exhibition (Tooling 2022)

Örebro, Sweden I www.tooling2022.org

MAY 11-13, 2022

International Bosphorus Heat Treatment Symposium

Milan, Italy I www.sct-2020.com

JUNE 19-23, 2022

6th International Conference on Steels in Cars and Trucks

Salzburg, Austria I www.sct-2020.com

SEPTEMBER 5-8, 2022

27th IFHTSE Congress / European Conference on Heat Treatment

Salzburg, Austria I www.ifhtseecht2022.org

OCTOBER 10-14, 2022

Advances in Materials and Processing Technologies

Portorož, Slovenia I www.ampt2022.org

NOVEMBER 2-4, 2022

HTS – 14th International Exhibition and Conference on Heat treatment

Mumbai, India I www.htsindiaexpo.com

APRIL 21-24, 2023

5th International Conference on Heat Treatment and Surface Engineering of Tools and Dies

Liangzhu Dream Town, Hangzhou, China

NOVEMBER 13-16, 2023

28th IFHTSE Congress

Yokohama, Japan

For details on IFHTSE events, go to www.ifhtse.org/events



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INDUSTRIAL HEATING **EQUIPMENT ASSOCIATION**

93 years of helping heat treaters worldwide



Training seminars are taught by industry experts.

t's hard to believe that an industry organization has been around for 93 years, but that's how long the Industrial Heating Equipment Association has been serving the industry. While the association has certainly changed throughout the years, it still serves as a valuable connection between suppliers, customers, and government agencies. Here's a little bit more on IHEA and the important mission it provides.

WHO IS IHEA?

Established in 1929, IHEA was started by a small group of industrial furnace manufacturers. Over the years, IHEA has grown to include an induction division and the infrared equipment division along with the original combustion division.

WHAT IS IHEA'S MISSION?

IHEA drives member success by providing the knowledge base and authoritative voice for industrial process heating worldwide. With our vast amount of expertise in all things related to process heating, IHEA members keep the industry informed and advancing. We

believe by bringing together key executives who share our sense of responsibility, we improve our industry, and we enjoy being the catalyst for that improvement.

WHY ARE ASSOCIATIONS IMPORTANT?

Associations foster a positive environment by which we educate and train those in our industry, continuously helping members and the industry improve their manufacturing operations related to thermal processing. Involvement in an industry association gives members a network for idea exchange, a voice in the development of industry standards both in the U.S. and globally, and a chance to both educate and be educated on a wide variety of thermal processing technologies.

WHAT IS IHEA'S STRUCTURE?

We have a corporate membership structure, meaning that the company becomes a member and everyone within the company is entitled to membership benefits. For many years, IHEA's membership was limited to industry suppliers. We launched an "end-user"



IHEA committees & divisions meet several times each year.

membership category; the great thing about this category is that everyone at a company can take advantage of member discounts on IHEA's training activities. The cost savings for sending two or three individuals from a company to IHEA seminars pays for the cost of membership. Dues vary based upon your membership category.

IHEA members are welcome and encouraged to participate on a committee or in a division. The association's committee and divisional structure ensures that future, as well as immediate, concerns of members and others in the industry will receive attention by planning projects and establishing priorities based on changes and development as they emerge in the industry. IHEA has the following committees and divisions: Induction Division, Infrared Equipment Division (RED), Safety Standards and Codes Committee, Government Relations Committee, Education Committee, and Marketing Communication and Membership Committee.

WHAT TYPES OF PROGRAMS DOES IHEA OFFER?

IHEA offers a variety of training seminars and online learning courses as well as a plethora of resources that can be found on the website. Training seminars covering combustion, infrared, and safety standards and codes are offered yearly. IHEA's fall seminars also typically include a tabletop exhibition that allows seminar attendees the opportunity to visit and meet with industry suppliers alongside our seminars.

IHEA's online training courses are offered several times each year. The Fundamentals of Industrial Process Heating is normally offered each spring and fall. The Advanced Industrial Process Heating course is currently under revision, with a planned launch in the fall of 2022.

Finally, IHEA's Annual Meeting, held each spring, gives members a chance to connect in an informal atmosphere that includes high quality presentations, social activities, IHEA committee meetings, and our annual President's Reception.

WHAT ELSE DOES IHEA DO?

IHEA is also active in government relations to ensure our members are informed about government issues that affect our industry. Over the years, we've worked closely with the Department of Energy (DOE), Environmental Protection Agency (EPA), and the National Fire Protection Agency (NFPA). Involvement with these organizations that affect our industry is vital to ensure our member companies' voices are represented.

IHEA also maintains a close relationship with the European Committee of Industrial Furnace & Heating Equipment Associations (CECOF) and the Japan Industrial Furnace Manufacturers Association



Networking at IHEA events is key to the success of the industry.

(JIFMA). Additionally, IHEA has coordinated a resource center at two previous ThermProcess shows in Dusseldorf, Germany, to support members wishing to exhibit at the show.

If you are not a member, consider joining as we continue to serve our industry. For more information on IHEA, visit www.ihea.org.

IHEA 2022 CALENDAR OF EVENTS

FEBRUARY 15-16

Powder Coating & Curing Processes Seminar

The day and a half Introduction to Powder Coating & Curing Processes Seminar will include classroom instruction and hands-on lab demonstrations.

Alabama Power Technology Applications Center | Calera, Alabama Registration Fee: IHEA members: \$325 / Non-members: \$425

MARCH 14-17

Electrification 2022 International Conference & Exposition

This event will share what's new in the electrification of buildings, vehicles and industry. Spend time with your colleagues and explore efficient, equitable solutions for a net-zero economy.

Charlotte Convention Center | Charlotte, North Carolina

MARCH 24-28

IHEA 2022 Annual Meeting

IHEA's 92nd Annual Meeting will be held on Royal Caribbean's
Brilliance of the Seas, sailing from Tampa, Florida. In addition to
IHEA's committee meetings, business presentations and networking
opportunities, the itinerary includes a day to enjoy Costa Maya, Mexico.

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

INDUSTRIAL HEATING EQUIPMENT ASSOCIATION

P.O. Box 679 I Independence, KY 41051 859-356-1575 I www.ihea.org



METAL URGENCY ///

JUSTIN SIMS



MECHANICAL ENGINEER /// DANTE SOLUTIONS

A material's conduction limits the significance of convective heat transfer.

Heat transfer: Convection's reach

any years ago, as a mechanical engineering undergraduate student, an analogy was offered to help explain the interplay between convection and conduction in heat transfer. The analogy goes as follows: The solid material can be thought of as an island, surrounded by an ocean of fluid. On this island, there are tired tourists trying to leave the island, much like thermal energy trying to escape a hot part. To accomplish the task of transporting tourists off the island, two modes of transportation are required. First, buses are required to transport the tourists from all over the island to the coasts. The buses can be thought of as conduction. Ferries are then needed to transport the tourists from the island, back to the mainland. The ferries can be thought of as convection.

Generally speaking, a material's bus system is set, and is described by its thermal conductivity. And like any good coordinator, materials understand that it is beneficial to provide more buses during busy times; thermal conductivity is increased in response to a red-hot part full of tired and cranky tourists trying to leave the island. However, the number and size of ferries can vary widely from tiny, gas-quenching ferries to massive, water-quenching ferries. This variation means coasts can become packed with angry tourists waiting to get on one of the tiny ferries provided by low convection or can create packed buses struggling to keep up with the demands of the large ferries provided by high convection. The limit of a material's bus system is an important concept to understand in light of how critical cooling rates are to a material's properties and ultimate service performance.

Using simulation to help visualize the limits of conduction, a steel and aluminum cylinder were quenched from their respective solutionizing temperatures, 925° C and 525° C, to room temperature. Aluminum has, on average, a thermal conductivity a

full magnitude greater than steel; meaning aluminum has more seats on its buses. The convection coefficient, commonly referred to as the heat transfer coefficient (HTC), was then varied over values commonly experienced in the thermal processing industry and the cooling behavior at various depths below the surface evaluated. The difference between the time-temperature histories at different depths, induced by a variation in the HTC, is of significance. There will be a depth and HTC combination that will be the cooling limit

of the material, where a faster HTC will not cool that depth any faster.

For reference and in general, average HTCs of 0.5 kW/m2K are common for high pressure gas quenching, 5 kW/m2K for oil quenching, 10 kW/m2K for water quenching, and 20 kW/m2K for intensive water quenching. An HTC of 30 kW/m2K was also evaluated as an additional data point, though is outside the range of common quenching processes.

At a depth of 1 mm below the surface, the cooling behavior of steel and aluminum are similar, as shown in Figures 1A and 1B, with an approximately 100° C difference at any given time between 450° C and 250° C for the 5 and 10 kW/m2K HTC values. These two HTC values, 5 and 10 kW/m2K, are significant as they represent the aver-

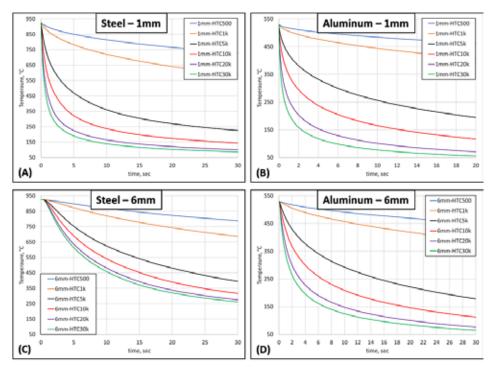


Figure 1A-D: Time-temperature history for a range of HTCs for A) steel at 1 mm depth, B) aluminum at 1 mm depth, C) steel at 6 mm depth, and D) aluminum at 6 mm depth.

Understanding the relationship between conduction and convection when determining quenching media for a given material and cross-sectional thickness is imperative in ensuring the specified properties are met.

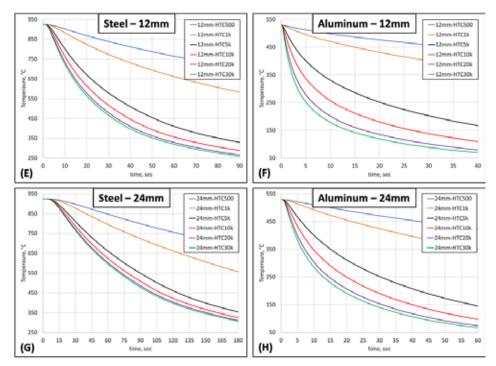


Figure 1E-H: Time-temperature history for a range of HTCs for E) steel at 12 mm depth, F) aluminum at 12 mm depth, G) steel at 24 mm depth, and H) aluminum at 24 mm depth.

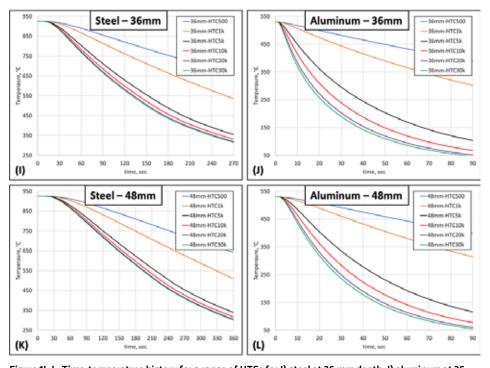


Figure 11-L: Time-temperature history for a range of HTCs for I) steel at 36 mm depth, J) aluminum at 36 mm depth, K) steel at 48 mm depth, and L) aluminum at 48 mm depth.

age values for oil and water quenching, respectively, and generally span the range of all common liquid quenchants. At 1 mm depth, convection is the dominating transport mode, although there is little difference between the two highest HTCs evaluated.

At 6 mm depth, there is also little difference between steel and aluminum, as shown in Figures 1C and 1D. While the temperature differences have shifted to slightly longer times when compared to the cooling behavior at 1 mm, the temperature differences during cooling at 6 mm are approximately the same as 1 mm for both materials. At 6 mm depth, convection is still the dominating phenomenon driving heat transfer.

Traveling deeper into the part, down to 12 mm, differences between the two materials, and between shallower depths in the same material, begin to materialize, as shown in Figures 1E and 1F. The difference between 6 mm and 12 mm is more pronounced in the steel than in the aluminum, with an approximately 50 percent tightening of the temperature difference between 5 and 10 kW/m2K for the steel part and only 25 percent for the aluminum. Conduction's role becomes even clearer at a depth of 24 mm, as shown in Figures 1G and 1H. Here, steel has a noticeable difference in the cooling behavior provided by various HTCs, compared to 12 mm. However, the difference for aluminum is much less. It is also worth noting that for steel at depths greater than 24 mm, there is no significant difference between 10 and 20 kW/ m2K. This means steel's buses are running at full capacity at this depth and using alternative means to increase the HTC greater than 10 kW/m2K are futile, as the cooling rate will not increase at this depth with an increased HTC. For aluminum, there is still a significant difference in the cooling behavior using an HTC of 10 or 20 kW/m2K at a depth of 24 mm.

Reaching 36 mm and 48 mm below the surface, Figures 1I – 1L show that any HTC greater than 5 kW/m2K will not provide any increase to the cooling rate of steel deeper than 36 mm below the surface. The difference provided by the two slowest HTCs and the faster HTCs is also beginning to significantly diminish at a depth of 48 mm for steel. Aluminum, on the other hand, still provides enough thermal energy transportation to continually supply the ferries with new tourists trying to leave the island, as shown in Figure 1L. Even HTC values of 10 and 20 kW/m2K provide a cooling difference at a depth of 48 mm for aluminum.

In conclusion, understanding the relationship between conduction and convection when determining quenching media for a given material and cross-sectional thickness is imperative in ensuring the specified properties are met. Simulation can be a powerful tool to quickly evaluate the effect of

a quenching media on providing the necessary cooling power at a given depth for a specific material.

ABOUT THE AUTHOR

Justin Sims is a mechanical engineer with Dante Solutions, where he is an analyst of steel heat-treat processes and an expert modeler of quench hardening processes using Dante software. Project work includes development and execution of carburization and quench hardening simulations of steel components and analysis of heat-treat racks and fixtures. He has a mechanical engineering degree from Cleveland State University.

///// D. SCOTT MACKENZIE, PH.D., FASM

 $/\!\!/$ SENIOR RESEARCH SCIENTIST-METALLURGY $//\!/$ QUAKER HOUGHTON INC.

Paying attention to detail, from gathering the sample to packaging it properly, is the key to getting an accurately processed evaluation from the lab.

Sampling of quench oil for proactive maintenance

n this column, I will discuss the sampling of quench oil for quarterly checks as required by many internal and external auditing agencies (CQI-9, NADCAP, etc.).

Many auditing agencies require that a quenchant be checked quarterly for suitability of use. These tests are shown in Table 1.

It is critical that these parameters be determined accurately to avoid safety issues, or to avoid work piece soft spots or cracking. The oil should be checked for staining potential and that the heat extraction rate is within specification. Water content should be measured to avoid potentially hazardous fires or cracking of parts. The first step is to make sure the sample is representative of the quench oil, and that a sample is taken properly.

SAMPLING OF QUENCHANT

Quench oil samples should be taken directly from the quench tank in open system, for instance, in continuous furnaces, or open quench tanks. It is important that the agitation system be turned on prior to taking the sample — preferably for one hour or more to allow for mixing of all contaminants and water. If possible, samples should be taken near the bottom of the quench tank. This can be accomplished using a long ladle or by taking the sample from the agitation line, if it pulls quench oil from the bottom. Samples should be taken before the filtration system to obtain a true representative sample of the oil.

In integral quench furnaces, the situation is more difficult. It is nearly impossible to pull a sample directly from the quench tank because of the closed outer door. If the outer door is opened, then the flame curtain is actuated, and sampling is hazardous. If the flame curtain is shut off, then there is the risk that the flame curtain may not be turned back on — causing an explosion hazard. Because of this, the only real way of obtaining a proper sample is from the lines used for filtration or the use of a petcock located on the quench tank heat exchanger line.

The sample container should be clean and dry, with no moisture present. It should also be appropriate for the temperature of the oil. The use of plastic containers for hot mar-tempering oil is inviting

disaster. The use of new, unused solvent cans is preferred. These cans are easily sealed and capable of withstanding the temperatures of quench oils. These solvent cans are also sturdy for shipping. They are readily available at most hardware or paint stores. Make sure that a label can be affixed to the can, with the furnace designation and date sample taken (Figure 1). Ambiguous labels are not acceptable. With no customer or system information given, it is difficult to know the details when several hundred samples arrive per week (Figure 2).

Test	ASTM Test Method
Water Content	D 45
Flashpoint (COC)	D 92
Precipitation Number	D 91
Viscosity	D 445
Total Acid Number	D 664
GMQS	D 3520
Cooling Curve	D 6200

Table 1: Typical quarterly tests required.

	r
City/Stat	te
Product .	
Date Tak	en
System N	lo
□ F	Microbiological Only Iuid Analysis Only Other
	Quaker Houghton.
	QUAKER HOUGHTON

Figure 1: Typical label used for samples cans.

For routine maintenance checks (water content, viscosity, precipitation number, total acid number, etc.), the use of pint cans is acceptable. If cooling curves or GMQS is to be determined, then one-gallon

or half-gallon cans are recommended. The label or accompanying paperwork should indicate a return address and name. A contact phone number is recommended.

Once the sample has been taken, typically a half-gallon if cooling curves are also going to be measured, it must be capped or sealed immediately. While it is convenient to allow the oil to cool with the lid off, this will cause false positives for moisture — especially if mar-tempering oils are used. This is because the cooling oil can absorb moisture from the air. This is particularly a prob-



Figure 2: An improper sample label.





Figure 3: Two different types of lid locks.



Figure 4: A poorly packed sample as it arrived for testing. The carrier provided the bag because the package contents spilled during shipment. No lid locks were provided.

The oil should be checked for staining potential and that the heat extraction rate is within specification. Water content should be measured to avoid potentially hazardous fires or cracking of parts.

lem in hot, humid locations such as the South and Midwest in the summer, or on rainy days when the relative humidity is high. Once capped immediately after the sample has been taken, the container can be allowed to cool in any fashion. Once cool, the sample is ready for shipping to the oil supplier for testing, or submittal to the laboratory for water, viscosity, and other necessary testing.

Once the cap has been placed on the can, it is important that the cap be prevented from coming off during shipment. Electrical tape around the cap and solvent can is usually adequate. For half-gallon and gallon cans the lid should be secured using either can lid locks

or rings to properly secure the lid (Figure 3).

Once the sample has been properly sealed, and the cap or lid firmly secured, it should then be placed in a sealable plastic bag. Once the bag is sealed, the sample can and bag are placed in the container for shipment. Surround the samples with a packing material to minimize their movement in the box during shipping and handling. Use fillers like crumpled newspapers, foam "peanuts," or bubble wrap. Absorbent materials such as rags or starch "peanuts" work best. Make sure there is no open air-space in the box that would allow the samples to shift or bounce during shipment. Improper packing can result in a jumbled mess upon arrival (Figure 4).

Samples sent with hazardous classifications must only be shipped using a certified DOT shipper (FedEx or UPS). It is always a good idea to enclose the Safety Data Sheet for the product in the package, if the package becomes compromised and starts to

leak. This way the shipper can identify any hazards and perform any clean-up of a spill.

CONCLUSIONS

In this article, we have discussed the proper methods of taking a quench oil sample and preparing it for shipment. Proper packaging can prevent loss of the sample during shipment and prevent leaks and spills. This ensures that the sample arrives on time and that the quenchant supplier's lab can properly process the samples. Samples can then be processed in a timely fashion, without headache.

As always, should you have any comments or questions regarding this or any other article, or have suggestions for further columns, please contact the editor or myself. \lozenge

ABOUT THE AUTHOR

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

QUALITY COUNTS ///



Advancements in technology and computing power provide the foundation for better and automated decision making as a path forward to improved automation and IIoT growth.

Industrial automation and labor in heat treating

here is a changing landscape on two fronts in the thermal processing market. Without a doubt, there are technological opportunities that companies can take advantage of for quality, productivity, and financial gains. In addition, the labor market has changed due to a large part of the experienced workforce retiring and a lack of willing and knowledgeable workers to step in. Of course, this is one of many changes taking shape in the thermal markets today, but let's talk about how these impact the quality of thermal processing.

DATA

The Industrial Internet of Things (IIoT) is certainly not new and has been discussed often when it comes to manufacturing. The foundation of the IIoT is data—data derived from smart devices and sensors. What this means for businesses is the opportunity to use informa-

tion to refine and develop more efficient processes to achieve the desired metallurgical results. Process refinement has always been built into manufacturing processes through a focus on continuous improvement through process feedback. In many cases, this is done through studies and evaluation of the existing process and specific to heat treating the metallurgical results.

Technology is creating an opportunity to take the improvement one step further. Automated controls and digital data have been available for many years, putting more and more new information in the hands of systems and people to perform more efficiently, meet industry specifications, and deliver quality. Sensor and control technology provide insight into equipment health and operation costs - and with current costs and readily available technology, these are all within reach for implementing on existing thermal-processing equipment. The additional sensors tied into the right control system can deliver the proper atmosphere, temperature, and precise time that is just right for the metallurgy desired. The IIoT, or Manufacturing 4.0, are all about data and cre-

ating a view into operations, looking at people and equipment with an opportunity to plan and anticipate.

Most heat treaters today have electronic information readily available for validation of the thermal treatment performed on the parts they are running. What is missing is the ability to provide a centralized view with specific data for the person evaluating that slice of information, which is relevant to their contribution of the manufacturing/heat-treating process. With this shared approach, a synchronized operation can be achieved, creating understanding across job responsibilities and the ability to squeeze out more efficiencies.

PEOPLE

There are two pieces to the labor puzzle as I see it. The first is what we are battling with an aging work force, experience, and headwinds from the pandemic. The second addresses the changing in technology and how to maximize the tools that we have or can have in the future.

The implementation of continuous improvement should constantly involve evaluating areas in the business where quality and efficiency can be increased through change. In some cases, this is



The automation and technology bring a new challenge to the mix when it comes to labor. Yes, we are battling a lack of work force on the manufacturing floor using the technology, but we are also introducing the need for a skillset that might not be in place.

through automation. For years, industrial automation has been introduced into manufacturing to combat workforce challenges and increase throughput. Very large manufacturing operations have used automation and robotics because they can justify the capital for these projects. Projects on a smaller scale, both from a capital and scope standpoint, are being rolled out to smaller companies because they

are within reach to implement and there is flexibility in their use. No longer do you need millions of dollars for automation and years of a specific program to justify the investment.

The automation and technology bring a new challenge to the mix when it comes to labor. Yes, we are battling a lack of work force on the manufacturing floor using the technology, but we are also introducing the need for a skillset that might not be in place. Using the earlier topic of data, most compa-

nies have so much of it they don't know how to take advantage of it all. There are hundreds of thousands to millions of data points being logged in a commercial or captive heat-treat operation on a single day. There is a multitude of benefits hidden in the millions of data points, but only a small subset of that data is ever being used.

If we start to look deep into the data and explore the predictive nature in the information that is available, we can see where maintenance, scheduling/planning, and process setup could all benefit from data mining and even process learning. This not only requires infrastructure such as computers and networking, but software tools to learn and create meaningful information. To fully benefit from technological advancements and investments, some additional resources or partners will be necessary to support the industry in the area of Information Technology and Data Analytics.

Along the same lines of technical resources for data, there is also demand for resources with the ability to address automation and more sophisticated controls and sensors. With a very "connected"



shop floor, maintenance knowledge needs to incorporate new technology to ensure that equipment is properly maintained and meeting operating objectives. In some cases, there is a need for specialized automation or robotics technicians and engineers to deploy and support the operation and to redeploy when change is necessary.

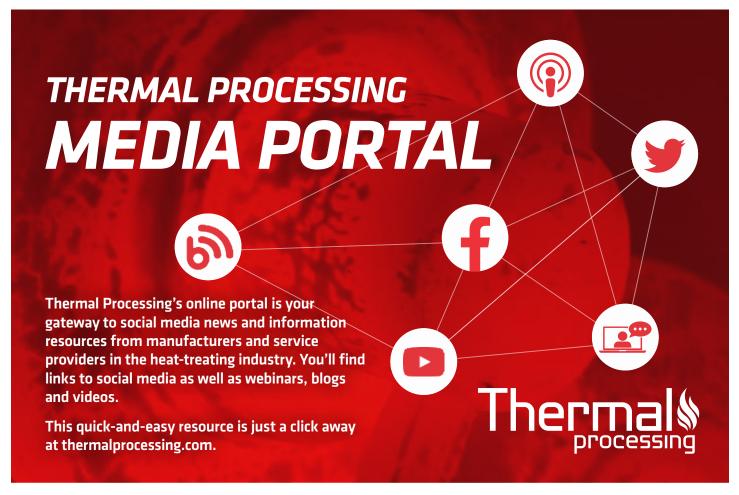
CONCLUSION

The industrial automation market undoubtedly will continue to grow and the heat-treat-

ing industry will reap the advantages, which include lower operating cost, reduction in human error, lower wastage, efficient manufacturing, synchronization of procedures, and quality production. The advancements of sensor technology and computing power provide the foundation for better and automated decision making. Many in the heat-treat community have this in place today as a foundation for a path forward to tomorrow's automation and IIoT advancements.

ABOUT THE AUTHOR

Jim Oakes is president at Super Systems Inc (SSi). He is a graduate of the University of Buffalo with a Bachelor of Science in electrical engineering. Since joining SSi in 2005, he has been involved in all aspects of SSI's business including sales, marketing, business development, product strategy, and product development. He has helped develop product innovation strategies in conjunction with customer feedback, and driven SSI's commitment to quality and continuous improvement in the products that SSi offers.





Heat-transfer fluids perform important functions in industrial applications and have taken on a more prominent role in electric vehicles.

By DR. NEIL CANTER

he growing use of electronics in many applications is leading researchers to better understand the reasons for using heat-transfer fluids. Electronics generate substantial amounts of heat, which needs to be dissipated in order to maintain performance. For the lubricant field, a primary example is the electric vehicle (EV).

EV batteries need to operate at a temperature range between 15° C and 35° C to achieve optimum performance [1]. Heat generation during charge/discharge cycles becomes so intense that it is proving difficult to maintain batteries within that desired temperature range. The result is a loss of battery capacity and potentially a reduction in battery life due to degradation at high temperatures.

Heat-transfer fluids are now assuming a more prominent role in EVs due to their ability to quickly remove heat. This article will examine the role of heat-transfer fluids in EVs. But before addressing this issue, the use of heat transfer fluids, in general, will be discussed, as they have been employed in industrial applications for a long period of time.

Key industry experts were contacted to obtain their expertise on heat-transfer fluids and on thermal management challenges with EVs.

Those experts included:

- >> Dr. Bethan Warren, Croda Europe Ltd.
- >>> Thiago Alonso, Dow Chemical.
- >> Michael Bates, Duratherm.
- >>> Dr. Serya Dutta, Dynalene.
- >>> Dr. Satish Mohapatra, Dynalene.
- >>> Dr. Babak Lotfi, ExxonMobil Chemical.
- >>> Alex Sammut, The Lubrizol Corp.
- >>> Edward Cass, Paratherm.
- >> Ryan Ritz, Paratherm.

FUNCTIONS OF A HEAT TRANSFER FLUID

"The basic function of a heat-transfer fluid is to move heat from one location to another," said Michael Bates, technical director for Duratherm in Lewiston, New York. "This process either leads to heating or cooling a specific system in a particular application."

Edward Cass, technology manager for Paratherm, division of The Lubrizol Corp. in King of Prussia, Pennsylvania., indicated that heat-transfer fluids are used to indirectly, uniformly, and efficiently transfer or move energy in the form of heat from one region to another at low system pressures.

"Most often, the fluid is circulated through a heating or cooling source and, subsequently, through a process loop that contains one or more thermal process units," he said. "These units may include tanks, reactors, kettles, rollers, dryers, ovens, dies, etc."

"The main function of a heat-transfer fluid is to remove heat from a sourcing point and supply it to different consumers such as reactors, extruders, distillation and extraction towers, among many other applications that demand heat for proper operation," said Thiago Alonso, technical services and development scientist and global innovation leader for energy and heat management at Dow Chemical in Lake Jackson, Texas. "Heat-transfer fluids operate in an efficient way with reduced risks of handling fuels in a centralized and controlled unit, run at lower pressures compared to steam, exhibit low flammability, and excellent process and temperature control."

"The main function of a heat-transfer fluid is to transport thermal energy from one component of a system to another," said Dr. Satish Mohapatra, president and CEO of Dynalene in Whitehall, Pennsylvania. "It also transfers the heat into or out of the component, thereby either heating or cooling it."

HIGH-TEMPERATURE VS. LOW-TEMPERATURE FUNCTIONS

Ryan Ritz, global director of technology for Paratherm, said the functions of heat-transfer fluid operating at high temperature versus low temperature are no different.

"The difference between fluids suitable for one or the other is contingent on physiochemical properties advantageously exploited for their intended use," he said. "For example, low-temperature fluids will usually have low viscosities, higher vapor pressures, and narrower boiling ranges as compared to high-temperature fluids."

Mohapatra contrasts high-temperature heat-transfer fluids with low-temperature fluids.

"High-temperature heat-transfer fluids are primarily used for heating a system component, whereas low-temperature fluids are primarily used for cooling the components," he said. "In certain cases, a high-temperature fluid can be used to cool a system component by removing the heat from it. Similarly, a low-temperature fluid can be used to heat a component that is very cold."

Alonso said he feels the distinction between high and low temperature is somewhat artificial.

"The terms are used in general to distinguish between mineral oil, organic and silicone-based fluids, and glycol/water-based fluids," he said. "In general, glycol/water-based fluids exhibit advantages over other chemistries in the 25°C to 150°C operating range due to their lower cost and superior physical properties. Certain silicone and organic fluids can be used at operating temperatures less than minus-25°C and down to minus-100°C where it is not practical to use glycol/water-based fluids due to their higher viscosities and the possibility of use temperatures being below the glycol-water freezing points."

Alonso continued with a discussion of high-temperature heattransfer fluids.

"Mineral oils, synthetic oils, and silicones are typically used at temperatures above 150°C and up to 400°C," he said. "They can be used in the glycol-water-use temperature range but typically are not cost effective. However, there may be situations, for example, where a process will require the use of an organic or silicone-based fluid

in the minus-25°C to 150°C temperature range due to water reactivity with the process material. The choice of fluid chemistry in this temperature range will depend primarily on the maximum desired use temperature and on fluid physical properties, environmental profile and cost."

Bates indicated requirements for low-temperature heat-transfer fluids are different than for high-temperature heat-transfer fluids.

"Low-temperature heat-transfer fluids can range from as low as minus-80 $^{\circ}$ C to approximately 150 $^{\circ}$ C," he said. "One of the most

important properties for low-temperature heat-transfer fluids is viscosity. They must display low enough viscosity, ideally to achieve turbulent flow, to be useful in cooling or keeping systems such as chillers operating at their desired temperature."

In contrast, high-temperature heattransfer fluids must avoid degradation by mechanisms such as oxidation and thermal breakdown, according to Bates.

"Factors such as the heat source and whether the flow of the heat-transfer fluid is turbulent have to be considered in evaluating a high-temperature heat transfer fluid," he said.

Degradation issues due to overheating (coked heaters) and oxidation (sludged expansion tank) are shown in Figures 1 and 2.

EXAMPLES OF HEAT-TRANSFER FLUIDS

Mohapatra divides the types of heat-transfer fluids into low temperature and high temperature types.

"High-temperature heat-transfer fluids range from aromatic and aliphatic hydrocarbons to silicones and, in some cases, molten salts," he said. "Low-temperature fluids can be aromatic and aliphatic hydrocarbons, glycols, alcohols, salt brines, and silicones."

Bates said he distinguishes the high-temperature from the low-temperature types of heat-transfer fluids.

"Many of the high-temperature heattransfer fluids are hydrocarbon or synthetic based that can operate at elevated tem-

peratures, though not all of them are oxidatively stable," he said. "Aromatic-based fluids such as hydrogenated terphenyls are more likely to be stable at very high temperatures. Water glycols are the most commonly used low-temperature heat transfer fluids but are not able to achieve efficient cooling below minus-18°C because they tend to get thicker and can get slushy. For lower temperatures, silicones, alcohols, special hydrocarbon fluids, and some aromatic-based fluids need to be used."

Cass classified heat-transfer fluids into aqueous, mineral oil, and synthetic categories.

"The most common heat-transfer fluid in the world is water because its unique properties make it efficient for heating and cooling but limit its practical operating range," he said. "Water glycol blends and brine solutions extend the operating capabilities of aqueous fluids but still have limitations."

"High-temperature fluids may include both natural organic

hydrocarbon and synthetic chemistries," Cass said. "Natural organic fluids are generally suitable for operation from 120°C to 300°C. Fluids formulated with Group II and Group III base oils are usually superior in terms of thermal stability and fouling potential vs. their Group I counterparts. For operating temperatures in excess of 300°C, synthetic aromatics are preferred. There are many options available in this fluid class, including alkylated benzenes, alkylated biphenyls, aryl ethers, hydrogenated terphenyls, and diphenyl ethane blends."

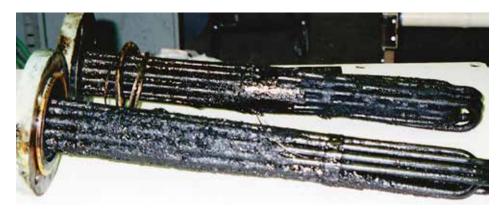


Figure 1: Overheating is one cause of heat-transfer fluid degradation as shown by this image of a coked heater. (Courtesy: Duratherm)



Figure 2: Heat-transfer fluids can oxidize during use, which will lead to premature failure as shown by this image of a sludged expansion tank. (Courtesy: Duratherm)

Cass said low-temperature fluids are able to achieve minimum operating temperatures as low as minus115°C.

"Low-temperature fluid types include glycols, silicones, synthetic hydrocarbons, ethers, esters, and fluorinated hydrocarbons," he said.

SELECTION CRITERIA

Bates outlined at least several parameters that need to be considered in selecting a heat transfer fluid.

"For high-temperature properties, the flash point of the fluid is often desired to be greater than the operating temperature," he said. "The most important consideration is the bulk fluid temperature in a particular application as well as the skin or film temperature. Other parameters to evaluate include the physical properties such as heat capacity, density, and viscosity. The heat-transfer coefficient, which takes all of the properties of a fluid into consideration, also is an important parameter that should be determined. Safety criteria,



Figure 3: The experimental setup for evaluating the foaming of a water-glycol heat-transfer fluid using ASTM D1881 is shown. (Courtesy: Dynalene)

such as toxicity, are important for low-temperature heat-transfer fluids. Above all, a user selecting a heat-transfer fluid for a specific application must not look at just one property."

Ritz indicated no "one-size-fits-all" solutions exist for heat transfer fluids.

"The fluid should be matched to meet or exceed the minimum and maximum operating temperatures and minimum startup temperatures of the process," he said. "A properly specified fluid also is matched to maximize heat-transfer efficiency and safety of the operation. Therefore, physical properties such as viscosity, density, specific heat, thermal conductivity, boiling range, and vapor pressure should all be considered and optimized for an efficient process."

Mohapatra listed seven criteria that need to be followed in picking a heat transfer fluid.

"Criteria for selecting a heat-transfer fluid include temperature range, thermophysical properties, toxicity, flammability, environmental qualities, availability, and cost," he said.

Alonso's input on selection criteria includes maximum temperature of use, pressure, degradation profile, health and safety concerns, flammability, odor and, of course, cost.

MAINTENANCE PRACTICES

Alonso discusses maintenance practices that apply to high-temperature and low-temperature heat-transfer fluids.

"The manufacturer's maximum-use temperature guidelines should not be exceeded," he said. "Use above the maximum recommended operating temperature can result in excessive fluid degradation and, potentially, damages to processing equipment due to fouling/coking. For fluids operating at elevated temperatures, exclusion of oxygen is critical to ensure long fluid life. Fluid condition should be periodically monitored to keep fluid within recommended operating parameters. Levels of degradation products such as low and high boiling compounds also need to be monitored. For glycol/waterbased fluids, the focus should be on analysis of the condition of the glycol concentration and inhibitor package."

Alonso said many fluid suppliers offer a fluid-analysis program to monitor the condition of the fluid and make recommendations for fluid maintenance.

Mohapatra said he believes sample testing by the fluid manufacturer needs to be done periodically to ensure the health of the heat transfer fluid.

"Air/oxygen, high temperature, and moisture are the biggest threats to most of the heat transfer fluids," he said. "Care should be taken to have an inert head space and prevent thermal runaways."

Water-glycol heat transfer fluids also can be vulnerable to foaming during use.

"Foaming in water-glycol heat-transfer fluids can be caused by the presence of contaminants, certain supplemental coolant additives, and the presence of air in the system due to cracks or leaks," said Dr. Serya Dutta, R&D manager for Dynalene. "Addition of defoamers can suppress the foaming tendency of the heat-transfer fluid, which could have otherwise led to problems during filling a system or operation. It is recommended to inspect the health of an aging heat transfer fluid to make sure that the defoamers are not depleted, no contaminants or debris are present, and the heat-transfer system is not facing any mechanical issues."

Dutta recommended ASTM D1881 be used to evaluate the foaming potential of a water-glycol heat transfer fluid. Figure 3 shows how a specific heat-transfer fluid can generate foam during a test.

Cass said he feels proactive system maintenance is key to maximizing fluid performance over time.

"Fluid lifetime is a function of many real-world variables, which makes it critical that all system components — fluid, heaters, chillers, pumps, valves, etc. — be properly maintained, according to OEM recommendations," he said. "Deviation of physical properties outside of established optimal ranges should be investigated and corrected to ensure fluid longevity and safety. Heat-transfer systems should be routinely assessed to ensure temperatures, pressures, and cycle times are continuously stable. Thermal fluid leaks should be addressed and corrected with haste as they can lead to dangerous situations."

Maintenance of heat-transfer fluids is very important because there are typically no visible signs of degradation until actual failure, according to Bates.

"Heat-transfer fluids have operating timelines that can be as small as 3,000-5,000 hours and as long as 12-15 years depending upon the application," he said. "During this time, analysis of such parameters as acid number, viscosity, and flash point are important to assess the condition of the heat-transfer fluid. Operators need to keep a history of analyses done on a specific system to monitor the condition of the heat-transfer fluid and determine if corrective actions are needed to prevent failure."

IMPORTANT APPLICATIONS

Ritz included not just applications but also specific process equipment that may use heat transfer fluids.

"Heat-transfer fluids are used in a plethora of applications including oil and gas refining, chemical processing, polymer manufacturing, industrial drying processes, food and beverage processing, pharmaceutical processing, biomass processing, extraction sciences, electronics cooling, steam generation, etc.," he said. "Specific process equipment utilizing heat-transfer fluids may include tanks, jacketed vessels, reactor vessels, reboilers, distillation towers, thermal oxidizers, autoclaves, calendar rolls, platen presses, molds and dies, dryers, ovens, and fryers."

Bates highlighted the use of heat-transfer fluids in food and pharmaceutical applications and, in general, chemical manufacturing. Alonso pointed out that any unit operation in the chemical engineering world will most likely use heat-transfer fluids as the most efficient way to transfer and consume heat in different processes. He included the following list of applications: liquid natural gas production, refineries, synthetic fiber production, polyethylene terephthalate resin production, petrochemicals, HVAC, climate chamber, food and beverage processing, and many others.

Mohapatra contributed the following applications: beverage production, ice rinks, cold storage, electronics, and automotive.

RENEWABLE ENERGY SOURCES

Heat-transfer fluids are assuming a large role in the generation of energy from renewable sources. The contributors were asked to provide input on solar-energy, geothermal-energy, and thermal-energy storage. "Heat-transfer fluids are used in several solar applications," Alonso said. "Water-glycol fluids have been used in roof top-mounted solar collectors to provide heat for domestic hot water heaters and hydronic heating systems. Synthetic aromatic-based fluids have been used for a number of years in parabolic trough concentrating solar power plants. In this application, the heat-transfer fluid is heated to approximately 400°C in the parabolic solar collectors and used to produce superheated steam that can be used to drive a turbine generator that produces electricity."

"Thermal-energy storage is very important in the concentrated solar power (CSP) plants in order to produce electricity when the sun is not shining," Mohapatra said. "Heat-transfer fluids also are used to transport the thermal energy obtained from the solar collectors to the

The importance of dissipating heat generated by the battery, electric motor, transmission, and power electronics has led to the push to commercialize immersion cooling, which is more efficient than indirect cooling. But challenges remain that will need to be overcome.

component where it is used to generate electricity and also to charge the thermal energy storage system. Hydrocarbon mixtures with very high temperature stability (biphenyl/diphenyl oxide mixture) are typically used as heat transfer fluids up to 390°C, and nitrate-based molten salt mixtures are used as a thermal storage medium."

"In CSP-generation applications, a configuration of mirrors concentrates the sun's energy onto some type of receiver where heat-transfer fluids are circulated to transport that thermal energy into a power generator (turbine)," Cass said. "The two most common CSP technologies utilizing heat-transfer fluids are parabolic troughs and 'power towers.' Due to the extremely high energy output from the sun, CSP applications demand the use of a high-temperature, synthetic-based heat-transfer fluid, usually a vapor phase fluid designed to maximize temperature capacity." Cass indicated that thermal energy storage uses a molten-salt-based fluid medium.

"The reason is that salts display very low rates of heat loss over time and still can be circulated with the proper system technologies," he said. "The importance of thermal energy storage in CSP systems is to ensure that energy production is maintained when there is no daylight." There is a greater use of water-based heat-transfer fluids in geothermal energy applications because energy transfer occurs at very moderate and consistent temperatures.

"Demand for thermal stability of the heat-transfer fluid is not as high as CSP," Cass said. "Glycols, brines, and even alcohol-based fluid formulations are common in geothermal heat pumps." Bates confirmed extreme high-temperature, aromatic-based heat-transfer fluids operating in the vapor phase are critical in extracting solar energy from concentrated collectors

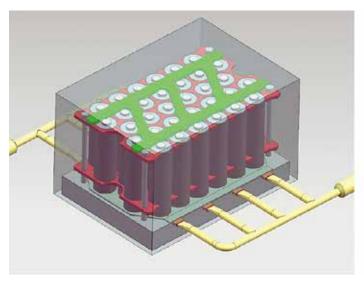
"Another side to this is thermal energy storage, which acts as a thermal battery to conserve energy until it is needed," he said. Waterglycol heat-transfer fluids are mainly used in a loop in geothermal applications.

"Unfortunately, this energy source has not taken hold in the marketplace with the emphasis for heat-transfer fluids placed on solar power," Bates said.

EFFECTIVENESS OF HEAT-TRANSFER FLUIDS

Ritz said he feels the current heat-transfer fluids are effective as long as they are monitored while in use to ensure optimum long-term performance.

"Heat transfer fluids all degrade over time when exposed to thermal energy," he said. "The ability to monitor the relative rates of degradation and take action quickly are key to not only extending the life of the fluid but, more importantly, preventing the accumulation of degradation products that can interfere with proper system functionality. Any heat energy that is not transferred from the heat



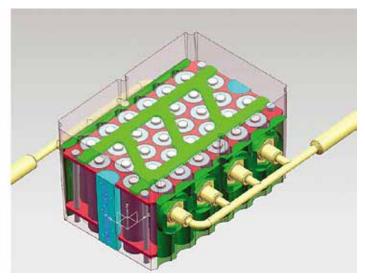


Figure 4: A model battery module based on cylindrical cells is shown for direct or immersion cooling (a) and for indirect cold plate cooling (b). (Courtesy: D2H Engineering)

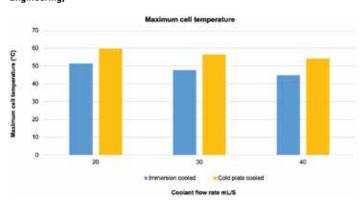


Figure 5: The maximum battery cell temperature for immersion cooled (direct) vs. cold plate cooled (indirect) at three cooling rates is shown. (Courtesy: Croda/D2H Engineering)

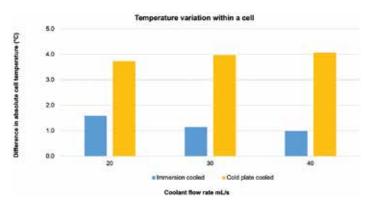


Figure 6: Temperature variations within the battery cell for immersion cooled (direct) vs. cold plate cooled (indirect) at three cooling rates indicate that direct cooling leads to a more uniform temperature, which is favored to extend battery life. (Courtesy: Croda/D2H Engineering)

source to the process unit can ultimately be used to break down the fluid molecules; therefore, more efficient fluid (based on thermophysical property ratios) will inherently last longer."

Alonso agreed.

"Fluids can be effectively used for extended periods of time (years) when properly maintained and operated within the fluid manufacturer's recommended operating conditions," he said. "Exceeding maximum use temperature should especially be avoided. Thermal stability, or fluid life at a given set of conditions, is determined by

the molecular structure of the components comprising the heattransfer fluid. The maximum use temperature of a particular fluid is a measure of the fluid's thermal stability. A fluid with a maximum recommended use temperature of 400°C that is used in a system operating at 300°C will undergo very little degradation and have a very long service life. That same fluid operating at 410°C will have a far shorter life, exponentially shorter in fact."

Alonso pointed out aromatic hydrocarbon and polydimethylsiloxane-based heat-transfer fluids are limited in operational temperature to between 400°C and 425°C. For higher use temperatures, he indicated eutectic mixtures of inorganic salts are practically the only alternative.

FUTURE TRENDS

One common theme among the respondents is that future heat-transfer fluids will be developed with health and safety and sustainability in mind.

"There is a need to identify more environmentally friendly, hightemperature heat transfer fluids that are less toxic than the current technology based on aromatic chemistry," Bates said.

Alonso also agreed more eco-friendly fluids with better environmental, health, and safety profiles are needed.

"Heat transfer fluids with higher maximum use temperatures are desired mainly for CSP units," he said.

"The traditional goal for development of superior heat transfer fluids has always been the optimization of cost, performance, and service life," Cass said. "Current and future demands are calling for the heat-transfer fluid industry to look deeper into sustainability of materials and the ability to customize performance capabilities depending on the specific needs of niche applications. This will lead to some more demanding innovations than the 'one-size-fits-most' style of industrial heat-transfer fluids that dominates the market today. As technologies advance in the world around us, the demand for more specialization and customization of heat-transfer fluids will increase as well. This will likely lead to fluid providers working more collaboratively with OEMs and end-users to design bespoke solutions."

FUNCTION OF A HEAT-TRANSFER FLUID IN AN ELECTRIC VEHICLE

Excessive heat generated by an EV during use has been found to reduce the operating life of key components such as the electric motor and the battery. STLE member Dr. Babak Lotfi, product development technologist at ExxonMobil Chemical Co. in Baytown, Texas, indicated that EV design has rapidly evolved to the point where the electric motor poses challenges from both thermal management and tribological standpoints.

"Many automotive manufacturers have been adopting the integrated drive-unit design," he said. "In this approach, a single fluid is used for cooling the electric motor and electrical components in addition to lubricating gears, bearings, and possibly clutches in the drive unit. This design provides more efficiency due to the EV's smaller size and reduced weight. In this design, the drive-unit fluid is typically a hydrocarbon (such as a synthetic polyalphaolefin, PAO) which is being used for direct cooling and lubrication, and it can potentially provide superior thermal management compared to water-glycol indirect cooling methods."

Lotfi said he feels the battery may require advanced thermal management to optimize safety, performance, and potentially driving range.

"Different options that can be used for battery thermal management include air, water-glycol fluids, dialectic (e.g., hydrocarbon)

fluids, phase-change materials, and refrigerants," he said. "Dielectric fluids can provide a direct cooling approach that offers a more uniform thermal management distribution in the system potentially leading to improved safety, thermal management, performance, and extending the life of the battery in the EV."

Dr. Bethan Warren, lead application scientist, energy technologies, Croda Europe Ltd. in Snaith, United Kingdom, said thermal management is a key consideration for an EV in the same way it is in an internal combustion engine.

"Components in both engines generate heat and have limited endurance at high temperatures," she said. "Therefore, heat-transfer fluids are utilized in order to remove heat as

well as manage component temperatures to keep them at their optimum for best efficiency and longevity. An EV is generally made up of a battery, an electric motor, some form of transmission, and power electronics. Each of these components may generate heat and the ambient temperature, as well as the function the EV is performing (e.g., driving or charging), can have rapid and significant influences on component temperature. Heat-transfer fluids are used to manage these temperatures and enable each of these components to operate at their optimum temperature."

As an example, Warren said a lithium-ion battery operates optimally at a narrow temperature range discussed earlier in the article. At higher temperatures, performance degradation can occur, and the risk of thermal runaway increases significantly. Charging also can be impaired as the electrical resistance increases as the temperature increases. At lower temperatures, poor performance, reduced range, and reduced charging ability will occur. Circulation of the heat-transfer fluid through the battery compartment will minimize the chance of the battery being exposed to either high or low temperatures.

Alex Sammut, senior manager, global electronic vehicle applications for The Lubrizol Corp. in Wickliffe, Ohio, said he believes heattransfer fluids are needed to protect electronics during operation and to facilitate the development of high-speed charging.

"During normal operation, EV systems will generate heat, which



Figure 7: This schematic shows the benefits of direct cooling where the heat-transfer fluid is in direct contact with the battery and electronics. (Courtesy: The Lubrizol Corp.)



Figure 8: A schematic shows the indirect cooling method known as side cooling. (Courtesy: The Lubrizol Corp.)

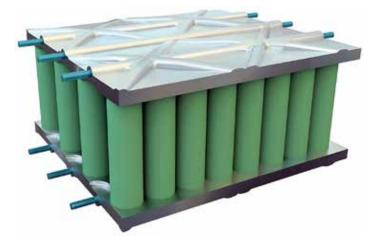


Figure 9: Another indirect cooling technique is known as bottom tray cooling. (Courtesy: The Lubrizol Corp.)

needs to be managed to prevent damage to batteries and electronics," he said. "As charging times decrease, the need for temperature control becomes essential. High-speed charging in excess of 300 kilowatts of power is spreading globally. Even with high efficiency charging, a significant amount of heat (greater than 12-15 kilowatts) is generated and must be managed."



Change In Electrical Conductivity Of an Ethylene Glycol/Water Based Heat Transfer Fluid on Holding at 80°c for ~ 5,000 Hrs

DAYS	HOURS	CONDUCTIVITY (µS/cm)
0	0	0.082
5	120	0.3
28	672	0.36
63	1512	0.396
108	2592	1.53
209	5016	1.4

Table 1: An inhibited ethylene glycol/water-based heat-transfer fluid displayed stable electrical conductivity (in microsiemens per centimeter) over a 5,000-hour period at 80°C. (Courtesy: Dynalene)

DIRECT OR IMMERSION COOLING

The potential for an EV to generate high levels of heat means an alternative to the indirect cooling used in an internal combustion engine is required. A logical approach is to place the heat-transfer fluid directly in contact with the sensitive components in an EV in a process known as direct or immersion cooling.

"Current battery packs are cooled by having the heat travel from the battery through a heat conductive compound to a heat exchanger that rejects the heat to the heat-transfer fluid," Alonso said. "The heattransfer fluid is circulated to a radiator where the heat is rejected to air. Direct or immersion cooling would have the heat transfer in direct contact with batteries, eliminating the heat conductive compound and the heat exchanger."

Warren defined indirect and direct cooling:

"Indirect cooling utilizes a coolant circuit with cooling plates or jackets," she said. "These cooling components are filled with the cooling fluid, and the plates are thermally bonded to the components to be cooled. Heat generated by the component must flow through the bonding, through the plate, and into the cooling fluid before being taken away."

Warren revealed direct cooling is more efficient than indirect cooling because the path the heat has to take is much shorter, and heat can be removed at the source. Due to this greater efficiency, the temperature across a component is more homogeneous when using direct cooling. Indirect cooling needs additional components, including the cooling plates that require more metal, more mass and volume, which is undesirable to optimize the efficiency of an EV.

To evaluate the differences between direct and indirect cooling, a model battery module based on cylindrical cells was created and used for testing (See Figure 4a and 4b). The direct or immersion cooling set up is shown in Figure 4a, while a cold plate cooled scenario is shown in Figure 4b.

"Across the flow rates tested, the maximum temperature of the immersion cooled cells were, on average, 20 percent lower than the indirect system, and, in addition, the temperature variation across a given cell was reduced by approximately 50 percent when immersion cooling was used, meaning the cell had better homogeneity," Warren said.

Figure 5 shows the maximum battery cell temperature for direct vs. indirect cooling at three different flow rates. As the flow rate increases, the difference between direct and indirect cooling also increases. Temperature variations within the battery cell for direct vs. indirect cooling are shown in Figure 6. The benefit of direct cooling is shown by the lower temperature variation at the three flow rates

Sammut indicated with direct cooling, the heat-transfer fluid is in direct contact with the battery and electronics allowing for a greater cooling surface area with the hottest parts of the EV system. A schematic showing direct cooling is shown in Figure 7.

In contrast, indirect cooling systems separate the fluid, typically water-glycol, from electronic components. Figures 8 and 9 show two examples of indirect cooling: side and bottom tray cooling.

Sammut considers direct immersion cooling to provide several efficiency benefits, including improved safety, lower system cost, and extended battery life.

"Immersion cooling can reduce the peak temperature of the battery and of bus bars," he said. "The latter are short strips of conductive metal used in high-current electrical connections. This gives designers freedom to either downsize components, saving cost, or to extend the life of the battery pack. Better battery safety can be achieved because the direct immersion requires a dielectric fluid that will be less conductive and can prevent electrical injury if the fluid leaks or spills. Cost is reduced due to better efficiency and more precise/targeted cooling that does not need cooling jackets and leads to a reduction in the size and cost of battery pack systems."

Sammut said peak battery temperatures can drop by 8 percent to 12 percent during battery charging. Additionally, battery pack temperature can be more uniform improving range estimations and reducing the likelihood of a cell failure.

Lotfi said direct cooling has a unique advantage in providing a more uniform thermal management compared to the indirect method.

"Desirable electric properties are the key in enabling direct cooling," he said. "This is where hydrocarbon fluids provide an advantage compared to the water-glycol fluids used in indirect cooling."

TESTING

Alonso said he believes the chemical industry is in the early phase of developing fluids for immersion cooling for EVs, and no industry-wide tests have been established.

"The fluid must have the correct electrical properties (conductivity and dielectric properties), fluid compatibility with component materials, high thermal conductivity and a low freezing point (less than minus-40°C), and reasonable viscosity or operating conditions will be required," he said. "Good performance in the battery nail penetration test will probably be required, and the fluid must have acceptable environmental, safety, and health properties."

Besides studying basic properties (such as viscosity, density, thermal conductivity, and heat capacity) of heat transfer fluids, Lotfi said he feels viscosity plays a critical role in thermal efficiency.

"Lower viscosity can improve thermal efficiency as it improves heat transfer and reduces pump resistance within the system," he said. "The best approach to evaluate the effectiveness of a heat-transfer fluid is in an actual system (such as an e-motor and battery) as design parameters also can impact thermal efficiency within the system."

Sammut pointed out safety testing is important to evaluate the effectiveness of a heat-transfer fluid in providing direct cooling.

"If in the event of a single battery cell failure, understanding how the fluid behaves and working to prevent a comlet battery pack failure is essential," he said.

Warren indicated physical characteristics such as volatility, flash point, pour point, material compatibility, and oxidation stability must be evaluated.

"Lower volatility means evaporation losses are lower, and the cooling system does not have to be topped up as frequently," she said. "A higher flash point means better safety under high-temperature conditions. The fluid must have a low pour point so as not to freeze or become too viscous to pump at low temperatures. Materials within the cooling system such as elastomer seals, copper, insulating materials, or any materials found within the cooling system must not be harmed by the heat-transfer fluid. The heat-transfer fluid must be oxidatively stable under elevated temperatures to the point that it may be expected to perform over the lifetime of the vehicle."

Two other characteristics to be evaluated are electrical conductivity and breakdown voltage.

"The fluid must have limited electrical conductivity to prevent arcing within the motor and/or power electronics," Warren said. "A high-performance coolant suitable for use in contact with energized components will have measured conductivity in the range of picosiemens per centimeter. Breakdown voltage, defined as the minimum voltage required to get current to pass through the fluid, should be as high as possible. Desired values should be in the 40-80 kilovolts (kV) range, if not higher."

Low and stable electrical conductivity properties are important for heat transfer fluids not just in EVs but in other electronics cooling applications such as fuel cells. As an illustration, Table 1 shows data produced in the evaluation of an inhibited ethylene glycol/waterbased heat-transfer fluid.

"This particular fluid exhibits stable electrical conductivity for 5,000 hours when maintained at 80°C," Mohapatra said.

CHALLENGES TO COMMERCIALIZE IMMERSION COOLING

The importance of dissipating heat generated by the battery, electric motor, transmission, and power electronics has led to the push to commercialize immersion cooling, which is more efficient than indirect cooling. But challenges remain that will need to be overcome.

"Developers of immersion cooling fluids will need to keep three main areas in mind before achieving commercialization," Warren said. "Fluid compatibility is the first issue specifically with the very low viscosity fluids desired for more efficient pumping. But fluids with low viscosity have a negative impact on seals and other polymers. The reason is that lower viscosity fluids, in general, have smaller molecules that are more likely to interact with other materials. EV manufacturers will need to consider the careful selection of certain materials, such as elastomers, while fluid manufacturers will need to be mindful of the formulation blends to mitigate compatibility issues."

Warren said she feels the automotive industry must adopt standardized testing methodologies to facilitate the commercialization of immersion cooling.

"In contrast to the internal combustion engine, the drivetrain technology in EVs is not mature; the market is developing rapidly, and different OEMs approach cooling challenges differently — with competing designs," she said. "While there are industry-established

specifications for current engine oils or transmission fluids, no such standards exist for coolants. This creates additional challenges for fluid ingredient suppliers; without standardized assessment methods, we must work closely with OEMs and suppliers to understand their specific needs and design with them, fluids that suit their exact performance requirements."

For the future, Warren predicted immersion cooling will be a niche solution, at least for the next five years.

"We see total immersion cooling as part of the package for highperformance, higher-priced EVs," she said. "The presence of this technology may prompt the EV market to start to splinter into different categories – like we have now. For example, automobiles used in urban environments tend to have smaller engines and lower performance than larger vehicles. Smaller automobiles with smaller batteries and cheaper battery technology will be utilized in low-cost vehicles for shorter, urban journeys. EVs for cross-country, longer distances will need to have higher performing batteries that can be charged rapidly during short breaks in driving. Immersion cooling, with its engineering challenges, may be adopted by manufacturers creating high-cost, high-performance, long-range vehicles, where customers are happy to pay the price for the fastest charging. The result is that consumers will be faced with a cost vs. need trade-off, where cheaper, smaller vehicles will probably continue with base plate cooling. Immersion cooling will remain as a secondary option until the EV market matures with growing production driving down the prices to the level of internal combustion engine-powered vehicles."

Lotfi said he believes selection of the proper base oil is critical in the development of a suitable fluid that can be used in immersion cooling.

"There is a trend for EVs to move to lower viscosity fluids to increase energy efficiency and thermal management in the drive units," he said. "Balancing low viscosity with other base oil properties such as volatility, flash point, and tribological properties is critical to optimize performance and safety over the lifetime of EV fluids. Improved thermal conductivity and heat capacity can be realized with synthetic base oils compared to Group I, II, and III base oils. Novel synthetic base oils with excellent balance of low viscosity and volatility and superior tribological properties can further enhance future technology advancement in EVs. They can help to push boundaries in EV fluid development and maximize performance in EVs."

Heat-transfer fluids perform important functions in industrial applications, and their use has expanded into renewable energy sources such as solar power. Concern about the significant heat generated during the operation of EVs has placed heat-transfer fluids into a newer role where their use will be critical to optimize performance and efficiency. Immersion cooling has emerged as a new approach to enhance EV development and commercialization. The use of this technique will further highlight the important role heat-transfer fluids play now and in the future.

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[1] Please go to the following link: www.evcreate.nl/ideal-battery-temperature.

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Burners are an essential part of a furnace, and it is necessary to optimize them based on combustion processes to find the ideal balance when mixing the fuel with the air to ensure complete combustion and, therefore, a desired temperature in the required time.

By VALERIA ESTHEFANIA QUIROZ CABASCANGO and VLADIMIR YUREVICH BAZHIN

n recent years, due to climate change, environmental sustainability programs have been created that require the search for alternatives to reduce air emissions and reduce fuel consumption. The combustion industry is looking for an effective solution to increase the life cycle of its equipment and improve combustion efficiency without neglecting safety or savings. The efficiency of the medium pressure natural gas burners associated with chemical energy, which is converted into heat, that is, the hotter the gaseous products of combustion, the more efficient the burner. The work analyzes the combustion process and their chemical reactions; combustion products obtained in accordance with various conditions; combustion characteristics and factors that influence; and measurement methods needed to optimize combustion and their equipment. In the metallurgical production of nickel, optimization of the burners is very important due to the high temperature used in the reverberatory furnace. That is, the use of a large excess of air would be unfavorably energetic, and the use of a very low excess would result in small intimate mixtures of air and fuel, followed by the release of unreacted reagents and the formation of toxic gases arising at high temperatures. For this reason, the results of this work are an important source of information. The innovation is to automate the use of non-invasive sensors to control the combustion process. The sensors play a fundamental role in the industry, because the information they provide supports the enhanced use of data in the enterprise and increases productivity, efficiency, and safety.

1 INTRODUCTION

Combustion is a chemical process in which oxidation of the fuel components occurs, in our case, natural gas combined with oxygen (O_2) from the air. If natural gas contains high sulfur content when burned, sulfur oxides are formed, which in turn form corrosive products; therefore, if combustion water is allowed to condense, sulfur oxides dissolve in it. On the other hand, if natural gas contains nitrogen and this is combined with oxygen, it forms nitrogen oxides (NO_x) [1].

The fuel is given two combustion heat values: The higher calorific value: In this, the water from the combustion products is extracted in a liquid form. In the lower calorific value, the water from the combustion products is extracted in the form of steam.

All this in view of the latent heat of vaporization is not useful in combustion processes [2].

To achieve efficient combustion, sufficient combustion air is needed but not excessive; meaning that a mixture should be produced within the flammability range. In the case of natural gas, the range goes from 64 percent to 247 percent. The combustion air must fulfill its function under the slogan of the three Ts: time, in a short period; temperature, at high temperatures; and turbulence—you must create

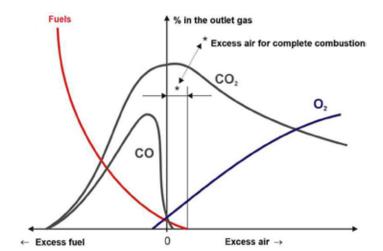


Figure 1: Major components in the outlet gases.

a very turbulent flame [3].

Turbulence is an important aspect to consider in a nickel reverberatory furnace as the working temperature exceeds 1,450°C. Natural gas and well mixed air will cause complete combustion; therefore, the flame temperature will be high according to the desired atmosphere for the furnace, and the burning time will be short. Medium pressure natural gas burners play a very important role in this research since, after the study, an automation of them will help us to obtain a complete combustion [4].

Analyzing the composition of combustion gases based on the amount of air with possible variables leads us to conclude the importance of adhering the right amount of air. See Figure 1.

With an excess of air (excess oxygen), excess gases (N_2 and O_2) causes a decrease in the outlet temperature and a low yield that has been represented in Equation 1:

$$CH + O_2 \rightarrow CO_2 + H_2O + O_2$$
 Equation 1

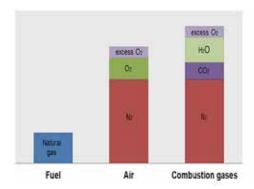
With a lack of air (lack of oxygen), natural gas does not burn completely, and they appear unburned in the flue gases, as shown in Equation 2:

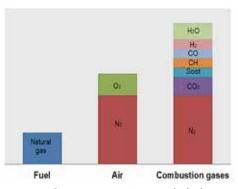
$$CH + O_2 \rightarrow CO_2 + CO + H_2O + CH + H_2$$
 Equation 2

The ideal stoichiometric chemical reaction with the necessary oxygen is described in Equation 3:

$$CH + O_2 \rightarrow CO_2 + H_2O$$
 Equation 3

The composition of the flue gases, depending on the excess/lack of oxygen, is shown in Figure 2.





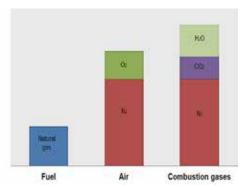


Figure 2: Composition of the flue gases in a reverberatory furnace: a) with an excess of oxygen (0₂); b) with a lack of oxygen (0₂); c) stoichiometric amount of oxygen (0₂) assuming the perfect mix.

Nitrogen oxides (NO_x) are also produced at high temperatures (>1,450°C). The O_2 and N_2 molecules dissociate, and free atoms are formed that react with each other, as shown in Equation 4:

$$[N] + x[O] \square NOx$$
 Equation 4

The air used for combustion is a mixture of oxygen and nitrogen. To supply 1 kg of oxygen for combustion, it is necessary to provide 1/0.2315 = 4.32 kg of air. In this quantity, there will be 4.32 kg $\cdot 0.7685 = 3.32$ kg of nitrogen, which does not directly interfere with the combustion process, but this is always present.

The medium pressure burners do not do a good job in the mixture between natural gas and air, although we achieve the best turbulence conditions. For this reason, it is necessary to create an algorithm based on the thermal function of the reverberatory furnace.

To ensure complete combustion, it is necessary to supply more theoretical air. This ensures any molecule of natural gas can find the necessary oxygen molecules for combustion. Total air would be equal to theoretical air plus excess air. Figure 3 describes the composition of the gas at the outlet as a function of the air flow for natural gas [5].

2 MATERIALS AND METHODS

The literature tells us the efficiency of reverberatory furnaces is defined as the relationship between the heat transferred to the required process fluid and the energy content of natural gas. The efficiency may vary depending on the individual furnace design, the furnace load, the excess air, the flue gas temperature, and the furnace maintenance. A loss of efficiency of 1% can be caused by a 2% increase in excess oxygen or a 23°C increase in the temperature of flue gases [6].

The general efficiency of the furnace consists of two cases: the combustion efficiency—which is part of the total energy available in the combustion chamber after the combustion process, and the efficiency of the furnace—which depends on the design and its operation.

To make any of the two cases effective, we need to optimize resources. If we optimize manually, the manual adjustment of the furnace will determine the point of minimum losses and will change the working conditions at this time. If we optimize automatically, the control system will work by continuously determining the point of minimum losses at a given load and changing the working conditions at this time [7].

During automation, we must take into account the temperature of the flue gases. The amount of energy lost through the chimney depends on the amount of excess air and the temperature of the outlet gases. The exit temperature is a consequence of the load, the infiltration of air, and the state of the heat transfer surfaces.

The literature indicates that, to start and optimize a reverberatory furnace, a table must be created where we present the temperature of the gas at the outlet depending on the load. This serves as the

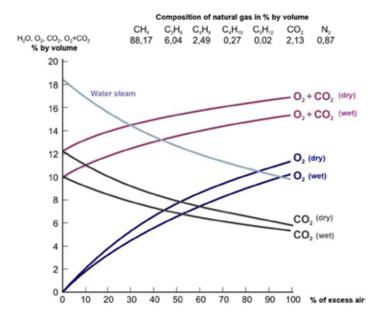


Figure 3: Composition of the outlet gas as a function of excess air for natural gas.

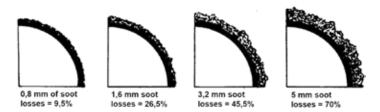


Figure 4: Effect of soot deposition in the tubes.

basis for assessing the subsequent characteristics, if the temperature rises above this baseline; this indicates a loss of efficiency. With each temperature rise of 23°C, the efficiency of the reverberatory furnace decreases by 1%.

The contamination of the heat-transfer surfaces in the air heater, the progressive oxide coating inside the furnace tubes, and the progressive soot coating (see Figure 4) on the outside of the reverberatory furnace pipe are the reasons why the outlet temperature can increase [8].

For this study, we worked with the ex situ method. The installation is shown in Figure 5.

A representative sample of the gas to be analyzed (combustion gas) was extracted. Firstly, this gas was passed through a conditioning unit that consists of cleaning the particle gas, and it was then cooled to a fixed temperature below the dew point to dry it. Finally, the gas passed to the analyzer (see Figure 5).

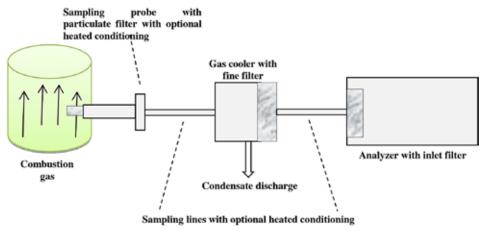


Figure 5: Installation diagram of the ex situ method (dry base).

	Nitrogen	CO ₂	SO ₂	H ₂ O	02
Stoichiometric air/dry base	83.5	16.3	0.20	0	0
Excess air/dry base	82.5	13.35	0.15	0	4.0

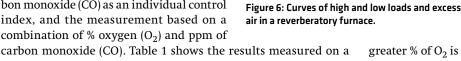
Table 1: Result of the analysis of the samples of combustion gas on a dry basis.

The combustion gas is extracted by means of sampling probes introduced inside the duct and a pump that aspirates the gas to be analyzed. The maximum analysis temperature was 1,500°C and was measured with sensors that also helped measure the pressure [9].

The unit consists of an analyzer that is separated and protected; the conditioned gas has a defined state thus comparable.

The following measurements were made for the analysis of flue gases: % of oxygen (O₂) as an individual control indicator, carbon monoxide (CO) as an individual control index, and the measurement based on a combination of % oxygen (O₂) and ppm of

dry basis.



3 RESULTS AND DISCUSSION

The analysis of oxygen as an index of individual control in any combustion process gives us the idea there is a balance between fuel, carbon monoxide, and oxygen, as we see in Equation 5:

$$[CH_2] + 1.5 O_2 \square H_2O + CO + 0.5 O_2 \square H_2O + CO_2$$

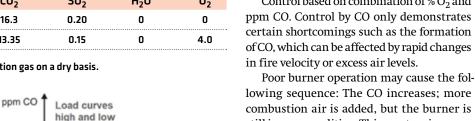
Equation 5

Constant flow

The oxygen shifts the equilibrium to the right. In a well-mixed system with excess air, the concentration of unburned fuels must be less than the concentration of carbon monoxide. If CO is controlled within satisfactory limits, the hydrocarbon concentration will necessarily be low.

In the same way, it is very important to control the content of oxygen in combustion gases since this implies an implicit control of carbon monoxide in equilibrium with oxygen. However, the balance depends largely on the air-fuel mixture. An air deficiency at a point in the combustion zone can result in an increase in unburned fuels and CO, an inefficient atomization due to fouling in the burner can have a similar effect.

This means a control over oxygen does not necessarily ensure a



% of excess air

still in poor condition. This greater air causes a dilution of CO; the concentration of CO returns to the flow.

It is working with the correct concentration of CO, but the excess air is too large, and it is not possible to see it. To detect it, you must know the % O₂ in the flue gases.

A control system cannot improve the basic performance of a reverberatory furnace or its burners.

A good control system can bring the operation of the furnace close to its best operating level for a particular load and other environmental conditions. At a lower load,

greater % of O₂ is required to burn all the fuel (see Figure 7) [12].

With the results of the analysis of combustion gases, we determine that we can control the % of O₂ and the amount of ppm of the fuel described:

The control of O₂ is obtained by setting a certain percentage of excess air from the measurement of % O2. Under test conditions, it is established that the excess O₂ flow must be so that the losses in the reverberatory furnace are minimal. A programmed O₂ flow should be used to be set based basically on the furnace's fire demand. A small safety margin (3 to 4% excess air) is added to cope with variations in a reverberatory furnace or burner operation regarding the test conditions.

Control from the ppm of fuel in the flue gases: We could assume that, for furnace loads and for better economic performance, we should keep this measure at a relatively constant value since the excess air needed would automatically increase for different loads. But from data obtained, it is observed that the temperature in the flue gases increases at a higher load in the furnace, and a change in the shape of the fuel loss curve vs. excess air is observed when the load changes. As a recommendation, the optimum ppm content for each load value should be determined from tests carried out in the reverberatory furnace. A CO flow programmed with the load would be used, as is done with O_2 (see Figure 8) [13,14].

The CO as an individual control index is

based on maintaining a constant flow of CO

at all charges. This function is determined based on an analysis of the composition of

natural gas, excess air, the temperature of combustion gases, tests on the reverberatory furnace to determine the shape of the ppm curve of CO vs. excess air (see Figure 6). The ranges of CO range from 0 to 1,000 ppm. If we receive signals of a change to 100 ppm of CO, this change is accompanied by a change in the % of O₂ of 0.1, and this change in turn is equivalent to a % of 0.5 of excess air [11]. Control based on combination of % O2 and

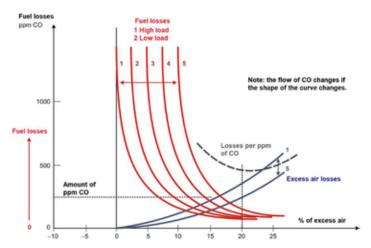
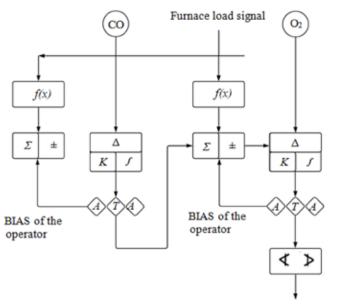


Figure 7: Sample of losses due to excess air and unburned fuels.



To the control system that changes the air and fuel flow rates

Figure 8: Control scheme by % oxygen and ppm of CO.

4 CONCLUSION

The melting temperature is the most important factor that affects the efficiency of the main technological operations in gas reflecting furnaces. The temperature determines the quality of the future product, the effectiveness of the multi-stage refining processes in a liquid metal bath during the fusion process, as well as the intensity of the saturation of the fusion gas, its obstruction with impurities, and irreparable losses [15].

The burners are an essential part of a furnace, and it is necessary to optimize them based on combustion processes to find the ideal balance when mixing the fuel with the air, to ensure complete combustion, and therefore a desired temperature in the required time.

One of the necessary requirements is the supply of a larger amount of theoretical air so any fuel molecule can find the oxygen molecules necessary for combustion. This excess of air and oxygen depends on the fuel. In the case of natural gas, the minimum % of excess air must be between 4 and 16 percent, and the % of O_2 present in the combustion gases is 0.5 to 3.2 percent. This excess air will come out in the flue gases. The percentage of oxygen (% O_2) in the flue gas can be used to determine the percentage of excess air, and we can use the % carbon dioxide (% CO_2) to determine the percentage of excess air. The amount

of excess air required will depend on the type of fuel, the burner design, the characteristics and preparation of the fuel, the reverberatory furnace design, the load as a percentage of the maximum load, the degree of air penetration, and the environmental conditions.

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For a hundred years, SECO/WARWICK has shaped the global metallurgical and heat-treatment industry, designing and manufacturing industrial furnaces to a host of industries, including aviation, automotive, machinery, medical, tooling, power, and commercial heat treatment.

By KENNETH CARTER, Thermal Processing editor

n the everchanging world of heat treating, it's vitally important that a company stays on top of the latest technologies and applications in order to deliver the optimum services and equipment.

To that end, SECO/WARWICK takes that directive seriously, and, in doing so, has been adding to its impressive portfolio since it opened its doors almost a hundred years ago.

"Our largest product line is our vacuum product line," said SECO/WARWICK Group CEO Sławomir Woźniak. "We offer vacuum furnaces for various applications starting from a typical high-pressure gas quench as well as oil quench applications, low-pressure carburizing, melting, tempering, and many, many other applications including nitriding. About 30 to 40 percent of our revenue is generated by vacuum technology or our vacuum product line."

ALUMINUM INNOVATIONS

But as Woźniak pointed out, vacuum technology is only the beginning of SECO/WARWICK's expertise, as the company also has an extensive line working with aluminum.

"Our second product line is aluminum," he said. "It includes aluminum brazing and various other solutions for heat treatment of aluminum products — brazing and brazing of aluminum heat exchanges. Especially today, it is a very interesting technology because we have a unique solution for the brazing of aluminum heat exchanges dedicated for battery coolers of electrical vehicles. This is a topnotch product that is very well received by the Asian market. Here in Europe, we do a lot of projects for OEMs, including some car manufacturers as well as electrical vehicle manufacturers. We see quite good potential in this product line."

SECO/WARWICK's thermal division is another source of pride for Woźniak as it offers a wide range of products dedicated to technologies that include carburizing, spheroidizing, and brazing.

"This is a quite competitive business segment, and we try to limit our portfolio to very well-developed solutions, which can be applied to commercial heat treaters but also aviation industry and automotive as well," Woźniak said.

VACUUM METALLURGY

In 2008, SECO/WARWICK acquired a company dedicated to vacuum metallurgy, according to Woźniak, which allowed the group to dedicate products for aerospace, aviation, and energy projects.

"We acquired Retech and made a very wide product line with high tech equipment like electro-beam furnaces for melting of various metals, plasma applications, vacuum arc melting, and vacuum induction melting furnaces," he said. "And nowadays, there is quite a big interest in the extraction of rare earth metals, and we also



A VertiQuench® Solution HT and aging drop bottom type furnaces. (Courtesy: SECO/WARWICK)

have some applications for that technology as well as powder metal production equipment, which has become a popular product since additive manufacturing is playing a more important role in the industry market."

Through all its massive inroads in innovation, Woźniak emphasized that SECO/WARWICK's primary goal is to become the No. 1 supplier in the world.

"When somebody is thinking about that investment in new capital equipment or about some services, then we would like SECO/WARWICK to be the first choice for our customers," he said. "How would we like to achieve it? We base it on our values — we have five values as a company, but the core value is innovation," he said.



SECO/WARWICK has nine companies in the group with four locations in Europe; three locations in North America; and a location in Asia, India, and China with almost 800 employees worldwide. (Courtesy: SECO/WARWICK)

"We're based on innovation. We would like to develop our products, but we also have partnerships. And when we say partnership, we see our customers, we see our employees, we see our stakeholders as partners."

A SAFE COMPANY

Other company values essential to SECO/WARWICK are safety and stability, according to Woźniak.

"We'd like to be recognized as a safe company and also as a stable partner that can stay with the customer through good and bad times and be supportive in solving problems," he said. "We also see ourselves as a real label company, as a real label supplier with good quality, with a long-term vision where we can stay and support our customers."

SECO/WARWICK also bases its future on its credibility, according to Woźniak.

"We see ourselves as a flexible company, because, besides our standard products, which are mainly vacuum furnaces, we are also quite flexible in providing complete solutions for our customers to meet their demands," he said. "And very often they are very highly technological demands. For that, we have our R&D centers to provide the support for our customers to develop new solutions and new technologies. We provide quality equipment, which is built on our values and innovation that stays with the customers, which sees them returning to us for their future needs."

RESEARCH AND DEVELOPMENT

That all circles back to SECO/WARWICK's innovation as it continues to improve its current products while developing new ones, according to Woźniak.

"We have two R&D centers: One is located in the U.S.; currently, we have moved it from California to Buffalo, New York, where we have our vacuum metallurgical division R&D center," he said. "And another center is located in Poland where we develop many vacuum furnaces and aluminum and aluminum brazing."

SECO/WARWICK uses these R&D centers to develop new products and new solutions, according to Woźniak. The company also cooperates and collaborates with universities in Europe, Asia, and the U.S. in order to meet market demands, especially when it comes to ecological solutions.

"There is a lot of discussion with carbon footprint," he said. "So, we have adjusted the direction of the development of our products to meet all these requirements, but on the other hand, a lot of custom-

"We see ourselves as a flexible company, because, besides our standard products, which are mainly vacuum furnaces, we are also quite flexible in providing complete solutions for our customers to meet their demands."



A mesh belt furnace. (Courtesy: SECO/WARWICK)

ers are fighting with the cost, so we have to also focus on efficiency and the cost reduction so that customers can meet all the market expectations."

INDUSTRY 4.0

Never a company to back down from a challenge, Woźniak said a part of that challenge is dealing with the development of automation where the Industrial Internet of Things and Industry 4.0 are involved.

"These are quite interesting technologies," he said. "We have

already implemented some solutions into our equipment. This is also the direction we see in the market as there is more and more automation and robotization required because the human factor in the long run will be costlier. There's a trend to eliminate the human factor even from key treatment processes."

As of now, that includes applications where robots have been implemented in place of human operators, according to Woźniak.

"We can reduce the cost for our customers, and our equipment is designed in a way that can fully cooperate with robots; this allows for some good added value, which we can transfer to our customers," he said. "We have to be very open and ready to pivot if there is a need and market demands require us to change direction and follow the trends."

CUSTOMER EXPECTATION

That ability to change quickly is important when SECO/WARWICK works with customer expectation, according to Woźniak.

"It's very important to be open and to discuss the customer's expectations and the customer's needs," he said. "SECO/WARWICK



The SECO/WARWICK facility in Poland. (Courtesy: SECO/WARWICK)

has always been recognized as a very flexible company and open to offer very customized solutions. Although we have a standard product line, I can say that about 50 percent of our applications are often customized. From a standard modification of standard furnaces, we can completely design from scratch a new solution for, let's say, development projects. We can do that because we have experience with thousands of reference projects. We can use this experience from every location in our group. Our R&D centers can offer some processes, some tests, and trials to develop some new materials but also to change some new solutions or check some solutions that we can then later implement that we will offer to the customer."

FROM THE U.S. TO POLAND

These solutions in one form or another have been at the heart of SECO/WARWICK's operating procedure since it started life in the U.S. 98 years ago.

In 1924, Warwick Furnace Company opened its doors. Years later, that company partnered with the Sunbeam Equipment Corporation,

and SECO/WARWICK was born in 1984. In 1991, a joint venture was formed between SECO/WARWICK and a small company in Poland. At that time, the joint venture was a 50/50 partnership, according to Woźniak.

As that small operation in Poland grew, developing new products and acquisitions along the way, a reverse takeover happened in 2005 where SECO/WARWICK Poland acquired the mother company of SECO/WARWICK Corporation.

"Since then, the head office of SECO/WARWICK as a group was moved to Poland, and that was the first step to prepare the company to be listed on the Polish stock market in 2008; since then, the company SECO/WARWICK Group is a stock-listed company on the Polish Warsaw Stock Market," Woźniak said.

Today, SECO/WARWICK has nine companies in the group with four locations in Europe; three locations in North America; and a location in Asia, India, and China with almost 800 employees worldwide.

Among the company's acquisitions, SECO/WARWICK acquired the previously mentioned Retech, a U.S.-based company from California

known for its unique metallurgical technology used for electron-beam furnaces, plasma furnaces, and more.

"It brought to our group a new insight to vacuum metallurgical equipment, but it also opened more widely the door to the aerospace industry, which is a very lucrative business," Woźniak said. "It stands for about 30 percent of our annual revenue."

NEW SOLUTIONS, NEW DEVELOPMENTS

As SECO/WARWICK moves into its next 100 years, Woźniak said the company is continuously working on new solutions and developments, with a strong emphasis on additive manufacturing technology.

"We are developing a dedicated solution for that technology from our vacuum product line, but also for the vacuum metallurgy sector," he said. "We also are doing some test and trials on metal powder equipment production."

Woźniak emphasized the company is also working on new heat-treating develop-

ments for low-pressure carburizing, nitriding, and a technology for jet heating for aluminum sheeting coil.

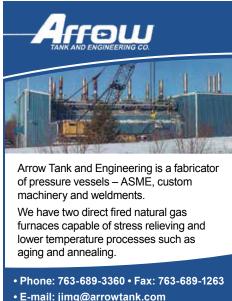
With a constantly evolving industry, Woźniak said SECO/WARWICK is poised to be ready for a quick change in order to adjust to any market situation.

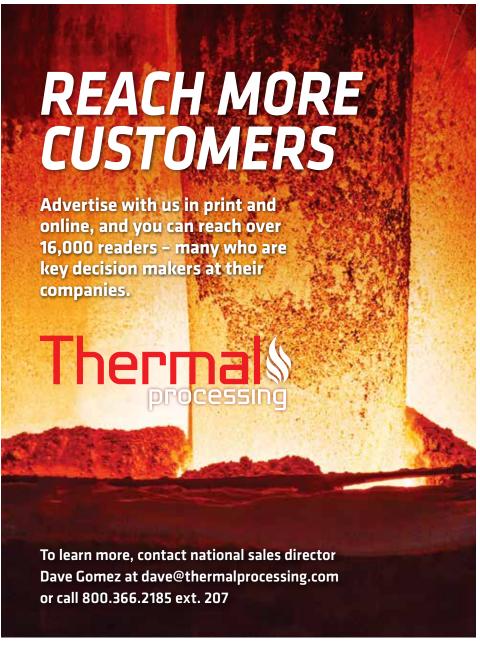
"We see less people involved in the heat-treatment process because complete heat-treatment plants or commercial heat treaters in particular will be more and more fully automated; you can plan completely the layout of the heat-treatment plant and then also have a supervisory control system to manage a complete plant to use less energy or use it more efficiently and then also plan better ways to utilize your existing equipment," he said. "As the manufacturer and supplier of industrial equipment for the heat-treatment industry, we have to watch all of this and be ready to offer the best solutions for our customers so they can get the best benefit out of our equipment."

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Q&A /// INTERVIEW WITH AN INDUSTRY INSIDER



JEFF MARSHALL /// VP AND GENERAL MANAGER /// METALLURGICAL HIGH VACUUM CORP

"Our customers are coming to us with a wide variety of service questions, and we're troubleshooting entire systems now."

What does Metallurgical High Vacuum Corporation do for the industry?

We remanufacture pumps. That's probably the core of our business, but that's changing because of what's happened over the last two years. Our customers are coming to us with a wide variety of service questions, and we're troubleshooting entire systems now, not just pumps.

In addition to that, customers have asked us to start designing equipment that we hadn't designed before, which are related to the heat-treat business. For instance, one example is we're being asked to design a furnace door and then manufacture it for this customer. Another example is we designed and manufactured a rotary feed test stand. The customer called us and said, "You are repairing our vacuum equipment. Can you design this?" We looked at it and said, "Yes. We've got the engineering expertise. We'll do it." We designed it and manufactured it in eight weeks. So, we've become much more diverse in what we do. It is a more turnkey approach.

What steps need to be taken in order to analyze and restore pumping equipment to OEM specifications and tolerances? What do you do to make that happen?

In our particular case, first it's the analysis. We will tear a pump down, take all the measurements and compare them to what the OEM specifications are. If it requires replacing a worn part, we'll purchase and install or manufacture it. We machine other parts onsite that can be returned to OEM specs to make sure everything is exactly to those specifications. By not outsourcing our machining, we control quality. But we don't stop there.

Our testing is rigorous and validates the pump will perform when installed. A standard test is to run the pump for 20 hours. But that simply tells you that the pump runs. It doesn't tell you how well it functions in the process. We have a test stand, which we constructed with PLC controls, that has the capability to draw the pump down to process required levels. It is measured against the performance to the published curves of when that pump came off the assembly line. It has to match up, or we go back in and determine what has to be done.

Your onsite services include predictive maintenance and preventive maintenance. What's the difference between them?

Predictive maintenance is being able to determine ahead of time, "This equipment will approach failure in this number of hours." Preventive maintenance is maintaining the equipment and extending its life-cycle as long as possible. That's how to distinguish between the two terms. We just recently had a customer who came to us and asked, "What can we do so that we don't have process interruptions? These pumps are unreliable and failing frequently." We developed a monitoring program that included testing the pump oil at regular

intervals. Oil cleanliness has a direct bearing on pump failure in many cases — especially in liquid ring pumps. Every month we'll sample the oil on that particular series of pumps and determine the solids content. When it gets to a point where oil needs to be changed, that's the point where we now have set the preventive maintenance schedule. We've also taken that a step further and looked at one of our customers, who is cutting edge. Vibration analysis has been performed, and a baseline has been established. We worked together and developed a run time setpoint for the pumps. In a certain number of hours, each pump is pulled before it goes to failure. Because this procedure has been established, the re-manufacture cost is substantially reduced.

You're able to reverse engineer obsolete parts. How do you approach a customer when they bring you that challenge?

We'll review the economics. If he's a large customer and has a pump that is obsolete, which he does not want to replace, we will reverse engineer and produce it. If it's a machined part, we'll make a CAD drawing properly toleranced with material and heat-treatment callouts as needed. If it's a casting, we'll make a CAD drawing and get a foundry to quote on patterns and the casting. And then we machine it. We've got four CNC Mazaks, and we'll turn the obsolete part into an exact replica. That engineering is how we've propelled ourselves into the newer field of designing things that are related to the pump systems but not part of the pump system.

Where do you see the industry in the next decade and your place in that future?

Most industries have had a hiccup, but especially in aerospace. But currently, that industry is rebounding nicely. Our place in that future is to assist customers with improving their systems, reducing equipment costs and maximizing production time.

What types of aerospace projects do you work on?

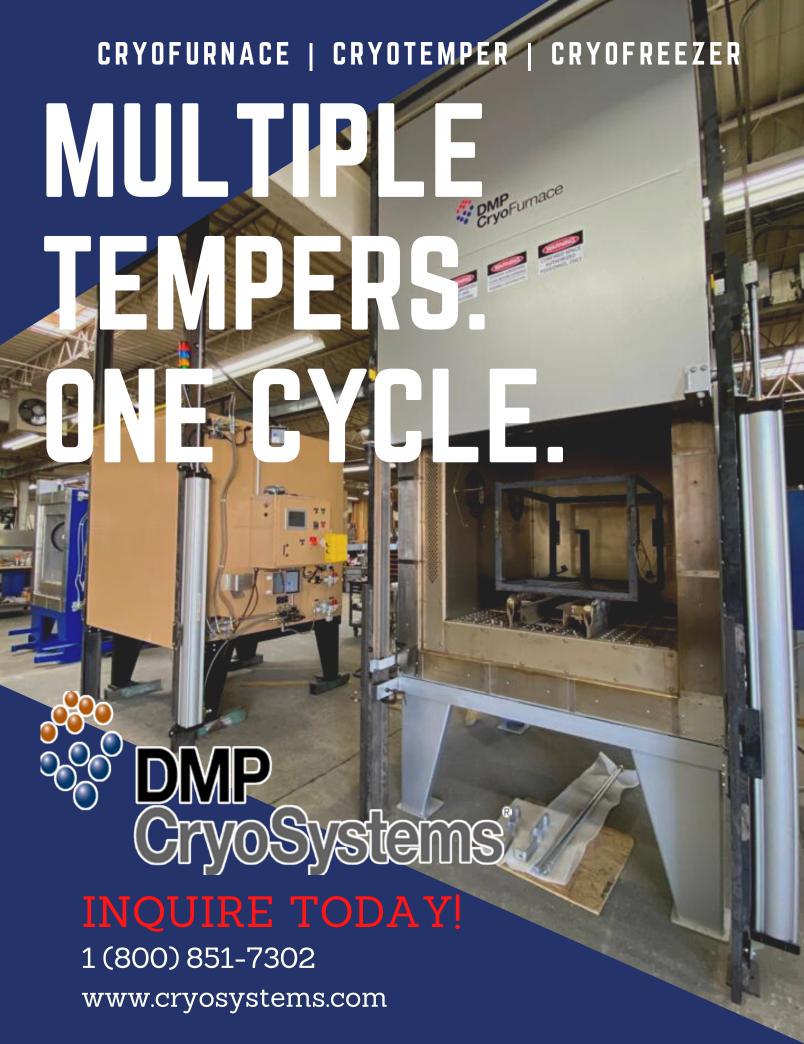
We work with the subcontractors, who are the companies that make jet engines, turbine blades — all of the vacuum heat-treat processes. This includes the titanium and aluminum processed parts that are assemblies in commercial and military aircraft.

Anything else you'd like to mention?

Heat treating is a stable business. Our service business was 5 percent of our gross revenue, but with the shift in demand, we are now growing at 20 to 25 percent in that sector. And that's not just standard preventive maintenance, that's heavy trouble shooting of entire systems.

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