MICROALLOYED STEELS FOR HIGH-TEMPERATURE CARBURIZING

FLOWMETER OVERVIEW – PT 2

PAGE 7

PAGE 10
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Editorial Opportunities for HTPro in 2014

The editorial focus for HTPro in 2014 reflects some key technology areas wherein opportunities exist to lower manufacturing and processing costs, reduce energy consumption, and improve performance of heat treated components through continual research and development.

November

Atmosphere/Vacuum Heat Treating

To contribute an article to one of these issues, please contact Frances Richards at frances.richards@asminternational.org. To advertise, please contact Erik Klingerman at erik.klingerman@asminternational.org.

7 DEVELOPMENTS IN MICROALLOYED COARISING-RESISTANT STEELS FOR HIGH-TEMPERATURE CARBURIZING

Marvin McKimpson

There is growing interest in steels microalloyed with titanium, niobium, and molybdenum for use in high-temperature carburizing applications.

10 OPERATIONAL PRINCIPLES OF FLOWMETERS: PART 2

Daniel Herring

Flow measurement is an increasingly important part of quality control systems in the heat treating industry.

TABLE OF CONTENTS
TMI ATC Project Moving Forward

The Thermal Manufacturing Industries Advanced Technology Consortium (TMI ATC) AMTech project led by ASM International was formed to lead and coordinate a national effort that identifies common thermal manufacturing needs across industries and solicits input from key stakeholders. Roadmapping workshops will identify technologies ready for implementation in thermal manufacturing industries, as well as high-priority areas for development.

In support of this effort, a diverse group of experts including Heat Treating Society members are being surveyed to identify barriers and opportunities for advancement in thermal manufacturing. This information will provide a picture of the state of thermal manufacturing, and help shape the process for conducting workshops. Planned workshops include one at Furnaces North America, October 9–10 in Nashville, Tenn., with a stronger focus on heat treating, and one at MS&T 2014, October 16–17 in Pittsburgh, with a stronger focus on other thermal processes (melting, drying, curing, etc.).

CALL TO ACTION!

Please provide your responses to the following survey questions keeping in mind your specific area/expertise in thermal manufacturing:

• What is your role/area of activity in thermal manufacturing?
• What are the major opportunities for advanced manufacturing technology in your area of thermal manufacturing?
• What specific technology or technologies would make the largest impact?
• What are the primary barriers to implementation of advanced manufacturing technology in your area of thermal manufacturing (e.g., cost, lack of available technologies, staff constraints)?
• What needs can the TMI ATC fulfill for you?
• What type of engagement would be most valuable to you?
• What financial and resource commitments are you willing to make to participate in TMI ATC?

HTS will be represented at these workshops, so please provide your input by sending responses to stan.theobald@asminternational.org.

First ASM HTS/Surface Combustion Emerging Leader Award to Be Presented in 2015

The ASM HTS/Surface Combustion Emerging Leader Award was established in 2013 to recognize an outstanding early-to-midcareer heat treating professional whose accomplishments exhibit exceptional achievements in the heat treating industry. The award was created in recognition of Surface Combustion’s 100-year anniversary in 2015.

The award acknowledges an individual who sets the “highest standards” for HTS participation and inspires others around him/her to dedicate themselves to the advancement and promotion of vacuum and atmosphere heat treating technologies.

Rules for submitting nominations:
• Candidates must be a member and an active participant in ASM International and HTS.
• Nominees must be 40 years of age or younger and employed full time in the heat treating industry for a minimum of five years.
• Candidates must be submitted by an ASM International or HTS member.
• Three letters of recommendation must be submitted with the nomination form. Nominations should clearly state the nominee’s impact on the industry and/or service and dedication to the future of the HTS.
• The award shall be presented to one recipient every two years at the General Membership Meeting at the HTS Conference and Exposition.
• **Recommendations must be submitted to ASM Headquarters no later than April 1 in the year in which the award is to be presented.**
• **The first award will be presented in 2015.**
• Winner receives a plaque and $4000 cash award funded by Surface Combustion.

A selection committee consisting of five members will be appointed every two years by the HTS Awards and Nominations Committee. Three members of the selection committee will be appointed by Surface Combustion. The selection committee will submit a report for approval by the HTS Awards and Nominations Committee and the HTS Board, which shall include the rationale and documentation used for award selection.

For rules and nomination form for the ASM HTS/Surface Combustion Emerging Leader Award, visit the Heat Treating Society Community Website at http://hts.asminternational.org and click on Membership & Networking and HT Awards.

CALL TO ACTION!

Please provide your responses to the following survey questions keeping in mind your specific area/expertise in thermal manufacturing:

• What is your role/area of activity in thermal manufacturing?
• What are the major opportunities for advanced manufacturing technology in your area of thermal manufacturing?
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• What financial and resource commitments are you willing to make to participate in TMI ATC?

HTS will be represented at these workshops, so please provide your input by sending responses to stan.theobald@asminternational.org.

Stan Theobald
**Senior Director, Business Development**
ASM International
HTS Names New Board Members for 2015

The HTS Board, at the recommendation of the Awards and Nominating Committee, named new board members including Timothy DeHennis, Eric Hutton, and Zbigniew Zurecki Sr., to serve on the HTS Board for the 2014–2017 term; Lee Rothleutner to serve as student board member for the 2014–2015 term; and Piyamanee Komolwit to serve as young professional board member for the 2014–2015 term. Terms begin September 1, 2014. Remaining on the board are Roger A. Jones (president), Steve Kowalski (vice president), Thomas Clements (past president), John Keough (board liaison), William Disler (member), Robert Goldstein (member), Richard Howell (member), Stephen Mashl (member), James Oakes (member), and Jin Xia (member).

Tim DeHennis is a senior metallurgist at The Boeing Co., Military Aircraft Div. in Philadelphia. With the company for more than 15 years, he is responsible for technical oversight of the manufacture of gears, bearings, and other flight critical components, support of failure investigations, and process development including investigating low pressure carburizing, high-pressure gas quenching, and corrosion resistant gear and bearing materials. Tim is currently Boeing Materials Engineering’s subject matter expert and prime technical contact pertaining to heat treatment and gear manufacturing of CH-47 Chinook helicopter components. He received his B.S. in materials science and engineering from Pennsylvania State University in 1999, and is currently pursuing an M.S. degree from Drexel University in the same discipline.

Eric Hutton is vice president of operations, Automotive North America, Bodycote Thermal Processing Inc., Detroit, responsible for sales and operations of 11 Bodycote plants located in the U.S., Canada, and Mexico. Before joining Bodycote in 1998, he was employed at Michigan Induction. He received his B.A. in marketing from Bob Jones University and his MSM from Walsh College of Accountancy. Eric has 20 years of experience in commercial heat treating, and his well-rounded background in the automotive industry and executive experience with Bodycote provides a valuable foundation for working with HTS leadership. Eric has been involved in Heat Treating Society activities including the Heat Treat Conference and Expo and HTS Committees, and is a member of the ASM Detroit Chapter.

Zbigniew Zurecki is research associate at Air Products & Chemicals Inc., Allentown, Pa. He has spent the past 30 years in research aimed at the development of new industrial gas application technologies for processing metals in the heat treating, powder and process metallurgy, thermal spray coatings, combustion, metalforming, and electronics packaging industries. His new technological alternatives resulted in improved product quality and increased productivity of industrial operations. Zbigniew has over 30 U.S. patents with multiple foreign derivatives, and has authored papers in about 60 publications. He is a graduate of Politechnika Warszawska, Poland, with a degree in mechanical technologies, and of Drexel University with a degree in materials engineering.

Piyamanee Komolwit is senior engineer, surface technology, Kennametal, Latrobe, Pa. Joining the company in 2010, she is technical lead for the heat treatment competency team, responsible for global heat treatment capability, quality control on heat treatment processes, and related equipment and consumables at all Kennametal plants. Prior to that, she was research associate, Carnegie Mellon University, Pittsburgh, and research assistant, Thailand Environmental Institute, Bangkok. Piyamanee earned a Bachelor of Engineering in metallurgical engineering at Chulalongkorn University, Bangkok, Thailand, in 1996; an M.S. in environmental management at the University of San Francisco in 2002; and an M.S. and Ph.D. in materials science and engineering at Carnegie Mellon University in 2005 and 2009, respectively. She coauthored several conference papers. She served as a volunteer for various ASM activities and served as a member of the executive committee of the ASM Pittsburgh Chapter.

Lee Rothleutner is a graduate research assistant and Ph.D. candidate in materials science and engineering (2015) at the Colorado School of Mines, Golden. His research focuses on linking structure, processing, and properties in ferrous alloys. Specific areas of interest include induction processing, phase transformations, precipitation, and fatigue. Lee also earned a B.S. and M.S. in materials science and engineering at Colorado School of Mines in 2009 and 2012, respectively. He served as student representative to the Advanced Steel Processing and Products Research Center (ASPPRC) Industrial Advisory Board and as a teaching assistant for a statistical process control (SPC) course. He authored and coauthored several journal papers and conference presentations. Lee served in the U.S. Coast Guard (2000–2005).

Heat Treating Society Looking for Volunteers

Get Involved! Serve on a Heat Treating Committee!

The HTS Board is seeking enthusiastic, committed members to serve on various HTS Committees. HTS committees monitor technical advances and other areas of member interest to bring new information to members through products and services including conference and exposition programming, course development, reference and periodical publications, and research and development planning and implementation. The Board is currently looking for members for the following committees:

- Awards and Nominating Committee
- Education Committee
- Technology & Programming Committee
- Exposition Committee
- Finance Committee
- Membership Committee
- Research and Development Committee

Interested members should review the Committee Purpose on the HTS website and contact sarina.pastoric@asminternational.org.
Pershing Receives CHTE Award for Outstanding Service

Michael Pershing, senior technical steward, Caterpillar Inc., Mossville, Ill., received the Center for Heat Treating Excellence (CHTE), WPI, Worcester, Mass., Award for Outstanding Service. Each year, CHTE acknowledges the accomplishments of a person, who in the judgment of the board made significant, commendable, and long-standing contributions to the promotion of CHTE. Criteria include membership in good standing for a minimum of three years and exceptional contributions to CHTE. Pershing is a member of the Heat Treating Society.

Soliciting Papers for ASM HTS/Bodycote ‘Best Paper in Heat Treating’ Contest

This award was established by HTS in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in a substantial way, or represents a clear advancement in managing the business of heat treating. The award is endowed by Bodycote Thermal Process-North America.

The contest is open to all students, in full time or part time education, at universities (or their equivalent) or colleges. It also is open to those students who have graduated within the past three years and whose paper describes work completed while an undergraduate or post graduate student. The winner receives a plaque and check for $2500.

To view rules for eligibility and paper submission, visit the Heat Treating Society website at hts.asminternational.org/portal/site/hts/HTS_Awards.

Paper submission deadline is December 12. Submissions should be sent to Sarina Pastoric, ASM Heat Treating Society, 9639 Kinsman Rd., Materials Park, OH 44073, 440.338.5151 ext. 5513, sarina.pastoric@asminternational.org.

CALL FOR PAPERS

HT 2015 – 28th ASM Heat Treating Society Conference and Exposition
October 20-22, 2015
Cobo Convention Center
Detroit

The ASM Heat Treating Society and the American Gear Manufacturers Association once again are co-locating to create an exciting mix of education, technology, networking, and exposition opportunities—all at the 28th Heat Treating Conference and Exposition and Gear Expo. It is the event recognized by industry, academia, and government professionals as the premier heat treating gathering in North America. The event will offer a full technical program covering a broad scope of heat treating technology, networking opportunities, and a first-hand look at equipment, supplies, and services from exhibitors.

HTS 2015 organizers are seeking original, previously unpublished, noncommercial papers for oral and poster presentations. Technical areas of interest include, but are not limited to, the following:

- Advances in Heat Treating
- Aluminum, Titanium, Copper Alloys, Refractory Metals
- Applied Energy
- Atmosphere Technologies and Process Controls
- Brazing
- Cleaning Processes and Control
- Deep Cryogenic Treatment of Metals (and Some Non-Metals)
- Emerging Technology
- Energy Conservation
- Equipment Innovations
- Global Issues
- Heat Treating in Additive Manufacturing Processes
- Heat Treating of MMC, CMC, and Ceramic Materials
- Heat Treating Processes for Production of Advanced High Strength Steels
- Heat Treatment for Producing Nanostructured Steels
- Lean Heat Treating Processes
- Light Metals
- New Processes for Bainitic Alloys
- Processes and Applications
- Quenching and Cooling
- Surface Engineering
- Thermal Processing of Carbon Fiber Composite Materials
- Vacuum Processes and Technology

Abstract submission deadline: January 26, 2015. Visit the HTS website for details on submitting an abstract: hts.asminternational.org, and click on Events tab.
CALLING ALL AUTHORS!

Share your latest information with the Heat Treating community through an oral or poster presentation at Heat Treat 2015!

Only a few months remain to submit your paper! Presenting at Heat Treat 2015 gives you a chance to display your work in front influencers and decisions makers in the heat treating industry.

Visit asminternational.org/heattreat to submit your paper for consideration.

Deadline: January 26, 2015

Exhibitor space is 75% sold out! Reserve your space today!
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Because alloy steel hardenability is such an important factor in part manufacturing, the Center for Heat Treating Excellence (CHTE) is conducting research aimed at learning more about the performance of gas quenching systems used to harden newer alloy steels. The primary goal of the study is to establish a standard method to evaluate gas-quench steel hardenability. Heat transfer coefficients will be determined for different gas pressures and during the cooling phase.

“The world is improving its alloys,” notes Richard D. Sisson, George F. Fuller professor of Mechanical Engineering at WPI and director of CHTE. “New alloys are being developed to be much harder and to be processed by gas quenching, and we need to understand how these alloys perform. We also need to be able to characterize how fast new furnace designs can cool the part.”

Another objective of the research project is to evaluate the cooling performance of high-pressure gas-quench systems. Researchers will explore what equipment is needed and what conditions are required to ensure the desired hardenability standard.

CHTE member Lynn Ferguson of DANTE Solutions explains, “Newer furnaces with higher cooling capability can quench using gas pressures of 10 to 20 bar. High-pressure gas quenching (HPGQ) is gaining market share in the United States, but because gas quenching is a slower process than oil quenching, hardenability becomes more critical.”

Though it is a slower process, HPGQ is displacing oil quenching, especially in Europe, because it avoids part discoloration, quenching vapors, potential for fires, and other cleanliness and environmental issues associated with the use of oil.

The project is being conducted through simulation and lab testing, with much of the work being carried out simultaneously. Researchers are working with commercial software companies like DANTE Solutions, Dassault Systèmes Simulia Corp. (ABAQUS) and Sente Software Ltd. (JMatPro), whose software can simulate the response of heat-treated parts. Specifically, simulations help researchers understand the relationship between steel hardenability and cooling performance in gas-quench systems. The simulations also help predict the actual behavior of the parts given the amount of gas used.

Currently, lab testing is being conducted at WPI and will eventually be conducted in manufacturing facilities. Notes Kevin Rong, Higgins Professor of Mechanical Engineering and director of the Computer-Aided Manufacturing Laboratory at WPI, and principal investigator for the project, “In our testing to date, we compared liquid quenches with gas quenches to identify how the microstructures of the material behave and determine the differences. The findings have been interesting.”

About CHTE
The CHTE collaborative is an alliance between the industrial sector and university researchers to address short-term and long-term needs of the heat-treating industry. Membership in CHTE is unique because members have a voice in selecting quality research projects that help them solve today’s business challenges.

Member research process
Research projects are member driven. Each research project has a focus group comprising members who provide an industrial perspective. Members submit and vote on proposed ideas, and three to four projects are funded yearly. Companies also have the option of funding a sole-sponsored project. In addition, members own royalty-free intellectual property rights to precompetitive research, and are trained on all research technology and software updates.

CHTE also periodically undertakes large-scale projects funded by the federal government or foundations. These endeavors keep members informed about leading edge technology.

CHTE current research portfolio
Other projects now in progress include: Nondestructive Testing for Hardness and Case Depth, Induction Tempering, Gas Quench Steel Hardenability, Enhancements to CHTE Software (CarbTool, CarboNitrideTool, and NitrideTool), and Cold Spray Nanomaterials (supported by ARL).

For more information about CHTE, its research projects, and member services, visit wpi.edu/+chte, call 508.831.5592, or email Rick Sisson at sisson@wpi.edu, or Diran Apelian at dapelian@wpi.edu.
DEVELOPMENTS IN MICROALLOYED, COARSENING-RESISTANT STEELS FOR HIGH TEMPERATURE CARBURIZING

THERE IS GROWING INTEREST IN STEELS MICROALLOYED WITH TITANIUM, NIOBIUM, AND MOLYBDENUM FOR USE IN HIGH-TEMPERATURE CARBURIZING APPLICATIONS.

Marvin McKimpson,* Caterpillar Technical Center, Mossville, Ill.

There is growing interest in steels, particularly carburizing steels, that have improved resistance to austenite grain coarsening during heat treating. The driver for much of this interest is the increased use of low-pressure (i.e., vacuum) carburizing furnaces in commercial heat treating operations. These furnaces are capable of processing steels at higher temperatures and substantially shorter cycle times than conventional atmosphere furnaces. The higher-temperature capability is due to both furnace construction and a lower potential of the furnace to cause intergranular oxidation in the steels being processed.

Figure 1 shows that increasing carburizing temperature from 950° to 1050°C (1740° to 1920°F) potentially can shorten carburizing time by up to 60%\(^1\). However, when carburized above 950°C, many current commercial steels show excessive austenite grain size coarsening. For example, Fig. 2 shows the grain growth in a commercially available modified SAE 4120 steel vacuum annealed at 1100°C (2010°F) for 10 hours. The large grain size is apparent, with grains approaching 1 mm in size. Such grain coarsening degrades both the toughness and fatigue resistance of carburized components, and is generally not acceptable for commercial products.

**Grain coarsening control**

Most commercial carburizing steels rely on submicron aluminum nitride (AlN) precipitates to control grain size coarsening during heat treating. The nitrides pin austenite grain boundaries, restricting grain growth. Unfortunately, at temperatures above 950°C, the particles begin to coarsen and dissolve, allowing austenite grain growth. Research organizations worldwide are exploring ways to improve coarsening resistance of these steels by incorporating submicron precipitates (generally either nitrides or carbides) having greater thermal stability than AlN. The additional precipitates both increase the volume fraction of particles available to retard austenite grain boundary migration and resist precipitate coarsening (i.e., Ostwald ripening) more effectively than AlN.

Only a few elements, primarily titanium, boron, and niobium, form nitrides, carbides, and carbonitrides likely to be useful for improving austenite grain coarsening resistance. Early research focused on using titanium nitride (TiN) due to its high thermodynamic stability. This work showed that titanium additions to steel can substantially improve grain coarsening resistance. Unfortunately, as is well known within the industry, even small titanium additions often lead to large cuboidal TiN or Ti(N,C) inclusions that degrade both the toughness and fatigue resistance of the steel. Accordingly, using titanium for grain size control in commercial alloys is likely to require very careful control of steelmaking practices.

Recent work has focused on using niobium, or a combination of niobium and titanium, to improve austenite grain coarsening resistance. Consider, for example, a carburizing steel with microalloy additions of both titanium and niobium. If titanium levels are sufficiently low to avoid formation of large cuboidal TiN particles in the melt (typically 0.02 wt% or lower), only small TiN precipitate particles form in the steel as it cools through the austenite temperature range.

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*Member of ASM Heat Treating Society
ture region. Then, as the steel is hot worked, niobium carbide (NbC) and/or carbonitride precipitates also form, sometimes on preexisting TiN nuclei. For example, Fig. 3 shows a TiN cuboid approximately 30–40 nm in size (gray phase) containing numerous coprecipitated Nb(C,N) particles (white phase).

Molybdenum additions
Additional research indicates that supplementing titanium and niobium microalloy additions with molybdenum can be particularly attractive for improving austenite grain coarsening resistance. For example, a recent U.S. Department of Energy study shows that a modified SAE 4120 steel containing nominally (wt%) 1.1 Cr, 0.4 Mo, 0.02 Ti, 0.06 Nb, and 260 ppm nitrogen has substantially better coarsening resistance during simulated carburizing cycles than a similar modified SAE 4120 steel without Ti and Nb additions[2]. Figure 4 shows the prior austenite grain size of this quenched and tempered microalloyed steel after various thermal cycles. After holding at 1050°C for 8 hours, the material still exhibits an ASTM grain size number of 6 or finer. For comparison, the control material with no Ti or Nb additions shows a duplex prior austenite grain size ranging from ASTM grain size number 5 down to 2 after holding at 900°C (1650°F) for 8 hours.

Researchers at the Colorado School of Mines, Golden, are working to better understand the role that molybdenum plays in improving austenite grain coarsening resistance. In a recent study, Enloe looked at several microalloy-modified SAE 4120 steels containing nominally (wt%) 0.01 Ti, two different levels of Nb (0.04 and 0.1), and two different levels of Mo (0.01 and 0.3)[4]. These steels were given various thermal processing sequences and examined using a combination of optical and electron microscopy, precipitate extraction, and atom probe tomography. Results show that molybdenum additions cause a significant decrease in the rate of carbide and nitride precipitate coarsening. In addition, molybdenum tends to partition from the precipitates to the austenite during extended holding times at elevated temperature. However, molybdenum enrichment at the precipitate-matrix interface is not observed. Accordingly, the observed decrease in carbonitride particle coarsening is probably not due to Mo segregation at this interface.

Commercialization
Despite extensive ongoing research, commercialization of microalloyed coarsening-resistant steels appears to be proceeding slowly due to several factors. Because these alloys are likely to be of greatest value to companies interested in low-pressure carburizing, market pull for these materials is somewhat smaller than that for other steels. In addition, because development of microalloyed, coarsening-resistant steels is a dynamic international research topic, a careful review of global patent literature may be needed before determining how new intellectual property can be

Fig. 3 — A 30–40 nm cuboidal titanium-nitride (TiN) particle (gray) containing fine niobium carbonitrides Nb(C,N) (white). Source: Ref 3.
protected most effectively. Finally, optimized steelmaking practices, including hot working, are critical for successful commercialization of these alloys, and this optimization can be challenging with the small heat sizes typically used for new steel compositions targeted toward emerging markets.

Nevertheless, progress is being made. The German company Buderus Edelstahl GmbH is active in this area and has reportedly supplied custom heats of microalloyed case-hardening steels to some customers. Recent work at Buderus is described by Hippenstiel [5]. Other industrial activities related to commercialization are summarized by Mohrbacher [6]. The potential benefits of microalloy additions for pinning austenite grain boundaries could also extend beyond carburizing alloys. Jansto notes that rolled medium- and high-carbon steels can also benefit from such additions [3]. In this case, the microalloy additions minimize grain coarsening and grain size variations caused by temperature fluctuations and inhomogeneities during reheating and hot rolling. This, in turn, can facilitate development of new, ultrafine grain steels with improved toughness, strength, and uniformity compared with current products. HTPRO

References

Acknowledgment: A portion of the work described in this article was supported by the U.S. Department of Energy under Award No. DE-EE0003474.

PART 2
OPERATIONAL PRINCIPLES OF FLOWMETERS

Once a “set it and forget it” technology, flow measurement is an increasingly important part of quality control systems in the heat treating industry.

Daniel H. Herring,* The Herring Group Inc., Elmhurst, Ill.

In most heat treating applications, important flowmeter selection criteria include reliability, accuracy, ruggedness, ease of calibration, and ease of maintenance. Given the high accuracy and reliability of today’s instruments, users can run their processes more economically. Part 1 of this article (June 2014 HTPro) discussed the most commonly used flow measurement instruments and compared their operating principles. This article covers selection basics, sizing, mass flowmeter overview, and FAQs about flowmeters.

Flowmeter Selection Basics
There are many flowmeter features that must be considered to select the one that best meets the requirements of the application (Table 1). The first step in selecting a flow sensor is to determine if the required flow rate information should be continuous or totalized, and whether these data are needed locally or remotely. If remotely, should the transmission be analog, digital, or modally. If remotely, should the data be continuous or totalized? And, if shared, what is the required minimum data-update frequency? Once these questions are answered, the properties and flow characteristics of the process fluid (gas or liquid), and the properties and configuration of the piping that will accommodate the flowmeter should be evaluated.

Next, determine the required flowmeter range by identifying the minimum and maximum flows (mass or volumetric) that will be measured and the required flow measurement accuracy. Typically, accuracy is specified in percentage of actual reading, percentage of calibrated span, and percentage of full-scale units. Accuracy requirements should be separately stated at minimum, normal, and maximum flow, otherwise meter performance might not be acceptable over its full range.

Representative mass flowmeter. Courtesy of MKS Instruments.

Flowmeter sizing
When purchasing a new flowmeter to measure gas flow in heat-treating applications, it is important to remember the distinction between the operating range and design range of the instrument. Some variable-area flowmeters offer full-scale operation, while others offer a limited range such as “not below 25% and not above 90% of scale capacity.” For example, a flowmeter rated for 0 to 2000 cubic feet per hour (cfh) only provides accurate readings when the flow is between 500 and 1800 cfh.

If flow measurement must cover a wide flow range, select a flowmeter that has a high turndown. An alternative, but costly, approach is to install several flowmeters of different sizes with automatic or manual switching based on flow range.

A rule of thumb for sizing a flowmeter is to purchase one “in the middle third,” that is, size it so the actual flow will be no less than 33% and no higher than 67% of the scale selected. This enables compensating for unexpected changes in flow requirements that might occur during actual operation. Over the life of a flowmeter, or in the event of unexpected changes in the flow rate, it is necessary to recalibrate the flowmeter.

Is it easier to control a gas or a liquid?
Liquids are easier to measure and control because of their small compressibility. For most volumetric flow applications, it is not necessary to closely control the incoming pressure in liquid systems. By their nature, liquids are easily captured and measured to a high degree of accuracy. By comparison, gases, due to their compressibility, require more complex sensing and control methods.

Is it necessary to maintain flow devices?
All flowmeters eventually require maintenance, and some units require more maintenance than others, so this factor should be considered when selecting a unit. However, in most heat-treating operations, the equipment manufacturer has already made that choice for you, so understanding what maintenance is required and when it should be performed is of paramount importance.

Flowmeters have moving parts and require internal inspection, especially if the fluid is dirty or viscous. For example, in furnaces using endothermic gas, flowmeters often become contaminated with soot (carbon) and must be cleaned by carefully disassembling the flowmeter and cleaning all internal moving parts, plus replacing the dirty fluid in the flowmeter tube. CAUTION: This involves isolating the flowmeter, or performing maintenance when the unit is shut down, and must be done in a safe manner.

*Member of ASM International

FLOWMETER DESIGN RANGES

<table>
<thead>
<tr>
<th>Flowmeter Type</th>
<th>Design Range</th>
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<tr>
<td>Variable-Area</td>
<td>“Not Below 25% and Not Above 90% of Scale Capacity”</td>
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<tr>
<td>Volumetric</td>
<td>“In the Middle Third”</td>
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<tr>
<td>Mass</td>
<td>“In the Middle Third”</td>
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For a variable-area rotameter, if it is necessary to know the proper flow rate, be aware that a change in temperature, pressure, or specific gravity of the gas from that for which the meter was calibrated will cause a serious error in the indicated scale reading. It is quite common in a heat treat shop to find flowmeters operating at pressures and temperatures different from those for which they were calibrated.

### Mass flowmeters

Thermal-mass flowmeters also are used by heat treaters. In most industrial-grade devices, gas enters the flow body and divides into two flow paths. Most of the flow goes through the laminar-flow bypass, creating a pressure drop that forces a known fraction of the flow through the sensor tube (Fig. 1). A power supply is used to direct a constant amount of heat into the gas stream. Resistance temperature-detector (RTD) coils are placed around the bypass sensor tube at its upstream and downstream ends. Heat is transferred to the molecules of the flowing gas, independent of pressure and temperature fluctuations.

The gas flow carries heat from the upstream coil to the downstream coil. Therefore, the downstream coil has a higher temperature and more resistance than the upstream coil. The coils are legs of a bridge circuit with the resultant output voltage proportional to the difference between the coils’ resistance, which, in turn, is proportional to the mass flow rate. The two other parameters...
thers, heat input and coefficient of specific heat, are constant.

Another type of mass flowmeter uses one flow channel with a temperature sensor located in the path of the flow. The technology is simpler, but often less accurate, and is limited to higher flow rates.

**Accuracy and repeatability**

Thermal-mass flowmeters are gas-specific devices, and they must be calibrated using either the actual gas or a reference gas. This inconvenience led to the development of many “fixes,” and drives the development of smarter devices. However, primary calibration using the actual gas or a gas of similar molecular characteristics is currently the only way to ensure accuracy.

Two factors that determine the accuracy of mass flowmeters and mass flow controllers are flow calibration and repeatability. Proper instrument calibration ensures starting point accuracy. Repeatability is the measure of continuous performance-to-specification over the lifetime of the device. Most mass flowmeters and mass flow controllers have an accuracy of ±1% of full scale and a repeatability of ±0.25% of full scale.

Several factors affect repeatability. Highly stable materials and electronic components, as well as precise internal voltage and current regulation are used to compensate. Sensor and bypass design also play a major role in preventing errors caused by contamination and clogging. For example, U-type sensor tubes exhibit residual stresses from bending, which can cause long-term strains and unraveling of sensor coils. These sensors are also more likely to develop drift due to contaminant deposits.

Consideration should also be given to the bypass element. Accuracy is degraded by changes in temperature if the bypass is an orifice (or venturi), as opposed to a pure laminar-flow element. With an orifice bypass, the pressure drop is proportional to the square of the bypass flow. In this case, the ratio of bypass flow to sensed flow is not a constant, but instead is a complex nonlinear function having temperature-dependent terms such as gas viscosity.

Both the nonlinearity and temperature dependence of the orifice bypass can seriously degrade the accuracy of a mass flow controller.

**Mass flowmeters for use with vacuum furnaces**

A common heat processing application of thermal mass flowmeters and mass flow controllers is maintaining a specified gas flow rate into a vacuum chamber when the process requires a partial pressure of additive gas. Typically, a throttle valve or an orifice-limiting device is used to control the output of a vacuum pump. This is an extremely pressure-sensitive method and can result in inefficient gas delivery and poor product quality. Mass flow controllers automatically compensate for changes in system pressure caused by vacuum pump fluctuations and deliver a precisely controlled gas flow rate to the chamber.

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