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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.

- **September**  
  Surface Engineering

- **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.
ASM to Lead Thermal Manufacturing Industries
Advanced Technology Consortium

Thermal manufacturing, consisting of heat treating, melting, and other process heating methods, is used in nearly every manufacturing facility in the U.S. It affects the employment of an estimated 8.3 million Americans at more than 262,000 companies, according to the U.S. Census Bureau. The Bureau says these companies (98% of which are small and medium enterprises) produce $3.4 trillion in total value of annual shipments.

Advanced thermal manufacturing technologies potentially can improve the efficiency, productivity, and global competitiveness of many U.S. materials manufacturing and value-added, end-user industries. However, technical challenges identified in previous roadmapping efforts (such as the Heat Treating Technology Road Map) are still preventing development and deployment of these technologies. The main reason is because these roadmaps were developed independently from one another by different industries that rely on or supply thermal equipment and processes as a critical part of their operations. Understandably, these thermal manufacturing industries focused primarily on their specific areas of interest. As a result, there has been a lack of the necessary coordination and critical mass needed to address the technical challenges facing these industries. In addition, there has been an incomplete transfer of available technologies to the small and medium enterprises that make up a large segment of the thermal manufacturing industries.

To address these issues, the proposed Thermal Manufacturing Industries Advanced Technology Consortium (TMI ATC) will be formed to lead and coordinate a national effort to develop and deploy advanced manufacturing technologies across the broad thermal manufacturing community, including equipment manufacturers and end users. Specifically, TMI ATC will lead the development of a comprehensive R&D roadmap that identifies common thermal manufacturing needs across industries and solicits the input from key stakeholders in highly interactive, action-oriented technology roadmapping workshops. The results of these sessions will identify advanced manufacturing technologies ready for implementation in thermal manufacturing industries as well as high-priority areas for development. This 18-month process will generate a final roadmap in the first year, and will then begin to implement the recommendations during the remaining months.

The proposed structure of the consortium will facilitate technology implementation and sustainability. TMI ATC will be led by ASM International through a federal grant. ASM, from its founding roots, and now primarily through its affiliate Heat Treating Society, is a leader in collecting and disseminating thermal-manufacturing information, and has many relationships with industrial companies.

The ASM Heat Treating Society has been involved for the past 15 years in identifying and prioritizing key initiatives in heat treating-related areas of equipment and hardware materials technology, processes and heat treated materials technology, and energy and environment technology. This puts the society in a prime position to extend this work with the cooperation of other consortium participants.

Ed Kubel
Contributing Editor
The winner of the 2014 HTS/Bodycote Best Paper in Heat Treating Award is a paper entitled “Development of Methodology to Improve Mechanical Properties of 319 Al Alloy Engine Blocks through Cost-Effective Heat Treatment Optimization,” by Anthony Lombardi. Mr. Lombardi is a third year Ph.D. candidate in mechanical engineering at Ryerson University (Toronto) under the supervision of Dr. C. (Ravi) Ravindran, ASM President. Lombardi is the recipient of the prestigious NSERC Alexander Graham Bell Canada Graduate Scholarship - Doctoral (CGS-D). The HTS/Bodycote award will be presented at the ASM Leadership Awards Luncheon, Monday, October 13, 2014, during MS&T in Pittsburgh.

The ASM Heat Treating Society established the Best Paper in Heat Treating Award in 1997 to recognize a paper that represents advancement in heat treating technology, promotes heat treating in some substantial way, or represents a clear advancement in managing the business of heat treating. The award includes a plaque and $2500 cash prize endowed by Bodycote Thermal Process-North America. Visit asminternational.org/hts to read the winning paper.

HS Looking for Volunteers for Committees

Whether you are a seasoned professional or just beginning your career in the heat treating industry, HTS members are encouraged to become more deeply involved in the society through committee membership.

HTS committees capture key directional shifts in member needs and translate those needs into action items for potential development. Their input and recommendations enable the HTS Board of Directors to establish effective policies, set meaningful budgets, and oversee society operations.

HTS Directors and committees meet on a regular basis. As the eyes and ears of the HTS Board, society committees are invaluable for improving service to HTS members and customers. Volunteers are needed to grow HTS permanent committees to meet these objectives. The committees include:

- **HTS Awards and Nominations Committee**, whose mission is to nominate candidates who are representative of commercial and captive heat treaters; users of heat treating; suppliers of materials and equipment; researchers, educators and government agencies involved in heat treating for the positions of president, vice president, and members of the Heat Treating Society Board as well as the development and recommendation of awards to be given by the Heat Treating Society.

- **HTS Finance Committee**, whose mission is to supervise the financial affairs of the Society under the direction and with the approval of the HTS Board. It reviews the financial plan of the Society and recommends it to the Board for action.

- **HTS Membership Committee**, whose mission is to understand current, past, and potential HTS member needs, refocusing efforts to provide improved member value. The committee is charged with understanding and interpreting member needs as well as achieving the financial contribution for HTS.

- **HTS Technology and Programming Committee**, whose mission is to develop programming and technical information that provides practical, leading-edge global technology; and to foster the exchange, education, understanding, and exposure of technology within the heat treating industry.

- **HTS Research and Development Committee**, which is charged to work with the heat treating community, the Center for Heat Treating Excellence, and other research institutions, to identify, monitor, and provide updates on worldwide research and technology development relevant to the industry.

- **HTS Education Committee**, which is charged to research, develop, and support education programs that best respond to the needs of the heat treating industry. The committee reviews courses and revises them as necessary, and develops new educational services related to heat treating.

To express your interest, or for more information, contact Sarina Pastoric at Sarina.pastoric@asminternational.org.

Ferguson receives IFHTSE Fellowship 2014 Award

Dr. B. Lynn Ferguson, FASM, president, Deformation Control Technology Inc., Cleveland, was honored at the 21st IFHTSE Congress, recently held in Munich with an IFHTSE Fellowship 2014 Award.

The citation reads: In recognition of globally acknowledged leadership in the development and practical implementation of principles and practices of mathematical modeling and their application to the benefit and advancement of heat treatment industry and surface engineering. Ferguson is a long-standing member of the ASM Heat Treating Society, and past member of HTS Board of Directors.
Heat treating companies spend a significant amount of time and money replacing furnace parts and furnace fixtures. Extending the service life of these components and reducing the time to heat them up and cool them down could result in considerable savings. The Alloy Life Extension Project currently under way at the Center for Heat Treating Excellence (CHTE), Worcester Polytechnic Institute (WPI), is aimed at solving those problems.

The focus of the project is identifying and testing alloys and coatings that can improve the service life of parts like fans, burners, rollers, tubes and mesh belts, as well as fixtures like wire baskets that carry the parts to be heat treated.

Researchers are also analyzing fixture design and material selection to reduce the energy needed to repeatedly heat fixtures. The goal is to find alloys for use in the heat treating industry that will last twice as long as current materials, resulting in significant savings.

According to Rick Sisson, George F. Fuller professor of mechanical engineering at WPI and director of CHTE, “Manufacturers are spending lots of money for alloy fixtures that go into carburizing furnaces. The goal of this study is to explore options that will allow industry to work more efficiently, lessening fixture replacement costs, reducing energy consumption, and improving product quality.”

The project has already produced some interesting findings. For example, the main reason for alloy failure is excessive carburization, which causes furnace parts and fixtures to become brittle and easily fracture. Based on this information, a series of carburization-resistant alloys have been identified for commercial furnace testing, including RA602CA, Inconel 625, and Stellite 250. Samples of these alloys are being tested at the facilities of CHTE member companies Sikorsky Aircraft and Bluewater Thermal Solutions.

Different alloys are being assessed for their resistance to oxidation and carburization at two Bluewater facilities in Illinois. Multiple sets of each alloy are run for different times in test furnaces, and one of each set is removed periodically to evaluate the extent of alloy degradation. Based on visual inspection, samples are removed for metallographic characterization.

Another test being carried out at Bluewater is aimed at determining whether an aluminized section of an industrial furnace mesh belt holds up better than regular mesh belts. Craig Zimmerman, technical director at Bluewater, explains, “Mesh belts last only nine months and they are extremely expensive to replace. We are hopeful that this study will help us and everyone in the industry to identify which materials can drive down costs. If we can make any of the parts and fixtures last longer, it will be a huge savings.”

**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 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/cchte, call 508.831.5592, or email Rick Sisson at sisson@wpi.edu, or Diran Apelian at dapelian@wpi.edu.
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SIZING QUENCH TANKS FOR BATCH IMMERSION QUenchING

A QUENCH TANK MUST CONTAIN SUFFICIENT FLUID TO QUENCH THE LOAD WITHOUT AN EXCESSIVE RISE IN TEMPERATURE OF THE QUENCHING FLUID.


The size of a batch immersion quench tank depends on the dimensions of the workload, as well as the allowable temperature rise. The temperature rise permitted is dependent on whether the quenchant is oil, water, or polymer.

In a batch operation, care should be taken to ensure that a sufficient amount of quenchant covers the top of the workload. The physical dimensions of the tank should be large enough to ensure full immersion of the quench load and fixtures, and, at the same time, should allow enough space for agitators and manipulators. Depending on the size of the workload, it is generally appropriate to have at least 150–300 mm (6–12 in.) of fluid over the top of the workload, and preferably more.

When using hot quenching oils, it is necessary to make an allowance for thermal expansion of the oil, either by making provision for an overflow system, or by manual adjustment of the fluid level.

**Tank capacity**

A quench tank must contain sufficient fluid to quench the load without an excessive rise in temperature of the quenching fluid. In an uncooled tank, the quantity of quenchant required can be calculated from the basic equation:

\[
M_m C_p_m D_T_m = M_q C_p_q D_T_q
\]

Where \(M_m\) is the mass of metal, \(C_p_m\) is the specific heat of the metal, \(D_T_m\) is the decrease in temperature of the metal being quenched, \(M_q\) is the mass of quenchant, \(C_p_q\) is the specific heat of the quenchant, and \(D_T_q\) is the increase in temperature of the quenchant. Typical values for specific heat at 20°C (70°F) are:

- Steel — 0.17 cal/g/C (0.17 Btu/lb/F)
- Aluminum — 0.23 cal/g/C (0.23 Btu/lb/F)
- Quench Oil — 0.50 cal/g/C (0.50 Btu/lb/F)
- Polymer Quenchant — 0.95 cal/g/C (0.95 Btu/lb/F)
- Water — 1.0 cal/g/C (1.0 Btu/lb/F)

A general guideline for steel quenching (for a single quench) is that 10 liters of oil is required for each kilogram of total charge weight (1 gal/lb). This rule of thumb results in about a 40°C (70°F) temperature rise under nominal conditions, which is recommended to prevent the oil from reaching the flashpoint of the fluid. It is recommended that the maximum temperature during quenching using oils always should be at least 55°C (100°F) below the flash temperature, which mitigates the potential for a fire if a hung-up load occurs. This is illustrated in the following example:

**Flash temperature of the oil:**
- 175°C (350°F)
- Recommended temperature cushion: 55°C (100°F)
- Temperature rise during quenching: 40°C (70°F)
- Maximum recommended operating temperature: 80°C (180°F)

However, with successive quenches, some form of cooling is necessary to prevent the oil from overheating. The heat exchanger should be sized to recover the heat produced by the quenched load within one heat treating cycle.

For example, in quenching 2270 kg (5000 lb) of steel from 870°C (1600°F), a heat treater wants to remove the parts from the oil at 65°C (150°F). The “cold quench” oil used has a flash temperature of 175°C (350°F) and operates at a temperature of 60°C (140°F). Based on these process parameters, the maximum peak temperature of the oil (considering the flash point of 175°C), would be 120°C (250°F). What should the minimum size of the quench tank be? Using the equation given above:

\[
M_m C_p_m D_T_m = M_q C_p_q D_T_q
\]

\[
M_q = M_m C_p_m D_T_m / C_p_q D_T_q
\]

therefore

\[
M_q = 5000 \text{ lb (0.17 Btu/lb/F)}
\]

\[
(1600 - 150\)F / 0.50 Btu/lb/F (110F)
\]

\[
M_q = 22,409 \text{ lb (10,185 kg) oil}
\]

At a weight of 6.8 lb/gal (0.8 kg/liter), approximately 3300 gal (12,500 liters) are required for these conditions. However, this temperature rise is a bit excessive and could lead to premature oxidation of the oil. Alternatively, rearranging the equations using a fixed size quench tank allows solving for the temperature rise during quenching.

Water and polymer quenchants have a different limitation on temperature. This is not related to safety, as with quench oils, but effective cooling for water, and maximum operating temperatures for polymer quenching. For water, the maximum temperature is 100°C (210°F). However, this limit is rarely used as the cost of make-up and cooling becomes excessive. For polymer quenchants and water used in quenching aluminum, aerospace standards specify a maximum.
temperature rise of 5°C (10°F) with a maximum temperature of 45°C (110°F). For polymer quenchants, it is somewhat more difficult. The maximum temperature for polyalkylene glycol (PAG) quenchants cannot exceed the cloud point temperature. This is between 60° and 75°C (135° and 170°F) for most PAG quenchants, depending on the molecular weight of the polymer. It is also recommended that the maximum bulk temperature rise be at most 10°C (20°F) below the cloud point temperature. Polymer quenchants, besides being sensitive to agitation, are strongly affected by temperature. The cooling rate decreases significantly with increasing temperature. Small temperature rises during quenching reduce variations in cooling rate and quench rate effectiveness. This also reduces drag-out, produces more uniform quenching, and prolongs the life of the quenchant. Limiting the temperature rise greatly increases the quench tank size.

For PVP-type quenchants, there is no cloud point temperature. However, the maximum peak temperature is generally limited to 65°C (150°F) or lower to prevent destructive oxidation of the quenchant. This also reduces the amount of drag-out and chemical consumption in the system.

As an example, consider the design of a quench tank containing Aqua-Quench 3699, a hybrid polymer quenchant that does not have a cloud point. Steel parts will be quenched from 1095° to 205°C (1991° to 393°F), with a maximum load weight of 2270 kg (5000 lb). The quench tank operates at 45°C (110°F) nominally. What volume of quenchant is required in gallons?

To solve this, the maximum allowable temperature rise must first be determined. For this quenchant, the maximum temperature is 65°C (150°F). Because the quench tank is operating at 150°F, the temperature rise of the quenchant ($\Delta T_q$) is 40°F (i.e., 150°–110°F). From the equation above, and rearranging to determine the mass of water required:

$$M_w C_{p_m} \Delta T_m = M_q C_{p_q} \Delta T_q$$

or

$$M_q = M_w C_{p_m} \Delta T_m / C_{p_q} \Delta T_q$$

Therefore

$$M_q = 5000 \text{ lb} (0.17 \text{ Btu/lb/F}) \times (1600)/0.95 \text{ Btu/lb/F} (40 \text{F})$$

$$M_q = 35,800 \text{ lb} (16,270 \text{ kg})$$

polymer quenchant

A gallon of water weighs 8.33 lb/gal (1 kg/liter), so the number of gallons required to quench 5000 lb of steel is 4296 gal (16,260 liters). Temperature rise for polymer and oil quenchants are shown in Figs. 1 and 2.

**System temperature control**

Maintaining the temperature of the quench bath is as important as the size of the quench tank, which requires a means of temperature control.

**Quenchant cooling** is achieved using several methods, including electrical resistance heating elements, gas- and oil-fired radiant tubes, and waste heat from the furnace exhausts. In some systems, the quenchant is heated by quenching a “dummy” hot load of parts. The energy density of radiant tubes and electrical heating elements should not exceed 1.5 W/cm² (10 W/in²). This prevents heaters from preferentially oxidizing the oil and depleting the oxidation additive package. This energy density guideline should also be followed for polymer quenchants, with the additional provision that maximum heater temperature should be about 70°C (160°F) to prevent exceeding the cloud point of the material. Heaters should also be interlocked with the agitation system so they shut off if the agitation system is shut off or fails. The system should also be designed to make it impossible to turn on the heating system without the agitation operating.

**Quenchant cooling** Various methods are available to cool quenchants including:

- Submerged water-cooling pipes
- Cooling jackets
- External water-cooled heat exchangers
- Forced air-cooled radiators
- Refrigeration systems
Submerged water-cooling pipes and jackets are suitable only for small systems, and there is always the risk of water contamination of oil quenchants, which should be avoided at all costs. Water contamination of polymer quenchants is not critical. External water-cooled heat exchangers and air-cooled radiators are very efficient and widely used for cooling large quenching systems. For oil quenchants, air-cooled heat exchangers are nearly always used in the U.S. to prevent potential fires from water in quench oil. For polymer quenchants, water and chillers are predominately used. Air-cooled heat exchangers are generally limited to cool a quenchant to approximately 10°C (20°F) above ambient temperature. Because most polymer quenchants should be used around room temperature, the use of chiller water or other means is mandated by temperature and heat exchanger constraints.

To obtain maximum efficiency from cooling systems, the direction of circulation should be such that hot quenchant is removed from the top of the tank and then passed through the heat exchanger. Once cooled, the oil is returned to the bottom of the tank. Generally, the heat exchanger should be sized to recover the heat within one quench cycle. The equations above can be used to determine the size of the heat exchanger:

\[ Q = M_m C_{pm} D T_m \]

where \( Q \) is the total heat that must be extracted from the quenchant. This is the total heat given up by the quenched metal to the quenchant. To properly size the heat exchanger, the heat from the workload should be completely recovered prior to the next load. For instance, assume that an integral quench furnace is quenching an 1820 kg (4000 lb) charge into a 15,140 liter (4000 gal) quench tank at 60°C (140°F). The load is quenched from a temperature of 870°C (1600°F) and extracted from the quench at 65°C (150°F). The cycle time from one load quenching until the next load quenching is 90 minutes. The heat exchanger must recover this heat from the quench oil to return the temperature of the quench back to the original temperature of 60°C. Substituting and solving the equation gives:

\[ Q = M_m C_{pm} D T_m = 4000 \times 0.17 \times (1600 - 150) = 986,000 \text{ Btu} \]

The heat exchanger must extract nearly one million Btu from the oil in 90 minutes to recover the oil temperature. In other words, the heat exchanger must be rated for at least 660,000 Btu/hr (194 kW). There also must be an adequate safety factor to compensate for different heat treating cycles and ambient conditions.

**Conclusions**

This brief article describes the basics of sizing quench tanks for immersion quenching and offers a methodology for sizing the temperature-control system. It is recommended to contact your quenchant supplier or heat-exchanger supplier for more detailed, precise determinations for specific applications. **HTPRO**

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APPLICATION NOTE

TOOL FOR ATMOSPHERIC CARBON POTENTIAL ANALYSIS

A question frequently asked by heat treaters is: “What is the actual carbon in my furnace?” There are many tools for continuous atmosphere monitoring, verification, and troubleshooting. They address standard heat treating practices and industry requirements, such as AMS or CQI-9, to ensure continuous control and periodic verification of the furnace atmosphere used for the heat treatment process.

Heat treaters regularly seek ways to prevent and reduce rework and scrap loads by implementing procedures and tools to make sure the heat treating process meets customer expectations and specifications. One process parameter requirement is to ensure consistent atmosphere carbon content. Measuring carbon absorption into steel is commonly done to verify atmosphere consistency. Super Systems’s CAT-100 instrument is an atmosphere carbon potential analyzer that provides a cost-effective way to measure carbon using a wire coil that functions in a way similar to using shim stock.

Working principles

The CAT-100 measures carbon potential in a positive-pressure atmosphere. The value is determined by measuring specific properties of a steel wire coil inserted into an atmosphere made up of a carbon-bearing gas for a predefined time. The concept behind the instrument is similar to that behind the company’s Shim Port method. Both use metal pieces “soaked” in a carbon-containing atmosphere as the basis for carbon analysis. Two important differences between the instrument testing method and the shim-stock method are the time required to generate a carbon-potential reading and the cost associated with the measuring instruments.

CAT-100 is capable of providing on-site carbon-potential measurement in less than one hour, while the shim-stock method requires specialized equipment that many heat treaters do not have on site. This requires having an off-site laboratory measure the shim stock, adding several days to the process. Wire coils are available for use with the CAT-100, and instrument calibration is relatively easy.

Carbon potential measurement using the CAT-100 is based on the carbon content of the wire coil after soaking in the furnace, which is measured by analyzing changes in the metallurgical properties of the coil. For example, metallurgical changes caused by carbon diffusing into the coil affect its electrical resistance. Measurements are made on the coil after removing it from the furnace (at ambient temperature). Measurement accuracy is dependent on the coil temperature.

Measured carbon potential is also dependent on changes in surface metal properties. The steel surface eventually reaches equilibrium with a given gas composition and furnace temperature. Electrical resistance is directly proportional to the amount of carbon present in the fine-wire coil. Using the baseline electrical resistance and carbon content for the untreated wire, the addition and/or depletion of carbon in the heat treated wire can be accurately measured. The instrument provides a direct reading of percent carbon without the influence of gas composition.

The measurement can be influenced by nitrogen absorption into the coil from the furnace atmosphere. Because this results in erroneous readings, the instrument should not be used for carbonitriding processes.

Operating procedure

The instrument must be calibrated for use with a specific wire coil. The reason is that different lots of coils could have different carbon content, and the presoak carbon content of the coil is crucial for accurate carbon potential measurement. Before the testing process begins, the furnace atmosphere must be verified as suitable for a coil soak. Furnace temperature should be generally uniform before the coil is introduced to the atmosphere, and should not change greatly during the soak. A special insertion rod is used to place the coil into the furnace atmosphere; it must not be inserted within a furnace charge or in a basket. The coil soaks in the atmosphere about 30 to 40 minutes depending on the temperature, and is removed after the soak is completed.

When the coil cools sufficiently (quenching must not be used), it is attached to testing posts on the instrument and a carbon potential value is displayed after about 30 seconds. Readings can be stored in the instrument’s internal memory and can be downloaded to a computer using included software. Following proper procedures, carbon-potential readings are accurate and repeatable. The CAT-100 is designed to provide results within 0.03% of the carbon in an atmosphere containing 0.1 to 1.3% carbon (the effective testing range of the instrument).

For more information: Jim Oakes is vice president, Business Development, Super Systems Inc., 7205 Edington Dr., Cincinnati, OH 45249, 513.772.0060, email: joakes@supersystems.com, supersystems.com.
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.


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. This article discusses the most commonly used flow measurement instruments and compares their operating principles (Table 1).

Types of flowmeters

Flowmeters typically measure either volumetric or mass flow. Volumetric flow measurement looks at the flow of a given volume of the medium over time (e.g., ft³/h). This technology uses either mechanical flow rate indication or electronic output (Fig. 1).

Mass flow measurement looks at the flow of a given mass over time (e.g., lb/h). Industrial thermal mass flowmeters are often equipped with electronic output (Fig. 2). Conversions between the two measurements can be made if the pressure, temperature, and specific gravity of the flowing medium are known.

Flowmeters can be further subdivided into several general types. Of these, variable-area and thermal-mass flowmeters are most often used in heat treating applications:

- **Variable area**: Fluid flow rate is measured as the flowing medium passes through a tapered tube. The position of a float, piston, or vane placed in the flow path changes as higher flows open a larger area to pass the fluid, providing a direct visual indication of flow rate.
- **Differential pressure**: Calculating a fluid flow rate from the pressure loss across a pipe restriction is the most commonly used flow measurement technique in industrial applications. The pressure drops through these devices are well understood, and a wide variety of configurations are available, each having specific strengths and weaknesses. Variations on the theme of differential pressure flow measurement include the use of pitot tubes.
- **Mechanical**: In these instruments, flow is measured either by passing isolated, known volumes of a fluid (gas or liquid) through a series of gears or chambers (positive-displacement type) or via a spinning turbine or rotor. Measurements using a positive-displacement flowmeter are obtained by counting the number of passed isolated volumes.
- **Electronic**: Magnetic, vortex, and ultrasonic devices are available, all of which have either no moving parts or vibrating elements and are relatively nonintrusive.
- **Thermal mass**: In contrast to volumetric flow devices, thermal mass flowmeters are essentially immune to changes in gas temperature and pressure. Because measurements can be very accurate and repeatable, these devices are used in critical flow measurement applications.

Variable-area types

Variable-area flowmeters are simple, versatile devices that operate at a relatively constant pressure drop and measure the flow of liquids, gases, and steam. The popularity of this type of flowmeter in the heat treating shop is their direct-view design, where flow is indicated mechanically, which makes it easy to understand the operating principle. Several different designs of variable-area flowmeters are used throughout the heat-treating industry (Fig. 3).
Rotameter types

The glass or plastic rotameter (Fig. 3a), is the most widely used because of its low cost, low pressure drop, relatively wide range, linear visual flow indication, and simplicity of operation. To pass through the tapered tube, fluid flow must raise the float. The greater the flow rate, the higher the float is lifted. In liquid service, the float rises due to a combination of the liquid’s buoyancy and its velocity. With gases, buoyancy is negligible, so the float responds mostly to velocity.

The float moves up and down in proportion to the fluid flow rate and the annular area between the float and the tube wall. As the float rises, the size of the annular opening increases. As the area increases, the differential pressure across the float decreases. The float reaches a stable position when the upward force exerted by the flowing fluid equals the weight of the float. Thus, every float position corresponds to a specific flow rate for a particular fluid’s density and viscosity.

Features and advantages

Advantages of variable-area flowmeters include:
- Mechanical flow measurement with just a single moving part, ensuring measurement reliability
- Application versatility and availability of a variety of construction materials, inlet and outlet sizes, and types
- Easy installation with generally no straight pipe requirements
- Low pressure drops
- Linear scales, allowing easy flow measurement interpretation
- Electronic output availability, preserving the mechanical flow measurement

Advantages of tapered-tube rotameters include:
- Low instrument cost (when glass or plastic metering tube is used)
- Can be used for very low flow rates

Advantages of slotted-cylinder flowmeters include:
- Flow measurement accuracy determined by the precision of the slot manufacturing operation; good flow range of 25:1 results
- Instrument specifications can be changed by field replacement of the slotted tube and float without having to re-pipe the flowmeter vessel
- Ability to handle high flows and pressures
- Improved immunity to pulsating flows, with no minimum backpressure

Limitations common to both tapered-tube and slotted-cylinder variable-area flowmeters include the requirement of vertical mounting and the fact that they contain moving parts.
This is why it is necessary to size the rotameter for each application. When sized correctly, flow rate can be determined by matching the float position to a calibrated scale on the outside of the instrument. Many rotameters come with a built-in valve to manually adjust flow. Several shapes of floats are available for various applications.

Both glass and metal rotameters are available. Glass and plastic rotameters cost less and are more accurate than metal tapered-tube rotameters (Fig. 3b), but may not be able to provide the durability and reliability needed in a manufacturing environment. Metal rotameters are reliable, but the machined tapered tube limits the flow measurement range (turndown). Another limitation is that metal rotameters typically have brass or aluminum bodies, which can make them unsuitable for use in certain gases (ammonia, for example).

**Slotted-cylinder types**

The flowmeter most commonly used in the process industries substitutes a slotted cylinder for the tapered tube (Fig. 3c). Compared with a metal rotameter, a greater selection of construction materials and a flow turndown of at least 25:1 (vs. 3:6:1) are provided.

The lower portion of the float is a piston that can “plug” the slot in the cylinder wall. The float rises until enough of the slot has opened to create equilibrium between the two upward-acting flow forces and the single downward-acting force. As for rotameters, when in this equilibrium position, float height is proportional to flow rate. The basic equations for tapered tube and slotted cylinder flowmeters are similar, with their flowmeter coefficients (K factors) accounting for any differences.

**Flowmeter accessories**

Regardless of the design of variable-area flowmeters, flow measurement is taken at some equilibrium point where the fluid flow force is balanced by an opposing force exerted by a “flow element” (such as a float). Either the force of gravity or a spring is used to return the flow element to its resting position when the flow lessens. Gravity-operated flowmeters (Fig. 3a–c) must be installed in a vertical position, while vane or spring-operated devices (Fig. 3d–f) can be mounted in any position.

Some variable-area flowmeters can be provided with position sensors and transmitters (pneumatic, electronic, digital, and fiber optic) for connecting to remote displays or controls. Most flowmeters have only flow alarm output signals, although some provide a continuous signal that represents the flow rate.

A variable-area flowmeter or rotameter is typically provided with calibration data and a direct-reading scale for air or water (or both). To size a meter for other service, the actual flow must be converted to a standard flow. Instrument manufacturers use different standard flow units. For liquids, the standard flow is the water equivalent in gal/min at 70°F and 10 psi (20°C, 69 kPa); for gases, it is the air equivalent in standard cubic feet per minute (scfm) at 70°F and atmospheric pressure. Tables listing standard water and/or air equivalent values are available from flowmeter manufacturers, who also might provide slide rules, nomographs, and computer software for flowmeter sizing. HTPRO

Look for Part 2 of this article in the September 2014 issue of HTPro covering selection basics, sizing, mass flowmeter overview, and FAQs about flowmeters.

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