Daniel H. Herring | 630-834-3017 | heattreatdoctor@industrialheating.com

Flowmeter Basics

Everyone knows what a flowmeter is, and, yet, few of us really understand them the way we should. The sad reality is that once flowmeters are installed and operating we tend to take them for granted. This can often lead to serious flow errors and potential process or safety issues that compound themselves over time. Let's learn more.

What is a flowmeter, really?

A flowmeter is a device used for measuring the flow of gases or liquids. There are actually two different ways to measure flow – by volumetric means (Fig. 2a) and by mass-flow techniques (Fig. 2b). As heat treaters, we are probably more familiar with the volumetric-flow measurement of gases. The principle involves the displacement of the gas volume over time. Atmosphere furnaces, gas generators and combustion systems typically use these types of devices. Mass flow involves measuring the weight of a gas, and these are commonly found on vacuum furnaces that meter in gases for partial-pressure operation.

What types of flowmeters are there?

As heat treaters, we typically focus on the measurement of gases. Anyone who has seen a nitrogen/methanol system, however, is aware that liquid methanol must be metered into the furnace. Flowmeters are also used for measuring liquid flow. In addition to flowscopes and mass flowmeters, other common types include: orifices, rotameters, positive-displacement meters, electromagnetic meters, ultrasonic (Doppler-effect) devices, turbine meters, wedge flow devices, impact meters and turbine meters.

Fig. 1. Typical flow control panel (multiple-zone continuous furnace)

What are the features and advantages of the most common flowmeter types?

Variable-area flowmeters offer:

- Mechanical flow measurement with only 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 benefits of mechanical flow measurement

Tapered-tube rotameters offer:

- Low instrument cost (when glass or plastic metering tube is used)
- Accuracy at very low flow rates

Slotted-cylinder flowmeters offer:

- A flow range of 25:1 since flow-measurement accuracy is determined by the precision of the slot manufacturing operation
- Instrument specifications can be changed by field replacement of the slotted tube and float, without having to repipe the flowmeter body
- Ability to handle high flows and pressures
- Improved immunity to the effects of pulsating flows, with no minimum back-pressure

Limitations common to both tapered-tube and slotted-cylinder variable-area flowmeters are that vertical mounting is required and that they contain moving parts.

The user should also be aware that the accuracy of mass flowmeters and mass-flow controllers is determined by two factors: 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.

Is it easier to control a gas or a liquid?

Interestingly, liquids are easier to measure and control because of their small compressibility. For most volumetric-flow applications, the incoming pressure in liquid systems does not need to be closely controlled. By their very nature, liquids can be captured easily and measured to a high degree of accuracy. Gases on the other hand, because of their compressibility, require more complex sensing and control methods.

What is the accuracy range of a gas flowmeter?

When measuring gas flows in heat-treating applications there is an important distinction between the operating range of a flowmeter and the design range when purchasing a new meter. Plan to operate a flowmeter in a range not below 25% and not above 90% of the flowscope's scale capacity. In other words, if your flowmeter is rated for 0-2,000 cubic feet per hour (cfh), you can be assured of accuracy when the flow is between 500 cfh and 1,800 cfh. Flows outside these limits are not considered accurate.

A good "rule of thumb" for sizing a flowmeter is to purchase your meter "in the middle third." The flowmeter should be chosen so that the actual flow will be no less than 1/3 and no higher than 2/3 of the scale you select. This gives you the ability in actual operation to compensate for unexpected changes in flow requirements that may occur. Often over the life of a heat-treating furnace, process requirements and operating conditions change – sometimes dramatically – and you want your gas measurement to remain accurate.

Should I have my flowmeters recalibrated?

If a change of operating conditions is permanent, such as the desire to constantly operate at a different pressure, then recalibration of the flow measurement device is strongly recommended. As a rule, flowmeters used in heat-treating applications are designed for a maximum temperature of 150°F (66°C) and an operating pressure up to 50 psig (345 kPa). However, application-specific flowmeters have maximum operating pressures outside these ranges.

What affects my gas measurements?

If knowing the proper flowrate is important to you, 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. (These topics are covered in detail in the online portion of this column.) It is quite common in a heat-treat shop to find flowmeters operating at different pressures and temperatures than they have been calibrated for.

Do I need to maintain my flow devices?

All flowmeters eventually require maintenance. It is a sad truth that some units require more maintenance than others, so this factor should be considered when a unit is selected. 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, the flowmeters often become contaminated with soot (carbon) and must be cleaned by CAREFULLY disassembling the flowmeter and cleaning all internal moving parts as well as 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 as many of the gases involved are asphyxiants as well as being flammable, toxic and possibly life-threatening.

Remember also that electromagnetic flowmeters and all flow measurement devices that use secondary instruments such as pressure sensors to actuate a control valve or send a signal to a remote source must be periodically inspected, calibrated, repaired and/or replaced. Improper location of the flowmeter itself, the secondary sensor or readout devices can result in measurement errors and hidden costs.

Do I really need to learn about my flowmeters to be in control, stay in control, operate safely and keep the cost of my operation as low as possible?

Simply stated, yes. Hopefully, this discussion has helped reinforce this idea. Now go out today and check your flow devices! **IH**

This column concludes online.

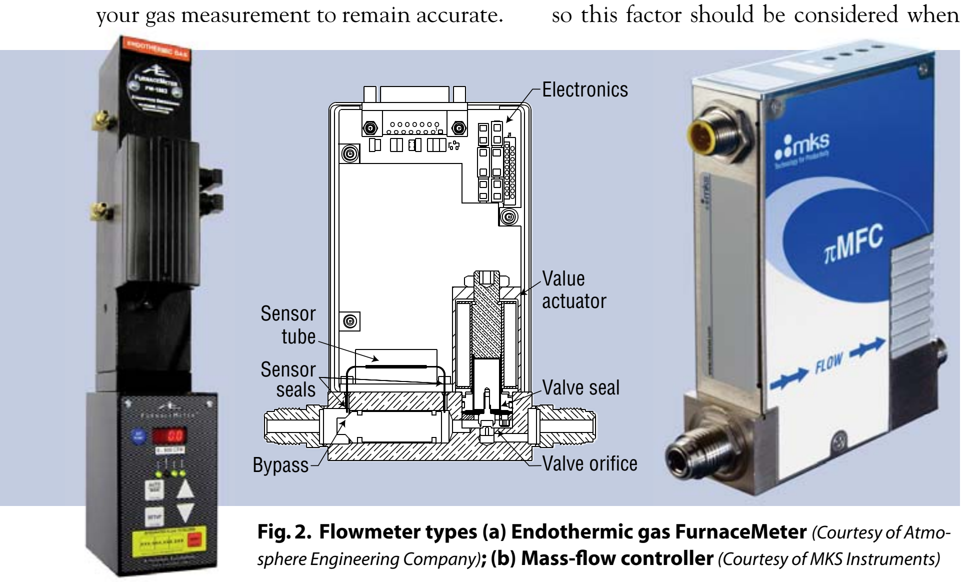

Fig. 2. Flowmeter types (a) Endothermic gas FurnaceMeter *(Courtesy of Atmosphere Engineering Company)*; **(b) Mass-flow controller** *(Courtesy of MKS Instruments)*

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There was too much good information to contain in this column.
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References:

1. "North American Combustion Handbook, 2nd Edition," North American Manufacturing Company, Cleveland, OH.
2. Braziunas, Vytas and Daniel H. Herring, "A Flowmeter Primer," *Heat Treating Progress*, March/April 2004.
3. Mr. Eric Jossart, Atmosphere Engineering Company, private correspondence.

On-Line Content

What do I need to consider if I want to use a flowmeter for one gas, but it is calibrated for another?

One of the most common problems seen in heat-treat shops is that operating personnel and supervisors are unaware of the consequences of a flowmeter that has been calibrated for use with one gas while having another gas flowing through it. When switching gases, the change in specific gravity of the two gases is the principle factor that must be taken into account. Specific gravity is the ratio of the density of the gas under consideration to the density of dry air (at standard temperature and pressure, 77°F (25°C) and 14.7 psi).

Table 1 provides a quick conversion chart. To calculate the actual flow rate of gas being metered, multiply the indicated scale reading of the flowmeter by the factor shown in the table.

Equation (1) allows us to calculate the actual flow when a change in specific gravity occurs.

$$Fa = Fi \times \sqrt{\frac{SG_1}{SG_2}} \qquad (1)$$

Where: Fa = actual flow
Fi = flow indicated scale reading
SG_2 = specific gravity of gas to be used in the flowmeter
SG_1 = nameplate (calibrated) specific gravity

How do I compensate for changes in pressure and temperature?

A change in temperature and/or pressure of the gas from for which the meter was calibrated will cause a serious error in the indicated scale reading. However, there is an easy way to calculate the effect of these changes.

Temperature Compensation

Equation (2) allows us to calculate the actual flow when a change in temperature occurs.

$$Fa = Fi \times \sqrt{\frac{T_1}{T_2}} \qquad (2)$$

Where: Fa = actual flow
Fi = flow indicated scale reading
T_1 = nameplate (calibrated) temperature + 460 (English system) or nameplate (calibrated) temperature + 273 (metric system)
T_2 = new temperature + 460 (English system) or new temperature + 273 (metric system)

A summary for some common values is shown in Table 2.

Table 2. Temperature conversion factors

Temperature, °F (°C)	Scale multiplier
50 (10.0)	1.02
60 (15.6)	1.01
70* (21.0)	1.00
80 (26.7)	.99
90 (32.2)	.98
100 (37.8)	.97
110 (43.3)	.965
120 (48.9)	.96
130 (54.4)	.95
140 (60.0)	.94
150 (65.6)	.93

* Flowmeter calibrated for 70°F (21°C)

Table 3. Pressure conversion factors

Pressure, psi (kPa)	Scale multiplier
0.5* (3.4)	1.00
1 (6.9)	1.03
2 (13.8)	1.06
3 (20.7)	1.10
4 (27.6)	1.13
5 (34.5)	1.16
10 (69.0)	1.30
15 (103.4)	1.42
20 (137.9)	1.53
30 (206.9)	1.75
40 (275.8)	1.93
50 (344.8)	2.10

*Flowmeters are typically calibrated for 0.5 psi (3.4 kPa)

GAS FORMULA	GAS THAT METER IS CALIBRATED FOR	SPECIFIC GRAVITY	SPECIFIC GRAVITY CONVERSION FACTORS																		
	AIR	1.00	1.00	1.050	1.302	1.841	.851	.704	.809	1.302	1.302	1.00	1.085	1.039	1.072	2.692	3.793	1.240	1.021	.951	.811
C_2H_2	ACETYLENE	.907	.953	1.00	1.240	1.754	.811	.670	.770	1.240	1.240	.953	1.033	.989	1.021	2.564	3.613	1.181	.972	.906	.772
NH_3	AMMONIA	.59	.768	.806	1.00	1.414	.654	.540	.621	1.00	1.00	.768	.833	.798	.824	2.068	2.914	.953	.784	.731	.623
	AMMONIA DISSOCIATED	.295	.543	.570	.707	1.00	.462	.382	.439	.707	.707	.543	.589	.564	.582	1.462	2.060	.674	.554	.517	.440
Ar	ARGON	1.38	1.175	1.233	1.529	2.163	1.00	.827	.950	1.529	1.529	1.175	1.274	1.220	1.259	3.162	4.456	1.457	1.199	1.118	.952
C_4H_{10}	BUTANE	2.02	1.421	1.492	1.850	2.617	1.210	1.00	1.149	1.850	1.850	1.421	1.542	1.476	1.524	3.826	5.391	1.763	1.451	1.352	1.152
CO_2	CARBON DIOXIDE	1.529	1.236	1.298	1.610	2.277	1.053	.870	1.00	1.610	1.510	1.236	1.341	1.284	1.326	3.329	4.690	1.534	1.262	1.176	1.002
	CITY GAS	.59	.768	.806	1.00	1.414	.654	.540	.621	1.00	1.00	.768	.833	.798	.824	2.068	2.914	.953	.784	.731	.623
	ENDOTHERMIC CRACKED	.59	.768	.806	1.00	1.414	.654	.540	.621	1.00	1.00	.768	.833	.798	.824	2.068	2.914	.953	.784	.731	.623
	EXOTHERMIC CRACKED (LEAN)	1.00	1.00	1.050	1.302	1.841	.851	.704	.809	1.302	1.302	1.00	1.085	1.039	1.072	2.692	3.793	1.240	1.021	.951	.811
	EXOTHERMIC CRACKED (RICH)	.85	.922	.968	1.200	1.698	.785	.645	.746	1.200	1.200	.922	1.00	.958	.988	2.482	3.497	1.144	.941	.877	.747
	FORMING GAS	.927	.963	1.011	1.253	1.773	.820	.677	.779	1.253	1.253	.963	1.044	1.00	1.032	2.592	3.652	1.194	.983	.916	.780
	FORMING GAS	.87	.933	.979	1.214	1.717	.794	.656	.754	1.214	1.214	.933	1.012	.969	1.00	2.511	3.538	1.157	.952	.887	.758
He	HELIUM	.138	.371	.390	.484	.684	.316	.261	.300	.484	.484	.371	.403	.386	.398	1.00	1.409	.461	.379	.353	.301
H_2	HYDROGEN	.0695	.264	.277	.343	.485	.224	.185	.213	.343	.343	.264	.286	.274	.283	.710	1.00	.387	.269	.251	.214
CH_4	NATURAL GAS	.65	.806	.846	1.050	1.484	.686	.567	.652	1.050	1.050	.806	.874	.837	.864	2.170	3.058	1.00	.823	.767	.654
N_2	NITROGEN	.96	.980	1.029	1.276	1.804	.834	.689	.792	1.276	1.276	.980	1.063	1.018	1.050	2.638	3.717	1.215	1.00	.932	.794
O_2	OXYGEN	1.105	1.051	1.104	1.369	1.935	.895	.740	.850	1.309	1.369	1.051	1.140	1.092	1.127	2.830	3.987	1.304	1.073	1.00	.852
C_3H_8	PROPANE	1.522	1.234	1.295	1.606	2.271	1.050	.868	.998	1.606	1.606	1.234	1.338	1.281	1.323	3.321	4.680	1.530	1.259	1.174	1.00
		SPECIFIC GRAVITY	1.00	.907	.59	.295	1.38	2.02	1.529	.59	.59	1.00	.85	.927	.87	.138	.0695	.65	.96	1.105	1.522
		GAS THAT METER IS USED FOR	AIR	ACETYLENE	AMMONIA	AMMONIA DISSOCIATED	ARGON	BUTANE	CARBON DIOXIDE	CITY GAS	ENDOTHERMIC CRACKED	EXOTHERMIC CRACKED (LEAN)	EXOTHERMIC CRACKED (RICH)	FORMING GAS	FORMING GAS	HELIUM	HYDROGEN	NATURAL GAS	NITROGEN	OXYGEN	PROPANE
		GAS FORMULA		C_2H_2	NH_3		Ar	C_4H_{10}	CO_2							He	H_2	CH_4	N_2	O_2	C_3H_8

Table 1. Specific-gravity conversion factors (Courtesy of Waukee Engineering Company)

Pressure Compensation

Equation (3) allows us to calculate the actual flow when a change in pressure occurs.

$$Fa = Fi \times \sqrt{\frac{P_2}{P_1}} \qquad (3)$$

where: Fa = actual flow

Fi = flow indicated scale reading

P_2 = new inlet pressure + 14.7 (English system) or new inlet pressure + 101.3 kPa (metric system)

P_1 = nameplate (calibrated) inlet pressure + 14.7(English system) or nameplate (calibrated) inlet pressure + 101.3 kPa (metric system)

A summary for some common values is shown in Table 3.

If it is necessary to compensate for both temperature and pressure, Equation (4) should be used.

$$Fa = Fi \times \sqrt{\frac{P_2}{P_1} \times \frac{T_1}{T_2}} \qquad (4)$$