Flow Measurement for Emissions Monitoring

Compliance with EPA regulations for boilers and process heaters results in efficient operation and lower greenhouse gas emissions. Understanding flow measurement technology can help in this effort

Monitoring emissions has been a major concern at industrial sites, including those in the chemical process industries (CPI), for the past few decades, but a number of factors are currently aligned that elevate the importance of proper monitoring, and amplify the consequences of failing to do so reliably and accurately.

Three factors in particular are driving this confluence. First, global climate-change mitigation efforts aimed at curbing emissions, including country-wide CO_2 emissions-reduction goals, have gained traction over the past two years, and are poised to expand further this decade. Second, companies are increasingly looking at their production operations and supply chains in search of ways to meet sustainability and environmental, social and governance (ESG) objectives. Third, the new administration in the U.S. means that there is a new pollution enforcement regime at the U.S. Environmental Protection Agency (EPA), and increased attention to the legal requirements for emissions regulations. In fact, there have been several recent examples of tightening regulations enforcement: In early May, the U.S. Senate voted to overturn rules from the former Trump administration that loosened requirements for methane emissions, and has begun aggressively enforcing previously approved rules.

Among the implications for the emphasis on emissions monitoring is a heightened importance to accurately measure gas flow for high boiler and process-heater efficiency. In emissions control and combustion applications, flowmeters are employed to measure the flow of fuel gas (most likely natural gas) and air to combustion burners within various types of process equipment to maintain a fuel-to-air ratio that will maximize efficiency while producing minimal pollutant products. Ratios that are either too rich in natural gas, or too lean, will result in unnecessary emissions and wasted fuel.

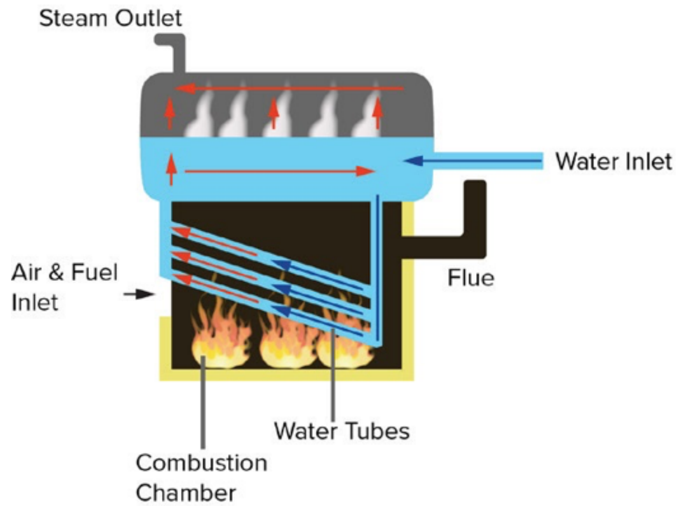

Figure 1. Flow measurement technologies can be used in industrial boilers to monitor the air and fuel inlet, as well as the water inlet and the steam outlet

If the flow of gaseous combustion products — including greenhouse gases like carbon dioxide, carbon monoxide, nitrogen oxides (NOx) and unburned methane — as well as the fuel input, can be measured accurately, users can gain a full picture of the boiler's efficiency. Accurate measurement of steam production determines whether a boiler is producing the expected amount of steam for the fuel input, or if the boiler needs to be tuned for increased efficiency.

Boiler MACT and tuning

Boilers and process heaters at CPI facilities must meet emissions requirements established in the National Emission Standards for Hazardous Air Pollutants

(NESHAP) for Industrial, Commercial, and Institutional Boilers and Process Heaters standards, issued by the EPA (https://www.epa.gov/compliance/national-emission-standards-hazardous-air-pollutants-compliance-monitoring). The NESHAP standards are based on maximum achievable control technologies (MACT), and so the rules are commonly known as Boiler MACT (https://www.epa.gov/stationary-sources-air-pollution/industrial-commercial-and-institutional-boilers-and-process-heaters). Subpart DDDD is focused on major stationary-source emitters (including petroleum refineries, chemical manufacturing facilities and large chemical processing sites). The rules require facilities to monitor the amount of emissions of carbon monoxide, particulate matter, mercury, HCl, and other pollutants.

The emissions mandate requires end-users to "tune" new boilers when they first start up, and then perform periodic tuning to measure the boiler's efficiency in combusting the fuel and turning the water into steam (Figure 2). Tuning a boiler or process heater involves inspecting the flame pattern and adjusting the burners, as well as inspecting the system that controls the air-to-fuel ratio to ensure it is correctly calibrated and operating properly. Facilities that tune their boilers to ensure the maximum boiler efficiency can simultaneously minimize the amount of air pollutants generated.

Figure 2. Flowmeters help engineers "tune" boilers to maintain the optimal efficiency, which minimizes greenhouse gas emissions

A well-tuned boiler is around 80% efficient. If the efficiency is lower than 80%, then energy is being wasted, and hazardous air pollutants are released into the environment unnecessarily. Improving the suboptimal efficiency could involve repairing leaks, adding insulation and cleaning heat exchanger tubes.

Highly efficient boilers and process heaters minimize the release of greenhouse gases, and flow measurement is a key part of achieving high efficiency. Flowmeter manufacturers with Boiler-MACT-compliant devices are capable of measuring the combustion gases produced.

Figure 3. Flowmeters, like the QuadraTherm 640i units shown here, measure the flow of gases at a flaring unit

Available flow measurement technologies
Process-monitoring devices, including flowmeters, can help meet Boiler-MACT emissions limits, and a wide range of technologies is available for the measurement of gas flowrate in closed pipes for applications involving combustion and steam. Flowmeters can be categorized in a number of ways, but one approach is to divide them into four classes: Mass, velocity, differential pressure and positive displacement. The operating principles of a few example types are discussed below.

Mass flowmeters detect the mass of the gas molecules that pass through a pipe in a given unit of time. Examples include thermal mass flowmeters and Coriolis flowmeters.

Thermal mass flowmeters operate by placing two resistance temperature detector (RTD) probes into the gas stream. One probe is a reference probe, measuring the temperature of the gas at rest. The other probe is heated in such a way that it maintains a constant temperature differential compared to the reference. As gas flows past the heated probe, the gas cools the probe. The cooling effect is proportional to the mass flow of the gas.

Coriolis mass flowmeters operate by splitting a process fluid into two streams, one of which is a tube energized to vibrate at a fixed frequency. As a fluid passes through the vibrating sensor tube, the flow changes the vibration and twists the tube slightly. This deviation can be measured and is proportional to mass flow.

Velocity meters generally measure the velocity of the fluid stream and calculate the volumetric flowrate. Examples include vortex, turbine and ultrasonic flowmeters.

Vortex flowmeters work by setting up an obstruction (known as a bluff body) to fluid flow in the pipe. As fluid flows past, a series of repeating vortices are formed in behind the bluff body in the flowing fluid. A mechanical sensor measures the frequency of higher and lower pressures from the vortices. This frequency depends on the fluid flowrate.

Turbine flowmeters measure the volume of a fluid as it passes a free-turning rotor. The rotational speed of the turbine is proportional to the fluid velocity.

Ultrasonic flowmeters pulse soundwaves through a flowing fluid and measure the reflected wave. The wave moves faster with the flow than against the flow, and this difference in transit time is proportional to fluid velocity.

Differential pressure flowmeters work by introducing a constriction, such as an orifice plate, into the pipe that forces the flowing fluid to flow out of the constriction at higher velocity than it had entering the constriction, due to the Law of Conservation of Mass. The increased fluid velocity results in a decrease in pressure, according to Bernoulli's principle. The magnitude of the pressure difference, as measured by pressure devices on either side of the pipe constriction, is proportional to the flowrate, and pressure difference and fluid velocity can be used to calculate volumetric fluid flowrate. Examples of this type include venturis, pitot tube arrays and orifice plates.

Positive displacement flowmeters require fluid to displace components mechanically and measure volumetric flow at the operating temperature and pressure. While they have sufficient accuracy, compensation for pressure and temperature is needed to achieve mass flow, and since they have moving parts, the user must consider gas cleanliness. An example of a PD meter is the diaphragm flowmeter used for natural gas measurement in many home and commercial applications.

Strengths and weaknesses

Key parameters for assessing the effectiveness of a flowmeter device include accuracy, durability, maintenance and total cost of ownership. The different strength-and-weakness profiles for flowmeters partly depend on the requirements of the application, including whether the fluid being measured is a gas or liquid.

<u>Ultrasonic flowmeters</u> have no moving parts, do not obstruct the flow path and tend to be extremely accurate, but are also can be expensive and have trouble with contaminated fluids and liquids with gas bubbles.

<u>Differential-pressure devices</u> can be used for extreme pressures and temperatures and are suitable for liquids, gases and steam. However, they are particularly sensitive to the formation of scale and so exhibit frequent plugging. Also, their low turndown ratio (4:1) may deliver erroneous readings at low pressures, and they require compensating devices to measure the mass flow rate.

Mass flowmeters have inherent advantages over volumetric types in gas-flow applications. As the temperature and pressure changes in a process pipeline, the volumetric flow rate will change as well. Mass flowmeters are able to accurately determine flowrates at varying temperature and pressure because they are determining the number of molecules of a gas through a pipe, not the volume those molecules occupy.

Coriolis mass flowmeters are highly accurate and reliable, with high turndown capabilities. They have no moving parts, so maintenance is minimal. However, Coriolis meters have a high initial cost to purchase and their accuracy for gas-flow applications is not as high as that for liquid-flow applications. Measurement of gas flow can be challenging for Coriolis meters because of the gas' low density.

Thermal mass flowmeters have excellent accuracy and repeatability and produce a direct gas mass flow measurement. This type of flowmeter is also generally easy to install, and they excel for gas-flow applications. Their sensitivity is highest at lower flows and at gas pressures that are in the low to medium range. Thermal mass flowmeters also have no moving parts, and are ruggedly constructed. Thermal mass flowmeters excel in applications such as measuring the flow of stack gases, emissions monitoring and those measuring gases in large pipes or ducts that may be cost-prohibitive with Coriolis meters. This is because thermal mass flowmeters are insertion instruments, so multiple meters can be used for large pipes and ducts.

Thermal mass flowmeters are not well suited for liquid flow applications because at zero flowrate, a majority of the heat is carried away by the liquid due to its higher thermal conductivity relative to that of gases. This reduces measurement sensitivity.

For gas-flow applications, thermal mass flowmeters often emerge as the best choice. The newest models of thermal mass flowmeters are often able to overcome the limitations of previous models. For example, the accuracy of new thermal mass meters rivals that of Coriolis meters, but at lower prices. In addition, thermal mass flowmeters have wider application flexibility, and the efficiency and capabilities of the latest thermal mass flow meters have been enhanced to include better turndown ratios, minimal pressure drop and the ability to install the instruments without having to shut down a process.

<u>About Sierra Instruments</u>

Sierra Instruments designs and manufactures high-performance thermal mass flow controllers, immersible thermal mass flowmeters, vortex flow meters and transit-time ultrasonic flow meters for nearly every gas, liquid, or steam application. The company also offers engineering help and expert flow advice for its products. Our flowmeter devices are available in both standard and customized versions for applications in laboratory, industrial and hazardous environments. Sierra's flowmeter instruments precisely measure or control very low flows down to less than 1 sccm full scale, as well as extremely high flows of gas, liquid and steam. With rugged product design, cutting-edge innovation, and a team of flow experts, Sierra Instruments' thermal flowmeters deliver long-term stability with patented no-drift DrySense™mass flow velocity sensor that allows for reliable in-situ calibration validation backed by a lifetime sensor warranty.