WHITE PAPER

Reduce Energy Costs:

Thermal Mass Flow Measurement to Enhance Emissions Monitoring Systems

A Study of Flow Measurement for Tracking and Reporting Fuel Consumption

Written by:

- Ria Edens, Marketing Communications Manager, Fox Thermal

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PURPOSE

Accurate, repeatable measurement of air and process gases is a key factor in improving accountability, productivity, and energy management processes.

ABSTRACT

The thermal mass flow meter's ability to deliver a direct reading of mass flow rates of air, natural gas and other fuel gases provides a simple, reliable, and cost-effective method for tracking and reporting fuel consumption.

Accurate, repeatable measurement of air and gas, at low and varying flow rates, is also a critical variable in combustion control. Conventional flow meters require pressure and temperature transmitters to compensate for density changes. The thermal mass flow meter, however, measures gas mass flow directly, with no need for additional hardware. The thermal meter also provides better rangeability and a lower pressure drop than orifices, venturis, or turbine meters.

Energy prices are subject to frequent and abrupt changes and fluctuations. When energy prices are high, daily accounting of natural gas usage should be made a priority for large industrial facilities with multiple processes and/or buildings. Fuel gas flow meters are used to analyze demand, improve operating efficiency, reduce waste and adjust for peak usage. Thermal mass flow meters are frequently used for these energy-accounting applications. In addition, thermal flow meters can help plant managers provide accurate usage reports for environmental compliance, as well as compare measured usage to billing reports from gas providers.

Although manufacturers have made significant improvements in process heating efficiency, the U.S. industry's total energy use for process heating is expected to increase. With overall thermal efficiency of process equipment varying from 15% to 80%, compared to the thermal efficiency of steam generation, which varies from 65% to 85%, there is clearly an opportunity to achieve significant energy savings, improve productivity and enhance competitiveness. The U.S. Department of Energy's Industrial Technologies Program has identified improved burner control systems as a significant opportunity for reducing energy operating costs, waste, and environmental emissions.

Plant managers seeking to improve combustion performance and product quality must balance fuel and energy-saving measures with emissions reduction priorities. In many process heating operations, such as drying, incineration and heat treating, excess air is often a process requirement.

In these cases, combustion air and excess air used to suppress emissions must be heated, which increases fuel consumption and may result in incomplete combustion. One of the most effective techniques for improving efficiency and reducing emissions in these applications is a precise control strategy, based on mass flow measurement of fuel and airflow.

Unlike orifice plates, turbine meters, and other volumetric flow devices, the thermal mass flow meter is virtually immune to changes in temperature and pressure, and is capable of providing a more accurate measurement of mass flow rate.

Flow Meter Technology Comparison		
Flow Meter Type	**Measures**	**Mass Flow Requirements**
Turbine Meter	Q	Needs P, T
Orifice Plate	Q^2	Needs P, T, √
Venturi	Q^K	Needs P^M, T^N
Thermal Meter	m	Measures mass directly

Figure 1: Comparison of gas flow measurement technologies

As shown in Figure 1, most conventional flow meters measure volumetric flow and require additional measurements of pressure and temperature to calculate density and mass flow. Because the thermal mass flow meter measures mass flow directly, it provides the most reliable, repeatable, and accurate measurement. The flow meter also provides better rangeability and a lower pressure drop than conventional flow meters.

Sophisticated burner control systems optimize air/fuel ratio control to obtain peak thermal efficiency over the entire range of the burner, and to facilitate proactive emissions control. Mass flow control of air and fuel is used to automatically compensate for changes in temperature or pressure that affect combustion performance. Many systems also utilize fuel totalizing and other data outputs for DCS interfacing and remote system monitoring. Thermal mass flow meters are designed for installation in fuel gas and air feed lines found in process heating and utility operations. In addition to the primary benefits of direct mass flow measurement, low-flow sensitivity, and fast response, the instrument's no-moving parts design also helps reduce maintenance costs.

EPA CLEAN AIR ACT

SECTION 112(r)
The Clean Air Act (CAA) consists of a body of regulations on air emissions from stationary and mobile sources.

AIR QUALITY STANDARDS
CAA established National Ambient Air Quality Standards (NAAQS) to protect public health and public welfare.

IMPLEMENTATION
The CAA directs states to develop State Implementation Plans (SIPs). SIPs are applicable to the appropriate industrial sources in each state.

SOURCES
Section 112 of the CAA addresses emissions of hazardous air pollutants (HAPs) and defines source types like "major sources" and "area sources". Standards for source categories are regulated through MACT (Maximum Achievable Control Technology) Standards.

THERMAL FLOW METERS HELP MANUFACTURERS MEET AIR QUALITY MANAGEMENT REQUIREMENTS

The Federal Clean Air Act (FCAA) requires the U.S. EPA to set national ambient air quality standards to ensure public health. State agencies, as well as regional and metropolitan air quality management districts, are responsible for ensuring attainment and maintenance of these standards. These agencies have published rules and regulations regarding NOx and CO emissions from industrial, institutional and commercial boilers, steam generators, and process heaters.

Owners or operators of units subject to these regulations may install a non-resetting totalizing fuel flow meter to measure the total fuel used by each individual unit, as shown in Figure 2. The regulations specify mass flow measurement of fuel usage and if a volumetric flow meter is installed it must compensate for pressure and temperature using integral gauges.

The thermal mass flow meter's ability to deliver a direct reading of mass flow rate of natural gas and other fuel gases - without temperature and pressure compensation - provides a simple, reliable and cost-effective method for tracking and reporting fuel consumption.

FLOW METERS & THE BOILER MACT

Boiler MACT limits HAPs from commercial and industrial boilers and process heaters. The rules are Area Source Boiler MACT 40 CFR 63, Subpart JJJJJJ for smaller boilers and Major Source Boiler MACT Subpart DDDD for large boilers.
Small boilers will be used in facilities such as stores, hotels, apartments, small manufacturers, etc.
Large boilers are typically found in chemical plants, large manufacturing facilities, refineries, etc.

To comply with the boiler MACT rules, facilities must:
1. monitor emissions of carbon monoxide, particulates, mercury, HCI, and other pollutants
2. tune boilers at start up and at periodic intervals to measure the boiler's combustion efficiency

Flow measurement technologies - like thermal mass flow meters - are the ideal solution to improve the efficiency of boilers of all sizes by "tuning" the air to fuel ratio fed to the boiler's combustion chamber.

The thermal mass flow meter features a variety of analog and digital output signals to easily interface with the emissions management system and an integrated, non-resetting totalizer helps manufacturers meet air quality management equipment requirements. The instrument also offers a very broad measurement range (100 to 1 typical) and is suitable for very low velocity flow measurement.

THERMAL MASS FLOW METERS FACILITATE ENERGY ACCOUNTING AND SUB-METERING

Large industrial facilities with multiple processes and/or buildings can find great value in daily accounting of natural gas usage. Fuel gas flow meters are used to analyze demand, improve operating efficiency, reduce waste and adjust for peak usage.

The thermal mass flow meter has become the preferred device for many energy accounting applications. In addition, these instruments help plant managers provide accurate usage reports for environmental compliance, and compare measured usage to billing reports from gas providers.

Insertion-type flow meters are easily mounted in suitable installation points throughout the facility, and provide an accurate, repeatable reading of natural gas consumption by plant, process, or tenant. In constrained areas, inline meters reduce the traditional requirements for straight, unobstructed upstream piping and simplify installation.

NATURAL GAS SUB-METERING

SUB-METERING BENEFITS

Industrial facilities and other organizations with multiple buildings or processes will see multiple benefits from accounting natural gas usage:

- Exposing high consumption points within large gas feed systems
- Identifying leaks in fuel feed lines
- Evaluations of equipment efficiency
- Diagnosing process efficiencies
- Promote conservation

Sub-metering natural gas consumption is ideal for:

- Applying energy costs to Cost of Goods accounting
- Analyzing aging process equipment
- Periodic equipment efficiency auditing

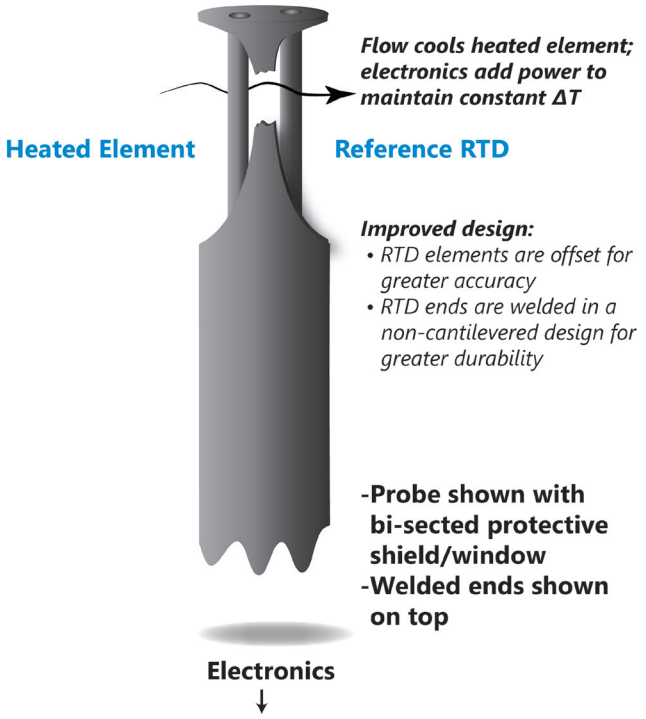
The use of natural gas metering equipment can lead to long-term savings.

Typical applications include:

- Sub-metering by department or process helps manufacturers assess inefficiencies, assign costs, and implement conservation measures.
- University campuses and industrial parks use totalizing flow meters to allocate fuel costs to various buildings and/or tenants.
- Natural gas check meters are often used to document usage, negotiate rates, and resolve billing disputes.
- Thermal mass flow meters may be used to monitor and bill for fuel consumption on skid-mounted generators and compressors.

In addition to the primary benefits of direct measurement of mass flow rate, low-flow sensitivity, and fast response, the flow meter's no-moving parts design also helps reduce maintenance costs. One manufacturer replaced a fuel measurement system that consisted of turbine meters with ancillary pressure and temperature transducers with thermal mass flow meters. Not only did they reduce the time and expense associated with servicing the turbine meters, they also found that the thermal flow meters' wide turndown provided a more accurate measurement at low

DDC-Sensor™



FOX THERMAL FLOW METER BENEFITS

Direct Mass Flow Measurement
Fox Thermal flow meters do not require pressure or temperature compensation.

Outstanding Rangeability
Fox Thermal flow meters' low-flow sensitivity improves measurement accuracy over a wide range of conditions.

Rugged, Low-Maintenance Design
Fox Thermal flow meters' no-moving-parts design makes them relatively immune to oils and particulates and reduces service requirements.

Low Installed Cost
Most Fox Thermal flow meters are available in both insertion and inline versions to suit any application.

Safety Approvals
Fox Thermal flow meters are FM/FMc approved for operation in hazardous areas and housed in NEMA 4X enclosures and CE approved. See back page for more approval information.

and varied loads, ensuring accurate cost-allocation and improving combustion control capability.

HOW IT WORKS

The Fox Thermal Instruments' flow meter uses a constant temperature differential (Δ T) technology to measure mass flow rate of air and gases. The flow sensor consists of two Resistance Temperature Detectors (RTD's). The sensor elements are constructed of a reference grade platinum wire wound around ceramic mandrels that are inserted into stainless steel or Hastelloy tubes.

As shown in Figure 3, the reference RTD measures the gas temperature. The instrument electronics heat the mass flow sensor, or heated element, to constant temperature differential (Δ T) above the gas temperature and measure the cooling effect of the gas flow.

The electrical power required to maintain a constant temperature differential is directly proportional to the gas mass flow rate. The instrument's microprocessor then linearizes this signal to deliver linear output signals.

SPECIFYING A FLOW METER FOR PROCESS HEATING APPLICATIONS

The most important consideration in flow meter selection is the appropriate technology. For example, some flow meters are suitable for air and gas applications, but not useful for liquids, while others may offer the most effective solution for steam monitoring. A thorough examination of the application parameters, including your plant layout, processes, and installation environment can help save you time, money and headaches down the road.

In addition to mechanical and electrical requirements, you may also want to consider other issues relevant to your plant's operation such as maintenance schedules, energy

TECHNOLOGY COMPARISON: FOX THERMAL FLOW METERS VS COMPETING FLOW TECHNOLOGY

Thermal mass flow meters operate by the constant temperature differential method and provide a direct mass flow rate without the need for temperature or pressure compensation.

	OTHER TECHNOLOGIES	THERMAL MASS FLOW BY FOX THERMAL
Flow Measurement of gases	Other technologies require multiple instruments to determine the volumetric flow rate at reference conditions.	Direct mass flow measurement of air and gases in standard volumetric units (ie MSCFD, SCFM, or NM3/H) or mass units (ie LBS/M or KG/H). Each meter has the option for the user to select a variety of flow units (see Operating Specs on product datasheets).
Pressure or temperature compensation	Differential pressure flow meters require pressure and temperature compensation.	No additional pressure or temperature compensation is required. This is a time and cost saving measure. No additional calculations or equipment are needed to calculate flow because the meter measures the mass flow rate.
Turndown	Vortex meters are only suitable for very high flow rates. DP meters do not have good turndown.	Repeatability and exceptionally broad measurement range: up to 1000:1 (100:1 typical). Whether the flow is at a very high or low velocity, Fox Thermal mass flow meters can measure it.
Pressure Drop	If a DP meter is used to measure low velocity flow, a very small orifice is required, resulting in high pressure drop.	Low pressure drop. The pressure drop of a thermal mass flow meter is negligible.
Moving Parts	A meter with moving parts, like a Turbine meter, will need regular maintenance.	No moving parts which means no problems with wear, binding, etc.
Price	Ultrasonic meters are especially expensive.	Cost effective. Thermal mass flow meters offer a low cost alternative.
Installation	Some meter technologies are complicated and difficult to install, require additional equipment, or long straight pipe run requirements.	Easy to install with insertion and inline configurations. Insertion meters are easy to install, inline meters come equipped with flow conditioners to help reduce the straight run requirements. Communication options available and intrinsic to meter electronics.
Operation	Most manufacturers build meters for a single purpose, gas calibration, or application. The customer must sift through pages of specs to find the right meter for their application. This is time consuming and ineffective.	Microprocessor based, field rangeable electronics. Fox Thermal pioneered the use of microprocessors in thermal mass flow meters and continues to create innovative solutions to measurement needs across many industries and applications. Gas-SelectX®, available in models FT1, FT4A, and FT4X, allows the user to change the gas selection in the field. Displays with configuration panels and free software allow users to interact and program the meter in the field. Using the online Product Configurator, the customer can enter process data into the system for an instant Fox Product recommendation: no need to search a list of meters for the one that's right for you!

conservation initiatives, and your maintenance personnel's familiarity with flow meter technology.

It is also critical to evaluate the piping requirements and flow characteristics of the fluid to be measured, including the expected minimum and maximum pressure and temperature values as well as normal operating values. In terms of the piping set-up, you should account for the following: direction, size, material, pipe schedule, flange-pressure rating, upstream or downstream turns, valving, and available straight-pipe run lengths.

Accuracy and rangeability are the most critical characteristics of a flow meter. Most manufacturers provide these specifications for water, air or a specific gas. Ensure that these specifications meet the requirements of your particular fluid or process.

Some flow meter installation procedures are more complicated than others, and it is important to determine if the meter you've chosen can be inserted directly into the process pipe or if the line must be cut, spliced or penetrated in various locations. The installation process can affect the complexity and cost of the flow meter, as well as the instrument's ability to maintain specified accuracy.

Most flow meters require a specific length of upstream and downstream straight-run pipe to generate a well developed flow profile and that length will differ from one technology to another. This is especially important in retrofit installations, where additional piping may increase the cost of installation.

Finally, consider the flow meter's cost-of-ownership over its life cycle. Some devices require frequent cleaning or removal from service for maintenance or recalibration. Some meters may have a low initial cost, but require frequent maintenance or have a short service life, whereas a more expensive instrument may be less costly to install, require less maintenance and provide a much better ROI.

Calibration Technician performing an actual gas calibration in the flow laboratory.

CALIBRATION CONSIDERATIONS

Fox calibrations are performed with NIST-traceable flow standards and meet MIL-STD-45662A requirements. Calibration equipment is subject to a meticulous metrology program that includes the selection, usage, calibration, control, and maintenance of measurement standards.

Process parameters, fluid compositions, and installation anomalies can dramatically affect the performance of flow instrumentation. The Fox Calibration Lab employs a wide

CALIBRATION ENSURES RELIABILITY

Fox Thermal's Calibration Lab offers our valued customers the services they need to ensure that their flow meters meet specified performance parameters and provide accurate, repeatable measurements in the field, day after year, year after year.

Automated data acquisition optimizes calibration accuracy and efficiency and reduces the opportunity for human error. It also facilitates access to calibration data, parameters, flow conditions and instrument variables.

The Fox Thermal Cal Lab employs a wide range of gases, gas mixtures, pressures, temperatures, and line sizes to simulate actual fluid and process conditions. This real-world approach improves installed accuracy and minimizes measurement uncertainty.

Calibration capability range from as low as 0.02 SCFM (.03 NM3/HR) and up to many thousands of SCFM (NM3/HR) using velocity equivalency methods. The Calibration Lab is also equipped to calibrate for applications with temperature ranges from -40 to 650˚F (-40 to 343˚C) and pressure ranges from 0 to 500 psig (0 to 35 barg).

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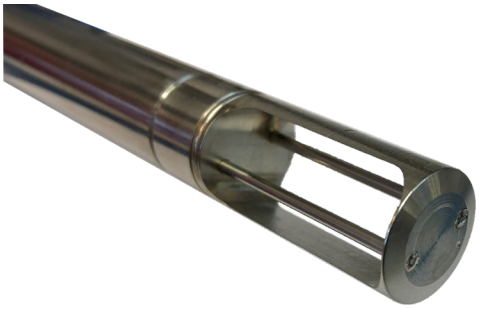
CALIBRATION VALIDATION

Sending flow meters for factory re-calibrations can be a costly inconvenience. CAL-V™ Calibration Validation tests were created by the Fox Thermal engineering team to avoid such inefficiencies and bring the power back to the user to confirm that their meter is running accurately in the field.

The Calibration Validation process is as easy pushing a button and receiving a pass/fail result within minutes. If the test is performed using the FT View™ software tool, a certificate can be generated at the end of the test for record-keeping.

WHY FOX THERMAL?

- NIST-traceable reference standards and a meticulous metrology program prevent out-of-tolerance calibrations.
- Accurate "actual gas" and "actual conditions" calibrations optimize repeatability and long-term stability of your flow meter.
- Automated calibration procedures and electronic record keeping facilitate uncertainty analysis and improve delivery times.
- Industry-leading calibration services are based on technological innovation and a commitment to total customer satisfaction
- DDC-Sensor™ has the digital platform for greater flow meter programmability and a more robust non-cantilevered RTD design.



SUMMARY OF BENEFITS

There are many benefits of thermal gas mass flow meters over other flow measurement technologies and Fox Thermal leads the industry for accuracy, quality, and innovative design.

Benefits of Thermal Mass Flow Technology:

- Direct mass flow measurement of air and gases in standard volumetric units (e.g., SCFM or NM3/H) or mass units (e.g., LBS/M or KG/H)
- No additional pressure or temperature compensation required
- Repeatability and exceptionally broad measurement range: up to 1000:1 (100:1 typical)
- Standard linear 4-20mA output proportional to mass flow rate
- Low pressure drop
- No moving parts
- Cost-effective
- Available in insertion, inline & remote styles
- Measures flow rate and temperature

Calibration Validation		
Typical Requirements of Competitive Models	Other Thermal Flow Meters	Fox Thermal flow meter with CAL-V™
Stop the flow*	Required	Not Required
Remove meter from pipe		
Disconnect wires from flow meter		
Look up data on flow meter's calibration certificate		
Measure electrical characteristics with volt ohm meter		
Perform calculations to evaluate flow meter performance		
Set process pressure to manufacturer's calibration pressure		
Connect auxiliarty test equipment and/or test gases to flow meter		

**When using a retractor assembly for calibration validation test*

CONCLUSION

Thermal mass flow meters provide the real-time measurement required for sophisticated combustion control systems, as well as other critical flow measurement applications.

Based on the thermal sensing principle, a proven direct mass flow measurement technology, thermal mass flow meters offer one of the most accurate, repeatable and reliable methods for measuring flow rates of air and gases in combustion processes. Measuring the flow of air and gases allows users to improve accountability, productivity, and create best practicces for energy management. These improvements lead to a reduction in energy costs while improving the efficiency of process equipment.

Disclaimer: Fox Thermal has made every effort to provide an accurate interpretation of the regulations mentioned in this paper; however Fox cannot be held responsible for errors, local differences, or recent changes. Contact the U.S. EPA or other regulatory body for the latest information on these laws and regulations.

AUTHOR BIOGRAPHY / CONTACT INFORMATION

Ria Edens, Marketing Communications Manager at Fox Thermal and Air Monitor, is a marketing professional with over ten years experience in technical writing along with application, market, and regulation research involving thermal mass flow meter technology and applications.

Phone: +1 (831) 384-4300
Email: redens@foxthermal.com
Website: www.foxthermal.com

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399 Reservation Road | Marina, CA 93933
Office: 831.384.4300 | Fax: 831.384.4312
foxthermal.com