A SAGE METERING White Paper

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Flare Gas Measurement Using Thermal Mass Flow Meters

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Introduction

Flare gas and vent gas systems are used around the world in various industries including: oil and gas production, refining, chemical processing, gas plants, wastewater treatment facilities and landfills. The systems are utilized to burn off waste gases, dispose of surplus gases and protect people, equipment and the environment. The measurement and monitoring of flare gas is necessary to assure that the flare system is operating correctly. Additionally, strict environmental regulations often require the measurement of flare gas emitted to the atmosphere. Unfortunately, there are inherent challenges to measure and/or monitor flare gas that need to be overcome which include: extreme flow variation, potential for changing gas composition and working in hazardous locations. Thermal mass flow meters offer solutions for flare gas measurement and monitoring in many of these applications.

What is Flare Gas?

Flare gas systems are commonly used in industrial plants all over the world. **Flare gas** is the surplus gas or vapor which is typically burned through a **gas flare**, also known as a **flare stack**. **Gas flaring** or **venting** is the process of burning off combustible gas (flare gas). A gas flare is a gas combustion device used to burn off excess hydrocarbons that cannot be processed. This is a safety measure. If the gases were not burned and released into the atmosphere it could create a combustible condition.

The purpose of gas flaring has historically been to dispose of excess combustible gases or relieve the gas pressure within a system. When global warming wasn't considered an issue, gas flaring became a widely accepted process. Back then there were no significant concerns relating to the environmental impact of emissions and no incentives were given to maximize or recycle the gas destroyed in the flaring process.

Today there is a shift from burning flare gas to reducing the amount of flare gas released into the atmosphere. Natural gas is a valuable resource and efforts to capture and recycle flare gas into renewable energy takes precedence over destroying it. Additionally, increasing pressure from global organizations, federal and state legislation, encourages the reduction of emissions, and flare reduction is being deemed as a significant method to achieve the desired goal. By recycling the waste gas, we reduce the CO_2 footprint as well as provide a source for onsite energy.

Today, gas flares are subject to stringent regulations, frequently requiring operators to measure, record and report the amount of flared gases. Aside from the *measurement* of the flared gases, it is often necessary to *monitor* flare gas flow at various points within a complex run of pipes including the actual flare stack. Flow monitoring provides the user with an understanding of the gas source flowing to the flare, as well as a relative flow rate.

It is typical that gas flows to the flare system during the following:

- Operational upsets, interruptions or emergencies when process equipment must be quickly depressurized to avoid equipment damage.
- During start up or shut down when the gases cannot be safely channeled back to the systems storage or process. Venting gas may also be required for maintenance or regeneration.
- Continuous flare operation may include uninterrupted sweep gas through the piping systems to maintain positive pressure and prevent the buildup of combustible gases. It is also typical to provide process venting of equipment such as analyzers, gas seals and pressure control. Additionally, pressure relief valve leakage is commonly flared.

Flow Meter Challenges

Within many flare gas applications there are inherent challenges for operation or measurement engineers to select the proper flow meter. When considering the appropriate instrument, the following must be considered:

Mixed Gases and Calibration – Thermal mass flow meters (TMFMs) measure heat transfer and relate heat transfer to mass flow based on the calibration. Since various gases have different heat transfer properties, the thermal mass flow meter (TMFM) must be calibrated with the specified gas to accurately measure the flow rate. The Sage Metering (SAGE) flow meters are calibrated using the actual gas mixture (or a mixture as close as possible to the specified composition). This method of calibration is more accurate than using air with correction factors for different gases which is another commonly used calibration practice.

Whenever there is a mixture of gases, it is unlikely that the composition will remain consistent. Often the variations in gas mixture occur on a seasonal basis. SAGE is able to predict the variations in performance based on the different gas compositions, if known.

Wide Turndown Ratio Required – It is critically important that the instrument be able to measure extremely low flow associated with normal venting conditions, while simultaneously be able to accurately measure extremely high flow during an emergency or upset situation.

Environmental Regulations – Flow meters must meet accuracy and calibration requirements established by the EPA and/or emissions trading regulations. Some environmental agencies and emissions trading regulations require flow meters to be accurate to ±5% or better, as referenced in 40 CFR 98.3.

Hazardous Location – Because of the combustible and flammable properties of the flare gas, the flow meter must be approved for use in a hazardous location by the appropriate agency. The approval should not rely on an enclosure-only classification, but rather the entire flow meter.

Pipe Access Limited – Access to areas where flow meters need to be installed, serviced and maintained can be challenging in flare gas applications. Ultrasonic spool-type meters can typically require lengthy shut-down time and high labor costs to install and maintain these meters.

Large Pipes – Effective flow meter options reduce as pipe sizes are increased.

Limited Straight Run – Some facilities have limited space, such as offshore platforms, and obtaining sufficient straight run to attain repeatable flow precision can be difficult to achieve.

Changes in Gas Composition and Hydrogen

Other unique challenges for engineering, when selecting flow meters for flare gas applications involve changes in gas composition and the presence of hydrogen.

Gas Composition Impact

It is likely that the most significant issue with measuring gas flow using a TMFM is changes in gas composition. This is not as much of a concern when measuring biogas, landfill gas and natural gas. These gases may have some minor changes in overall gas composition, but the impact is insignificant. Conversely, gas composition variation at refinery and chemical plant applications can significantly influence flare gas flow measurement resulting in unpredictable performance.

Hydrogen Impact

A small amount of hydrogen within the flare mix can generate inaccurate results using TMFMs. A TMFM measures heat transfer caused by gases as they flow past a heated sensor, and gases have different heat transfer characteristics. With hydrogen (H_2) having a high thermal conductivity combined with low density, H_2 has a significantly higher cooling capacity than other gases. Therefore, a small amount of hydrogen can create a high level of heat transfer which will result in a higher measurement of the gas flow.

It is typical that a main flare gas line at refineries and chemical plants contain a mixture of gases depending on where in the facility or unit the gas is coming from. At times the gases have a relatively constant composition; however most of the time there can be significant variations. This can be further complicated when hydrogen is in the formation, or there are changes in hydrogen content. Additionally, when reporting environmental emissions or determining a mass balance greater accuracy is required. All flow meters are affected by variations in gas composition; however, by knowing the gas composition it is possible that SAGE can determine changes in accuracy.

For this reason, in petroleum refineries or chemical plants with varying gas compositions TMFMs are *not* traditionally suitable for accurate emission measurement or obtaining a mass balance for the main flare header. TMFMs however *can* be used in branch or feed lines in these facilities to detect which operation, or unit is sending flow to the flare.

New Sage Metering Engineering Approach

By knowing the gas composition, even in refineries and chemical plants, SAGE can predict accuracy with knowledge of the typical base gas composition and the variation in gas composition. SAGE has developed a method for modeling heat transfer characteristics of a gas mixture. By analyzing the variations in gas composition, SAGE can use this model to predict variations in accuracy caused by deviations in gas composition. Due to the complexity in the analysis of convective heat transfer, this determination of changes in convective heat transfer caused by varying gas composition *cannot* currently be done in real time, thus requiring analysis by SAGE engineers.

Flare Flow Measurement

EPA 40 CFR part 98

There are many operations or applications where waste gas is flared to atmosphere. Flare stacks are typically seen at oil and gas wells, refineries, well drilling rigs, natural gas plants, wastewater treatment plants, chemical plants and landfills. Strict regulations, like the Mandatory Reporting of Greenhouse Gases Rule (40 CFR 98), require operations to measure, record and report the amount of flare gas emitted to the atmosphere. EPA 40 CFR part 98 requires reporting by 41 industrial categories. The categories are further divided into subparts. For more information on EPA 40 CFR 98 and its subparts refer to SAGE white paper “Greenhouse Gas Emissions Monitoring Using Thermal Mass Flow Meters.”

European Union Emissions Trading Scheme

The European Union’s Emissions Trading Scheme (EU ETS) is an approach to reduce air pollution through economic incentives, specifically by trading greenhouse gas (GHG) emissions allowances. The program began in 2005 and covers facilities in 30 countries. In this scheme each country is given a cap on total emissions allowed. Each facility in the program is required to measure and report their emissions each year, and surrender one allowance for every metric ton of CO_2, or the equivalent amount of nitrous oxide (N_2O) and perfluorocarbons (PFCs) they emit. If the facility emits less than their allowance, they can sell their credits, otherwise they may buy credits from other installations. We are currently in the third phase which has a trading period from 2013 to 2020.

Flare Gas Measurement

When flare applications of known gas composition exist, and water vapor isn't condensing, TMFMs offer an attractive solution for flare gas metering. The SAGE meter has wide turndown, or up to 1000:1 rangeability, which means it accommodates extreme flow conditions and large flow swings. Under normal venting situations, low velocities are associated with flare gas, yet high velocities are typical in upset conditions. Additionally, their fast response to flow changes, low pressure loss, accuracy (1% of reading plus 0.5% of full scale over a 100 to1 turndown) and reproducibility make the meter a contender to ultrasonic flow meters in flare applications.

Companies are taking advantage of the installed cost savings associated with TMFMs which are $5,000 or less, versus $50,000 or more for an ultrasonic application. Operators are realizing that by identifying the gas at the flare application, SAGE can adjust the meter to measure the known flare gas. This works for applications where compositional changes are known or are seasonal. While a bit more inconvenient than an ultrasonic meter, in many cases the savings warrant the minor difficulty.

SAGE Insertion Style TMFMs provide the wide turndown required to cover both the extremely low flows (low velocities) associated with normal venting, as well as the extremely high flow (high velocities) associated with an upset condition. Their fast response to flow changes, low pressure drop, and reproducibility are important characteristics for a flare application.

In-Situ Calibration Verification

In addition, SAGE products provide the customer with a unique in-situ calibration check at a "no flow" (0 SCFM) condition. This important procedure, assures that the meter has retained the original NIST Traceable Calibration, verifies the meter's accuracy, confirms that the sensors are clean, and that the flow meter hasn't drifted or shifted. This is a tremendous benefit, since it eliminates the cost and inconvenience of annual calibrations on the flow meter, and also provides the data needed to comply with a number of environmental protocols.

Applications

Biogas and Landfill Gas

Biogas, digester gas and landfill gas can be produced from industrial wastewater treatment, farming operations, municipal solid waste landfills and industrial waste landfills. These gases contain a mixture of methane (CH_4), carbon dioxide (CO_2) and minor quantities of other constituents. The gases can also be converted to renewable energy and fuel onsite boilers with the excess gas being flared. They can also be used to generate electricity, sell the energy to local industries or even create fuel for natural gas fueled vehicles.

If the operator is allowed to, they may choose to either release the flammable gas directly to the atmosphere or burn it with a flare. With a focus on reducing greenhouse gas (GHG) emissions, flaring the gas provides an opportunity to lower emissions. Biogas from a digester is a mixture of approximately 65% CH_4 and 35% CO_2, while landfill gas is closer to half CH_4 and CO_2. This gas can then be captured and destroyed in a process called **methane destruction**, which is accomplished by flaring the gas. While the process creates carbon dioxide, a greenhouse gas, it destroys methane which is 21 times more potent than CO_2. For this reason, flaring biogas, digester gas and landfill gas is a viable method for lowering GHG emissions.

Natural Gas Production

Whether natural gas production wells are on land or off-shore, a flare is always either at or near the wellhead. Once a well has been drilled for gas, the well is tested to determine flow rates, pressure and commercial viability. During the testing and until the well is functioning under normal operation, the natural gas is flared while the infrastructure is put in place to collect and transmit the natural gas to downstream processing. During normal operation, the gas may also be flared if there is over pressurization of the gas pipeline. Additionally, when maintenance is required at the well, flaring the gas would be appropriate.

If natural gas wells are not located near a pipeline it may be easier to flare off the gas. Similarly, if the amount of gas at a well is not deemed sufficient enough to justify the expense of building a pipeline, the gas may also be flared.

Natural Gas Processing Plants

Natural gas processing is the complex process of cleaning raw natural gas to eliminate its impurities and non-methane hydrocarbons and fluids. It begins at the wellhead and often involves the separation of oil and water from natural gas. Natural gas processing plants produce pipeline quality natural gas. A natural gas processing plant may consist of a flare system with multiple branch lines connecting secondary process units to the main flare header. Throughout this system the waste gas would be recycled through a vapor recovery system where the gas is recovered and returned to the process operation.

Natural Gas Pipelines

Natural gas pipelines route natural gas across long distances to and from compressors and distribution centers. Flares may be found at compressor stations to flare gas from pressure relief valves or blow down valves. Additionally, gas leakage from compressor seals may also be flared or vented.

Offshore Platforms

On offshore production platforms when natural gas is a byproduct and the gas cannot be recovered or disposed of in any other manner, the gas is flared or burnt off. Flaring natural gas can be measured with the SAGE TMFM which has a special wide turndown by taking extra data points during calibration.

30 CFR Part 250 subpart K

Federal Regulation Title 30 CFR Part 250 subpart K Oil and Gas Requirements require operators to meter flare and vent gas volumes for deepwater facilities processing more than an average of 2000 barrels per day during a calendar month. As stated by 30 CFR 250.1163 (a) (2), “The flare/vent meters must measure all flared and vented gas within 5 percent accuracy.”

Crude Oil Extraction

During petroleum crude oil extraction natural gas is commonly produced. When oil is pumped from the ground it typically contains water and natural gas. For oil and/or natural gas to be considered pipeline quality they must be separated through a separator. Here the gas is removed and sent to a separate pipeline while the remaining oil and water are heated and treated, which separates the oil and water. Residual natural gas or hydrocarbons are generally vented to atmosphere or processed further, while the oil goes to storage tanks. The vented vapors are typically low flow within small pipes (4"). Alternatively, when oil wells lack the infrastructure required to recover the natural gas, typically because the wells are in remote locations, much of the associated gas is flared as waste gas.

Oil Refineries and Chemical Plants

At refineries, the facility may consist of a flare system with multiple branch lines connecting secondary process units to the main flare header. Throughout this system the waste gas would be recycled through a vapor recovery system where the gas is recovered and returned to the process operation. As previously indicated TMFMs are *not* traditionally suitable for accurate emission measurement or obtaining a mass balance for the main flare header due to the extreme variations in gas composition. TMFMs however can be used in refineries or chemical plants to detect which specific operation is sending flow to the flare.

Oil Refinery Regulations

EPA 40 CFR Part 60 Subpart Ja

EPA 40 CFR Part 60 Subpart Ja are standards of performance for petroleum refineries and include flare flow measurement. The regulations require that all flares, with the exception of emergency flares, be continuously monitored for gas discharges to the flare. The thrust of this regulation is that the EPA encourages refineries to install flare gas recovery systems which will "reduce emissions of SO_2 by 3,200 tons/year, NO_x by 1,100 tons/year, VOC by 3,400 tons/year and CO_2 by 1,900,000 metric tons/year from the baseline."[1] While these regulations comply to refineries only, the oil and gas industry is looking at this as a potential future standard. As previously indicated TMFMs are not suitable for this application due to potential for significant modifications in the gas composition.

Atmospheric Storage Tank Vent

Atmospheric storage tanks are large aboveground containers commonly used in oil and gas production, containing liquids of oil or gas condensate. Storage tank emissions from venting are primarily volatile organic compounds (VOC) and considered hazardous air pollutants (HAP). Regulatory agencies may require that the emissions be quantified and reported. Additionally, reporting tank venting for greenhouse gas emissions is required under 40 CFR part 98.

Direct measurement of the vented vapors using TMFMs provides an accurate method to quantify emissions. Emissions are generated from flashing, working losses and breathing losses:

- When a gas or liquid stream experiences a pressure drop or a temperature increase, **flash gas** is created. Flash emissions from tanks can occur at the compressor stations, gas plants, pigged pipelines, tank batteries or at the wellhead.

- **Working losses** are emissions which result from the change in liquid level within the tank. As the tank is filled, the vapors within the tank are displaced and flow out the vent. Typical locations include: the wellhead, storage tanks, and liquid loading and unloading facilities.

- **Breathing losses** occur when vapors are discharged from a tank due to changes in pressure and/or temperature. They also include vapors from evaporation of the liquid in the tank.

Mass Flow Measurement

Flow Measurement Technologies

Ultrasonic Flow Meters

Measuring flare gas becomes a challenge for most flow meters. **Ultrasonic Flow Meters** are very accurate and are an effective tool to measure flare gas. They tolerate some condensed liquid, are not affected by gas composition and endure fluctuations in pressure and temperature. With this type of performance however, come high costs ranging from $50,000-$100,000 per installation. The ultrasonic meter does require pressure and temperature measurement to obtain mass flow.

Ultrasonic flow meters measure the difference in transit time of pulses that travel from a downstream transducer to the upstream transducer, compared to the time from the upstream transducer back to the downstream transducer. It also has the ability to determine the molecular weight of the gas by measuring the speed of sound. This data is then used by the flow meter to get a mass flow measurement in real time, when variations in gas composition occur.

Averaging Pitot Tube

Averaging Pitot Tube is a differential pressure flow measurement device. The instrument has limitations with gas flow measurement; especially low flow sensitivity and has limited turndown. The measurement is contingent upon achieving velocity pressure. At low flow rates it is very possible that there is insufficient velocity to obtain a suitable signal. Additionally, if there are changes in gas specific gravity, the pressure drop is impacted which creates flow measurement error.

Thermal Mass Flow Meters

Thermal mass flow meters are suitable for measuring flare gas when gas composition is consistent and known and there is no condensation. Additionally, in some applications when the operator is willing to trade off lower accuracy, the TMFM can save money versus the expense of an ultrasonic flow meter.

Principals of Thermal Mass Flow Measurement

Thermal mass flow meters measure gas flow based upon the principal of convective heat transfer. Either insertion style probes or in-line flow bodies support two sensors that are in contact with gas. The sensors are resistance temperature detectors (RTDs), and the SAGE sensors consist of highly stable reference-grade precision matched platinum windings that are clad in a protective 316 SS sheath for industrial environments.

One of the sensors is heated by the circuitry and serves as the flow sensor, while a second RTD acts as a reference sensor and measures the gas temperature. The SAGE proprietary sensor drive circuitry maintains a constant overheat between the flow sensor and the reference sensor. As gas flows by the heated sensor (flow sensor), molecules of the flowing gas transport heat away from this sensor, the sensor cools and energy is lost. The circuit equilibrium is disturbed, and the temperature difference (ΔT) between the heated sensor and the reference sensor has changed. Within one second the circuit will replace the lost energy by heating the flow sensor so the desired overheat temperature is restored.

The power required to maintain this overheat represents the mass flow signal. There is no need for external temperature or pressure devices.

One of the advantages of TMFMs is that they have no moving parts which reduce maintenance and permit their use in difficult application areas. They also do not require temperature or pressure corrections to obtain mass flow and provide good overall accuracy and repeatability over a wide range of flow rates. This style of meter measures mass flow rather than volume and is one of the few categories of meters that can measure flow in large pipes and ducts.

Sage Metering Difference

SAGE provides TMFMs that are factory calibrated and configured for the specified application which provides easy installation. They are ready to be installed directly into the pipe without any need for field set up and calibration. SAGE offers insertion as well as in-line TMFMs, with built-in flow conditioners that monitor flow rates. These direct mass flow meters are highly accurate and repeatable, and have negligible pressure drop.

The SAGE meter has extraordinary rangeability of at least 1000 to 1. Because of its low-end sensitivity and wide turndown, the SAGE TMFM can accurately measure extremely low velocity, down to 5 SFPM, making it extremely effective for measuring the low flow rates associated with normal venting, yet can also accurately measure the extremely high flows associated with upset conditions. In addition to the 4 – 20 mA control output of flow rate, the meters also provide pulsed outputs of consumption, and Modbus compliant RS485 RTU communications. The meters feature bright graphical displays of flow rate, totalized flow and gas temperature, plus continuous diagnostics. For difficult to reach pipes, or for locations with extreme radiant heat, SAGE also offers a remote style flow meter, with up to 1000 feet of lead length compensated cable – all electronics and powering are done at the transmitter – thus, the probe or flow body simply has a terminal junction box.

Calibration Verification

The SAGE TMFM comes from the factory fully calibrated and can easily verify that it maintains its original factory calibration through an in-situ calibration verification.

All SAGE meters are able to perform the in-situ calibration check as long as a “no flow” (0 SCFM) condition can be created. “No flow” is easily created using an isolation valve assembly with the insertion meter style. Unlike other TMFMs, the SAGE In-Situ Calibration not only verifies that the unit is accurate; it also indicates that the sensor is clean. If the meter does not pass the calibration check the first time, in most cases simply cleaning the sensor, and re-testing will verify that the meter is accurate and hasn’t drifted or shifted.

Hazardous location

The SAGE Prime® is contained within a dual-sided NEMA 4 enclosure with easy access to a separate rear compartment. The Prime is CE compliant, and meets Class 1, Division 2 standards for hazardous service.

The SAGE Rio™ provides the same levels of performance found in the Prime with the added ATEX Zone 1 Flameproof approvals. The Rio is housed in an explosion proof, dual-sided NEMA 4X enclosure.

Summary

Flaring and venting systems are used globally to burn off waste gas, surplus gases and are also a safety means to protect process equipment, the system’s processes and the environment. Flaring systems are used extensively in natural gas drilling, production and transmission, oil drilling and refineries, chemical processing plants as well as wastewater treatment, landfills and farming operations.

The extraordinary rangeability and ease-of-installation of SAGE Thermal Mass Flow Meters offer economical solutions for the measuring, monitoring and reporting of flare gas in various systems, including biogas, landfill gas and natural gas; as well as applications at oil refineries and chemical plants, when the gas composition is known.

In addition, in cases of variable composition, SAGE can provide an error analysis, which if acceptable to the operator may offer an alternative to the expense of ultrasonic flow meters.

We welcome the opportunity to review your application, and to recommend the best solution to achieve your objective.

[1] Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency and RTI International (2012). Regulatory Impact Analysis: Petroleum Refineries New Source Performance Standards Ja. 65.