Gas Flow Monitoring
CEM Design Characteristics & Applications
by Ed Wadington

The primary purpose of continuous gas flow measurement is to establish, in concert with species concentration monitoring, the mass flow of various constituents (SO_2, NO_x, CO, VOC, etc.). Other purposes exist but the bulk of applications fit into continuous species mass flow evaluation. Such purpose is almost exclusively ‘driven’ by existing and impending regulatory requirements.

During the past thirty years the author has participated in the testing (certification) and data evaluation of continuous emission monitor (CEM) systems including numerous gas flow monitoring devices and technologies. As a result it has become clear which gas flow monitoring system characteristics yield successful performance results. These include:

- Minimization of **vulnerable** *in situ* (gas stream) components.
- Minimization of on-stack (duct) components.
- Location of critical components at a point of convenience for maintenance personnel.
- Simple **primary reference** calibration capability.
- Simplicity of design allowing for ease of installation.

All of these ‘characteristics’ must be considered when one designs or applies a design to ‘represent’ a gas stream velocity. The following discussion elaborates on each of the outlined design parameters and other parameters relevant to the monitoring of gas flow.

It must be noted that the author is the designer of the EMRC Gas Flow Monitor and president of EMRC. As such this discussion is biased in favor of the EMRC design. This bias, however, is primarily the result of fifteen years of very successful applications with over nine hundred units installed and certified in a wide variety of industries world-wide. It must also be noted that a variety of domestic industrial processes have been regulated by mass flow for over two decades. Accurate and precise gas flow monitoring of hostile streams is nothing new.

Prior to further discussion of the outlined points it is critical to comment on how the gas flow monitor represents the average gas stream velocity. A variety of technologies are deployed within the gas stream each measuring velocity at one of more traverse points. The primary technologies considered in this discussion are pressure differential (Dp), ‘beam’ instruments (Ultrasound and/or Acoustic), and thermal sensing (heat loss differential). Dp and thermal methodologies are invasive techniques utilizing one or more ‘sensing’ points within the gas stream while the non-invasive method projects a single plane beam across the gas stream (Ultrasound and Acoustic). It is not really important how sensing is implemented, instead, it is critically important that whatever approach is used it represents the total gas stream.

The method as to how the ‘total stream’ is represented seems to stir the greatest amount of confusion and controversy. In a ‘nutshell’ the question is “How many traverse points are needed to accurately reflect the 'total' stream flow? Is a single plane 'beam' more accurate that a single point Dp' sensor, etc.?" As previously stated the author has spent the past several decades involved in the measurement of gas stream constituents including gas flow, and as a result has come to some fundamental considerations. These are:

> *The number of gas flow measurement traverse locations in the vast majority of gas streams is unimportant. What is important is the proper placement of the sensor and its relationship to the total stream.*
>
> Such placement is established by pretesting of the stream via EPA Methods #1-2. Stratification is thus determined, and the probe(s) are placed in representative positions. As previously noted the number of traverse points has proven to be less important. Data derived from literally hundreds of gas streams indicates that a single and/or very limited number of sample points can represent the total stream with only a few exceptions. These exceptions are almost always obvious, and are the product of duct design not conducive to flow measurements including EPA Method #2. Power boiler stack gas streams, for example, are rarely stratified enough to negate single point representative gas flow measurement.

One area of concern is that the stratification profile may alter when the stream velocity changes. The strategy normally deployed in such circumstances is to 'profile' the stream at significant flows or velocity levels, and assign a flow related 'correction' to the velocity computation thereby maintaining representativeness at all flow regimes. It is important to note that it does not matter what gas flow measurement technology is deployed or how many points or planes are utilized. Representativeness must be pre-established by manual (reference) profiling of the gas stream.

Finally, surely it follows that more measurement points are better than one. A 'beam', for example, would better 'cover' the stream and thus negate the impact of stratification variations. The fact is that two or more points or a 'beam' must be related to the total stream in the same way, that is, by pre-establishment of the total traverse profile. The certification data, in the vast majority of streams, as previously noted, indicates that little is gained by utilizing an increased number of points. If one accepts this conclusion then it is usually unnecessary to establish multiple point or beam systems. Instead, it makes more sense and is more important to establish a strategy of sensing that enhances reliability. This is accomplished by keeping the *in situ* portion of the system simple (preferably single points with backpurge) or less preferably deploying two or more separate probes (one point, however, is more than adequate in nearly all streams). The two probe strategy is easily implemented with a pitot system since both probes 'feed' to a common transducer. If it is ever necessary to remove one probe the other, by connecting or 'closing' the pressure lines, will continue to operate. **Reliability** (up time) of such systems has proven to be **>99%** and in most cases 100%, that is, the system has never been off line due to total *in situ* failure.

Gas Flow Monitor Design Considerations

1) Minimization of Vulnerable *In Situ* (Gas Stream) Components

Process gas streams are generally hostile with some streams being **extremely hostile**. Placement of **critical** components within the gas stream diminishes long term reliability. Each gas flow measurement technology has advantages and disadvantages in a variety of streams.

A. Some pressure drop systems invade the stream with rugged components not easily vulnerable to severe stream conditions. Materials are utilized selectively that can survive in each stream. (EMRC has probes in extremely hostile *in situ* environments - far more onerous than power plant flue gas streams.) Thermal gas flow monitors also invade the stream, however, critical electronic *in situ* components are utilized. As a result these vulnerable systems are exposed and thus limited in application and reliability. 'Beam' instruments (Ultrasound, Acoustic, etc.) are non-invasive, and as such, have an <u>'apparent'</u> advantage over invasive techniques. Signal 'windows', however must be kept clean requiring <u>on stack</u> air purging.

B. There has been some commentary concerning particulate 'plugging' of pressure differential system probes. In those streams where plugging is possible backpurge is employed, and has proven to be effective. Backpurging of thermal systems is not always viable. Particulate buildup or corrosion is critical to the thermal sensor. Probes must be 'placed' only in 'compatible clean' streams. Experience with on stack 'windows' particulate buildup, similar to that utilized in the Ultrasound system, has proven to be more of a continuing problem than *in situ* EMRC probe plugging. This is because the 'window' must be kept very clean in order to function accurately and reliably.

C. Gas stream temperature does not limit Dp systems, however thermal and ultrasound techniques are limited to ~450-550 ^{o}F. The S-type pitot (EMRC) Dp system functions up to the melting of the sensor material itself (~2,000 ^{o}F with metal or ~3,000 ^{o}F with ceramics).

2) Minimization of On-Stack (Duct) Components

It is self apparent that access to large stacks or ducts is at best inconvenient and at worse difficult. As a result reliable routine maintenance is not always practiced. Those who have spent time up on a stack know that any permanent monitoring device is best located elsewhere preferably at a 'lower' point where vibration and environmental conditions are improved and routine maintenance is easily deployed. The increasing popularity of extractive gas monitoring systems bears witness to this observation. Instruments packed with critical optics and electronics 'hanging' on the stack have proven to require high maintenance. The demise of *in situ* instrumentation was not a surprise to those middle-aged stack testers who patiently waited for technicians to put or bring back 'on line' a 'beam' or other *in situ* instrument so that certification testing could proceed.

Some pressure differential systems like the EMRC Monitor place minimal equipment on the 'top' (probe and connecting lines) while critical instrumentation is placed at locations easily and desirably frequented by instrument technicians.

"Beamed' and thermal instruments are especially vulnerable to 'top side' realities. Alignment criteria and complicated electronics do not lend themselves to vibration, thermal changes and instrument technicians who fail to 'climb or ride' to the instrument. Some Dp instrumentation designs also place electronics on the stack, and are equally vulnerable to environmentally induced failure.

3) Location of Critical Components at a Point of Convenience for Maintenance Personnel

If delicate components should not be placed on the stack in harms way, where should they be placed?

As already noted a viable design places as much of the instrument in a environmentally protected and convenient location as possible. This location should be conducive to ease of maintenance for the convenience of the technician not the instrument and/or its manufacturer.

The S-type (EMRC) Gas Flow Monitor places only the probe(s) and thermocouple on the stack, while the instrument can be placed at any desired location anywhere on the plant site. All functions including calibration are conducted at the instrument - not 'upstairs'.

4) Simple Primary Reference Calibration Capability

What is meant by calibration of a gas flow monitor?

There are two basic means to calibrate any instrument system - static and dynamic. Static calibration is a check, usually electronic, of a limited number of system components. This is usually implemented by inputting (simulated) electronic signals into various subsystem components. While those components 'checked' are validated critical 'other' components are neglected. The result is the system appears to be functional but one or more of the critical non-validated components can remain significantly biased.

In order to evaluate total system function a dynamic calibration must be routinely implemented. A primary reference check means that the output of the instrument is directly relatable to a reference method (EPA Method #2, etc.). Not all gas technologies are capable of performing *in situ*, dynamic calibration.

Dynamic calibration can be conducted by deploying a reference test series (EPA Method #1-4, etc.), and adjusting the monitor as needed. This approach on a routine basis is unacceptable due to excessive costs. Dynamic calibration of pressure differential systems can and is implemented by controlled pressurization of the 'Dp' instrumentation. Concurrent routine back purging of the EMRC S-type probe, for example, ensures stable *in situ* geometry thereby evolving a system with dynamic primary reference calibration.

'Beam' instruments such as the Ultrasound project a reference signal across the gas medium (stack or duct). This calibration technique, however, is less than a true dynamic calibration (more a static) in that ultrasound travel time is impacted by gas stream constituents and physical changes (temperature, density, etc.). The degree of induced reference error thus depends on stream variation and *in situ* alignment. Ultrasound and/or Acoustic system dynamic calibration must be designed in a way not yet available on the market.

Current thermal systems cannot be dynamically calibrated without removal from the gas stream (to a wind tunnel). Unfortunately thermal systems are the most vulnerable to *in situ* bias (particulate buildup, corrosion, etc.) and as such need frequent dynamic validation.

5) Simplicity of Design Allowing for Ease of Installation, Maintenance, and Operation

If a gas flow monitor is easily installed, easy to operate and easy to repair, it would be more reliable and cost effective. In short, it will pay for itself relative to its competition. It has been frequently stated that many sources do not care what the system costs to buy, operate and repair. The only thing that counts is its accuracy and precision. This approach is nonsense because those systems that are easy to install, operate and repair will be least vulnerable to frequent indeterminate bias and downtime due to improper installation, operation and untimely repair. Field experience indicates that complexity evolves downtime and biased data more frequently than less demanding systems. These comments, of course, assume that any considered system meets regulatory specifications.

Dp systems involve the least complexity of all the gas flow monitor technologies. The S-type (EMRC) monitor is designed to install easily by placing its critical hardware away from the stack. The placement of critical components greatly simplifies operational checks and any potential repairs. Some Dp vendors locate their hardware on the end of the probe and/or at the stack. In addition, most of the stack located components are 'packaged small', therefore decreasing repair ease, especially up on the stack. The 'beam' technologies such as the Ultrasound put the majority or all of their packaged (compacted) hardware on the stack. Serious maintenance checks require the use of an oscilloscope or other electronic entourage. As a result installation costs for on-stack 'gear' requires platforms and other on stack access equipment. The S-type strategy, in contrast, has no stack electrical, electronic and/or optical gear. Instead all that is needed is one three or four-inch flange from which a small pressure umbilical bundle 'drops' to wherever the instrument is located. On stack access equipment and associated costs are minimal.

Several system vendors suggest procurement of maintenance contracts. This is understandable considering the complexity of some Dp, thermal and especially the Ultrasound and/or Acoustic system designs. EMRC, utilizing the S-type design, doesn't have maintenance contracts - nobody wants one. In fact, a majority of our customers don't stock and haven't requested spare parts (they should).

Again, the total **lifetime** cost of a viable system is a reflection of its performance. Performance cannot be bought and its initial cost need not be necessarily excessive. Performance is the product of design. ***There is elegance in simplicity.***

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