THERMAL FLOW MONITOR DESIGN AND PERFORMANCE IN ACID RAIN STACK

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ABSTRACT

This paper offers an overview of thermal flow monitor performance in Part 75 utility applications for Phase I and II flow measurement. The paper first addresses the history and evaluation of thermal technology for CEM applications. Next, the paper outlines performance results.

PREFACE

General information presented applies to both manufacturers of thermal systems used in Title IV applications. Results information pertains only to applications of equipment manufactured by the author's company.

INTRODUCTION

Implementation of Title IV of the Clean Air Act greatly expanded the market of mass flow measurement in utility flue gas ducts and stacks. Lessons learned from recent experience in this demanding application resulted in the rapid evolution of equipment designed to ensure accuracy, reliability and ease of maintenance. Thermal technology, one of three accepted methods of mass flow measurement, had proven to be an extremely accurate and reliable means of measuring mass flow for utility emissions monitoring purposes.

Thermal Applications

Thermal technology was not initially approved for use in Part 75 applications. Proposed Part 75 rules specified ultrasonic-type flow meters with no mention of thermal-type of differential-type systems. Consequently, initial CEM users commonly demand the use of ultrasonic-type flow meters. Specifications were further swayed away from thermal due to integrators' and users' lack of familiarity with thermal equipment. Engineering overhead was also a factor in selection. Integrators could use boilerplate designs for some technologies regardless of stack size. Thermal system configuration varied with each stack. Further concerns of potential clogging and fouling coupled with the initial system cost of thermal systems for large stack made thermal the arguable last choice technology in 1991.

Initial Thermal Roadblocks

- Excluded by proposed Part 75 rules
- Ultrasonic typically specified
- Requirement to engineer systems for each stack
- Clogging and fouling concerns
- Cost

A 1991-92 flow monitoring equipment evaluation conducted by TVA and IT Corporation provided data that changed users' views of thermal systems. This test evaluated two ultrasonic-type and two thermal-type (one constant temperature and one constant power) flow monitoring systems. While one of the ultrasonic systems was installed on a single boiler fed stack, the thermal systems were placed on a larger stack with six boiler inlets. Of all systems tested, only the constant temperature thermal system surpassed a 10 percent relative accuracy standard for all loads. The system continued to provide accurate and dependable data over the course of a year-long test.

Growing acceptance of thermal technology resulted in the installation of more than 60 systems for Phase I and Phase II Title IV applications. While thermal applications cover a variety of stack and duct sizes, temperatures and configurations, thermal applications are typically characterized by one or more of the characteristics listed in the following chart:

Typical Thermal Application Characteristics

- Multi-Breach stacks
- Short straight runs with widely varying low profiles
- Ducts
- Cyclonic flow conditions
- Dry (temperature above condensation point) ducts and stacks
- Dirty environments

Thermal manufacturers were commonly challenged with difficult applications outside other manufacturers' equipment specifications or that other manufacturers refused to accept. Compliance specialists and engineers should keep this in mind when comparing results with those of other manufacturers.

System performance success coupled with greater affordability that resulted from design advances resulted in the widened acceptance of thermal systems over the past two years.

Thermal System Design Evolution

Thermal flow system manufacturers, just as the manufacturers of most flow measurement systems, were initially unprepared for the requirements specified by 40CFR75 and demanded by the applications. Thermal manufacturers who chose to enter the CEM market were forced to modify, and in some cases redesign, their products. Product change is traceable to one or more of five factors: compliance driven design changes, system modifications to accommodate in-situ calibration, cost competition driven advancements, application required improvements, and improvements intended to ensure optimal accuracy and repeatability.

Basis of Change

- Compliance requirements

- In-Situ calibration
- Cost competitiveness
- Harsh application conditions
- Accuracy and repeatability

Compliance Driven Changes

The publication of the proposed Part 75 rules specified ultrasonic-type flow meters as the only type of flow monitor with daily zero and span capability. Thermal manufacturers were quick to design zero and span calibrators. This design was, for the most, the first step taken towards entering the CEM market. The typical thermal zero and span drift check module was designed to provide prescribed signal levels for zero and span ranges to the system transmitter in lieu of the normal input from the sensors. Thermal manufacturers demonstrated zero and span modules in early 1992. EPA stated in July 1992 that “other types of flow monitors, such as differential pressure and thermal monitors, do indeed have daily zero and span calibration capability equal to that of ultrasonic flow monitors.”

The second compliance-related design issue focused on the thermal system’s ability to meet interference check requirements pursuant to the final draft of the regulation. The accepted method for interference check is, essentially, an alarm function that indicates severe drift outside established parameters. This technique has worked well to date.

The major regulatory hurdle facing thermal manufacturers was daily zero and span drift check capability. Resolution of the issue opened the door for thermal manufacturers to enter the market.

Thermal System Cost Competition

Customers initially perceived thermal technology as the most expensive on the market. Thermal manufacturers argued the advantages of simple installation on a single scaffold level, long-term operating savings, etc. Regardless of arguments stating the cost of ownership to be less than other technologies, initial purchase price was a detriment to wider acceptance of thermal-type flow meters.

Thermal manufacturers approached this issue in two ways. First, manufacturers looked to streamlined designs that allowed more efficient manufacture. The two leading thermal CEM flow vendors both made major modifications to their insertion multi-point elements. An arguable intent of the design change was to produce an easily manufacturable product.

Secondly, thermal systems were, and still are, priced somewhat in relation to stack size. Typically, larger stacks require more sensors, longer bars, more material and larger flanges. Excessively long cantilever distances also require truss supports in some of the larger stacks. Trusses increased system cost by as much as 30% to 50% in some cases. This was of particular concern when dealing with more costly corrosion resistant alloys such as C-276.

One thermal manufacturer modified its design to provide up to a 50% increase in unsupported cantilever distance for some large duct and large stack applications. This improvement allowed manufacturers to configure later systems without the need for trusses. (See Figure 2). This reduced system cost in all but the largest of duct and stacks.

Design modifications that lowered manufacturing costs and, in some cases, allowed system installation without truss support, resulted in thermal-type systems average cost decreasing over the 1992-1994 period. This trend of lowered system cost will certainly continue with the installation of thermal-type flow meters in smaller stacks for follow on CAAA applications (See Figure 1).

In-Situ Calibration

The obvious need to provide mass flow measurement data in close accordance with Method II traverse results prompted manufacturers of various technologies to review their products' ability and ease to be in-situ calibrated. The majority of existing systems originally included, as a minimum, a single correction or bias factor adjustment. Optimal results required greater capability. Customers demanded the ability to apply independent corrections at multiple load levels to accurately meet accuracy requirements at various flow rates.

As a first step, thermal-type manufacturers offered microprocessor-based transmitters exclusively for CEM applications. Dated analog-based averaging circuits were abandoned in favor or more versatile programmable transmitters. Programmable transmitters offered three levels of in-situ calibration sophistication.

The most basic of these was a single programmable correction or calibration factor. Use of this single factor corrected at a single load level. The use of uniform bias could, however, potentially introduce error at other load levels.

A more accurate and common technique was the use of multiple calibration factors at various levels. This essentially provided the user the ability to curve-fit his output to match traverse data at the different loads, therefore accounting for changing profiles at the different loads.

The most sophisticated and most widely used technique was the use of special accuracy and redundancy software in conjunction with microprocessor-based transmitters. This particular approach allowed thermal vendors to fully utilize their unique ability to gather flow measurement data from independent sensor inputs ideally located in 40CFR60 Method II prescribed locations. Engineers essentially "foot printed" Method II traverse patterns with their sensors. The most sophisticated of schemes allows the user to input reference method values into the microprocessor. The microprocessor compares individual sensor readings to the reference average. The flow computer then computes its own calibration factors. (Refer to Table 1).

This technique also provides system configuration redundancy by means of calibration factor recalculation if any number of sensors are removed from the average (Refer to Table 1). This technique was demonstrated in a test in 1992. Results indicating minimal relative accuracy change were forwarded to the EPA. The capability was field proven when one utility removed 50% of their insertion elements from each stack for material upgrade in 1994.

Application Driven Product Changes

While thermal mass flow technology was proven by years of use in numerous industries, flue gas CEM measurement presented a number of challenges. Flue gas mass flow measurement is arguably one of the most difficult and challenging of mass flow instrument applications. Excessive temperatures in ducts, corrosive gases, cyclonic flow and uneven velocity profiles combine to create a formidable measurement situation. Thermal advances to satisfy the flue gas application demands included sensor redesign, rigorous product burn-in testing, probe material and construction improvements and improved electrical interference protection safeguards.

The most critical component of any thermal system is the sensor. CEM requirements for dependable systems that would provide maximum on-line time created a focus on sensor design. The most significant advancement was in the materials of construction. The most widely used thermal sensor was constructed of alloy C-276 with CB-20 base components. These sensors proved to be extremely dependable, with no recorded failures of the 620, in operation to date, as a result of primary causes.

A further advance included modification of one manufacturer’s design from a threaded to a welded construction. This change was intended to reduce potential moisture and corrosion infiltration paths into the sensor electronics area.

Increased focus on quality control procedures was a final factor that greatly elevated the performance of thermal sensors in CEM applications. Rigorous burn-in procedures designed to identify manufacturing defects and remove the weaker sensors from production resulted in excellent performance. A thermal system with 12 sensors was now operated on the direct outlet side of a boiler at a temperature of 750°F for 19 months with no sensor problems. Identical sensors are in operation in RECLAIM applications in a Southern California Refinery to temperatures in excess of 1100°F.

The most notable of design changes was the use of heavier weight corrosion resistant materials in highly corrosive applications. While C-276 was recommended for most applications, stainless steel was most commonly selected due to cost concerns. One utility requested the use of C-276 from the flange to the rear of the first sensor. They achieved improved corrosion resistance in the area of the flange well and stack wall, where condensation is most prevalent, while controlling their costs. Insertion flow elements of this design have performed with no corrosion problems. An all Inconel system has performed in a like manner. Stainless steel elements fared less well. Twelve systems, originally requested in stainless steel, were retrofitted to C-276. The systems operate with no corrosion related problems.

Interference protection was the final major design accommodation for CEM applications. The majority of thermal systems in operation are outfitted with special lighting protection circuitry that is designed to protect the sensor/bridge board combination and the microprocessor-based transmitter. Protection at both ends isolates the most sensitive of components. Thermal systems survived direct lightning strikes to stacks with no memory loss and no hardware damage.

Fouling

Bias associated with sensor fouling was a major concern of CEM users. Thermal vendors insisted that fouling and build-up would have negligible effect on system accuracy and repeatability. This argument seems to hold merit. Thermal manufacturers have recommended the installation of systems one to two weeks prior to RATA testing. This allows sensors to develop a slight amount of residue coating that reaches an equilibrium in typical coal, oil and gas fired stacks. While the total drift associated with such build-up varies, systems have proven to be repeatable from this point on.

Manufacturers planned to deal with potential fouling and build-up in three ways: by leaving the systems undisturbed as just described, by flash heating the sensors to remove build-up, or by purging.

One thermal manufacturer experienced significant drift problems in a particular stack that emitted gases from a coal and tire fuel blend fired boiler. The stack particulate included fine stringy material that wrapped the probe sensor in an insulating coat. Installation of a purge option designed to periodically blow the sensors clean proved to be successful.

Another system displayed drift after 16 months of operation in an outlet directly off a fluidized bed. This was an unusually severe and dirty application. Sensors showed little drift initially since the abrasive properties of the ash prevented build-up from occurring on the leading edge of the sensors. Build-up occurred on the rear edge of the RTD sheaths. This build-up eventually bridged the gap between the RTD's and caused noticeable error. The user solved the problem by initiating a regular cleaning program.

Thermal design has rapidly progressed over the last two years. The majority of thermal flow systems used in Title IV ducts and stacks have performed well. This is mainly a result of sound design and good application engineering.

Results

Performance information is summarized for convenience. RATA results are listed in table form. Performance summaries and conclusions are listed in an itemized format. The results presented include all information available to the author at time of publication.

Thermal System Performance Summary

! 94% of systems meet annual recertification requirements. All loads<10% RA. (Refer to Table 2).

! Three quarters of systems exceed year 2000 annual requirements of 7.5% RA (Refer to Table 2).

! 93.4% first run certification of systems. One second run resulted from failure to execute Pre-RATA, another from improper Reference Method conversion.

! A 92% system recertification on initial run. Manufacturer software error resulted in recertification error in one case, user selected programming was cause in another.

! Excellent system repeatability after one year of operation in dirty stacks (See Table 3).

! System corrosion in unusually harsh stacks resolved through use of corrosion resistant materials.

! Over 600 C-276 sensors in use with no failures due to primary causes.

! Clogging problem in unique application solved through use of purge system.

! Successfully applied in high temperature applications to 1100°F.

! Excellent performance in short-straight-run large ducts.

Summary

Thermal-type mass flow measurements systems are proven to be a dependable and accurate means of mass flow measurement for compliance requirements. Thermal manufacturers developed and evolved products designed for accuracy and availability that satisfied user needs.

Successful applications typically are the result of much more than sound equipment and good technology. User understanding, technician training, proper maintenance and thorough application engineering are critical. Selection of the proper technology for the application is the keystone to any successful instrument application.

Performance success and greater system affordability should result in wider use of thermal-type mass flow systems by utilities. One application need will be for system retrofits that come as a result of more stringent relative accuracy requirements. Another is for control purposes intended to improve process efficiency and reduce emissions. Thermal's proven accuracy and reliability in the most difficult of Title IV applications demonstrates the suitability of thermal for multiple utility mass flow measurement needs.

References:

Gibson, Gary, Mowery, Michael S., Weldon, Jill, "Flow Monitor Equipment Evaluation at Two Large Coal-Fired Boilers Initial Results", in *Continuous Emissions Monitoring, A&WMA 1993*.

Sensors in Operation	**Avg. Velocity SFPM (Corrected Output)**	**C Factor**
8	1930	1.058
7	1936	1.055
6	1920	1.049
5	1942	1.055

4	1929	1.051
3	1920	1.062
2	1920	1.050
1	1914	1.086

Table 1 Corrections Capability of Redundancy Software

Application	Low	Medium	High	Average
1	2.53	2.52	4.85	3.3
2	9.08	3.46	6.14	6.22
3	1.9	2.02	0.9	1.60
4	5.39	6.43	1.86	4.56
5	5.0	5.9	4.5	5.13
6	6.6	5.2	4.9	5.56

7	9.76	6.65	7.39	7.93
8	5.62	1.16	4.26	3.68
9	3.2	6.5	7.9	5.86
10	2.6	0.73	6.3	3.21
11	4.21	3.26	6.90	4.79
12	4.6	1.62	11.65	5.95
13	3.51	1.55	2.28	2.44
14	6.3	2.86	3.62	4.26
15	3.41	5.23	3.77	4.13
16	8.69	7.54	6.77	7.66
17	8.86	3.93	1.48	4.75
18	2.67	1.70	3.72	2.69
19	4.41	1.43	3.35	3.06
20	5.43	2.73	2.64	3.60
21	1.9	2.95	3.40	2.75
22	3.34	3.94	2.57	3.28
23	6.99	9.66	13.35	10.00
24	4.38	5.36	3.43	4.39
25	0.52	3.59	1.97	2.02
26	9.75	7.35	2.54	6.54
27	2.20	1.59	2.30	2.03
28	3.72	2.65	4.91	3.76
29	7.32	6.83	5.94	6.69
30	1.6	2.1	1.4	1.70
31	6.5	4.0	4.5	5.00
			Average: 4.46	

Table 2 Thermal RATA Results

Date	Low	Medium	High
1993 1994	7.4 3.34	6.65 3.94	9.76 2.57
1993 1994	6.6 6.99	5.2 9.66	4.94 13.35
1993 1994	4.85 4.38	5.90 5.36	5.00 3.43
1993 1994	2.57 0.52	.74 3.59	6.26 1.97
1993 1994	3.23 9.75	6.52 7.35	7.87 2.54

1993 1994	5.62 2.2	1.16 1.59	4.26 2.3
1993 1994	5.39 3.72	6.43 2.65	1.86 4.91
1993 1994	2.53 7.32	2.52 6.83	4.85 5.94

Table 3 System Repeatability in Annual Recertifications