Energy Measurement using Ultrasonic Flow Measurement and Chromatography
The Technician's Perspective
Class 5140.1

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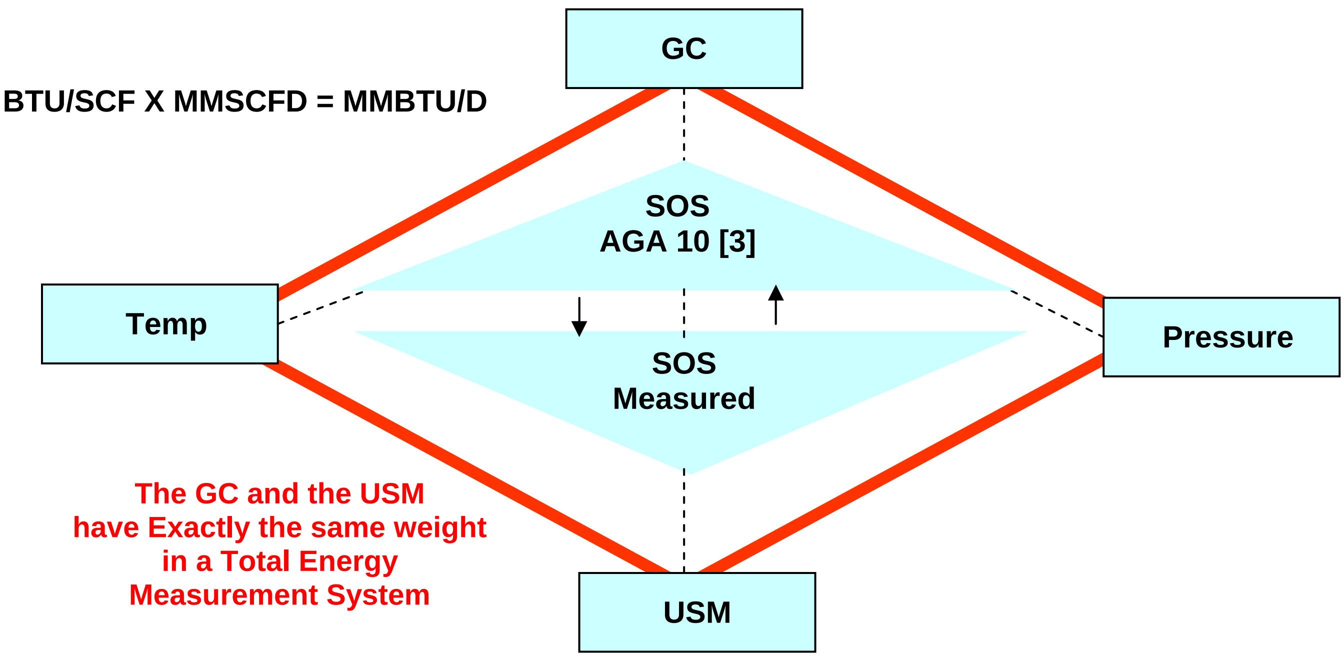
Do you need a fully interlocked GC/USM Energy Measurement Station?
Your Company exchanges all money on gas custody transfers on Total Energy, not on MMSCFD or BTU/SCF



Speed of Sound (SOS) Measured vs Calculated; on-line continuously,,,,,when they do not equal to within reasonably tight limits….Something is wrong with one of these 4 measurements. The Diamond of Excellence in Energy Measurement!

The demand for global energy increases with time as surely as the world population of users of gas energy has increased each year. Energy will ALWAYS be in demand. Good 'Systems' for measuring it accurately and reliably are a Must. This paper will put some of the realities of assembling and operating an Energy Measurement Station for natural gas into perspective; into ***A Technician's perspective!***

Introduction

Gas energy rate stations are becoming more sophisticated and more common. New power units across the country are now typically metering with ultrasonic meters in concert with gas chromatographs. This issues some new challenges to the field metering professional. Familiarity with each technology is a good start. Appreciation of how to maximize the two; gas chromatograph (GC) and Ultrasonic meter (Usm), to produce more than the sum of it's parts is a valuable asset to a gas company's operation. Each technology assists the other in advanced troubleshooting and proof of measurement integrity.

Technicians will invariably be the link to the success of any changing technology that would survive and thrive in the real field pipeline environment. Meter stations must be maintainable and provable. The system and requirements will be examined from that field perspective.

Perspective of Measurement Error Cost

(First; a brief appreciation of heat energy)

Definition: Heat energy (or just *heat*) is a form of energy which transfers among particles in a substance (or system) by means of the kinetic energy of those particles. In other words, under kinetic theory, the heat is transferred by particles bouncing into each other.

Definition: Thermal energy is generally considered to be a term used in physics, and refers to the energy created when the kinetic and potential energy of an object in motion is combined. As the name implies, thermal energy refers to heat that is created through the process of thermal energy.

Definition: A British Thermal Unit (BTU) is the amount of heat energy needed to raise the temperature of one pound of water by one degree F at one atmosphere of pressure. This is the standard measurement used to state the amount of energy that a fuel has as well as the amount of output of any heat generating device.

Take one gallon of water (8.3 pounds) and put it on your stove. If the water is 60 degrees F at one atmosphere of pressure and you want to bring it to a boil (212 degrees F) then you will need about 1,200 BTUs to do this. It takes about one cubic foot of good rich 1,200 btu/scf natural gas to boil one gallon of water! We talk about a million cubic feet of gas commonly in this industry. It's enough heat energy to boil almost a million gallons of water! The volume of the average water tower!

A one megawatt generator operating at full capacity for 1 hour will generate 1 megawatt-hour of electrical energy. If the 1 MW power unit has a heat rate of 10,000 Btu per kilowatt-hour, which is equal to 10,000,000 Btu per megawatt-hour, it would use 10 million Btus of fuel per hour at full capacity. If the natural gas has a heating value of 1,000 Btu per cubic foot, the 1 MW plant would consume 10,000 cubic feet per hour or 10 Mscf per Megawatt hour. At this rate a 100 Megawatt power unit needs 24 MMscfd of 1000 btu gas. 24 MMscfd costs $125,000 per day or $3,750,000 per 30-day month. This would easily flow through a 6" gas ultrasonic meter. It should be sobering to think that when you look at that 6" meter at that flow rate that a 0.25% measurement error would cost: $3,750,000 X 0.0025 which equals a $9,375 error per 30-day month! This equates to an error of $114,062 per year.

Accuracy is inexpensive; compared to inaccuracy. There is no capital savings on an accuracy compromise. In terms of fiscal responsibility, settling for mediocre accuracy is inexcusable.

The Ultrasonic Gas Flow Meter – A brief view

An ultrasonic meter measures gas flow rate by sending bursts of high frequency sound upstream and downstream diagonal to the flow and measuring the transit time in each direction. Measuring the time difference to travel upstream and downstream along a known fixed path length gives path velocity. Correcting for the angle between the path and the axial flow gives average axial velocity for the portion of the meter's area represented by that path. Path average axial velocity times path weighted area gives actual volume rate for that portion of the meter's area represented by that path. All paths summed gives meter actual volume rate.

Sound will take longer to travel the path length against the flow than it will with the flow. The time difference is proportional to the flow velocity. The total time to travel both upstream and downstream divided into two path lengths gives speed of sound (SOS). It will become ***significantly important*** to remember that the speed of sound is measured with the same two "path timings" as the gas velocity. A significant error in the SOS measurement means that you are making a significant error in measuring flow. *Excellent agreement means that you are probably doing an accurate job of measuring flow*.

The speed of sound can be calculated by use of the AGA 10 [3] Report for Speed of Sound calculation and by entering the gas composition percentages from a chromatograph, line temperature and pressure.

Usm Installation Checklist

Follow the AGA 9 [1] recommendations for a properly specified energy station Usm

Construct a checklist. *Example:*

___ Meter arrived mechanically undamaged
___ Calibration lab. data is available
___ Dimensional info. available
___ Meter is oriented correctly
___ No gaskets protruding inside
___ Meter bore matches the tube bore within +/- 1 %
___ Flow conditioners correctly installed
____ Meter tube spools aligned/pinned
___ Minimum upstream and downstream pipe diameters available
___ Meter supported

___ Thermowell the correct number of diameters from the meter and correct insertion depth
___ Factory data is correctly entered into the Digital Signal Processor (head) of the Usm
___ All pressure bearing components in place
___ No low areas are in the run (which will collect liquids and restrict the meter's area)

Plan ahead and build a complete checklist!

Understanding “Calibration” on Usm’s

The terms, “volume rate”, “flow rate” and “energy rate” are used daily in the business of measuring gas flow. “RATE” is literally Distance/Time; like feet per second or miles per hour.

Ultrasonic flow meters are pure *rate* meters. They measure the time for sound to travel a known distance. ***Geometry is everything.*** During production, manufacturers should precisely measure path lengths, placement, angles, bores, etc. Knowing these measurements precisely makes an “inherently” calibrated or “DRY” factory calibrated meter. Inferring angles and lengths by “tweaking” them to correctly read SOS should be avoided.

Flow calibration on a properly measured “DRY” calibrated meter usually removes a slight zero offset and/or any small non-linearity. If flow calibrated then Meter Factors will be installed by the cal lab and should be verified at start up. Flow lab data should also accompany the meter for your records. The technician should logon to a new meter and save a record of the factory configuration prior to startup. The Technician should check that the diagnostics show that the flow dynamic parameters are reasonably close to what they were at the cal lab. The cal lab data should be the meter’s starting Baseline.

The technician will routinely check that the complete data base of the meter is correct, its performance parameters are correct and that the USM ‘s measured speed of sound is within a tight margin of agreement against calculated speed of sound. Maintaining the meter’s accuracy usually requires very little effort. Comparing measured to calculated SOS allows you to know if any of your primary energy system measurements have shifted or drifted as a function of a Usm timing problem.

The sensitivity to the SOS change is a function of the change in gas composition –vs- temperature –vs- pressure and is shown in the following example of comparing slightly different methane -vs- ethane contents, temperature changes and pressure changes. This example uses a real (and typical) rich production inlet gas to a gas processing plant. This composition is field captured from a gas plant inlet in S. E. Texas.

Natural Gas Composition

(Fig. 1a.)

Components	Mole Percentages
Methane	81.74501
Ethane	7.56130
Propane	5.50491
Isobutane	1.42323
n-Butane	1.49864
Isopentane	0.40214
n-Pentane	0.28643
n-Hexane	0.36973
Carbon Dioxide	0.96299
Nitrogen	0.24562

Temp & Press – vs. - S.O.S. (in ft./sec.)

(Fig. 1b.)

	800 psig	850 psig
65 F	1142.00	1138.26
67 F	1145.79	1142.11
69 F	1149.54	1145.93
71 F	1153.27	1149.72
73 F	1156.97	1153.48
75 F	1160.64	1157.21

Example: **Sensitivity of each measurement:**

In the tables above; note that the mole % of Methane is 81.74501%. From 65 F. to 67 F. the SOS changes 3.79 fps; or just less than 2 fps per degree F. At 65 F. a pressure change from 800 psig to 850 psig only changed the SOS by 3.74 fps. Each psi of change only changes the SOS by 0.074 fps. If we exchange Ethane for Methane by 1 %; or, in this example; Methane becomes 82.74501 and Ethane becomes 6.56130 at 65 F. and 800 psig the SOS would change from 1142.00 fps to 1149.42. The 1 % Methane increase changed the SOS by 7.42 fps!

Meas't Change	**SOS Change**	**% SOS Change**
1 % Methane	**appr. 7.5 fps**	**0.65%**
1 psig	**appr. 0.07 fps**	**0.0061%**
1 Deg. F	**appr. 1.90 fps**	**0.166%**

The technician should ensure that the calibration techniques and online equipment used are accurate enough to measure light hydrocarbon percentages to better than 0.1 mole percent, and to measure temperature to better than 0.5 Deg F. As an observation; most measurement group's largest potential measurement obstacles will be encountered in performing proper chromatograph sampling and particularly in measuring ***temperature****!*

More errors occur from temperature measurement practices than may be realized!

For good ultrasonic meter verification you need to have field standards which yield the equivalent of a final result of 1-2 feet per second accuracy on your SOS determination. One-tenth percent Methane error plus 1 Deg F error ***is not good enough!***

When you can meet the field accuracy called for in this example you can determine whether the meter is performing its measurement tasks properly or if some condition has changed it. The field result expected is SOS agreement to appr. 0.2%. This rounds to typically a little less than +/- 3.0 fps. This audit is not extremely difficult and will become *"routine"* to the field measurement professionals. Commercial programs exist which allow hand entry of composition, temperature and pressure and they calculate SOS, density and compressibility. *This is an alternative to an automatic SOS auditing system now available to some meters which can poll a GC directly and perform on-line real-time SOS comparisons.*

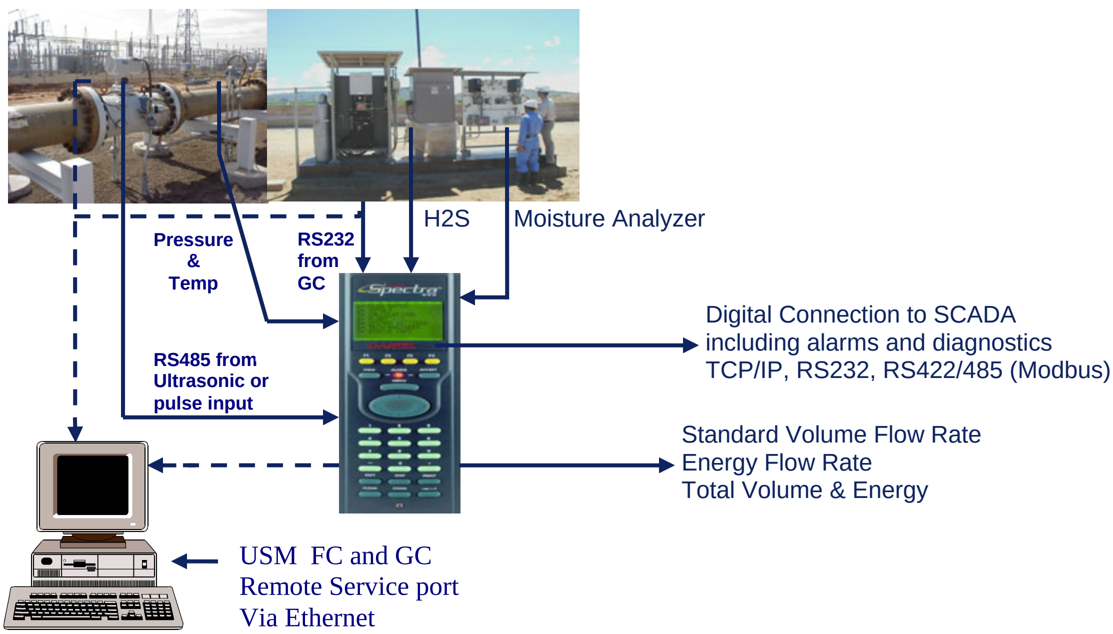
The technician should refer regularly to the company or contractually recommended practices for the equipment used , such as (for the ultrasonic meter):

The Measurement of Gas by Multipath Ultrasonic Meters"; "Transmission Measurement Committee Report No. 9 [1] ", "American Gas Association" ; was copyrighted in 1998 and print issued in June 1998 and was revised in 2007. This is a comprehensive document that serves as a "recommended practice" for properly using these meters to full advantage.

The Technician's Perspective (The Usm)

Ultrasonic meters are spooled meter bodies with typically 2-10 transducers and an onboard electronic transmitter which has serial data, frequency and analog outputs. They require very similar piping considerations to other meters. There are minimum meter run requirements for upstream unobstructed pipe diameters, downstream unobstructed pipe diameters, specific locations for pressure taps and thermowells, liquid drainage considerations and slightly different test and auditing procedures. The key things to remember are that they are not exceedingly difficult to learn and there is no real reason for fear of the unknown. Without fail, the technicians who have specialized in operating orifice and turbine meters have had no difficulty in readily adapting to these meters. Being "Usm and GC fluent" is a real career asset to a Technician. Those two major components of an energy system are the Company's cash register.

The Role of the Gas Chromatograph in Modern Energy Measurement



Gas energy flow rate is determined by multiplying the measured volumetric flow rate by the measured calorific value. Volumetric flow is measured in accordance with AGA 3, 7, or 9 as required by the choice of primary flow elements. When used with AGA 3(Orifice) and AGA 7 (Turbine) flow rates, the gas chromatograph serves not only to report the energy, but also to refine (standardize) the volumetric flow measurement. With AGA 9 (Usm) the chromatograph takes on a new role. In addition to providing measured calorific values, it serves as a cross-checking partner in the process of ensuring quality flow measurement by providing compositional data necessary to calculate AGA 8 in the Flow Computer (and/or Usm) and the SOS via AGA 10 in the Flow Computer (and/or Usm).

The Ultrasonic Meter

An initial concern of many users when evaluating ultrasonic measurement is the prospect of continuing confidence in the factory calibration or in the initial flow calibration. The calibration is not usually reset at the metering station. Physical inspections are an alternative possibility, but some physical inspections could become a matter of lost measurements and raise safety issues. Usm's now have varying degrees of *advanced flow dynamic diagnostics* [2] useful to the field person to assure no flow profile changes of significant distortion levels have occurred. An installation of a gas chromatograph in an ultrasonic meter station gives the technician a method to quickly evaluate the meter station's performance and pinpoint metering issues. The SOS real-time cross-check ability is a very strong diagnostic to prove good Usm timing and good GC analysis.

Chromatograph requirements for energy measurement and verification

- Compositional measurement of all hydrocarbons from Methane through C6+ and the measurement of the inert components such as Nitrogen and Carbon Dioxide
- Certified calibration standards maintained at safe temperatures
- Adequate means to remove, transport and maintain a representative sample to the sample loop in the chromatograph
- Practical reporting of measured data to a computer or system that resolves AGA 8 formulas
- Cycle time – sufficiently fast to provide compositional updates and energy updates to reduce uncertainty at a re-sample rate faster than significant gas composition changes

The Instrumentation in the Modern Energy Measurement System

- Multi-path Ultrasonic flow meter with conventional pressure and temperature transmitters, (typically used in concert with a flow computer)
- BTU gas chromatograph to poll and report the Ultrasonic metered rates and diagnostic points
- Resident program in the Usm or FC or both to calculate the speed of sound for mathematical comparison to the SOS for chords measured by the ultrasonic meter
- Program which includes a reporting system to view, print and report the data to a master host and provides deviation alarm closures

The Technician's Perspective (Chromatograph)

While the role of the chromatograph has increased, the same standards for chromatography that have been employed for energy measurement during the last two decades are still effective and sufficient to calculate the SOS of an ultrasonic meter. In addition, the field technician can expect to find the system SOS check to be better able to provide assurance of quality energy measurement than the previous typical energy calibration check of the chromatograph alone. The sum of all the parts of the systematic SOS check provides a better check of the GC than was once known. Many GC sampling problems are detected by the observed mis-match of SOS measured (Usm) versus SOS calculated (GC composition data).

An Example of the Value of Equivalent Proof

During a start up of an energy measurement system on a residue stream, comparisons of the measured speed of sound to the calculated speed of sound revealed an excessive deviation. To resolve the problem, technicians checked the following items:

- The BTU Gas Chromatograph – the unit was checked against the certified calibration gas for repeatability and the response factors were verified.

- The GC sample system – The GC service is on three streams which are a residue, bypass and a plant inlet. The sample lines were visually checked to make sure that no liquid had migrated into the GC.
- Since the GC sample system points were clean and dry the assumption was made that the ultrasonic transducers and the GC were not contaminated.
- The pressure and temperature transmitters were re-checked.

After eliminating the possibilities of problems on the ultrasonic meter and its pressure and temperature transducers, the technicians checked the GC sample system purging and found that an inlet stream was not sufficiently purged thereby altering the methane measurement, from cross-stream contamination due to an inadequate high-speed bypass. Once the proper sample flow rates were established for all streams, the measured and calculated SOS came into range.

The Complete Energy System

"Energy Measurement using Ultrasonic Flow Measurement and Chromatography" is best served with the complete system that along with the Usm, GC and FC; the Usm is direct connected to the GC via a serial port which polls the GC for latest the component update and continuously calculates SOS onboard the Usm's transmitter using AGA 10 [3] that then produces continuous *Equivalent Proof* of Usm timing integrity and GC analysis cross-check integrity. Many other operational problems have been "trapped" by this continuous SOS cross-check system. The following example has now been isolated several times at gas plants that have this system on their residue outlet:

The Operating Scenario:

The combined system with direct Usm/GC hook up is running with excellent agreement between the continuous measured and calculated SOS. Suddenly the measured speed of sound drops off by approximately 30 ft/sec! After about 7-8 minutes the measured SOS ramped up and returned to approximately the reading of the Usm's AGA 10 calculated SOS. The villain was that the plant operators were not getting the liquids trucked out fast enough on the tower and when the tower began to load up on ethane; the tower was being dumped to the residue outlet several times per day. Each ethane dump sent the residue gas ethane rich for 7-8 minutes, changing the residue gas by a 4-6% increase in ethane. A 3-stream GC was on an 18 minute wrap-around before it got back to the residue stream. Two out of three (typically) of these ethane dump excursions happened in between GC residue stream re-samples, The flow computer for the residue stream sales gas was using a compressibility (Zf) of about 0.891 when, during the excursion, had the FC been processing its AGA 8 compressibility with the real stream 4-6% ethane, it would have had a real compressibility of about 0.877. The FC was (during the excursion) calculating the Std volume low by 0.891/0.877; or a 1.6% under-registered flow at the leaner gas retained analysis. The Btu rate during the excursion was really running an ethane rich, higher Btu. This operation had been experiencing this (big $$$) loss for a long time. The real time calculated versus measured SOS trapped it. This system for energy billing was functioning as more than the sum of its parts by showing this. Use the total measurements that a system is doing, to ensure operational excellence.

Conclusion

Integrating the chromatograph into an ultrasonic metering system provides energy measurement, AGA 8 detailed method compressibility values for standardizing volumes and additionally the gas composition knowledge allows verifying Calculated SOS via AGA 10 [3] against the Usm measured SOS. This cross-check assures the field technician that the entire system is within specifications and that the system is now expected to meet custody transfer specification, as illustrated in the previous examples.

The Energy System that uses a GC in harmony with a USM becomes more than sum of the parts working together to provides better information than checks on individual components will provide on their own. When multiple measurements triangulate on each other; in this case Speed of Sound, Composition, Pressure and Temperature, you have a system that has VERY HIGH INTEGRITY.

This Usm/GC maximized energy measurement system yields: MMBtu/day, Btu/scf, MMscfd, MMacfd, Lbs/d, Density, SG, Wobbe Index, Pressure, Temperature, Gas constituent composition (which may have the addition of water content), SOS measured, SOS calculated, Average flow Velocity, Accumulated Actual Vol, Accumulated Std Vol, Accumulated total energy and a host of advanced diagnostics including meter approach flow dynamic parameters.

When your company transfers custody of that "100 MMscfd" of gas to another company for one year for a total billing of $185,000,000 USD at 2010 prices of $5+/mscf; a ½ Btu error costs $92,500 USD/year or a 0.1% volume meter error would cost $ 185,000 USD/year. *You can afford to do it right because the stakes are too high not to!*

Acknowledgements:

[1] AGA Report No. 9, "Measurement of Gas by Multipath Ultrasonic Meters", First Edition, June 1998; AGA Report No. 9, "Measurement of Gas by Multipath Ultrasonic Meters", Second Edition, April 2007, American Gas Association, All Rights Reserved, 400 North Capitol Street, NW, 4TH Floor, Washington, DC 20001 USA

[2] K. J. Zanker, "diagnostic Ability of the Daniel Four-Path Ultrasonic Flow Meter", SE Asia, HFMW, March 2003.

[3] AGA Report No. 10,""Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases", Catalog #XQ0310, Prepared by Transmission Measurement Committee, Copyright 2003, American Gas Association, All Rights Reserved, 400 North Capitol Street, NW, 4th Floor, Washington, DC 20001 USA