FLUIDIC OSCILLATION MEASUREMENT

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Abstract

The scientific community has known about Fluidic Oscillation as a measurement technology for many years. Recent advances in this technology now make this a highly robust, cost-effective solution to metering needs. This paper will discuss the advances and benefits.

Based on Bernoulli’s Theory - A slow moving high pressure gas becomes fast moving low pressure gas at the nozzle exit forming a jet of gas. The jet, once formed can be controlled by the Coanda effect using an obstacle in the flow that is designed to optimize the performance of the meter. Controlling the jet path enables formation of feedback nodes of pressure on either side of the jet. This provides a predictable oscillation of the jet.

The metrology of the meter is only related to the mechanical design of the oscillation chamber and flow tranquilizer. The jet oscillations are detected using a thermo-resistive sensing device, which provides the data to the electronic index.

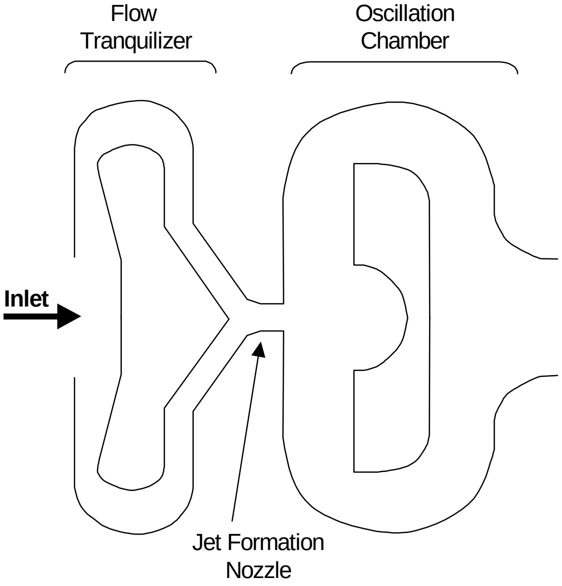
In addition to the commonly known benefits of static metering (no moving parts and possible integrated volume correction and AMR), fluidic oscillation provides high rangeability and tolerates dirty gas.

Introduction

Fluidic oscillation metering has been known in the process industry for many years but with limited accuracy and small dynamic range. As a result, it has not been used for fiscal metering. With recent developments this technology has become a robust and accurate 'custody transfer' metering option that is viable for the future needs of a competitive market place.

Oscillation principle

The oscillation principle of a re-circulating fluidic oscillator is based on the formation of zones of different pressure either side of the jet that will control the direction of the flow.

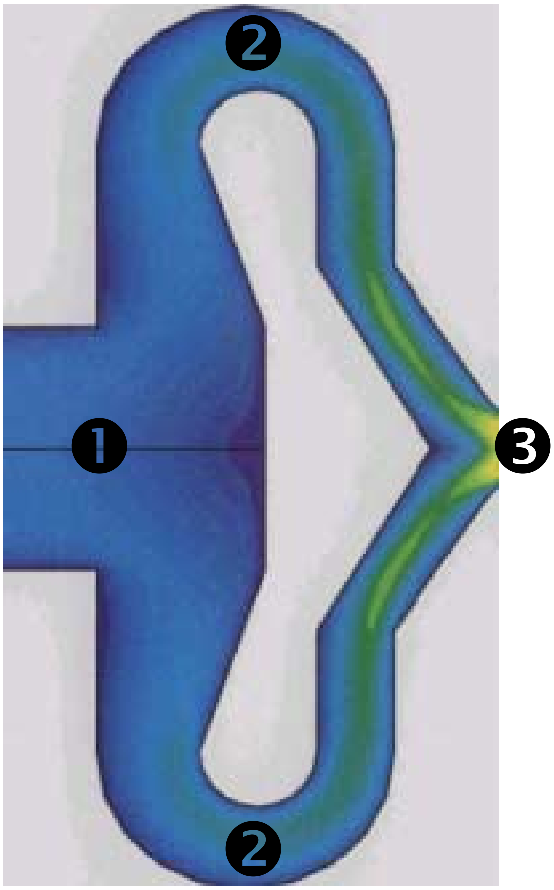


The fluidic oscillations occur in the measuring chamber but the formation of the gas jet and the conditioning of the gas prior to this are both critical functions in the design of a robust and accurate measuring device.

A re-circulating type fluidic oscillator can be described by taking the three main functions separately: the flow tranquilizer, the jet formation nozzle, the oscillation chamber.

Flow tranquilizer

The flow at the inlet to a meter can vary due to piping configurations, such as elbows which create swirl or short lengths after a pressure regulator. To eliminate the effect of pipe configurations on the meter performance a flow conditioning element that produces a known flow profile at its exit has been developed. The flow tranquilizer can be explained by its three main phases. Initially the flow will impact onto a perpendicular wall that has the effect of dividing the flow. In the next phase the flow is presented with two equivalent paths that have parallel walls in order to recondition the flow. The final phase of the conditioner is to recombine the two paths and accelerate the flow, a function that will eliminate any dissymmetry in the initial separation. These three phases can be seen in figure 1 where the velocity magnitude shows the division of the flow, linearization and recombination.



Jet Formation Nozzle

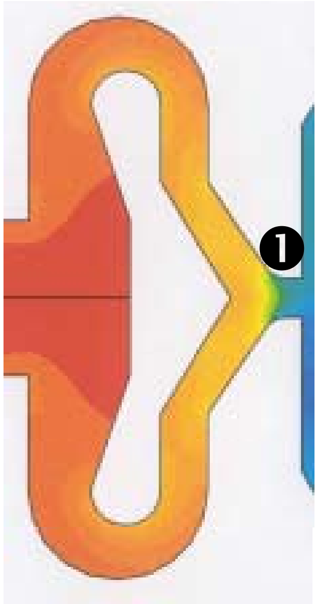
The acceleration of the fluid is a critical step in the fluidic oscillator. It is achieved by reducing the cross section presented to the flow and then quickly expanding the cross section by way of an 'oscillation chamber'. The effect of this is to have the formation of a distinct jet that will become unstable and hence easily controlled. The area of the fluidic oscillation device that provides the acceleration is called the nozzle. Bernoulli theory explains the jet formation by the conservation of energy as shown below:

$$P_1+\frac{1}{2}\rho\, U_1{}^2=P_2+\frac{1}{2}\rho\, U_2{}^2+\mathit{other\ energy}$$

Simply stated a slow moving high pressure gas will turn into a high speed low pressure gas. The pressure drop at the nozzle exit is therefore the key to the formation of the jet and hence the fluidic oscillation.

The Nozzle section can be seen below on a simulation of the nozzle exit showing the instantaneous static pressure in the meter. The fastest pressure transition can be seen to be in the nozzle section (1).

The sudden expansion into a cavity also has the effect of separating the jet from the boundaries.



Oscillation chamber

In the oscillation chamber an obstacle is located in the path of the jet. The function of this obstacle is to 'control' the jet and ensure the ratio of static pressure either side of the jet varies directly with the volume cycle of gas in the meter.

The design of the obstacle and the measuring chamber exploits the coanda effect to 'bend' the jet, which will have a propensity to follow the curved surfaces. The flow of the gas will therefore cause re-circulation on one side of the chamber an effect that increases the difference in pressure either side of the jet. Once the difference in pressure exceeds the 'stiffness' of the jet the jet will be forced towards the lower pressure zone, which is on the opposite side of the cavity. Re-circulation of the flow from the jet will again cause an increase in the static pressure in the node being created. This is therefore the principle of oscillation of the meter.

The jet impinges on the obstacle and the difference in pressure either side of the jet will cause the jet to 'bend' to the side with the lowest pressure. Once, in this position the fluid is steered in a feedback path in order to create a pressure node. The pressure in the node will increase until it is greater in magnitude than the previously created node on the other side of the jet which is concurrently evacuating from the chamber. The jet will therefore 'flip' to the other side again - an effect which will continue all the time that gas is being supplied to create the pressure nodes.

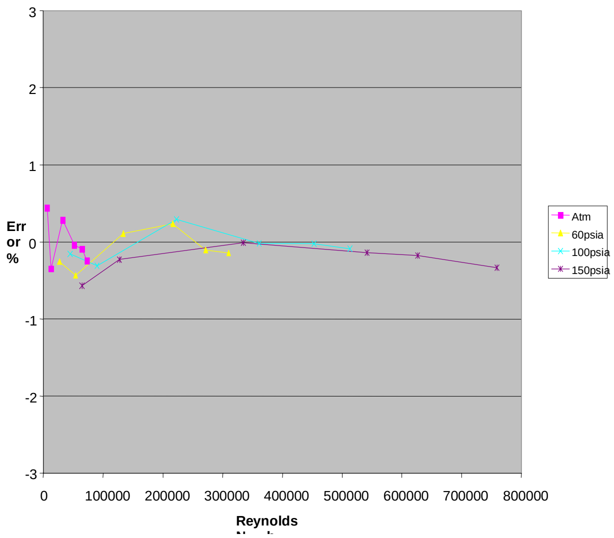
The linearity of the fluidic technology developed by Schlumberger is due to the unique design of this oscillation chamber and obstacle which ensures that the formation of the pressure nodes is carried out independently of flow rate.

Reynolds relationship

When characterizing the behavior of a fluidic meter (one in which the mechanical effects such as bearing friction etc. can be ignored) whether it be a fluidic oscillator, turbine meter or other, the flow rate, which is traditionally used can be replaced by Reynolds Number. The Reynolds Number describes the mass flow rate which takes account of the gas composition, gas pressure, gas temperature and flow rate. The Reynolds number (Re) expression is shown below as a function of gas density ( ), dynamic viscosity ( ), nozzle width (d) and gas velocity (U).

$$\mathrm{Re} = \frac{\rho . d . U}{\mu}$$

Once a meter has been characterized for different Reynolds numbers then the predicted result for a given pressure, flow rate, temperature and gas composition can be interpolated. For example if the characterization of the meter was carried out on air, the different Reynolds numbers could be tested by varying the air pressure in the meter. A typical characteristic curve in air is shown below.



Re Min

The oscillation principle relies on the formation of a jet of gas and therefore there is a theoretical minimum flow rate at which this occurs. Below the theoretical minimum rate the gas will simply diffuse into the measuring chamber passing evenly both side of the obstacle.

The minimum flow is determined in terms of a Reynolds Number and has a value of approximately 50. With natural gas at atmospheric pressure this would give a theoretical minimum flow rate of approximately 5cfh for an oscillator sized to have a pressure drop of 0.5" at 2600cfh.

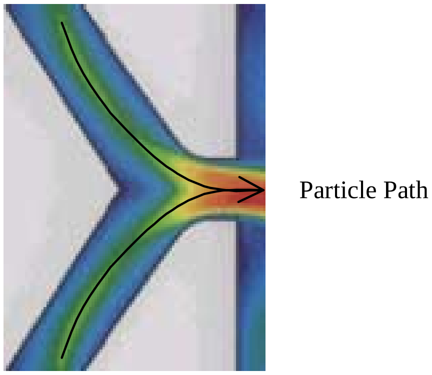
From the formula representing Reynolds number we can see that as pressure and hence density increases then the theoretical minimum flow rate will decrease.

Characterisation

A fluidic oscillator once charaterized will have an 'incremental volume' associated with that meter. The 'incremental volume' is the volume of gas at metering temperature and pressure that is needed to flip the gas jet once and is determined at the time of calibration of the meter. The only factors that could influence the characteristic 'incremental volume' are dimensional changes in the jet formation nozzle or oscillation chamber and so with no moving parts these dimensions are stable with respect to time.

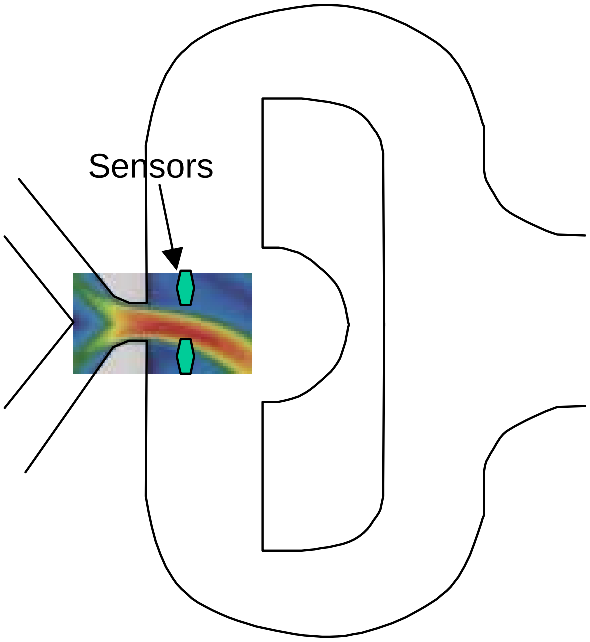
Self Cleaning

The critical dimensions in terms of metering accuracy are at the areas of highest velocity in the meter and so there is a 'self cleaning' action. Dust and other particles are carried through the meter, suspended in the flow and the nozzle section, which is dimensionally sensitive, is protected from abrasion by the recombination of fluid in the flow tranquilizer.



Sensing method

The most common methods of detecting fluidic oscillations are pressure detection or thermal sensing. The thermal detection method has proved to be the most robust system available where a change in the density of the fluid produces a signal. The thermo-resistive sensor detects the passage of the jet using a common mode with two elements. The two elements are positioned either side of the gas jet and hence subjected to the same K, p and Cp of the gas.



The only difference in signal between the two sensors is, therefore the momentary difference in density that each sensor 'sees' due to the different velocities in the gas jet. As the jet deflects towards one of the sensor elements the density of the fast moving gas will be lower than the density over the other element.

Electronics

The metrological function of a fluidic oscillation device is in the mechanical portion of the meter and hence once the meter has been characterized, the electronics has only a signal detection and volume totaling function. The meter electronics also carries out a diagnostic function that will verify the operation of the meter and has the ability to report alarm conditions.

The integration of volume correction, communications, data logging etc. within the meter become a viable option providing a level of integration that ensures no loss of data between the seperate functions.

Commercial Advantages

Implementation of Fluidic Oscillation technology results in many new benefits in fiscal measurement. As the technology incorporates no moving parts, accuracy shifts due to wear are non-existent. In addition, the meter can be over-sped without damage and in the unlikely event of failure, gas service is not compromised.

The electronic nature of the technology lend itself to integration of enhanced measurement functionality. Electronic temperature and pressure conversion, data logging and communications capabilities can be integrated into the product.

Finally, the most interesting feature of Fluidic Oscillation Measurement is the large dynamic range that is possible. Turn-down ratios dramatically exceed those possible with current mechanical or other static technologies.

Prototype Testing

With the benefit of utility participation, eleven prototype meters were deployed across North America in 1998. Sites were chosen for climatic diversity, subjecting the prototypes to weather conditions around US and Canada.

Meters were installed in actual field applications, in series with existing billing meters. Results were mixed, allowing the Engineering Team the opportunity to learn a great deal about “real world” measurement, as opposed to laboratory conditions.

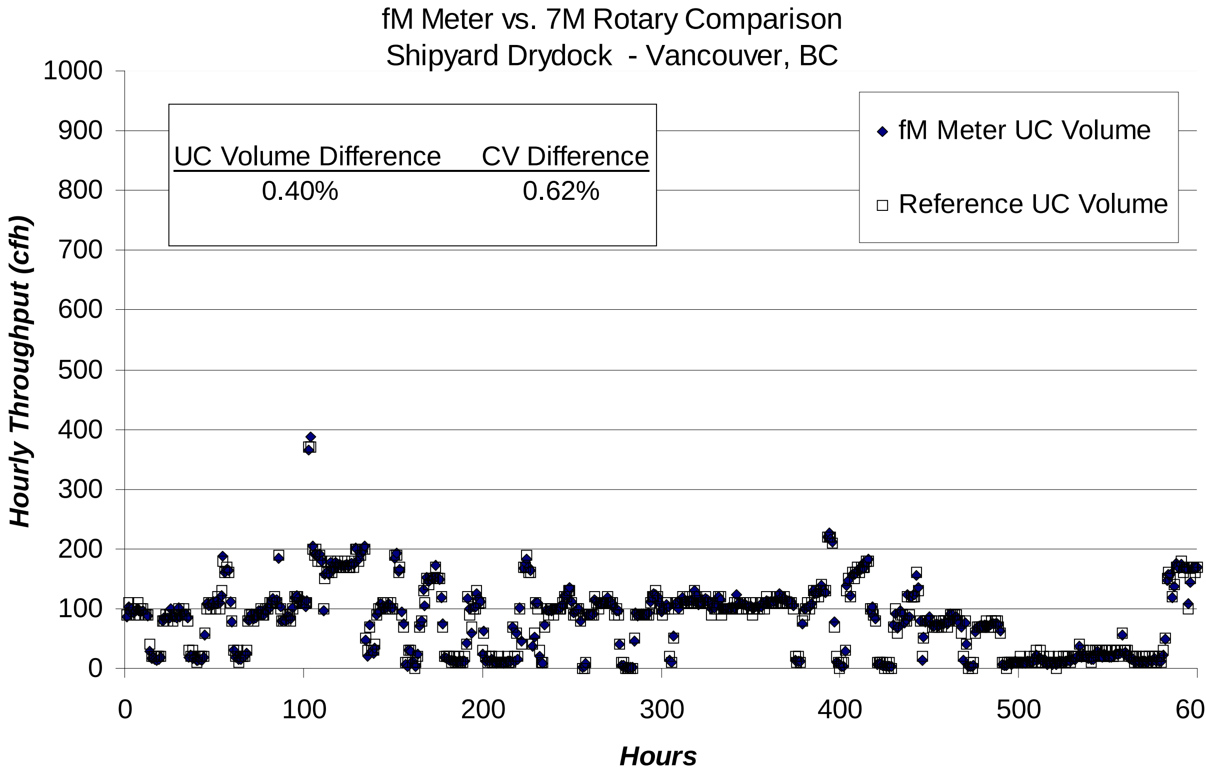
Field Trials

Real world experience in hand, the engineering implementation of Fluidic Oscillation Measurement was completed at the end of 1999. Beta test meters were deployed to the field in January of 2000. A total of 17 meters were installed with the same utilities that participated in the prototype testing.

Again, meters were placed in “real world” measurement applications, in series with a comparison rotary or diaphram meter equipped with a corrector and data logger. Hourly interval data was recorded for comparison. Some examples of comparison data, as well as a summary of the comparison data follow.

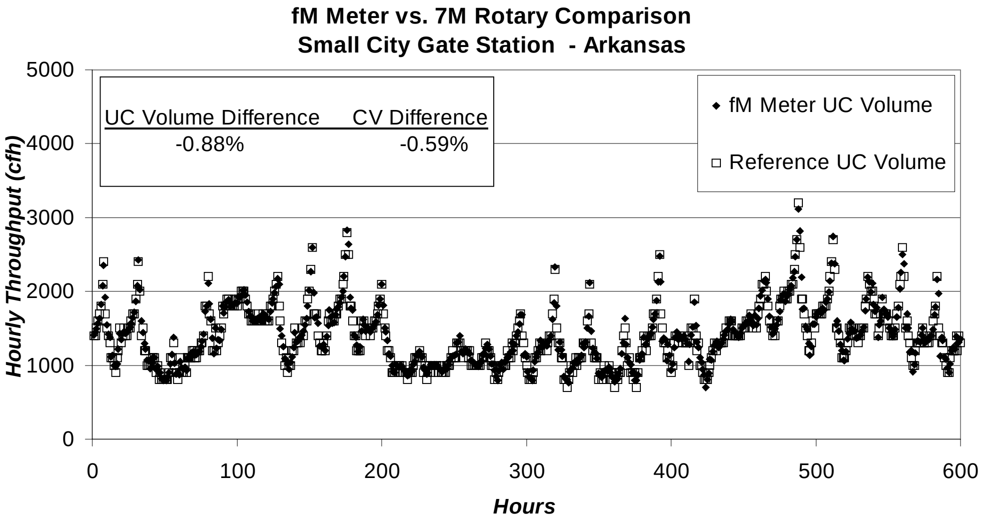
Field Installation Example Data

The first example of field data comes from an installation in Vancouver, BC. This geographic location was chosen for its wet, cold climate – an interesting variation to test the robustness of the prototype meter design. This data represents interval data for the month of April 2000. Overall tracking was very good – better than 1% difference on both uncorrected and corrected volume indexes. Measurement pressure averaged 62 psig and the average gas temperature was 48 degrees Fahrenheit.



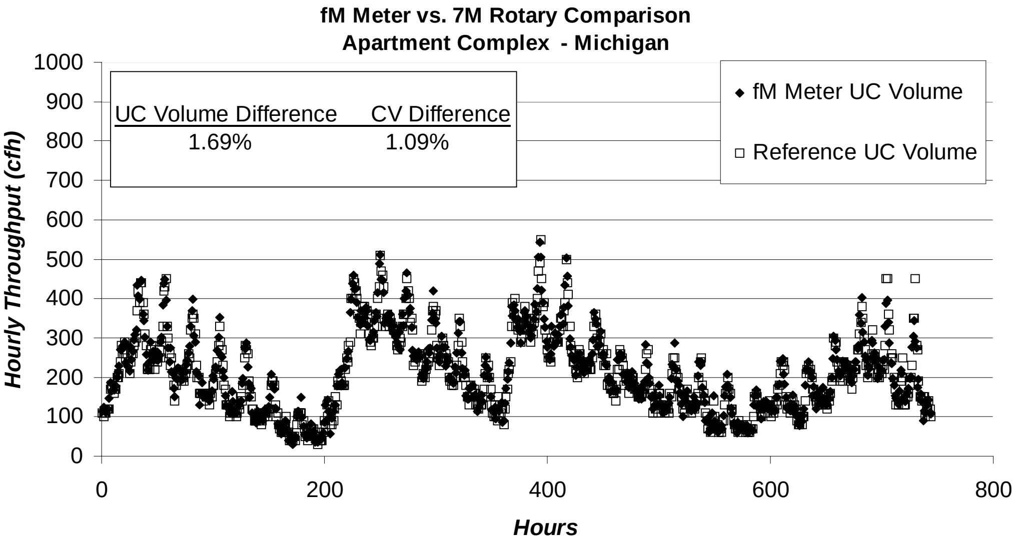
Heating & Hot water load.

The second example of field data comes from an installation in Arkansas. This geographic location was chosen for its hot, humid climate – another interesting variation to test the robustness of the prototype meter design. However this data represents interval data for the month of December 2000 – interesting for a relatively high load. Overall tracking was very good – better than 1% difference on both uncorrected and corrected volume indexes. Measurement pressure averaged 80 psig and the average gas temperature was only 12 degrees Fahrenheit.



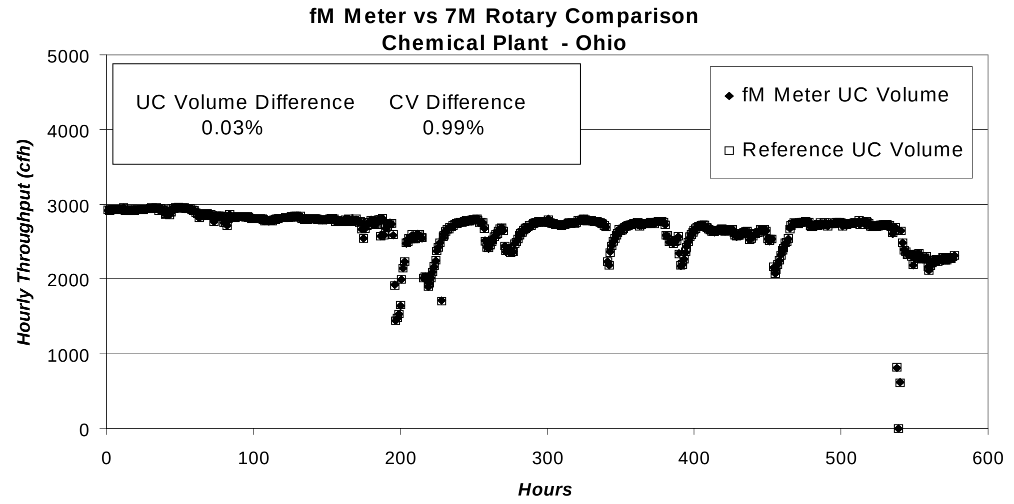
Average Flow rate varies for load (Heating, hot water, some cooking)

The next site was chosen as for its northern climate and low varying load. Data represented is from March 2000. Notice overall tracking is good, with average metering pressure 35 psig; average temperature 44 F.



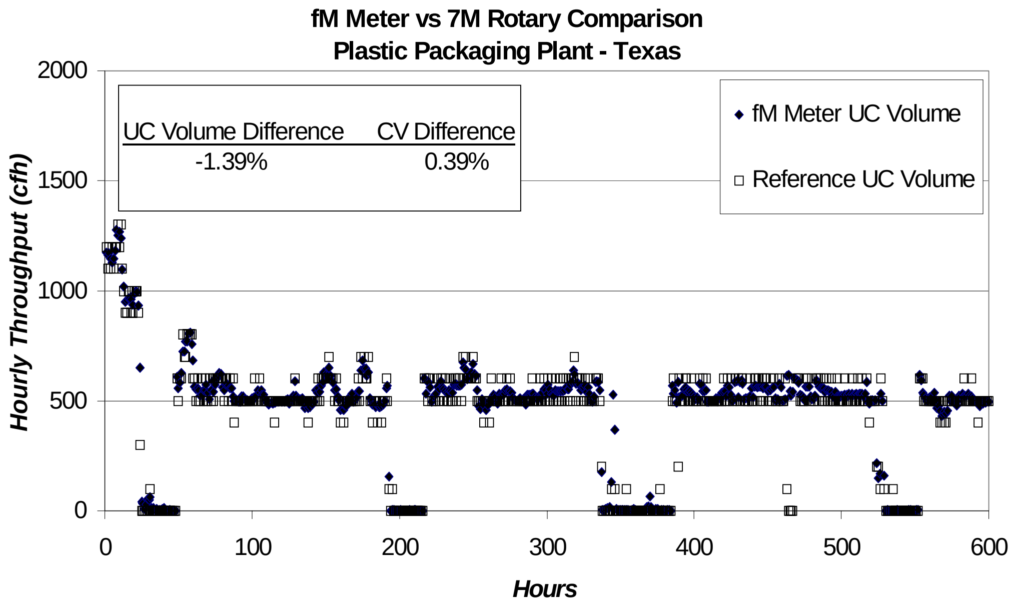
Flow rate varies for load (Heating, cooking, hot water).

The following chart represents September 2000 data from a Chemical Plant in southern Ohio. This site was chosen for its significant load. Overall tracking is very good, again better than 1% on Uncorrected and Corrected interval index reads. Average metering pressure was 26 psig; average T: 70 F.



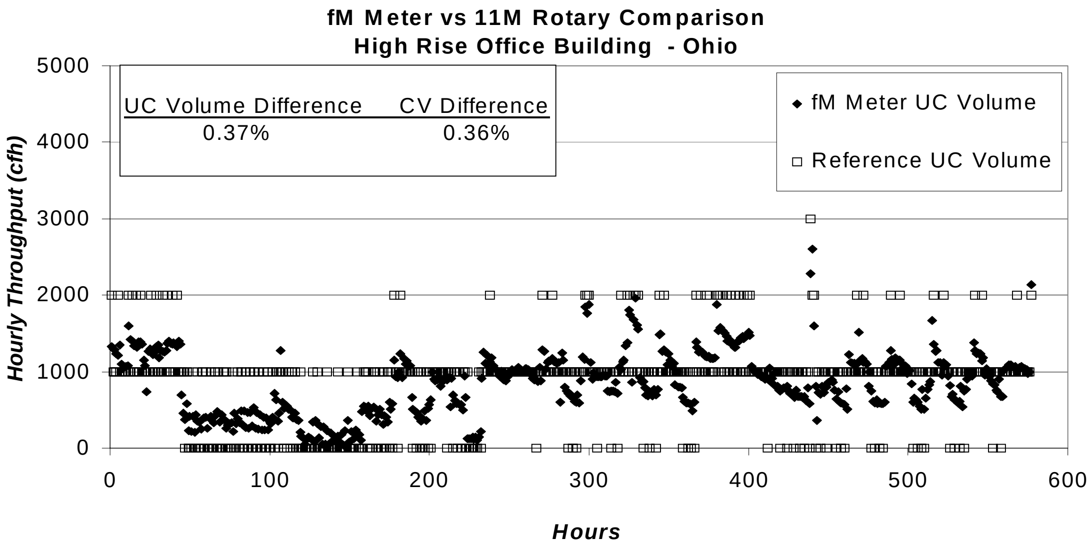
Average Flow rate is 2800 cfh.

The next site located in Texas was chosen to evaluate higher pressure performance of the fM Meter. The hot climate was also of interest. Overall tracking was good, excellent on corrected index values. Average metering pressure was 113 psig. Correction was performed at fixed Tof 60 F. Ambient temperature averaged 100 F during the summer.



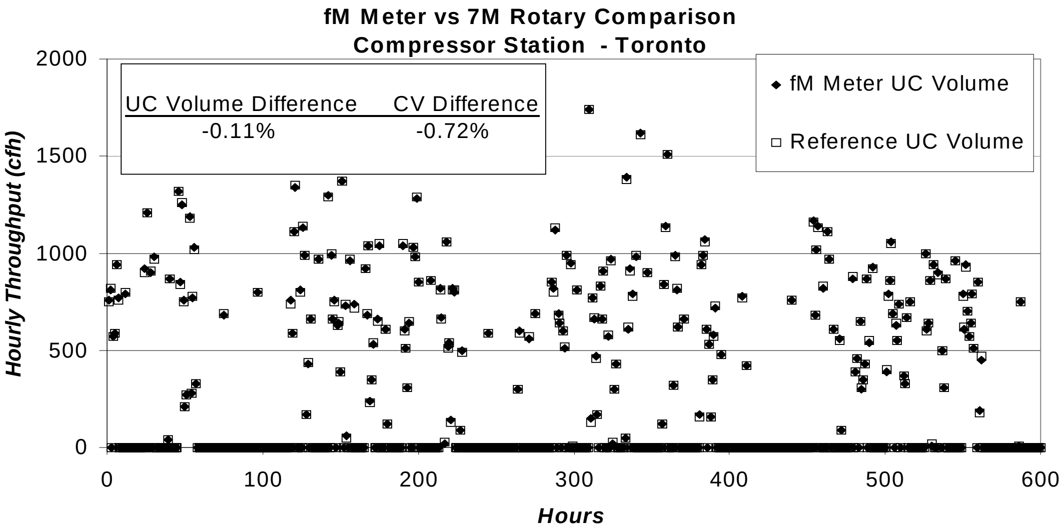
Average Flow rate varies for process.

Installed in an office building in Ohio, the following site was chosen for diversity of location and application. Overall accuracy was excellent, better than 1% on both corrected and uncorrected reads. Average metering pressure was 39 psig; average temperature 68 F.



Average Flow rate varies for load (Heating, hot water, some cooking).

The final example shows results from a cyclic load varying from about 2900 acfh to zero flow. Measuring pressure on this Compressor Station site averaged 56 psig – located in Toronto, average gas temperature for this site during this shown winter load was 30 F. Both uncorrected and corrected index comparisons were excellent – better than 1% in both cases.



Flow is on/off with typical flowrate of 2900 cfh.

Summary of all Beta Test Site Results

Location	Site	Reference Meter	Uncorrected Volume Difference	Corrected Volume Difference	Total Throughput MCF	Test Date Range	
Vancouver	Dry Dock	7M	0.40%	0.62%	327	1/25/00	1/12/01
Ohio	Chemical Factory	5M	0.03%	0.99%	36414	5/12/00	1/25/01
Ohio	Office Building	11M	0.37%	0.36%	16736	1/21/00	2/5/01
Ohio	Beverage Plant	11M	0.69%	0.41%	24800	3/15/00	2/5/01
Michigan	Apartment Complex	7M	1.69%	1.09%	8515	2/9/00	10/13/00
Michigan	Steel Processing Plant	7M	1.53%	-0.17%	19427	2/9/00	10/13/00
Toronto	NGV Station	5M	-0.11%	-0.72%	6650	1/21/00	12/31/00
Toronto	Office Building	5M	0.14%	0.27%	18167	1/19/00	12/31/00
Arkansas	Spring Water Bottling Plant	3M	0.04%	0.48%	5866	1/14/00	1/25/01
Arkansas	City Gate	7M	-0.88%	-0.59%	59664	1/14/00	1/25/01
Texas	Industrial Laundry	7M	2.54%	-0.05%	26827	1/13/00	1/31/01
Texas	Plastic Bags Factory	7M	-1.39%	0.39%	11930	1/13/00	1/31/01
Minnesota	Meter Shop	7M	0.70%	0.60%	294	8/16/00	10/31/00
Minnesota	Middle School	7M	0.07%	2.16%	461	8/15/00	12/8/00
Utah	Steel Processing Plant	7M	1.20%	1.13%	1969	1/12/00	5/22/00
California	Test Loop	5M	0.97%	N/A		5/23/00	8/23/00

Conclusion

Recent advances in Fluidic Oscillation technology make this a highly robust, cost-effective solution to metering needs.

Improvements in Oscillation chamber design and sensor technology have allowed previously impossible performance goals obtainable.

In addition to the commonly know benefits of static metering technology (no moving parts and the possibility of integrated volume conversion and AMR), fluidic oscillation provides high rangeability in a robust design that tolerates un-clean gas.

Field evaluation of Beta meters in 2000 has shown the technology to be viable in across a wide range of Commercial and Light Industrial type applications.