AGA / API Auditing Requirements of Fiscal Gas Metering Systems and FCRI Experiences

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ABSTRACT

Realization of standardized form of accounting of the business leads the evolvement of formal auditing. Though started with financial audits, now it encompasses, technical activities, fiscal measurements etc. Technical auditing of custody quantity and quality of gas measurement system is significantly relevant as it is directly tied to the monetary value. Digital systems, while improving the performance, add more complexity in the process of measurements, calibration, maintenance etc. Sophistication of instruments alone cannot guarantee the accurate reliable output and assurance of the integrity of the measurement systems and processes is required.

Flow measurement Industry has evolved many national/international standards (OIML, AGA, ISO, API etc.) for primary, secondary and tertiary elements of custody transfer measurement system. Adaptation and adherence of the standards is vital to ensure the integrity of electronic gas measurement. Though the maximum permissible tolerances specified are 0.9% and 1% respectively for Volume and Energy, the actual requirements are very stringent.

This paper discusses the functional requirements of the fiscal measurement systems, related standards. Audit objectives, detailed scope of audit, requirement of the auditors, collection and analysis of the data, reporting audit findings etc are elaborated. Application to typical audit verification of orifice meter, turbine meter and ultrasonic meter are presented. Method of uncertainty analysis of instruments and practical uncertainty estimation are presented. Uncertainties as found and post implementation of recommendations are given.

KEYWORDS

Audit, Standards, mpes, Check, Balances, Data, Uncertainty

1. INTRODUCTION

Installed meters in flow metering stations need to be accurate as the mass, volume and/or energy traded are expanding and prices are increasing. It is important to sustain the required accuracy in volume and energy. After the installation /commissioning of the metering station, flow meter, pressure and temperature transmitter, gas chromatograph, flow computer are checked and validated. Realization of standardized form of accounting of the business leads the evolvement of formal auditing. Though started with financial audits, now it encompasses, design, production, process, safety etc.

Technical auditing of fiscal gas measurement system is significantly relevant as gas measurement is directly tied to the monetary value (quantity and quality).However the gas measurement process is very complex as the commodity is hazardous, invisible, compressible, and measurement is made inferentially. Digital systems, while improving the performance, add more complexity in the process of measurements, calibration, maintenance etc. Flow measurement Industry has evolved many national/international standards for primary, secondary and tertiary elements of custody transfer measurement system. Adaptation and adherence of the standards is vital to ensure the integrity of electronic gas measurement.

This paper discusses the functional requirements of the fiscal measurement systems, related standards. Audit objectives, detailed scope of audit, requirement of the auditors, collection and analysis of the data, reporting audit findings etc are elaborated. Application to and Typical audit verification of orifice meter, turbine meter and ultrasonic meter are presented. Method of uncertainty analysis of instruments and practical uncertainty estimation for volumes/energy by of orifice meter, turbine meter and ultrasonic meter are presented. [1-2] provides comprehensive review of Electronic gas measurement systems and audit requirements of fiscal metering systems.

2. FISCAL METER FUNCTIONAL REQUIREMENTS

The total metering system shall comply with the accepted standards and the national legislation for volume/energy determination. Salient requirements are discussed below [3].

1. The Gas Company is responsible to make accountable measurements compliant with the applicable (legal) requirements and the latest international standards
2. The overall uncertainty on energy shall not exceed 1% [4-5].The operational uncertainty is within limits as per standards [6-8]
3. Type B / systematic errors are actively reduced using agreed procedures regardless of the sign of the deviation.
4. All parameters of the metering system shall be fully transparent.
5. Measurements shall be traceable to international standard, ISO 17025.
6. The degree of transparency on data, quality assurance and instrument maintenance shall be agreed upon with procedures for calibration for pressure, Temperature, gas chromatograph and flow computer, including tolerances and actions.
7. All instruments are calibrated using references, except for the flow meter.
8. The data handling including verifications, corrections and final approval of the measuring data must be documented
9. The instruments shall be used within their calibrated range.
10. The required availability for the measuring installation is 100%.This can be managed by using redundancy in the systems (e.g.: n+1) meter runs, double GC system, No-break power).Gas shall only flow if the measuring installation is available and is functioning within specifications.
11. The equipment used shall have a formal approved status by a legal metrology department
12. Flow meter shall be mounted according to the standards .An upstream flow conditioner shall be used; If a flow conditioner is not used it has to be proven that there is no installation effect on the flow measurement.
13. Flow meters shall be protected against pollution or dirt.
14. Active interpretation of diagnostic data of a flow meter must be used if present, for e.g. a comparison of Speed of Sound (SOS) when using an ultrasonic meter
15. The meter run shall be sufficiently thermally insulated from ambient temperature.
16. Calibration curve correction shall be applied to minimize systematic errors

17. Re calibration (as found) shall be done at least every 1-5 years based on type of meter.
18. Every primary meter shall have an individual calibration certificate and the calibration shall be performed complying to the requirements of standards
19. Calibration of the flow meters shall be performed at an internationally recognized calibration site that is accredited according to ISO 17025 using natural gas under operational pressure or as recommended standard. The conditions at flow calibration shall resemble the conditions during operation. All parameters that may adversely affect the performance of the meter shall be considered. All generally recognized differences between the conditions at flow calibration and conditions during operation shall be eliminated. If these differences result in a significant shift of the calibration curve, the flow meter, the relevant upstream piping and the flow conditioner shall be calibrated as a package.
20. Bi-directional meters are to be calibrated for both directions with the appropriate certificates for each direction.The flow meters shall be adjusted such that the weighted average deviation is as close as possible to zero. After adjustment, the flow meter deviations at all the calibrated flow points shall be less than the maximum permissible deviation. The errors in the flow rate range between 0.2 Qmax and Qmax shall be within a band of 0.3%.
21. Volumes at operational conditions shall be converted to volumes at agreed base conditions and shall be performed continuously by using live inputs of absolute pressure, temperature and Compressibility. Compressibility (Z) shall be calculated by using AGA/ISO standards [9-11].
22. The flow computer, pressure transmitter and temperature transmitter shall have approval, and mounted according to the relevant standards. Pressure shall be measured with an absolute pressure transmitter or with a gauge pressure transmitter and an atmospheric pressure transmitter. Ambient influences such as temperature, pressure, noise, moisture, Pulsations, sunlight etc. must be minimized.
23. The inputs shall be digital to eliminate additional uncertainty by transmission techniques.
24. Measured volumes shall be registered by using non-volatile counters. Counters shall be installed for volume at operational conditions, volume corrected for the calibration curve, volume at base conditions and energy.
25. All fuel gas shall be measured correctly with a corresponding flow computer.
26. A Gas chromatograph shall comply with the following requirements:
    i. Type approval by authorized body.
    ii. Mounted according to relevant standards.
    iii. Minimization of ambient influences such as temperature, pressure, noise, moisture, pulsations, sunlight etc.
    iv. A sampling system shall ensure that gas sample is representative to the gas in the gas station regarding composition and conditions and time.
    v. The GC should analyze all components with an influence <0.01% on the calorific value.
    vi. The use of the pseudo component C6+ for higher hydrocarbons is allowed only if the subdivision is constant in time. The use of a fixed component is allowed if the concentration is constant in time (Carrier Gas). This shall be demonstrated by analyzing spot samples.

vii. The uncertainty of the GC shall be demonstrated according to ISO10723.
viii. The GC shall be periodically tested by analyzing a certified natural gas, which resembles the process gas.
ix. It shall be demonstrated that the GC will function within the stated uncertainty by using a reference gas and a calibration gas

OIML [4-5] defines maximum permissible relative errors (mpes), positive or negative, for measuring systems are specified in Table 1-3 for Accuracy Class A meters. Maximum permissible errors on measuring volume at metering conditions apply to type approval or Initial verification where: the meter is adjusted at nominal operating conditions;

3. STANDARDS

OIML/ISO/API/AGA documents details manufacturing, installation, operation, and calculation guidelines used throughout the natural gas industry. OIML [4-5] Recommendation applies to gas meters based on any measurement technology or principle that is used to measure the quantity of gas that has passed through the meter at operating conditions. It also applies to gas meters intended to measure quantities of gaseous fuels or other gases. Built-in correction devices and devices for internal temperature compensation are included.

AGA reports [6-9] contain equations establishing the mathematical basis for the conversion process. As the reports in modified forms have been adopted by National Legal Metrology departments, compliance to the reports has become mandatory for any organization dealing with natural gas.

API [12] covers the minimum specifications for gas measurement systems of hydrocarbon and other related gases and attempts to minimize the uncertainties associated with electronic gas measurement. Various components, the algorithms necessary for adequate calculation, specifications for equipment installation and commissioning, and data security requirements are discussed. The standard also describes the minimum necessary data to be made available in order to allow for a thorough audit of the system. Audit and Reporting Requirements are highlighted.

4. AUDIT AND RESOURCES

With the introduction of electronics in gas measurement, new challenges are encountered in auditing. The benefits of electronic gas measurement audits have been proven to justify the costs and economics. The two most common uses of redundancy in gas measurement are balances and check meters.

Redundancy in metering is an extremely effective way to focus audit resources. Check meters measure the same gas as service meter. Check meter volumes and all other data can be directly compared to the audit station, increasing the probability of detecting errors and increasing the likelihood of settlement of a discrepancy. A check meter may be of same or different operating principle. They are invaluable when failures occur at critical stations. Besides failures, some types of measurement errors cannot be compensated mathematically, such as damaged or reversed orifice plates. Check meters allow for accurate replacement of missing or erroneous measurements and can carry tremendous weight in audit adjustment negotiations. For effectiveness and reliability of the check measurement, check stations should follow the same standards/ guidelines as applied to the audit station.

Balances or reconciliation compare volumes, energy and / or mass supplied into a system against delivered from the system. The measurements going into the system should match the measurements going out within an uncertainty tolerance. Differences outside the tolerance helps to isolate measurement problems and apply audit resources. A good networked enterprise measurement system will calculate the balance in differences automatically. In any balancing process, care must be taken to account for all gas. This also opens the scope of the audit and possible error points to the other measuring stations included in the balance.

Key Process Indicators (KPIs) are another means of focusing audit and gas measurements that can be directly associated to those key process indicators. Key Risk Indicators (KRIs) can be developed which help when and where to expand audits. An effective audit program also include random audits. The cost effectiveness of these random audits is enhanced with a risk-based approach by varying frequency, scope and depth of evidence required. Revenue recovered is not the only justification for the cost of an audit. The potential revenue not lost must also be considered, which is hard to quantify.

5. AUDIT OBJECTIVE AND SCOPE

The objective makes clear what the purpose of the audit is. The scope of the audit is the range of activities and the periods of records that are to be subjected to examination. The objective helps to determine the scope of the audit and the best approach to take in conducting the audit whether internal, office, external etc. Scope determines the breadth and depth of the audit and defines what material, equipment, information, processes, time periods and business departments / entities will be examined.

6. AUDITS AND REVIEWS

Audits provide a reasonable basis for expressing an opinion regarding the gas measurement process. Reviews do not provide the same basis. In the gas measurement, review is just an audit with a smaller scope. Views are also office audits or administrative audits. These reviews can be valuable, and less costly than a full scoped audit. Reviews can be witnessing or field auditing to confirm that the data from the electronic gas measurement matches the conditions, settings and sizes actually in use. Audit may also include any data or measurement from the primary devices to the corrected quantity transaction records, including how that data is normally derived, and any supporting documentation. Audits pull in data from regulations, tariffs, contracts, as well as standards and the documents. Flow device, transducers / transmitters, and the flow calculations, primary, secondary, tertiary and auxiliary devices are examined and tested, with supporting documentation.

7. AUDITOR

If the audit is an office review of data, auditor with a general knowledge of gas measurement and some guidance may be able to verify data applied to final quantity transaction records. Field audits require more expertise. Field auditors have to understand how instruments function and interact with each other and the process. They require knowledge of the limitations of various devices and the ability to recognize when those limitations are being exceeded. Skills required may include auditing, engineering / technical, and business management consulting skills. A team of auditors may also be required with different members being well-versed in different aspects of the audit. The auditor should be aware of the prevailing regulations, tariffs, industry standards and common industry practices. Understanding of the hardware, software, and operational specifications will also help. Auditor should be able to act independently and unbiased with an attitude of professional skepticism, critical of everything, but be willing to suggest a compromise if a win-win solution is unavailable or an equitable solution

8. AUDIT DATA COLLECTION

Data requested in writing depends on the scope of the audit. Auditing requires to acquire all existing information used in the determination of volumes. The following are typical source of data to perform a complete audit.

1. **Station Characteristic Report** with details on station.
2. **Calibration reports** of primary flow meters, meter tubes and field instruments
3. **Standard sample certifiable with** composition, preparatory tolerance with computed uncertainty.
4. **Quantity Volume Report** providing daily, hourly volumetric readings with averaged process data.
5. **Alarms** Listing daily alarm conditions such as low/high
6. **Event Report** giving details of all station activity and change made to the station parameters.
7. **Meter Calibration Test Reports** includes complete hard copy meter reports when tests are performed or changes are made
8. **Meter Change Reports** when changes are made in the metering system.
9. **Gas Composition Analysis Reports** with gas composition information from spot samples, or on-line chromatography.
10. **Existing Metering Station policy and Contract Documents**
11. **Piping Instrumentation diagram** of Metering Runs/ Terminals
12. **Technical specifications** of primary secondary and tertiary instruments
13. **Meter configuration** sheet of USM and Flow Computers
14. **SOS and Zero Flow Test** of USM
15. **Flow computer** Parameter Configuration report, System Configuration setup
16. **USM diagnostic display** report for normal operating flow
17. **Flow computer outputs** for known process variables i.e. key pad inputs for AGA 3,AGA7,AGA9,GPA 2172 /AGA8/ISO 6976 calculations
18. **Flow Computer Totalization Checks** - Flow computer/Flow transmitter outputs for known process variables i.e. key pad inputs (Computer Time must be recorded) – Initial and Final downloads
19. **Flow computer display dump** of various configurations as applicable for flow check
20. **Recent GC Calibration Report / Gas Chromatograph** calculations
21. **Calibration Certificate** of Master Pressure , Differential pressure calibrator , Master Temperature Transmitter calibrator , Dead weight testers, Temperature Baths

9. EXAMINING AUDIT DATA AND INFORMATION

An auditor must look for conflicts in the terms of the regulations, tariffs, contracts, standards, and procedures against what is practiced. If a procedure conflicts with a contract, the terms of the contract override the procedures. If a contract conflicts with a regulation, the regulation will override the contract or the measurement system may be required to comply with both. If the governing documents are silent regarding standards, the standards should be followed. The auditor determines if the measurement system is capable of complying with the terms of the governing documents. The phrases “Shall” and “shall not” indicate items which are required by the standard. “Should” and “should not” reference preferred items which are not necessarily required. Normative sections are required. Informative sections are informational only and are not required.

The flow computer manufacturer’s software may be required to view the original quantity transaction records, Contract information can be matched to the meter configuration log. Other components of the meter configuration log should agree with the specifications of the meter, the gas quality, and the calculation methods. Events should be reviewed for parameter changes, transducer verification, and calibration adjustments. Alarms can sometimes shed light on failure and override conditions (including no flow conditions), frequent out- of-range readings, power and communications problems. Meter configuration logs are reconciled to the final transaction records, adjusted by events, valid edits, and gas analyses.

Review of event reports ensures proper calibrations and that changes are posted properly. Electronic volumetric data allows for integration, recalculation, and comparison by computer. The computer will reduce time spent on audits by automatically flagging potential problems.

Gas chromatography has replaced almost all physical testing for density and heating value. Representative component percentages are very important for the analysis to be representative. If adjustments to previously calculated volumes are made for errors found prior to the audit, the period and amount of the adjustment should be confirmed. Adjustment periods which extend beyond the scope of the audit should prompt an automatic extension of the audit through the adjustment period.

10. AUDIT REPORTS, FINDINGS, RECOMMENDATIONS

The audit culminates in an audit report, the main medium for communicating the findings and recommendations. . It represents comments and assertions comprising objective, scope, findings, analysis, interpretation, suggestions, uncertainty statements etc. .Interested parties may desire to review the results of the audit.

11. AUDIT ACITIVITIES OF GAS TERMINALS

1. Checking specifications and suitability of the flow meter, accessary field transmitters for actual measurement requirements.
2. Scrutiny of recent calibration reports of transmitters with respect to the respective calibrated range against the current operating process conditions.
3. Study of reference standard equipment used for periodic calibration of the transmitters for their suitability, calibration traceability and uncertainties.
4. Loop checking between the field transmitters and the flow computers
5. Verification of calculations with average keypad values for the process variables as per AGA 3, AGA 7, AGA 9, AGA 8 as applicable.
6. Physical Inspection and measurement of straight lengths of the metering tubes/ /Thermowell etc. and Inspection of tapping locations of PT and RTD.
7. Assessments of uncertainties. Including all effects
8. Calibration of pressure, temperature transmitters and RTD probe with reference equipment.
9. Evaluation of environmental conditions for possible effects on metering electronic, mechanical equipment.
10. Scrutiny of API compliance of flow computer for calculations / reporting / storage / retention etc.
11. Verification of gas chromatograph calculations done against standard software.
12. Verification of conformity of the metering system as per AGA 3, AGA 7 /AGA 8/ AGA 9 ISO 6976, GPA 2172.

12. RECOMMENDATIONS FOR IMPROVEMENT

1. Installing PT 100, Class A, 4 Wire RTD with 4 wire connections.
2. Sizing Orifice, Turbine and Ultrasonic flow meters for current metering requirements.
3. Increase of calibration frequency of the transmitters to minimize the effects of

ambient/stability issues.

4. Fixing Frequency of recalibration of Gas Chromatograph to achieve methane repeatability less than 0.1%
5. Operating flow rate to be greater than 10-20 % of maximum capacity
6. Calibration of meter at the operating density / operating pressure
7. Calibration / checking the RTD probe at least at the average operating temperature periodically using temperature bath with calibrated reference Pt 100 class A RTD sensor.
8. Verification of flow computer calculations and flow totalizations using key pad data for process parameters.
9. Periodic inspection / cleaning aligned with routine calibration
10. Flow meter calibration in an ISO 17025 accredited laboratory with minimum uncertainty.
11. Incorporation of flow rates / frequencies / meter errors / K factors appropriately in the flow computer to improve the measurement accuracy
12. Calibration of master equipment in accredited laboratory with lowest possible uncertainties.
13. Using temperature bath only as a source
14. Implementation of Detail Characterization Method in flow computers
15. Insulation of transmitter enclosure/ thermo well/RTD/Pressure Impulse tubes / upstream / downstream metering tubes to control the effect of ambient temperature variations.
16. RTD shall be in contact with the bottom of thermo well with suitable thermally conducting fluid in the thermo well.
17. Updating flow computers instantaneously on completion of analysis
18. Calibration range for Calibrators / Temperature Bath/ Temperature Transmitter/ RTD both in source /measure modes to suit flow measurement purpose with more number of calibration points in the range.
19. Verification of master list of configuration data/ constant parameters inputted in the flow computer.
20. Provision of shelter for the metering skid components
21. Installation of flow profiler / thermo well / meter tubes as per recommended installation.
22. Use of certified diameters in Flow computer for flow calculations.
23. Review of Station Designs in view of current operating flow rate.
24. Calibration of the pressure/differential pressure calibrators against dead weight tester in accredited laboratory with lowest possible uncertainty.

13. UNCERTAINTY EVALUATION IN VOLUME AND ENERGY

Table 4 gives definition of some important terms related to uncertainty.

1. Express in mathematical terms the dependence of the measurand, output quantity Y on the input quantities X_i.
2. Identity and apply all significant corrections to the input quantities from calibration.
3. List all sources of uncertainty in the form of an uncertainty budget
4. Calculate the standard uncertainty $u(\bar{x}_i)$ for repeatedly measured quantities (Type A)
5. For single values, e.g. a single measured value, a resultant value of previous measurements, correction values or a reference value from literature (i) adopt the standard uncertainty when it is given (ii) calculate from unequivocal uncertainty data (iii) evaluate based on experience (iv) calculate from manufacturers data (v) data provided in calibration or other certificates (vi) uncertainty assigned to reference data taken from handbooks. When a probability distribution is assumed for the quantity X_i, based on experience or theory, then expected value and the standard deviation of the

distribution is taken as the estimate x_i and the associated standard uncertainty $u(\bar{x}_i)$ respectively.

6. For input quantities for which probability distribution is known or can be assumed, calculate the standard uncertainty $u(\bar{x}_i)$.
7. Calculate for each input quantity X_i, the contribution $u_i(y)$ to the uncertainty associated with the output estimate resulting from input estimate x_i and sum their squares to obtain the square of the standard uncertainty $u(y)$ of the measurand.
8. Calculate the expanded uncertainty U by multiplying the standard uncertainty $u(y)$ associated with the output estimate by a coverage factor k.
9. Report the result of the measurement comprising the estimate y of the measurand, the associated expanded uncertainty U and the coverage factor k in the calibration certificate.

For the measurement of flow rate, it is necessary to combine the values of a number of input quantities to obtain a value for the output. It is assumed that the sources of uncertainty are uncorrelated: If the functional relationship between the input quantities X_1, X_2, ….. X_n and the output quantity Y in a flow measurement process is specified as

$$Y = f(X_1, X_2, ...X_i, X_n) \quad (1)$$

then an estimate of Y, denoted by y, is obtained from Equation (2) using input estimates $x_1, x_2, ...x_n$

$$y = f(x_1, x_2, ...x_i, x_n) \quad (2)$$

The total uncertainty of the process may be found by calculating and combining the uncertainty of each of the contributing factors using

$$u_c(y) = \sqrt{\sum_{i=1}^{N} [c_i u(x_i)]^2} \quad (3)$$

Type B evaluation of uncertainty is carried out by means other than the statistical analysis of a series of observations. In case of flow measurement audit, only Type B uncertainties are involved. Type B evaluation of uncertainty requires knowledge of the probability distribution associated with the error/reported uncertainties in certificates.

Rectangular probability distributions include Instrument drift between calibrations, Error due to limited resolution of an instrument's display, Manufacturer’s tolerance limits. When the upper and lower limits of an input quantity X_i are possible to estimate without any specific knowledge of concentration of x_i within the limits, then it can be assumed that it is equally probable for X_i to be anywhere within this interval. The uncertainty is calculated from

$$u(x_i) = a_i / \sqrt{3} \quad (4)$$

where a_i is the half-range of the distribution.

Normal Probability Distribution includes calibration certificates quoting a confidence level of coverage factor within the uncertainty

$$u(x_i) = \frac{\text{Expanded uncertainty}}{k} \quad (5)$$

where k is 2 for 95% confidence level .

For combining uncertainties.it is necessary to consider the effect of each input quantity on the final result i. e. the sensitivity of an output quantity to an input quantity - the sensitivity coefficient. When the functional relationship is specified, then the sensitivity coefficient is defined as the rate of change of the output quantity y with respect to the input quantity x_i, and the value is obtained by partial differentiation of the function.

$$c_i = \frac{\partial y}{\partial x_i} \quad (6)$$

For Type B evaluation, when lower and upper limits are not known $\nu_i = \alpha$.

Tables 5-7 gives the details of typical uncertainty budget for the meters. Figs. 1-3 presents as found and achievable uncertainties after implementations of audit recommendations. Uncertainties are improved significantly on implementation

14. CONCLUSION

Natural gas measurement is truly a complicated, specialized task. Possibility of errors and mistakes makes auditing a necessity. Fiscal Measurement is responsible for balancing the purchase and sale of Natural gas. Metering Errors affect the balance of business. Auditing not only becomes desirable, but necessary. Audit resources, including the expertise of the auditor, can be applied with various objectives and scopes to capture the bulk of measurement errors and potential errors. The final result of this entire auditing process is an assurance of the integrity of an organization's electronic gas measurement business process. API 21.1 provides the guidance necessary to ensure the integrity of electronic gas measurement values. API 21.1 helps the auditor to transform the complexity of electronic gas measurement into an effective means of evaluating financial risk and financial opportunity. Uncertainty assessments confirms that after implementation of audit recommendations, the values improves significantly

15. ACKNOWLEDGEMENTS

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Table 1 mpes for measuring systems

Maximum permissible errors on determining:	**Accuracy class A**
Converted volume, converted mass or direct mass	± 0.9 % **(<0.3 %)**
Energy	± 1.0 % **(<0.75 %)**

Table 2 - mpes for modules

Maximum permissible errors on:	**Accuracy class A**
Measuring volume at metering conditions	± 0.70 % **(<0.3%)**
Converting into volume at base conditions or into mass	± 0.50 % (<**0.01 %)**
Calorific value measurement (only CVDD)	± 0.50 %**(<0.2 %)**

Table 3 mpes for instruments

Maximum permissible errors on:	**Accuracy class A**
Temperature	± 0.5 °C (<**0.27 °C)**
Pressure	± 0.2 % (<**0.1%**)
Density	± 0.35 % ((<**0.2%**))
Compressibility	± 0.3 % (<**0.1%)**

Values within ( ) are current practice

Table 4

Uncertainty	Parameter, associated with the result of a measurement, that Characterizes the dispersion of the values that could reasonable be attributed to the measured . For practical purposes, the uncertainty is taken to be twice the Standard deviation of a distribution. Also, the probabilities are assumed to be normally distributed. This implies that there is a 95%probability to remain within the uncertainty boundaries and that values are distributed symmetrically around the expectation value.
Standard Uncertainty, $u(\bar{x})$	Uncertainty of the result of measurement is the standard error expressed as a standard deviation of mean.
Combined Standard Uncertainty, $u_c(y)$	Standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances of these other quantities weighted according to how measurement result varies with changes in these quantities.
Expanded Uncertainty, $U = k\,u_c(y)$	Quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand. The fraction may be viewed as the coverage probability or the level of confidence of the interval.

Coverage factor, k	Numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty is typically in the range 2 to 3.
Type A Evaluation	Method of evaluation of uncertainty by the statistical analysis of a series of observations.
Type B Evaluation	Method of evaluation of uncertainty by means other than the statistical analysis of a series of observations.

Table 5 : Uncertainty in Orifice Metering System (Typical)

Uncertainty Budget for Orifice Metering System													
Sl.No	Source of Uncertainty	Estimate		Expanded uncertainty		Probability distribution		Standard Uncertainty		Sensitivity coefficient		Uncertainty	Degree of freedom
	x_i	x_i		$U(x_i)$		Type	Divisor	$u(x_i)$		c_i		$u_i(y)$	ν
		Value	unit	Value	unit			Value	unit	Value	unit		
1	**Coefficient of discharge,C_d**	**0.604264**	**-**	**0.002714**	**-**	**Type B, Rectangular**	**1.7321**	**0.001567**	**-**	**4.633619**	**kg/s**	**0.007260**	∞
2	**Velocity factor,Ev**	**1.042350**	**-**	**0.000010**	**-**	**Type B, Normal**	**2**	**0.000005**	**-**	**2.686170**	**kg/s**	**0.000013**	∞
	Orifice diameter,d	0.162027	m	0.000008	m	Type B, Normal	2	**0.000004**	m	1.112856	1/m	0.000004	∞
	Pipe diameter,D	0.305034	m	0.000008	m	Type B, Normal	2	**0.000004**	m	-0.591123	1/m	-0.000002	∞
	Beta ratio,β	0.531176	-										
3	**Expansion factor,Y**	**0.993699**	**-**	**0.074831**	**%**	**Type B, Rectangular**	**1.7321**	**0.000429**	**-**	**2.817684**	**kg/s**	**0.001210**	∞
4	**Orifice diameter,d**	**0.162027**	**m**	**0.000008**	**m**	**Type B, Normal**	**2**	**0.000004**	**m**	**34.561318**	**kg/s/m**	**0.000131**	∞
	Reference diameter,d_{To}	0.162	m	0.000007	m	Type B, Normal	2	**0.000004**	m	1.0001652		3.6506E-06	∞
	Expansion coefficient,γ_D	0.00001652	K^{-1}	0.0000004	K^{-1}	Type B, Rectangular	1.7321	**0.000000**	K^{-1}	1.620000	m.K	3.7412E-07	∞
	Reference temperature,T_o	20.00	^oC	0.50	^oC	Type B, Rectangular	1.7321	**0.288675**	K	-2.676E-06	m/K	-7.726E-07	∞
	Flowing temperature,T_f	30.0000	^oC	0.37	^oC	Type B, Rectangular	1.7321	**0.215388**	K	2.676E-06	m/K	5.7643E-07	∞
5	**Pipe diameter,D**	**0.305034**	**m**	**0.000008**	**m**	**Type B, Normal**	**2**	**0.000004**	**m**				∞
	Reference diameter,D_{To}	0.305	m	0.000007	m	Type B, Normal	2	**0.000004**	m	1.0001107		3.6504E-06	∞
	Expansion coefficient,γ_D	0.000011071	K^{-1}	0.0000004	K^{-1}	Type B, Rectangular	1.7321	**0.000000**	K^{-1}	3.050000	m.K	7.0437E-07	∞
	Reference temperature,T_o	20.00	^oC	0.50	^oC	Type B, Rectangular	1.7321	**0.288675**	K	-3.377E-06	m/K	-9.748E-07	∞
	Flowing temperature,T_f	30.0000	^oC	0.37	^oC	Type B, Rectangular	1.7321	**0.215388**	K	3.377E-06	m/K	7.2729E-07	∞
6	**Density**	**3.138239**	**kg/m^3**	**0.006067**	**kg/m^3**	**Type B, Rectangular**	**1.7321**	**0.003503**	**kg/m^3**	**0.446099**	**m^3/s**	**0.001563**	∞
	Pressure,P_f	400905	Pa	87.14356	Pa	Type B, Normal	2	**43.572**	Pa	7.828E-06	kg/m^3/Pa	0.00034107	∞
	Molecular Mass,Mr	19.52983	kg/kmol	0.0096317	kg/kmol	Type B, Rectangular	1.7321	**0.005561**	kg/kmol	0.161	kmole/m^3	0.00089358	∞
	Compressibility,Z_f	0.989834	-	0.000990	-	Type B, Rectangular	1.7321	**0.000571**	-	-3.170	kg/m^3	-0.0018119	∞
	Universal gas constant,R	8314.46	J/kmol/K	0.831446	J/kmol/K	Type B, Rectangular	1.7321	**0.480036**	J/kmol/K	0.000	kg/m^3/(J/kmol/K)	-0.0001812	∞
	Temperature,T_f	303	K	0.37	K	Type B, Rectangular	1.7321	**0.215388**	K	-0.010	kg/m^3/K	-0.0022297	∞
7	**Differential Pressure**	**7500**	**Pa**	4.1231056	**Pa**	**Type B, Normal**	**2**	**2.061553**	**Pa**	**0.000187**	**kg/s/Pa**	**0.000385**	∞
8	**Base Density**	**0.828498**	**kg/m^3**	**0.001071**	**kg/m^3**	**Type B, Rectangular**	**1.7321**	**0.000618**	**kg/m^3**	**-4.079095**	**sm^3/s**	**-0.002522**	∞
	Pressure,P_b	101325	Pa	0	Pa	Type B, Normal	2	**0.000**	Pa	8.177E-06	kg/m^3/Pa	0	∞
	Molecular Mass,Mr	19.52983	kg/kmol	0.0096317	kg/kmol	Type B, Rectangular	1.7321	**0.005561**	kg/kmol	0.042	kmole/m^3	0.0002359	∞
	Compressibility,Z_b	0.996944	-	0.000997	-	Type B, Rectangular	1.7321	**0.000576**	-	-0.831	kg/m^3	-0.0004783	∞
	Universal gas constant,R	8314.46	J/kmol/K	0.831446	J/kmol/K	Type B, Rectangular	1.7321	**0.480036**	J/kmol/K	0.000	kg/m^3/(J/kmol/K)	-4.783E-05	∞
	Temperature,T_b	288.15	K	0.00	K	Type B, Rectangular	1.7321	**0.000000**	K	-0.003	kg/m^3/K	0	∞
9	**Mass Flow Rate**	**2.79993**	**kg/s**	**0.015**	**kg/s**	**Type B, Rectangular**	**1.7321**	**0.008700**	***kg/s***	***1.207003***	***sm^3/kg***	**0.01050147**	∞
	Actual Volume Flow Rate	**3211.91**	**m^3/h**										
	Flow Velocity	**12.21**	**m/s**										
10	**Uncertainty in Mass flow rate**			**0.538**	%								
11	**Base Volume Flowrate**	**3.37952**	**sm^3/s**	**0.0216**	**sm^3/s**								
12	**Uncertainty in Volume flow rate**			**0.639**	%								
13	***Base Volume Flowrate***	***12166.283***	***sm^3/h***	***77.8***	***sm^3/h***				**Reynolds Number**		**717947.3**		
14	**Uncertainty in Volume flow rate**			***0.639%***									
	Base Voulme	12166.283	sm^3/h	77.7608	sm^3/h	Type B, Rectangular	1.7321	44.8952243	sm^3/h	43.943	MJ/sm^3	1972.84161	∞
	Gross Calorific Value	43.943	MJ/sm^3	0.0754946	MJ/sm^3	Type B, Rectangular	1.7321	0.04358681	MJ/sm^3	12166.283	sm^3/h	530.289528	∞
15	**Uncertainty in Energy Flowrate**	***534625.9***	***MJ/h***	***4085.737***	***MJ/h***	***0.76%***							
Post Implementation of Recommendations : RTD (Pt 100 Class A): 0.27 C : Pressure Transmitter 87 Pa : Differential Pressure Transmitter 4Pa : Flow Computer : FB 107 (Ins) : 0.24 C GC Repeatability 0.1%													

Table 6 : Uncertainty in Turbine Metering System (Typical)

Sl.No	Uncertainty Budget for Turbine Metering System												
Sl.No	Source of uncertainty	Estimate		Expanded uncertainty		Probability distribution		Standard Uncertainty		Sensitivity coefficient		Uncertainty	Degree of freedom
	x_i	x_i		$U(x_i)$		Type	Divisor	$u(x_i)$		c_i		$u_i(y)$	ν
		Value	unit	Value	unit			Value	unit	Value	unit		
1	**Frequency**	**100.31570**	**-**	**0.000000**	**Pulses/s**	**Type B, Rectangular**	**1.7321**	**0.000000**	**-**	**0.000941**	**m^3/pulses**	**0.000000**	∞
2	**K Factor**	**1062.86000**	**-**	**3.720010**	**Pulse/m^3**	**Type B, Normal**	**2**	**1.860005**	**-**	**-0.000089**	**m^6/s/pulses**	**-0.000165**	∞
3	**Density**	**4.881860**	**kg/m^3**	**0.009820**	**kg/m^3**	**Type B, Rectangular**	**1.7321**	**0.005670**	**kg/m^3**	**0.094383**	**m^3/s**	**0.000535**	∞
	Pressure,P_f	680860	Pa	490.3325	Pa	Type B, Normal	2	**245.166**	Pa	7.17E-06	kg/m^3/Pa	0.00175788	∞
	Molecular Mass,Mr	17.21904	kg/kmol	0.010335436	kg/kmol	Type B, Rectangular	1.7321	**0.005967**	kg/kmol	0.284	kmole/m^3	0.00169178	∞
	Compressibility,Z_f	0.985275	-	0.000985	-	Type B, Rectangular	1.7321	**0.000569**	-	-4.955	kg/m^3	-0.0028185	∞
	Universal gas constant,R	8314.46	J/kmol/K	0.831446	J/kmol/K	Type B, Rectangular	1.7321	**0.480036**	J/kmol/K	-0.001	kg/m^3/(J/kmol/K)	-0.0002819	∞
	Temperature,T_f	293.150	K	0.33	K	Type B, Rectangular	1.7321	**0.191138**	K	-0.017	kg/m^3/K	-0.003183	∞
4	**Base Density**	**0.728510**	**kg/m^3**	**0.000985**	**kg/m^3**	**Type B, Rectangular**	**1.7321**	**0.000569**	**kg/m^3**	**-0.868175**	**sm^6/s/kg**	**-0.000494**	∞
	Pressure,P_b	101325	Pa	0	Pa	Type B, Normal	2	**0.000**	Pa	7.19E-06	kg/m^3/Pa	0	∞
	Molecular Mass,Mr	17.21904	kg/kmol	0.010335	kg/kmol	Type B, Rectangular	1.7321	**0.005967**	kg/kmol	0.042	kmole/m^3	0.00025246	∞
	Compressibility,Z_b	0.997687	-	0.000998	-	Type B, Rectangular	1.7321	**0.000576**	-	-0.730	kg/m^3	-0.0004206	∞
	Universal gas constant,R	8314.46	J/kmol/K	0.831446	J/kmol/K	Type B, Rectangular	1.7321	**0.480036**	J/kmol/K	0.000	kg/m^3/(J/kmol/K)	-4.206E-05	∞
	Temperature,T_b	288.71	K	0.00	K	Type B, Rectangular	1.7321	0.000000	K	-0.003	kg/m^3/K	0	∞
5	**Actual Volume Flow rate**	**0.094383**	**m^3/s**	**0.000330**	**m^3/s**	**Type B, Rectangular**	**1.7321**	**0.000191**	**m^3/s**	**4.882**	**kg/m^3**	**0.00093105**	∞
6	**Mass Flow Rate**	**0.4608**	**kg/s**	**0.002148**	**kg/s**	**Type B, Rectangular**	**1.7321**	**0.001240**	***kg/s***	***1.3726653***	***sm^3/kg***	**0.0017021**	∞
7	**Uncertainty in Mass flow rate**			**0.466125462**	%								
8	**Base Volume Flowrate**	**0.6325**	**sm^3/s**	**0.004**	**sm^3/s**								
9	**Uncertainty in Volume flow rate**			**0.560**	%								
10	**Base Volume Flowrate**	**2276.907**	**sm^3/h**	**12.760**	**sm^3/h**	**Type B, Rectangular**	**1.7321**	**7.366980**	**sm^3/h**	**39.969**	**MJ/sm^3**	**294.451559**	∞
11	**Uncertainty in Base Volume flow rate**			**0.560**	%								
12	**Gross Calorific Value**	**39.969**	**MJ/sm^3**	**0.075**	**MJ/sm^3**	**Type B, Rectangular**	**1.7321**	**0.043380**	**MJ/sm^3**	**2276.907**	**sm$^{3/}$/h**	**98.7731713**	∞
13	**Uncertainty in Energy Flow rate**	**91005.932**	**MJ/h**	**621.153**	**MJ/h**								
14					**0.683**	**%**							

Post Implementations of Recommendations : Uncertainty in K Factor : 0.35 % ; GC Repeatability : 0.1%: Uncertainty in Pressure :490 Pa ; Uncertainty in Temperature (TT/RTD) : 0.27 C

Table 7: Uncertainty in Ultrasonic Metering System (Typical)

Sl.No	Uncertainty Budget for Ultrasonic Metering System												
Sl.No	Source of uncertainty	Estimate		Expanded uncertainty		Probability distribution		Standard Uncertainty		Sensitivity coefficient		Uncertainty contribution	Degree of freedom
	x_i	x_i		$U(x_i)$		Type	Divisor	$u(x_i)$		c_i		$u_i(y)=c_i{*}u(x_i)$	ν
		Value	unit	Value	unit			Value	unit	Value	unit	Value	
1	**Velocity**	**4.00000**	**m/s**	**0.012400**	**m/s**	Type B,Normal	2	**0.006200**	**m/s**	**6169.989778**	**sm^3/h/m/s**	**38.253937**	∞
2	**Meter diameter,D**	**0.188895**	**m**	**0.000070**	**m**	Type B, Normal	2	**0.000035**	**m**	**261309.147376**	**sm^3/h/m**	**9.145820**	∞
3	Expansion coefficient,γ_D	0.00001512	K^{-1}	0.0000004	K^{-1}	Type B, Rectangular	1.7321	**0.000000**	K^{-1}	15.002268	K	3.46463E-06	∞
4	Reference temperature,T_o	20.00	C	0.25	K	Type B, Rectangular	1.7321	**0.144338**	K	-0.000045	/K	-6.54814E-06	∞
5	Flowing temperature,T_f	25	C	0.27	K	Type B, Rectangular	1.7321	**0.155834**	K	0.000045	/K	7.06971E-06	∞
6	**Temperature Correction Factor**	1.0002268		0.00002	-	Type B, Rectangular	1.7321	**0.000012**	-	**24674.362545**	**sm^3/h**	**0.291751681**	∞
7	Calibration Reference Pressure	101325	Pa	101.33	Pa	Type B,Normal	2	**50.662500**	Pa	-4.93659E-11	/Pa	-2.501E-09	∞
8	Meter Pressure,P_f	5788743.991	Pa	3553.47	Pa	Type B, Normal	2	**1776.737**	Pa	4.93659E-11	/Pa	8.77102E-08	∞
9	**Pressure Correction Factor**	0.0002808		0.0000002	-	Type B, Rectangular	1.7321	**0.000**	-	**24673.031801**	**sm^3/h**	**0.00249987603**	∞
10	**Line Density**	**41.865764**	**kg/m^3**	**0.076456**	**Kg/m^3**	Type B, Rectangular	1.7321	**0.044142**	**kg/m^3**	**589.502173**	**sm^6/h/kg**	**26.021760**	∞
11	Meter Pressure,P_f	5788743.991	Pa	3553.47	Pa	Type B, Normal	2	**1776.737**	Pa	7.23227E-06	kg/m^3/Pa	0.01284984	∞
12	Molecular Mass,Mr	16.19314	kg/kmol	0.01010139	kg/kmol	Type B, Rectangular	1.7321	**0.005832**	kg/kmol	2.585	kmole/m^3	0.015078169	∞
13	Compressibility,Z_f	0.903214	-	0.000903	-	Type B, Rectangular	1.7321	**0.000521**	-	-46.352	kg/m^3	-0.02417121	∞
14	Universal gas constant,R	8314.4	J/kmol/K	0.831440	J/kmol/K	Type B, Rectangular	1.7321	**0.480032**	J/kmol/K	-0.005	kg/m3/(J/kmol/K)	-0.002417121	∞
15	Temperature,T_f	298.15	K	0.27	K	Type B, Rectangular	1.7321	**0.155834**	K	-0.140	kg/m^3/K	-0.021882015	∞
16	**Base Density**	**0.684900**	**kg/m^3**	**0.000935**	**Kg/m^3**	Type B, Rectangular	1.7321	**0.000540**	**kg/m^3**	**-36034.410703**	**sm^6/h/kg**	**-19.461800**	∞
17	Pressure,P_f	101325	Pa	0	Pa	Type B, Normal	2	**0.000**	Pa	6.75944E-06	kg/m^3/Pa	0	∞
18	Molecular Mass,Mr	16.19314	kg/kmol	0.01010139	kg/kmol	Type B, Rectangular	1.7321	**0.005832**	kg/kmol	0.042	kmole/m^3	0.00024667	∞
19	Compressibility,Z_f	0.997994	-	0.000998	-	Type B, Rectangular	1.7321	**0.000576**	-	-0.686	kg/m^3	-0.000395427	∞
20	Universal gas constant,R	8314.4	J/kmol/K	0.831440	J/kmol/K	Type B, Rectangular	1.7321	**0.480032**	J/kmol/K	0.000	kg/m3/(J/kmol/K)	-3.95427E-05	∞
21	Temperature,T_f	288.71	K	0.00	K	Type B, Rectangular	1.7321	**0.000000**	K	-0.002	kg/m^3/K	0	∞
22	**Volume Flowrate**	**403.750**											
23	**Base Volume Flow Rate**	**24679.95911**	**sm^3/h**	**102.038982**	**sm^3/h**	**Type B, Normal**	**2**		**sm^3/h**			**51.019491**	∞
24		**0.41345**	**%**										
25	**Base Volume flow rate**	**24679.96**		**102.039**	**sm^3/h**	**Type B, Rectangular**	**1.7321**	**58.912234**	**sm^3/h**	**38.007**	**MJ/sm^3**	**2239.083153**	∞
26	**Gross Calorific Value**	**38.007**	**MJ/sm^3**	**0.075**	**MJ/sm^3**	**Type B, Rectangular**	**1.7321**	**0.043200**	**MJ/sm^3**	**24679.959**	**sm$^{3/}$/h**	**1066.171233**	∞
27	**Uncertainty in Energy Flow rate**	**938013.7**	**MJ/h**	**4959.925**	**MJ/h**								
					0.529	**%**							

RTD (Pt 100 Class A) : Pressure Transmitter 3554 Pa : Temperature Transmitter(Ins) : GC Repeatability 0.1%: USM Expansion corrrection with 1.01325 bar and 20 °C and operating pressure and temperature to be done in FC . Pressure coefficient shall be calculated for operating conditions and inputted in FC . Calibration corrrection for velocity done in USM (assumed)

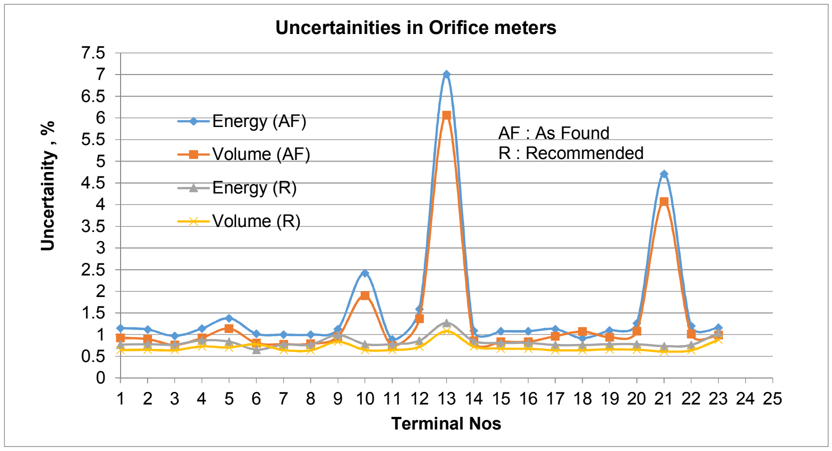

Fig.1

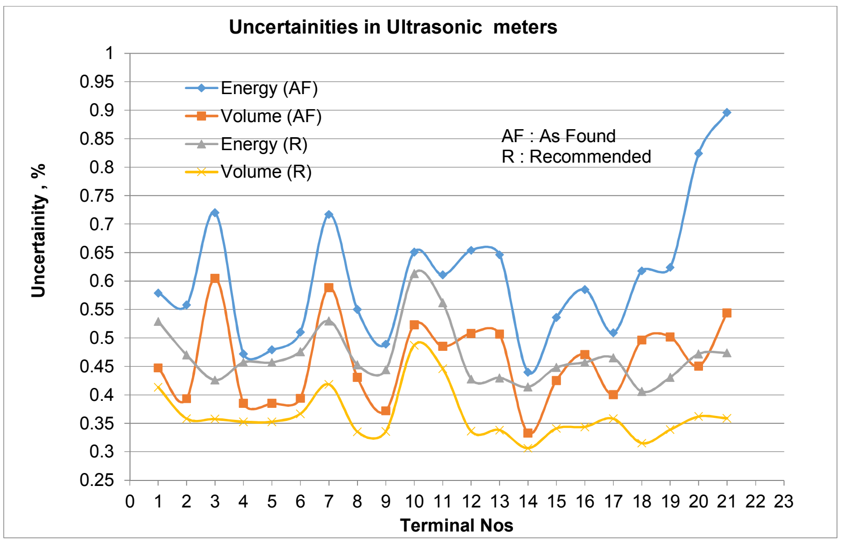

Fig.2

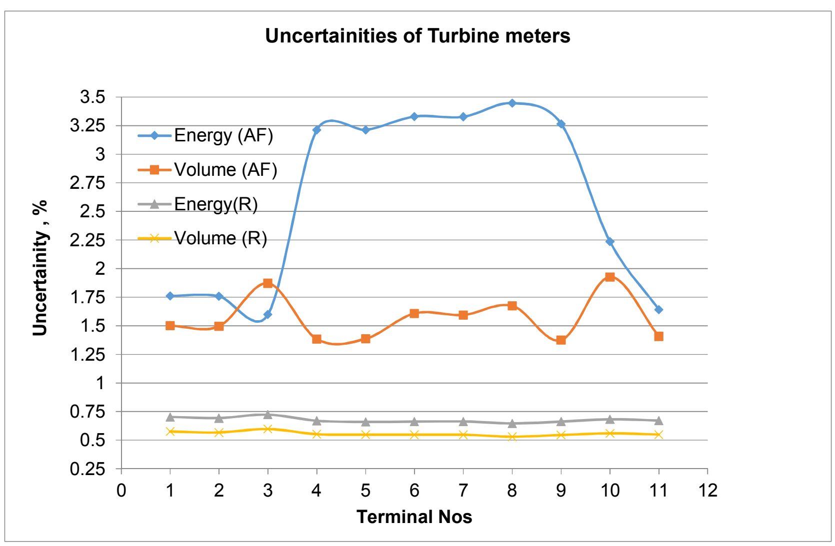

Fig.3