The Specification, Selection and Use of Liquid Flow Rate Measuring Devices

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Abstract: Description of an international standard that ensures all liquid flow rate measurement technology specifications are consistent for evaluation and comparison as well as to document and advance the state-of-the-art of liquid flow rate measurement technologies. The standard will cover all liquid flow rate technologies, error sources, fluid and temperature applications, and expected measurement uncertainties.

Keywords: flow, measurement uncertainty, standard

1. Introduction

Which liquid flow rate measuring technologies are appropriate for a user application? Are all liquid flow rate device manufacturers reporting measurement uncertainty using internationally agreed upon standards?

1.1 Problem

In order to select and specify the correct type of liquid flow rate measuring device(s) for an application and to compete in a level playing field, various users, industries and manufacturers would like to know the answers to the previous questions.

1.2 Solution

Create an international standard that lists all liquid flow rate measuring technologies, associated error sources, fluid and temperature applications, and expected measurement uncertainties. Update the standard annually to keep up-to-date with advances in technology.

1.3 Background

Several industries and government agencies publish liquid flow rate measuring standards specifying a single flow technology to be used in only one application. These standards are not practical for other applications and cause confusion for users.

Manufacturers do not state specifications in terms of measurement uncertainty or the same type of specifications. This difference in specifications causes confusion. Users cannot effectively compare different technologies or even the same technologies.

Users need to know how flow measurement works. Flow is a dynamic process with inter-relationships between pulsating fluid, turbulence intensity, and primary and secondary devices. Pressures fluctuate, velocity profiles change, vortices form differently and flow-measuring devices respond differently to these changes.

2. The International Standard

The international standard will define liquid flow terms not found in the VIM, such as laminar and turbulent flow. A section will describe issues that influence measurements: turbulence/cavitation and their sources, temperature effects, non-homogeneous/multi-state/compressible fluids. A summary table will allow quick review of technology performance. A section will describe how each technology works, influences and a measurement uncertainty calculation. A section will describe value-added electronics outputs, specifications and measurement uncertainty contribution. A section will describe calibration method versus real use and include discussions a variety of topics that influence the quality of the unit calibration.

2.1 Liquid Flow Terminology and Influences

This section will describe issues that can influence measurements, such as: a) turbulence and its sources, b) cavitation and its sources, c) temperature effects on viscosity, density, device clearances, and electronics performance, d) non-homogenous fluids (multiple viscosities or densities), e) multi-state fluids of gas, liquids, solids, f) compressible fluids, g) closed/open systems and closed/open channels, as well as h) calibration method versus real use. The turbulence topic will include a discussion of the Threshold Pulsation Index (2) and the Flow-Rate Correction Factor (3) as well as flow profiles based upon plumbing configurations and flow velocity.

2.2 The Summary Table

A table shall summarize technologies by use parameters, Table 1. The table terms will be described: a) method of measurement, b) standard temperature range, c) extended temperature ranges, d) best measurement uncertainty, e) fluid compatibility, f) sensitivity to density or viscosity, and g) use for liquids, gases, solids, slurries.

Table 1. Summary of Technology use Parameters.

Technology	Method	Std Temp	Extended Temp	Flow Range	Best MU	Fluid Compatibility	Sensitive to	Liquid, gas, slurries
Coriolis	Mass	0-100C	-40C to 200C	0,01g to 75kg/min	0,1% mass 0,2% volume	Stainless Steel	Density	Liquid, slurries
Turbine	Volume	0-100C	-40C to 200C	0,57 to 378,54 liter/min	0,27%	Stainless Steel	Viscosity	Gas, liquid
Orifice Plate								
Target								
Variable Area (rotameter)								
Thermal differential								
Pressure differential								

Ultrasonic								
Magnetic								
Gear								
Vortex Shedding								

2.3. Technologies

This section describes how each technology works, influences and a measurement uncertainty calculation. Coriolis, turbine, orifice plate, target, variable area (rotameter), thermal differential, pressure differential, ultrasonic, magnetic, gear, vortex shedding and other technologies are covered. Section 2.3.1 is an example.

2.3.1. Turbine Technology

A turbine measures volumetric flow rate based upon the rotational speed of a bladed wheel. The rotating wheel is sensitive to the viscosity of the fluid because the force of the fluid transferred to the wheel is dependent upon how much of the fluid slips by the blades. A low viscosity liquid will not transfer as much fluid force to the blades of the wheel as a higher viscosity fluid. A change in temperature of 5C can cause a 0,1% change in the reported flow rate measurement.

A compensation equation is used to predict turbine meter behaviour based upon temperature and viscosity. The compensation equation uses dimensionless Reynold's numbers (Roshko and Strouhal) that take into account the expansion effects of materials based upon temperature. It is important to have at least three viscosities characterized for the use range to verify the turbine meter behaves as predicted. Unless requested, turbine meter behaviour is generally measured for only one viscosity.

With a 7:1 range ratio of low to high flow rate, the best measurement uncertainty of a turbine meter on a single viscosity is 0,27% of reading with a fluid and ambient air temperature stable within +/-2C.

Table 2. Best Measurement Uncertainty Calculation.

Error Source	Type	Contribution	Distribution	Divisor	Contribution divided by Divisor	Squared contribution
Turbine Meter Repeatability (in a single viscosity)	A	0,05	Statistical	1	0,05	0,0025 U_a
Cal Lab Flow Stand – Flow Rate	B	0,05	Rectangular	1,732	0,029	0,0008 U_b

Cal Lab Flow Stand – Frequency	B	0,00	Rectangular	1,732	0,00	0,0000 U_b
Cal Lab Master Temperature Probe (+/-28C)	B	0,00	Rectangular	1,732	0,00	0,0000 U_b
Viscosity Measurement (or table calculation)	B	0,25	Rectangular	1,732	0,144	0,0207 U_b
Density, no need to calculate from base density; under 7 bar, pressure effects are under 0.01% of reading	B	0,00	Rectangular	1,732	0,00	0,0000 U_b
Standard Error Estimate (SEE)	B					
Strouhal No Calculation	B					
Roshko No Calculation	B					
Interpolation Error	B					
Piping/Inlet Mismatch (difference between pipe inner diameter and unit inlet diameter)	B					

2.4. Equations

All symbols used in equations will be defined in the Standard. Expanded measurement uncertainty is expressed using equation (1):

$$U_e = 2\sqrt{U_a^2 + U_{b1}^2 + U_{b2}^2 + ... + U_{bn}^2} \quad (1)$$

The pulsation index is defined by equation (2):

$$I_p = \frac{\left(\overline{V_f}\right)_{max} - \left(\overline{V_f}\right)_{min}}{2\left(\overline{V_f}\right)_{avg}} = \frac{\left(q_v\right)_{max} - \left(q_v\right)_{min}}{2\left(q_v\right)_{avg}} \quad (2)$$

The flow-rate correction factor, based upon the pulsation index, is defined by equation (3):

$$F_p = \frac{indicated\_f\,low}{average\_f\,low} = \left(1 + 4\alpha b_p I_p^2\right)^n \quad (3)$$

An axial flow meter compensation equation is based upon a Strouhal Number, equation (4), and a Roshko Number, equation (5).

$$S_r = \frac{f}{u} c^3 \quad (4)$$

$$R_o = S_t R_e = \frac{f L^2}{v} \qquad (5)$$

A coriolis mass flow meter is described in equation (6):

$$\dot{M} = S_k \frac{A_c}{A_e}\left(\frac{1}{f_v}\right) \qquad (6)$$

2.5. Electronics outputs and Uncertainty

This section describes electronics used in addition to the primary mechanical/electrical transducer element and the extra contribution of error to the measurement uncertainty calculation.

The additional output electronics adds value to the primary element signal, such as: a) producing a scaled voltage from a frequency, b) compensating for temperature or viscosity or density, c) dampening flow pulsations, d) producing a communications port signal, to mention a few. The additional electronics can usually be remote-mounted because the value added electronics are typically more sensitive to extreme environmental conditions than the primary sensing technology.

2.6. Calibration Method and its Quality

This section describes the calibration method versus real use and includes discussions on a variety of topics that influence the quality of the unit calibration. The calibration shall be in an environment as close as possible to the intended use of the flow measurement instrument, as per the Laboratory Management Standard ISO 17025. The flow points and number of flow points shall be selected based upon the use of the flow measurement instrument. The inlet plumbing shall be the plumbing attached to flow measurement instrument when use. The length and configuration of inlet plumbing to the unit under calibration shall conform to the turbulence influences stated in the technology section of this standard, such as a length of 1, 10, 100 or 1000 times the pipe inner diameter. The fluid viscosity, density and temperature shall be within an acceptable tolerance range for the use of the flow measurement instrument. The fluid used in calibration may be substituted with fluids of like fluid properties in order to ensure the safety of the personnel performing the calibration and be compatible with the calibration system as well as reduce the cost of the calibration. A 4:1 ratio of calibration system versus unit under calibration shall be maintained whenever possible. The fluid temperature shall be measured at the unit under calibration as well as the calibration references because mass flow and volumetric flow are not conserved. In some circumstances, the calibration must be performed in situation, such as flow measurement instruments used in pipelines for water or petroleum as well as in rivers and oceans.

3. Conclusion

Numerous industries and manufacturers have expressed interest in reviewing or contributing to this proposed standard. There is momentum to complete this technical document.

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