Measurement Assurance Program

Establishment and Maintenance of Measurement Quality

Introduction

This document describes the Measurement Assurance Program (MAP; Belanger [1]) for SoundWater's SWTC400 calibration system. This MAP was created to establish measurement traceability to the NIST, and to maintain quality of measurement overtime. It contains two parts: (1) determination of uncertainty for all variables in the measurement process, and (2) Statistical Process Control (SPC; Wheeler et. al [2]).

Methods

Mechanical Setup

The SWTC400 calibration system measures flow by driving fluid through a system of pipe, reference flow meters, and devices under test (DUT). The fluid may be driven by either pump or gravity. The system is closed (no leaks), and thermally controlled (indoors). Two full bore, inline, electromagnetic flowmeters are used for reference (secondary standard). Each reference flowmeter is accurate to 0.5% at 95% confidence, and was calibrated by a third party NIST traceable measurement system. An automated PLC system controls all timing, pulse counting, and thermal measurements (fluid and pipe temperature).

Electromagnetic and ultrasonic flowmeters are sensitive to fluid velocity profile, and operate under the assumption of fully developed and steady flow. To assure fully developed and steady flow, a flow conditioner and 30 diameters of straight pipe were installed upstream of the flowmeters. Prior to any flow measurement, a thermal and hydrodynamic steady state is first established.

Determination of Measurment Uncertainty and Traceability

The flow measurement system was modeled as a control volume (T.T. Yeh et. al [3]), with mass passing the DUT (primary mass), mass passing the reference (secondary mass), and mass contained between the DUT and reference (storage mass). Using conservation of mass, allowing for thermal changes, and assuming pipe temperature equivalent to liquid temperature (valid for Biot number << 1), a simple expression for flow rate and volume was obtained (Eq 1 & 2).

$$V_{DUT} = [(a_{pipe}\ \Delta T_{pipe}\ V_s) + (3\ a_{liquid}\ \Delta T_{liquid}\ V_s) + \Delta V_{ref}]] \quad (1)$$

$$Q_{DUT} = V_{DUT} / \Delta t \quad (2)$$

where Q is average flow rate (m³/s), T is temperature (Celsius), V is volume (m³), t is time (s), a is thermal expansion coefficient. Subscripts *DUT* is device under test, *pipe* is pipe enclosing the fluid, *S* is storage volume, *fluid* is fluid, and *ref* is reference flowmeter.

Flow rate and volume measurement uncertainty were calculated using equations (1) and (2) and the Law of Propagation of Uncertainty (McClintock et. al [4]). Uncertainties were tabulated for dependant variables (table I).

Table I This table lists uncertainties for variables used in flow measurements.

UNCERTAINTY VARIABLE	TYPE B	TYPE A
fluid temperature (C)	0.5	
time (PLC)	1.0e-1	
storage volume (m^3)	2.3e-4	
volume (reference; %)	2.5e-1	
CTE water	1.0e-4	
CTE PVC pipe	2.5e-5	

Statistical Process Control

SPC software was installed on the SWTC400 system and configured to measure flow rate prior to each day's use. Central tendency and disperson control charts are monitored automatically by the software. In the case of an out-of-control state, the software will send an email notification to the operations manager.

Results

Uncertainties for flow rate and volume measurement are display in Figure I. Uncertainties were less than 0.4% at the 95% cofidence interval.

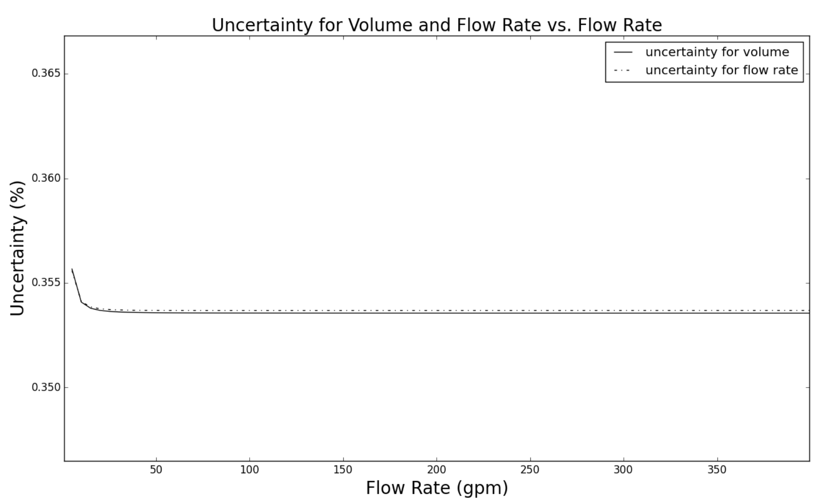

Figure I This figure displays uncertainties for flow rate and volume measurements for the SWTC400 calibration system.

Conclusions

Measurememt traceability to the NIST was established for the SWTC400 through the chain of uncertainties tabulated herein. SPC software was implemented and maintains this traceability overtime.

References

[1] B. Belanger, "Measurement Assurance Programs Part I: General Introduction," NBS Special Publication 676-I, U.S. Government Printing Office, Washington, May 1984.

[2] D. J. Wheeler and D. S. Chambers, "Understanding Statistical Process Control," SPC Press, Knoxville TN, May 1984.

[3] T. T. Yeh et. al., "An Uncertainty Analysis of a NIST Hydrocarbon Flow Calibration Facility," Proceedings of the 2004 Heat Transfer/Fluids Engineering Summer conference, ASME 2004.

[4] S. J. Kline and F. A. McClintock, "Describing Uncertainties in Single-Sample Experiments," Mechanical Engineering, January, 1953.