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CTI CODE TOWER Standard Specifications

Standard for Liquid Flow Measurement



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This guideline document summarizes the best current state of knowledge regarding the specific subject. This document represents a consensus of those individual members who have reviewed this document, its scope and provisions. It is intended to aid all users or potential users of cooling towers.

Approved by the CTI Executive Board.



This document has been reviewed and approved as part of CTI's Five Year Review Cycle. This document is again subject to review in 2011.

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CTI Executive Board

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STANDARD FOR LIQUID FLOW MEASUREMENT

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STANDARD FOR LIQUID FLOW MEASUREMENT

1.0 SCOPE AND PURPOSE

- 1.1 Scope - This standard covers methods for liquid flow measurement. Its application is limited to the measurement of water, water/glycol mixtures, and other homogeneous single-phase liquids for which acceptable physical property data are available.
- 1.2 Purpose - The basic intent of this standard is to provide liquid flow measurement procedures that are accurate and meet the requirements of

the Cooling Technology Institute test codes. The accuracy of the flow measurements depends on the location and type of instrument used and the stability of the test.

- 1.3 Units of Measure – This standard is written in Primary Rational SI (International System of Units) with secondary I-P (inch-Pound) units. For full details on appropriate conversions between SI and I-P units refer to CTI Standard STD-145.

2.0 NOMENCLATURE & SYMBOLS

The symbols used in this code are identified in the following table.

Symbol	Description &	Units of Measure
A	Cross sectional area of the pipe at the measurement location,	m ² (ft ²)
β	Beta Ratio – ratio of small to large diameter in orifices, venturis or nozzles, and contractions or enlargements in pipes	(d/D), dimensionless
C _o	Calibration coefficient for measurement device,	dimensionless
d	Orifice or nozzle throat diameter,	mm (in)
D	Pipe inside diameter,	mm (in)
D _c	Characteristic dimension. Used in Reynolds Number computation. It may refer to pipe diameter or pitot tip diameter depending on application,	m (ft)
DP	Abbreviation for “Differential Pressure” when referring to a class of flow measurement devices.	
δ	Manometer reading ,	mm (in)
ΔP	Differential pressure,	Pa (psi)
f	Multiplier on diameter to determine measurement position for equal annular area sectors within a closed conduit,	dimensionless (See Figure C-4)
g	Acceleration due to gravity,	nominally 9.80665m/s ² (32.1740 ft/s ²)
γ	Specific gravity, dimensionless	
H	Velocity head of flowing fluid,	m (ft) of flowing fluid
n	Number of points in a pitot traverse,	dimensionless
N _x	Specific station number of a pitot measurement location,	dimensionless
ν	Kinematic viscosity,	m ² /s (ft ² /s)
P _s	Static pressure,	Pa (psi or lb _f /in ²)
P _T	Total pressure,	Pa (psi or lb _f /in ²)

Pv	Velocity pressure,	Pa (psi or lb _f /in ²)
Q	Volumetric liquid flow rate,	L/s (gal/min or gpm)
Re	Reynolds Number – Defined by the formula vD_c/v ,	dimensionless
SL	Straight, unobstructed length of pipe in measurement location expressed in multiples of pipe diameter,	D
ρ	Fluid density,	kg/m ³ (lb/ft ³)
ρ_{ff}	Density of flowing fluid,	kg/m ³ (lb/ft ³)
ρ_{mf}	Density of manometer fluid,	kg/m ³ (lb/ft ³)
v	Fluid velocity,	m/s (ft/s)
V	Velocity, weighted average,	m/s (ft/s)
X	Distance from a reference point to a pitot location,	mm (in)

3.0 PIPING REQUIREMENTS

The flow measuring instrument position and orientation in the pipe is critical to the accuracy of the flow measurement. The contracting parties to a test shall evaluate the piping configuration to determine the optimum flow measurement location and instrument to be used.

- 3.1 Measurement Location** - Most of the commonly used flow measurement instruments require a fully developed velocity profile at the point of measurement, which is achieved with long, obstruction and disturbance free straight runs of pipe. To ensure the stated accuracy of the flow measurement devices, the flow measurement location should be situated in a section of straight pipe, free of any valves or fittings, extending ideally twenty pipe diameters (20D), but a minimum of fifteen pipe diameters (15D) in length. The measurement location should have a minimum of ten pipe diameters (10D), or 2/3 of the length, of the straight pipe upstream and a minimum of five pipe diameters (5D), or 1/3 of the length, of the straight pipe downstream.

Practical limitations on field piping often require taking flow measurements where the 15D minimum criteria for straight, obstruction-free pipe length is unattainable. Recognizing that compromising the 15D minimum straight run of pipe decreases the measurement accuracy, measurements with reduced, but generally acceptable, levels of accuracy shall be made with the measurement location set according to the 2/3 upstream - 1/3 downstream ratio of the available straight length of pipe. In very short straight lengths, deference should always be given to more upstream length than downstream length.

Measurement locations with disturbance free straight pipe less than five pipe diameters (5D) upstream or one pipe diameter (1D) downstream lead to unacceptable flow measurement errors for nearly all flow measurement methods. In these installations, location insensitive measurement methods such as dye dilution must be used.

Available Pipe Straight Length, SL	Device Location – Upstream	Device Location – Downstream
20D Ideal	15D	5D
15D Minimum SL for desired levels of uncertainty.	10D	5D
<15D Compromised levels of uncertainty.	2/3 · SL, but > 5D	1/3 · SL, but > 1D
<6D Unacceptable levels of uncertainty.	Special flow measurement techniques required.	

When the flow measurement location is in a vertical riser, the location must also be in a region of positive static head.

- 3.2 Safety** - In addition to the considerations for accuracy, it is also imperative that the flow measurement location be safely accessible to test

personnel during the test. The tower owner and/or site contractor shall provide the necessary equipment for safe access.

- 3.3 Flow Area** - The average measured pipe internal diameter should be used in the flow area calculations. The pipe internal diameter should be precisely measured on at least two (2) diameters 90° opposed at the plane of the flow measurement. It is the intent to establish the true cross sectional area of the pipe by the best means available. For flow measurements made with pitot tubes, the area used to calculate the water flow rate will depend on the method of pitot tube calibration. If the pitot tube is calibrated based on a “blockage correction” basis, then the area of the flow measurement, A_C , is determined by the total cross sectional area minus the average area of the cross section of the pitot tube at each of the measurement locations. If the pitot tube calibration is based on a “gross” area, then the area is equal to the uncorrected cross sectional area of the pipe at the pitot measurement plane. Other types of insertion meters may require similar flow area blockage correction.

- 3.4 Flow Conditioners** – Flow conditioners in the flow measurement section may be used to reduce swirl and improve the velocity profile.

4.0 CONTAMINANTS OR DISTURBANCES

Contaminants or disturbances in the flow stream can have a significant and adverse effect on flow measurement.

- 4.1 Particulates and/or Solids** - Particulates and solids may cause partial or total plugging of pressure taps and reduction in cross-section of the flow area. Appropriate flow measurement instruments tolerant to the liquid conditions must be selected prior to a test.
- 4.2 Air (Gas) Bubbles** - Any source of free air (or gas) bubbles should be eliminated during the test. Bleed valves should be installed at all high points in the instruments and on the instrument lines where air (or gas) may collect. These high points should be purged to eliminate all air (or gas) from the system at a frequency appropriate for the application.
- 4.3 Pulsating or Surging Flow** - Pulsating or surging adversely affects measurement accuracy. Flow measuring instruments shall be located as far as practical from the source of the pulsation. Any noticeable pulsation effects should be documented in the test report.

- 4.4 Swirl Flow** - Swirl is spiraling flow, which strikes the flow meter at an oblique angle. The severity of the swirl component is directly related to the pipe or valve configuration and disturbances which generate swirl flow. Flow swirl is inversely related to the distance between the disturbance and the flow measuring location.

Installation of flow conditioners may reduce swirl flow.

5.0 PRIMARY FLOW MEASUREMENT DEVICE AND METHODS

- 5.1 Pitot Tube** - The CTI's recommended flow measurement instrument is the pitot tube (see Appendix C). Properly applied, the pitot tube provides acceptable levels of accuracy over a broad range of pipe sizes and flow rates encountered in field testing. Assumptions about flow profile and flow area, required of some meters for stated accuracy, are eliminated because a pitot traverse measures actual local velocity profile in the pipe as well as pipe diameter. The pitot tube is simple in operating principle and construction, durable, portable, and may be inspected with each use for damage, clogging, or wear.

- 5.2 Other Flow Measurement Instruments** - The following listed flow measurement instruments, when properly applied, are acceptable to CTI for testing when the selected instrument is mutually agreed upon by the contracting parties.

A brief synopsis of these flow instruments is presented in the Appendix D of this Standard. Specific and full details for the flow instrument selected should be obtained from the instrument manufacturer.

- 5.2.1** Orifice Meter (Appendix D.2.).
- 5.2.2** Flow Nozzle (Appendix D.3.).
- 5.2.3** Venturi (Appendix D.4.).
- 5.2.4** Multiport Averaging Pitot Flow Meter (Appendix D.5.).
- 5.2.5** Vortex Shedding Meter (Appendix D.6.).
- 5.2.6** Turbine Meter (Appendix D.7.).
- 5.2.7** Magnetic Flow Meter (Appendix D.8.).
- 5.2.8** Transit time Ultrasonic Flow Meter (Appendix D.9.).
- 5.2.9** Tracer Injection Measurement Method (Appendix D.10.).

Flow measuring instruments and methods other than those listed may be required in certain applications if properly applied and agreeable to the parties of the test.

6.0 PRIMARY DEVICE CALIBRATION

- 6.1 Calibration Laboratory** - Flow measurement instruments must be calibrated at flow laboratories having both experience and qualification for a minimum of engineering grade primary device calibration. There are a number of flow laboratories available for calibration of flow meters. The typical considerations are flow capacity, maximum line size and cost.

Traceability of the calibration to primary measurement standards is required and should be considered in selection of the laboratory. The individual flow laboratory certification accuracy is generally from ¼% to 1% of true flow rate. The uncertainty of the calibration reference flow meter or laboratory flow standard shall not exceed ±1%.

Some laboratories state their uncertainty in terms of the % of reading value. The reporting of uncertainty in the calibration should be specified prior to calibration. Calibration reporting shall include sufficient data, description, and discussion of the calibration to satisfy the parties to the test where the calibrated device is to be used.

- 6.2 Calibration Requirements** - Calibration shall be completed for a minimum of two (2) average flow velocities on the order of 1.5 m/s (5 ft/sec) and 3 m/s (10 ft/sec) and on the order of the test flow velocity if it is significantly out of this range.

Calibration intervals shall be at least as frequent as specified in the governing CTI test code or immediately upon known or suspected instrument damage. For example, ATC-105 "Acceptance Test Code for Water Cooling Towers" and Multi-agency licensing agreements specify a maximum three (3) year calibration interval, if undamaged.

7.0 FLOW SIGNAL CONDITIONING AND READOUT

Regardless of the type of flow measurement instrument, all signal conditioning and readout components need to be consistent with the specified accuracy and operating principles of the flow measurement instrument. The operator must be aware

of the condition of the flow measurement readout device, its calibration and its use.

- 7.1 Manometer** - Manometers of various types are simple instruments for differential pressure (DP) measurements. The type of manometer selected must be suitable for both the differential and system pressures expected in a particular application.

7.1.1 Air over Liquid Manometer - The inverted U-tube manometer with air over the measured liquid is the CTI's standard instrument for DP measurements. The height differential between the two liquid menisci in the manometer indicates the velocity head caused by fluid flow. (See example of air-over-liquid manometer in Figure C-2).

7.1.2 Liquid-Liquid "U"-Tube Manometer - The upright U-tube manometer uses an indicating fluid other than air over the measured liquid. The indicating fluid must be totally immiscible and non-reactive with the measured liquid, must have a readily discernable interface to the measured liquid and its density must be accurately known. Refer to the manometer manufacturer for specific information regarding different indicating fluids and proper manometer operating procedures.

7.1.3 Manometer Readings

7.1.3.1 Manometer Fluid Fluctuations
Because most flows have fluctuations in velocity pressure (P_v) and static pressure (P_s), the time average of the deflection is used to indicate the ΔP . (Note: Averaging of the maximum and minimum deflection is not equivalent to the time average and should not be used.)

7.1.3.2 Manometer Indicating Fluid Choice
- If an indicating fluid other than air is used in the manometer, the density of the fluid must be low enough to produce an average deflection of 250 mm (10 inch) or greater DP indication.

7.1.3.3 System Pressure Considerations - Total system pressure values should be taken into account in choosing hardware and tubing.

7.1.3.4 Gas in the System - All gas bubbles must be removed from the tubing and fittings. Valve combinations and sequencing should facilitate filling of the lines and expulsion of gas bubbles.

7.1.3.5 Parallax - Caution should also be exercised in reading the manometer to prevent reading errors due to parallax.

7.1.3.6 Liquid Meniscus - The meniscus, or interface between the manometer indicating fluid and the measured liquid, can have a convex, concave or flat surface, depending on the particular manometer fluids present and fluid movement. Therefore, care should be exercised to read the manometer meniscus the same way (on the edge or at the top or bottom of the curvature) for each reading.

7.2 Other "DP" Readout Devices - There are a number of other types of readout devices for DP type flow meters which can be classified as mechanical, pneumatic or electronic. The most commonly used would be the electronic DP transmitter. The DP transmitters, must be accurate, stable, repeatable and linear. These units must also be properly calibrated for zero and span.

7.3 Other Readout Devices - Several other flow meters such as magnetic meters, ultrasonic meters, turbine meters and vortex meters use flow signal conversion and readout other than DP. The signal conditioning may be quite complex and non-linear and not easily verifiable.

Caution should be exercised in choosing and operating these meters and related readout. These devices must be proven for their application, accurate, stable, and repeatable. The unit calibration must be known and verified on a regular basis.

7.4 Calibration and Use - It is recommended that all flow signal conditioning and readout instrumentation be calibrated and inspected in accordance with accepted engineering practice and in accordance with the manufacturer's recommendations. Any required instrument calibration correction curves should be prepared in advance of the test and such curves, operating characteristics or other related factors are to be recorded in the test report. Flow measurement instruments as well as signal conditioning and readout instrumentation must be used in a manner consistent with their calibration method.

Regardless of the type of flow measurement device, all signal conditioning and readout components need to be consistent with the specified accuracy and operating principles of the flow measurement device. The operator must be aware of the condition of the flow measurement readout device, its calibration, and its use.

APPENDIX A. REFERENCES (Normative)

A.1 REFERENCES, STANDARDS AND CODES-NORMATIVE

Listed here are standards, handbooks, and other publications essential to the implementation of this standard. All references in this section are considered a part of this standard.

1. ASME, *Application, Part II of Fluid Meters, Sixth Edition 1971, Interim Supplement 19.5 on Instruments and Apparatus*, ASME PTC19.5-1972.
2. ASME Standard, *Measurement of Fluid Flow in Pipes using Orifice, Nozzle and Venturi*, ASME MFC-3M-1989.

APPENDIX B. REFERENCES (Informative)

B.1 REFERENCES, STANDARDS AND CODES-INFORMATIVE

Listed here are standards, handbooks and other publications which may provide useful information and background, but are not considered essential to the implementation of this standard. References in this section are not considered a part of this standard.

1. American National Standard, *Orifice Metering of Natural Gas*, ANSI/API 2530, First Edition
2. ANSI/ASME, *Measurement of Liquid Flow in Closed Conduits Using Transit-Time Ultrasonic Flow Meters*, ANSI/ASME MFC-5M-1985.
3. ASME, *Fluid Meters, their Theory and Application*, Sixth Edition 1971.
4. ASME, *Fluid Flow in Closed Conduits – Connections for Pressure Signal Transmissions Between Primary and Secondary Devices*, MFC-8M-1988.
5. ASME, *Glossary of Terms Used in the Measurement of Fluid Flow in Pipes*, MFC-1M-1991.
6. ASME, *Measurement of Fluid Flow in Closed Conduits by Means of Electromagnetic Flowmeters*, MFC-16M-1995.
7. ASME, *Measurement of Fluid Flow in Pipes Using Vortex Flow Meters*, MFC-6M-1987.
8. ASME, *Measurement Uncertainty for Fluid Flow in Closed Conduits*, MFC-2M-1983(R1988).
9. ASME, *Method for Establishing Installation Effects on Flowmeters*, MFC-10M-1994.
10. ASME, Power Test Codes, *Hydraulic Prime Movers*, PTC-18, 1949.
11. ASME, Power Test Codes, Instruments and Apparatus, Chapter 3, *Fluid Velocity Measurement, Part 5 - Measurement of Quantity of Materials*, PTC-19.5.3, 1965.
12. ASME, Power Test Codes, Instruments and Apparatus, Chapter 4 - *Flow Measurement of Quantity of Materials*, PTC-19.5-4, 1959.
13. ASME, Power Test Codes, *Atmospheric Water Cooling Equipment*, PTC-23-1986.
14. ASME, *Flow Meter Computational Handbook*, 1961.
15. ASME Transactions, Volume 61, Pages 465 to 476, 1939. *Pitot Tubes in Large Pipes*, Edward S. Cole and E. Shaw Cole.
16. ASME Transactions, August, 1935, *Pitot Tube Practice*, Edward S. Cole.
17. ASME Transactions, August, 1939, *Investigation of Errors of Pitot Tubes*, C.W. Hubbard.
18. CTI Bulletin TP-3A, Kent J. Bordelon, 1963.
19. CTI Bulletin FSP-156(00), 2000.
20. CTI Paper No. TP-183A, John P. Fath, 1978.
21. CTI Paper No. TP03-02, Mark S. Huber & Robert P. Miller, 2003.
22. *Flow Measurement Engineering Handbook*, R.W. Miller, McGraw-Hill Book Company, 1984.
23. ISA, *Flow, Its Measurement and Control in Science and Industry*, Volume 1, Parts 1, 2, and 3, 1974.
24. ISA, *Industrial Flow Measurement*, David W. Spitzer, First Printing, May, 1984.
25. ISO 2186:1973, *Flow in Closed Conduits – Connections for Pressure Signal Transmissions Between Primary and Secondary Elements*, International Organization for Standardization, Switzerland.