CALIBRATION OF:

8” ORIFICE
SERIAL NUMBER: 1023

FOR

BELL TECHNOLOGIES, LLC
PURCHASE ORDER NUMBER: 1006-REV 0
JANUARY 2020 - REPORT NO. 2201BEL001-R1

CERTIFIED BY

Philip Stacy

INTRODUCTION

Meters referenced within this report were calibrated at Alden Research Laboratory, Inc. (Alden). Alden's standard test procedures in QMSM-01 Revision 9 were used for testing. Flow meter performance is presented in both tabular and graphical format.

FLOW ELEMENT INSTALLATION

Each meter under test (MUT) was installed in one of the four test lines in the Allen High Reynolds Number Facility, which is shown in plan view in Figure 1. One or two 300 horsepower centrifugal pumps, which are used singularly or in parallel, provide a maximum head of about 130 feet at a flow of about 44 ft^3/second in Line 2. A separate pump provides a maximum head of about 300 feet at a flow of about 12 ft^3/s in Lines 3 and 4. Water is provided from a heated 180,000 gallon sump under the test floor. The Gravimetric Method was used to measure flow.

The detailed piping arrangement, immediately upstream and downstream of the flow element, including all significant fittings and pipe lengths, is shown in the included figures. Careful attention was given to align the flow element with the test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

TEST PROCEDURE

After checking the installation, water was introduced into the system to equalize line and primary element temperature to water temperature. The downstream control valve was then closed and vent valves in the test line were opened to remove air from the system.

Prior to the test run, the control valve was set to produce the desired flow, while the flow was directed to waste. Sufficient time was allowed to stabilize both the flow and the instrument readings, after which the weigh tank discharge valve was closed and the weigh tank scale indicator and the electric timer were both zeroed. To begin the test run, flow was diverted into the weigh tank, which automatically started the timer.

At the start of the water collection a computer based data acquisition system was activated to read the meter output, such that the meter output was averaged while the weigh tank was filling. At the end of the run, flow was diverted away from the weigh tank and the timer and data acquisition system were stopped to terminate the test run. The weight of water in the tank, elapsed time, water temperature, and average meter output were recorded on a data sheet. The data were entered into the computer to determine the flow and the results were plotted so that each test run was evaluated before the next run began. The control valve was then adjusted to the next flow and the procedure repeated.

FLOW MEASUREMENT METHOD

Flow was measured by the gravimetric method using a tank mounted on scales having capacities of 1,000, 10,000 and 100,000 pounds with resolution of 0.1, 0.2 and 1.0 pound, respectively. Alden's flow meter calibrations using the gravimetric flow measurement method comply with ASME/ANSI MFC-9M-1988 Measurement of Liquid Flow in Closed Conduits by Weighing Method. Water passing through the flow element was diverted into the tank with a hydraulically operated knife edge passing through a rectangular jet produced by a diverter head box. A Hewlett-Packard 10 MHz Frequency Counter with a resolution 0.001 sec was started upon flow diversion into the tank by an optical switch, which is positioned at the center of the jet. The timer was stopped upon flow diversion back to waste and the elapsed diversion time was recorded. An RTD thermometer measured water temperature to allow calculation of water density. Volumetric flow was calculated by Equation (1).

$$q_a = \frac{W}{T\rho_w B_c} \qquad (1)$$

where q_a = actual flow, ft^3/sec

W = mass of water collected, lb_m

T = time, sec

ρ_w = water density, lb_m/ft^3

B_c = buoyancy correction, $1-\rho_a/\rho_w$

The buoyancy correction includes air density calculated by perfect gas laws with the standard barometric pressure, a relative humidity of 75%, and measured air temperature. The weigh tank is periodically calibrated to full scale using 10,000 lbm of cast iron weights, whose calibration is traceable to NIST. Flow calculations are computerized to assure consistency. Weigh tank calibration data and water density as a function of temperature, are stored on disk file. Data were recorded manually and on disk file for later review and reporting.

DISCHARGE COEFFICIENT CALCULATIONS

If applicable, the MUT discharge coefficient, C, is defined by Equation (2) and plotted versus pipe or throat Reynolds number. Calculations of the discharge coefficient of differential producing flow meters are in accordance with ASME/ANSI MFC-3M-2004 Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi, and ASME 19.5-2004 Flow Measurement. The discharge coefficient relates the theoretical flow to the actual flow.

$$C = \frac{q_a}{q_{th}} = \frac{q_a}{F_a K_M \sqrt{\Delta h}} \quad (2)$$

where C = discharge coefficient, dimensionless

q_{th} = theoretical flow, ft^3/sec

F_a = thermal expansion factor, dimensionless

Δh = differential head, ft at line temperature

K_M = meter constant, $ft^{2.5}/sec$

The theoretical proportionality constant, K_M, between flow and square root of differential head is a function of the meter throat area, the ratio of throat to pipe diameter, and the local gravitational constant, as defined by Equation (3).

$$K_M = \frac{a_t \sqrt{2g_l}}{\sqrt{1-\beta^4}} \quad (3)$$

where a_t = throat area, $\pi d^2/4$, ft^2

d = throat diameter, ft

g_l = local gravitational constant, 32.1625 ft/sec^2 at Alden

β = ratio of throat to pipe diameter, d/D, dimensionless

D = pipe diameter, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number, the ratio of inertia to viscous forces. Pipe Reynolds number, R_D, or throat Reynolds number, R_d is determined by Equation (4).

$$R_D = \frac{q_a D}{a_p \gamma} \qquad \left(R_d = \frac{q_a d}{a_t \gamma}\right) \tag{4}$$

where a_p = pipe area, $\pi D^2/4$, ft^2, (throat area $a_t = \pi d^2/4$, ft^2)

γ = kinematic viscosity, ft^2/sec

HEAD LOSS CALCULATION

If applicable , to determine the unrecoverable head loss if the MUT, pairs of pressure taps were installed approximately two pipe diameters upstream and ten pipe diameters downstream of the flow meter. This gross head loss was measured during the determination of the discharge coefficient. Thereafter, the flow meter was removed from the test line and the head loss due to the pipe was measured over a similar range of flows to determine the unique coefficients of k_p and n in Equation 5 below.

$$k_p = \frac{\Delta H_{fric}}{{q_a}^n} \tag{5}$$

Where: k_p = friction loss coefficient, $ft^{5/2}/s$

ΔH_{fric} = pipe friction loss, feet

q_a = actual flow, ft^3/sec

n = Coefficient

Equivalent pipe losses were calculated by solving Equation 5 for pipe loss, ΔH_{fric}:

$$\Delta H_{fric} = k_p q_a{}^n \tag{6}$$

Pipe losses, characterized by Equation 6 were subtracted from the measured gross loss for the calculation of meter unrecoverable head loss as shown by Equation (7). The meter unrecoverable head loss is presented as a percent of the meter differential head.

$$\Delta H_{net\ meter} = \Delta H_{static} - \Delta H_{fric} \tag{7}$$

where: ΔH_{net} = meter unrecoverable head loss, feet

ΔH_{static} = measured static head difference, feet

FLOW METER SIGNAL RECORDING

The MUT indicated flow was recorded at the end of each weigh tank run. The method employed was according to the requirements of each meter and may include; gating the meter to totalize collected gallons, interrogating a mA output, totalized pulses, or manual reading of the MUT display. For MUT producing a differential pressure, the secondary element, which converts the primary element signal into engineering units, was one of several "Smart" differential pressure transmitters having a range of 250 inches of water column, 1,000 inches of water column and 100 psi. Each transmitter was calibrated with a pneumatic or a hydraulic dead weight tester having an accuracy of 0.02% of reading. Transmitter signals were recorded by a PC based data acquisition system having a 16 bit A to D board. Transmitter calibrations were conducted with the PC system such that an end to end calibration was achieved. Transmitter output was read simultaneously with the diversion of flow into the weigh tank at a rate of about 34 Hz for each test run (flow) and averaged to obtain a precise differential head. Average transmitter reading was converted to feet of flowing water using a linear regression analysis of the calibration data and line water temperatures to calculate appropriate specific weight.

TEST RESULTS

The results are presented in tabular and graphical format. The calculated flow, meter signal and meter performance are listed in the table(s) in the following pages.

Analysis indicates that the flow measurement uncertainty is within 0.25% of the true value for each test run. Calibrations of the test instrumentation (temperature, time, weight, and length measurements) are traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards) and Alden's Quality Assurance Program is designed to meet ANSI/NCSL Z540-1-1994 "Calibration Laboratories and Test Equipment-General Requirements" (supercedes MIL-STD-45662A).

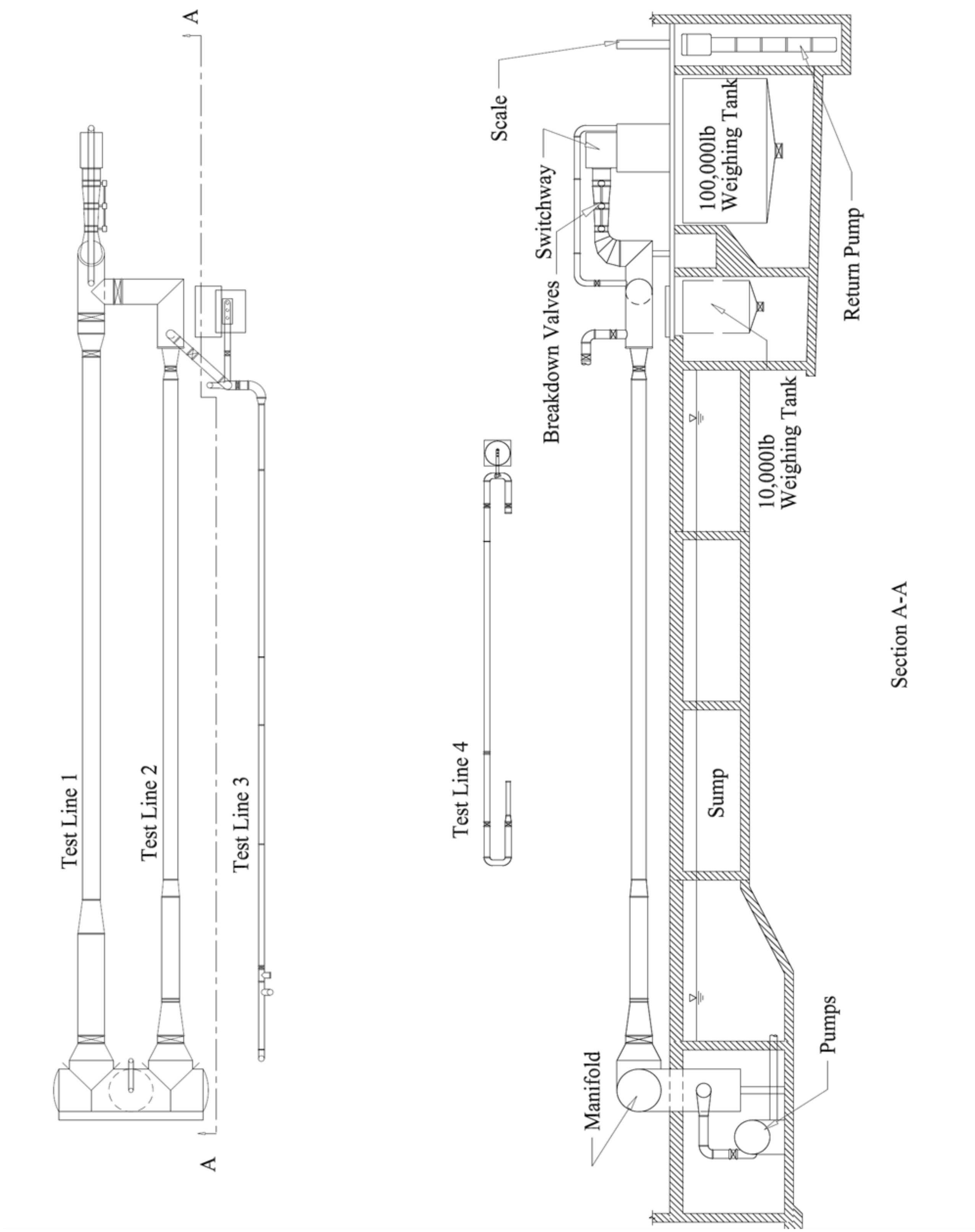

Figure 1
Allen High Reynolds Number Facility Test Lines 1, 2, 3 and 4

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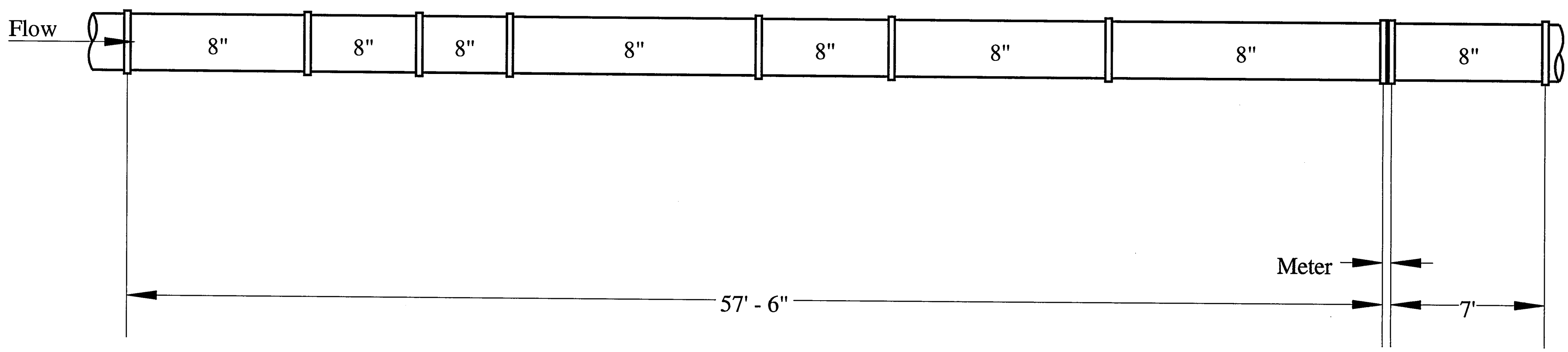
Plan View Allen facility Line 3



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CALIBRATION
DATE: January 8, 2020
PIPE DIAMETER = 7.9810
THROAT DIAMETER = 5.5872

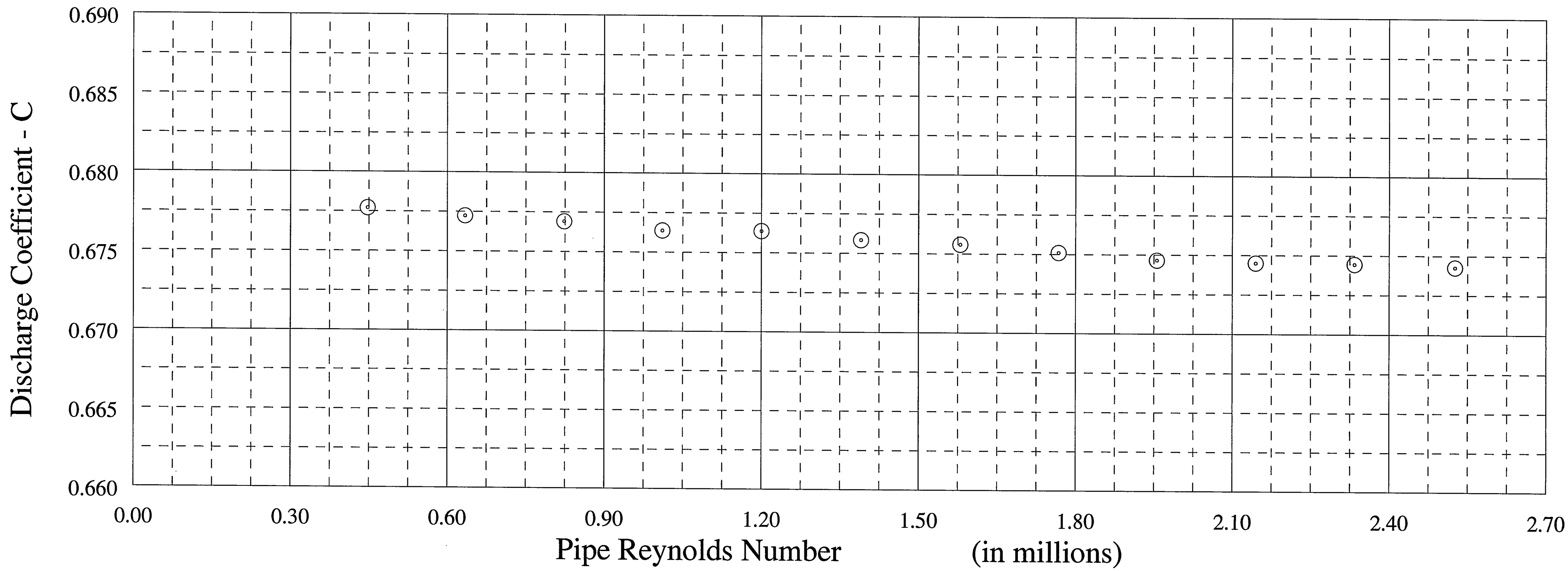
Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Output [see note]	Flow GPM	H Line FT H20	Pipe Rey. # x 10^6	Coef
1	107	73	63635	122.498	8.018~	3771.	63.151	2.3341	0.6744
2	107	73	59224	124.049	7.083~	3465.	53.331	2.1447	0.6745
3	107	72	63235	145.233	6.226~	3160.	44.335	1.9555	0.6747
4	107	72	48710	123.723	5.451~	2858.	36.201	1.7677	0.6751
5	107	72	47920	136.189	4.753~	2554.	28.876	1.5795	0.6756
6	107	73	44242	142.866	4.131~	2248.	22.349	1.3900	0.6758
7	107	72	32576	121.831	8.360~	1941.	16.636	1.1999	0.6764
8	107	72	27676	122.850	6.513~	1635.	11.809	1.0107	0.6764
9	107	73	22333	121.668	4.990~	1332.	7.827	0.8231	0.6769
10	107	73	21512	152.194	3.769~	1026.	4.637	0.6336	0.6772
11	107	73	20755	207.970	2.878~	724.4	2.308	0.4472	0.6777
12	107	73	69348	123.534	9.032~	4075.	73.790	2.5262	0.6743

~ dp transmitter volts

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST , following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CALIBRATED BY: DAV

CERTIFIED BY:



$$q_a = C F_a K_M \sqrt{\Delta h}$$

q_a =	Actual Flow (ft^3/sec)		
C =	Discharge Coefficient (Dimensionless)		
Δh =	Pressure Differential (Feet of Water at Run Temperature)		
K_M =	Meter Constant = $\dfrac{a\sqrt{2g}}{\sqrt{1 - \beta^4}}$	=	1.5666
F_a =	Average Thermal Expansion Factor	=	1.0007
a =	Throat Area (ft^2)	=	0.1703
g =	Local Acceleration of Gravity (ft/sec^2)	=	32.1625
ß =	Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.7001
	Pipe Diameter (Inches)	=	7.9810
	Throat Diameter (Inches)	=	5.5872

Dimensions By: BELL TECHNOLOGIES, LLC

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THERMAL EXPANSION FACTOR

The dimensions of a differential producing flow meter are affected by the operating temperature, requiring a Thermal Expansion Factor (F_a) to be included in the calculations. The calculation requires the temperature at which the meter dimensions were measured be known. If this information is not available, an ambient temperature of 68˚ F is assumed. The Thermal Expansion Factor is calculated according to the American Society of Mechanical Engineers Standard ASME MFC-3M-1989, Equation 17 (pg 11).

$$F_a = 1 + \frac{2}{1-\beta^4}\left(\alpha_{PE} - \beta^4{}_{meas} \propto_p\right)(t - t_{meas})$$

where	β	=	ratio of throat diameter to pipe diameter, dimensionless
	α_{PE}	=	thermal expansion factor of primary element, (in./in./°F)
	$\propto_p$	=	thermal expansion factor of pipe, (in./in./°F)
	t	=	temperature of flowing fluid, ˚F
	t_{meas}	=	temperature of measurements, ˚F

Thermal expansion factors, α, excerpted from MFC-3M-1989, are listed in the Table below for six typically used materials at three temperatures. Linear interpolation is used to determine the coefficients at flowing temperature.

Mean Coefficient of Thermal Expansion = $\frac{A}{10^6}$ (in./in./°F)

Material	Coef.	-50 ˚F	70 ˚F	200 ˚F
Bronze 4-10	A	9.15	9.57	10.03
300 Series Stainless Steel	A	8.90	9.11	9.34
Monel	A	7.15	7.48	7.84
.2 to 1.1% C Steel	A	5.80	6.07	6.38
5% Chrome Moly	A	5.45	5.73	6.04
410 to 430 Stainless Steel	A	5.00	5.24	5.50

WATER DENSITY*

Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3	Temperature Fahrenheit	Density lb_m / ft^3
32	62.4179	62	62.3549	92	62.0903
33	62.4201	63	62.3489	93	62.0788
34	62.4220	64	62.3427	94	62.0671
35	62.4235	65	62.3363	95	62.0552
36	62.4246	66	62.3296	96	62.0432
37	62.4255	67	62.3228	97	62.0311
38	62.4260	68	62.3157	98	62.0188
39	62.4262	69	62.3084	99	62.0063
40	62.4261	70	62.3010	100	61.9937
41	62.4257	71	62.2933	101	61.9810
42	62.4250	72	62.2855	102	61.9681
43	62.4240	73	62.2774	103	61.9551
44	62.4227	74	62.2692	104	61.9419
45	62.4211	75	62.2608	105	61.9286
46	62.4193	76	62.2522	106	61.9151
47	62.4171	77	62.2434	107	61.9015
48	62.4147	78	62.2344	108	61.8878
49	62.4121	79	62.2252	109	61.8739
50	62.4092	80	62.2159	110	61.8599
51	62.4060	81	62.2063	111	61.8458
52	62.4025	82	62.1966	112	61.8315
53	62.3988	83	62.1868	113	61.8172
54	62.3949	84	62.1767	114	61.8027
55	62.3907	85	62.1665	115	61.7880
56	62.3863	86	62.1561	116	61.7733
57	62.3816	87	62.1456	117	61.7584
58	62.3768	88	62.1348	118	61.7434
59	62.3716	89	62.1239	119	61.7284
60	62.3663	90	62.1129	120	61.7132
61	62.3607	91	62.1017	121	61.6978

* Distilled water values used in all calculation