Reference Manual
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Wet Gas Flow Measurement with Conditioning Orifice Meter Flow Test Data Book and Flow Handbook

ROSEMOUNT®

EMERSON™
Process Management

www.rosemount.com

405C and 1595

Wet Gas Flow Measurement with Conditioning Orifice Meter Flow Test Data Book and Flow Handbook

NOTICE

Read this manual before working with the product. For personal and system safety, and for optimum product performance, make sure to thoroughly understand the contents before installing, using, or maintaining this product.

Customer Central
1-800-999-9307 (7:00 a.m. to 7:00 P.M. CST)

National Response Center
1-800-654-7768 (24 hours a day)
Equipment service needs

International
1-(952) 906-8888

⚠CAUTION

The products described in this document are NOT designed for nuclear-qualified applications.

Using non-nuclear qualified products in applications that require nuclear-qualified hardware or products may cause inaccurate readings.

For information on Rosemount nuclear-qualified products, contact an Emerson Process Management Sales Representative.

CE Emerson Process Management satisfies all obligations coming from legislation to harmonize product requirements in the European Union

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Section 1 405C Compact Conditioning Orifice Meter and 1595 Conditioning Orifice Plate

PRODUCT FEATURES

The Rosemount 405C Compact Conditioning Orifice Meter and 1595 Conditioning Orifice Plate primary flow elements maintain the traditional strengths of orifice plate technology with improved features / performance.

The strengths of the 405C include:

- More Economical than a Traditional Orifice Plate Installation
- Accurate and Repeatable
- Short Straight Run Requirements
- Self Centering Mechanism
- Based on ASME/ISO Corner Tap Design

The strengths of the 1595 include:

- Based on the most common primary element in the world with established standards for manufacture and installation.
- Easy to use, prove, and troubleshoot
- Accurate and Repeatable
- Short Straight Run Requirements
- Based on ASME/ISO/AGA standards

The Rosemount 405C and 1595 primary flow elements are sized using Rosemount's Instrument Toolkit sizing program. This program provides accurate flow calculations using installation details and fluid properties for the flowmeter and presents this on a calculation data sheet or specification sheet.

TESTING

Tests performed on the 405C / 1595 primary flow elements are divided into two major categories:

- Mechanical and structural testing
- Independent laboratory testing

All categories are on going and continue to be a part of the current Rosemount test program for the 405C / 1595 primary flow elements.

Structural Testing

Rosemount performed integrity testing for:

- Allowable stress limits
- Hydrostatic Pressure
- Thermal Effects
- Vibration

At the following labs:

- Hauser Laboratories, Boulder, CO
- Rosemount Vibration Laboratory, Eden Prairie, MN

Independent Testing

Rosemount 405C and 1595 primary flow element models were tested in wet gas conditions at the following independent laboratories:

- Colorado Engineering Experiment Station, Inc. (CEESI)

Certified flow-data sheets were supplied from each of these facilities. Representative samples of tests conducted at the independent laboratories are in Section 3: Test Facilities and Flow Tests.

PRODUCT SPECIFICATIONS

The above testing has enabled Rosemount to provide product which conforms to the following specifications in wet gas applications. See Appendix A for graphical representations of how well the curve fit matched the actual data.

TABLE 1. Rosemount 405C Compact Conditioning Orifice

Beta Ratio	Discharge Coefficient Uncertainty
β = 0.40	±-2.0%
β = 0.65	±-3.0%

TABLE 2. Rosemount 1595 Conditioning Orifice

Beta Ratio	Discharge Coefficient Uncertainty
β = 0.40	±-2.0%
β = 0.65	±-3.0%

Section 2 Theory of Operation

OVERVIEW

The Rosemount 405C and 1595, based on orifice plate technology, is a device used to measure the flow of a liquid, gas, or steam fluid that flows through a pipe. It enables flow measurement by creating a differential pressure (DP) that is proportional to the square of the velocity of the fluid in the pipe, in accordance with Bernoulli's theorem. This DP is measured and converted into a flow rate using a secondary device, such as a DP pressure transmitter.

The flow is related to DP through the following relationship.

Equation 1

$$Q = K\sqrt{DP}$$

where:
Q = Flow rate
K = Units conversion factor, discharge coefficient, and other factors
DP = Differential pressure

For a more complete discussion on the flow equation, refer to Section 4: Flow Calculations.

TECHNICAL DETAIL

As stated previously, traditional orifice plate flowmeters are based on Bernoulli's theorem, which states that along any one streamline in a moving fluid, the total energy per unit mass is constant, being made up of the potential energy (the pressure energy), and the kinetic energy of the fluid. Where:

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2$$

where:
P_1 = Upstream pressure
P_2 = Downstream pressure
p = Density
V_1 = Upstream velocity
V_2 = Downstream velocity

When fluid passes through the orifice the velocity of the fluid through the orifice increases. This increase in fluid velocity causes the kinetic energy of the fluid immediately downstream of the orifice plate to increase, while simultaneously decreasing the static pressure energy of the fluid at that same point. By sensing the static pressure on the upstream and downstream sides of the orifice plate, the fluid velocity can be determined.

Some assumptions were made in deriving the theoretical equation, which in practice are not valid: a) Energy is conserved in the flow stream. b) Pressure taps are at ideal locations. c) Velocity profile is flat. These items are corrected by the discharge coefficient. Which is derived from experimental data and is different for each primary element.

$$\text{Discharge Coefficient } C = \frac{\textit{Actual Flow}}{\textit{Theoretical Flow}}$$

CONDITIONING ORIFICE METER TECHNOLOGY

The Rosemount 405C and 1595 Conditioning Orifice Plate has the added advantage of being able to operate with reduced straight run requirements. With its multiple orifices in the flow stream it is much less susceptible to velocity profile distortion, swirl, and secondary flows. If the velocity profile is skewed, each of the orifices will conduct a part of the total fluid flow within the pipe. According to Bernoulli's theorem, the velocity of the fluid through each of the orifices will increase. The fluid pressure on the downstream side of the conditioning plate that is attributable to each of the separate orifices will be averaged within the fluid to provide an average downstream pressure. The average downstream pressure is compared with the upstream pressure to provide an average differential pressure for whatever velocity profile is presented to the multiple orifice plate, resulting in an accurate measurement of the rate of fluid flow in the pipe.

As mentioned in an earlier section, every 405C and 1595 is flow calibrated as part of the manufacturing process. The purpose of this calibration is to determine a calibration factor which is applied to the flow calculations as an adjustment to correct for bias error from the ISO-5167 discharge coefficient equations. This results in an accurate flowmeter which conforms to the ISO-5167 equations.

Section 3 Test Facilities and Flow Tests

OVERVIEW

The following descriptions of tests and testing methods are abbreviated versions. For detailed descriptions of the individual laboratories contact the facility in question.

TESTING LABORATORIES

CEESI, Colorado

Colorado Engineering Experiment Station, Inc. (CEESI) in Nunn, Colorado has a multi phase flow test facility using natural gas and hydrocarbon liquids. The facility accommodates line sizes from 2 to 8 inch at a max pressure of 1440 Psi. The facility operates at temperatures ranging from ambient to 122°F. See Appendix A for a diagram of CEESI facility.

Lean natural gas is brought into the CEESI complex at a low pressure of near 0.3 Mpa (50 psi). A charging compressor is used to pressurize the test loop to the desired operating pressure for the test being conducted. The normal operating pressure range is between 0.7 to 9.9 Mpa (100 to 1440 psi). Once the loop is pressurized, any combination of the four positive displacement compressors can be used to circulate the natural gas around the test loop at the desired velocity. Both a turbine meter and a subsonic venturi measure the mass flow rate of the natural gas. The difference in mass flow rate between these two meters is monitored; and if the difference exceeds a specified amount, the data is scrutinized for detrimental effects such as pulsation. If the difference is within tolerance, then all other meters installed in the test loop can be compared to the natural gas mass flow rate as measured by the turbine meter.

The hydrocarbon liquid, which resides in the liquid storage vessel, can be injected into the gas stream by positive displacement pumps (triplex pumps). Coriolis meters measure the liquid mass flow rate and the density of the injected liquid. The gas stream carries the liquid through the meter test locations to the horizontal separator where it is then returned to the liquid storage vessel. Coriolis meters again measure the mass flow rate and the density of the returned liquid. When the injected liquid mass flow rate is equal to the return liquid mass flow rate and all pressures and temperatures within the loop are constant with time; the system is at a steady state condition and test data can be acquired.

FLOW TESTS

A summary of the tests provided on the following pages: (See Section 4 for descriptions of terminology and calculation methods used)

Figure 3-1.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/12/04

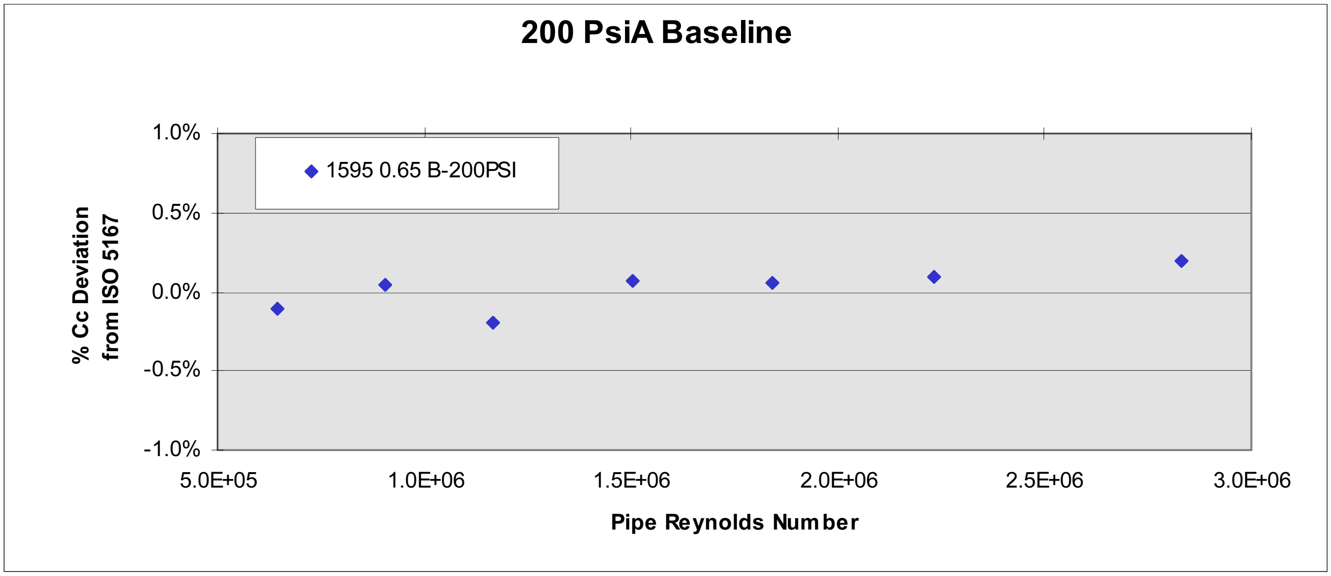


Figure 3-2.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/14/04

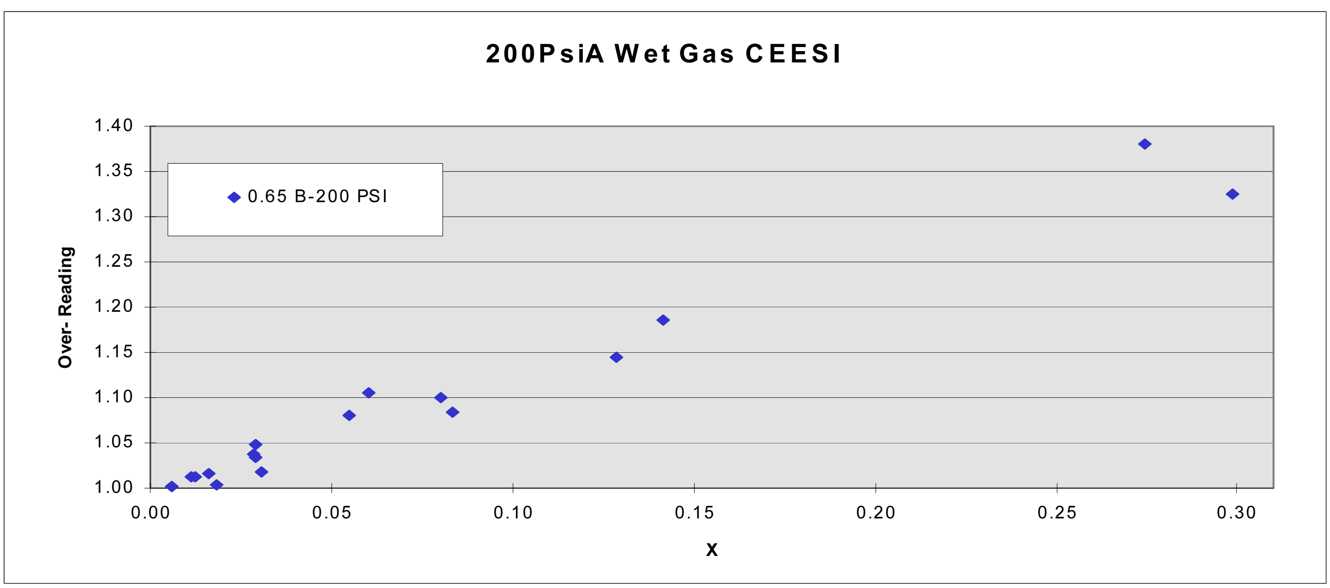


Table 3-1. 3" Rosemount 1595 0.65 Beta 200PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH$_2$0	lb/sec	Gas	C_c	C_d	%
1	73.6	23.1	235.3	16.2	0.0111	0.7996	341.651	4.2332	2,831,911	0.6047	0.6059	0.191
2	76.6	24.8	229.8	15.8	0.0111	0.7752	216.496	3.3430	2,232,940	0.6055	0.6061	0.095
3	78.1	25.6	227.7	15.7	0.0111	0.7654	147.801	2.7563	1,839,350	0.6060	0.6063	0.061
4	80.0	26.6	226.1	15.6	0.0111	0.7567	99.578	2.2559	1,503,546	0.6062	0.6066	0.071
5	80.2	26.8	225.0	15.5	0.0111	0.7527	59.566	1.7493	1,165,868	0.6081	0.6070	-0.192
6	80.1	26.7	223.6	15.4	0.0111	0.7479	36.180	1.3583	905,451	0.6071	0.6073	0.044
7	78.9	26.1	222.1	15.3	0.0111	0.7447	18.205	0.9648	643,829	0.6086	0.6079	-0.110

Table 3-2. 3" Rosemount 1595 0.65 Beta 200PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH$_2$0	lb/ft^3		lb/sec	lb/sec	Gas	C_d	X	%
1	70.7	21.5	219.1	15.1	0.0110	333.087	0.7344	46.0517	3.6243	1.7346	2,433,962	0.539	0.060	1.105
2	77.6	25.3	218.5	15.1	0.0111	312.433	0.7218	45.8610	3.6757	0.8496	2,456,430	0.569	0.029	1.047
3	83.0	28.4	218.3	15.0	0.0111	301.252	0.7128	45.7118	3.7110	0.3336	2,469,437	0.589	0.011	1.013
4	85.9	29.9	218.6	15.1	0.0112	297.782	0.7097	45.6324	3.7203	0.1762	2,469,592	0.595	0.006	1.003
5	86.4	30.2	218.4	15.1	0.0112	295.023	0.7085	45.6183	3.7352	0.0418	2,478,384	0.600	0.001	0.993
6	75.9	24.4	213.9	14.7	0.0111	156.427	0.7086	45.9172	2.5253	1.1183	1,690,692	0.553	0.055	1.080
7	78.4	25.8	213.0	14.7	0.0111	147.892	0.7020	45.8490	2.5455	0.5834	1,701,137	0.576	0.028	1.037
8	80.6	27.0	211.8	14.6	0.0111	132.986	0.6948	45.7915	2.4602	0.2514	1,641,548	0.589	0.013	1.013
9	81.6	27.5	211.7	14.6	0.0111	131.023	0.6930	45.7630	2.4681	0.1173	1,645,483	0.596	0.006	1.001
10	82.9	28.3	211.6	14.6	0.0111	131.203	0.6906	45.7270	2.4852	0.0263	1,655,136	0.601	0.001	0.993
11	74.6	23.6	212.3	14.6	0.0111	118.840	0.7053	45.9568	1.7247	3.8203	1,155,970	0.433	0.274	1.380
12	78.7	25.9	209.5	14.4	0.0111	82.033	0.6898	45.8481	1.6529	1.9085	1,104,828	0.505	0.142	1.186
13	80.5	26.9	209.3	14.4	0.0111	70.473	0.6865	45.7973	1.6476	1.0801	1,099,688	0.544	0.080	1.101
14	82.4	28.0	208.4	14.4	0.0111	61.381	0.6808	45.7452	1.6301	0.3862	1,086,450	0.578	0.029	1.034
15	84.8	29.4	208.4	14.4	0.0111	56.448	0.6775	45.6785	1.5871	0.2091	1,055,657	0.589	0.016	1.017
16	77.8	25.4	208.0	14.3	0.0111	28.593	0.6865	45.8749	0.8752	2.1386	585,501	0.452	0.299	1.325
17	79.8	26.6	207.5	14.3	0.0111	21.466	0.6817	45.8192	0.8758	0.9223	584,958	0.524	0.128	1.144
18	81.2	27.3	207.0	14.3	0.0111	19.366	0.6781	45.7822	0.8760	0.5997	584,499	0.553	0.083	1.084
19	81.5	27.5	206.6	14.2	0.0111	17.194	0.6763	45.7742	0.8775	0.2208	585,368	0.589	0.031	1.018
20	81.8	27.7	206.5	14.2	0.0111	16.763	0.6756	45.7661	0.8780	0.1327	585,564	0.597	0.018	1.004

Figure 3-3.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/21/04

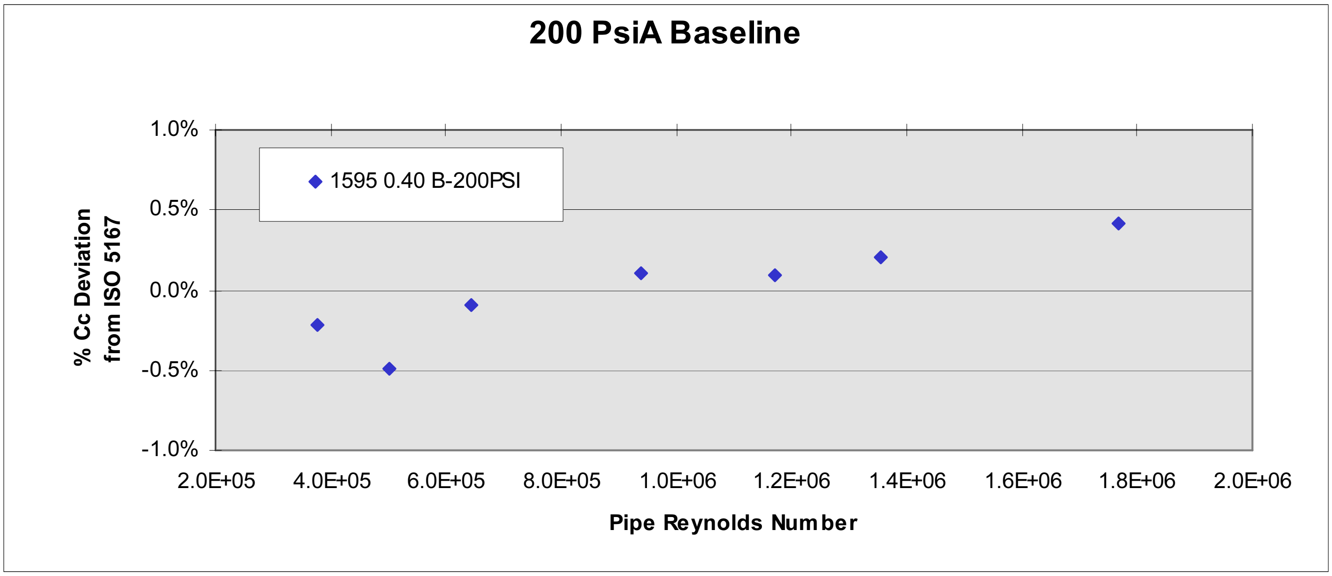


Figure 3-4.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/21/04

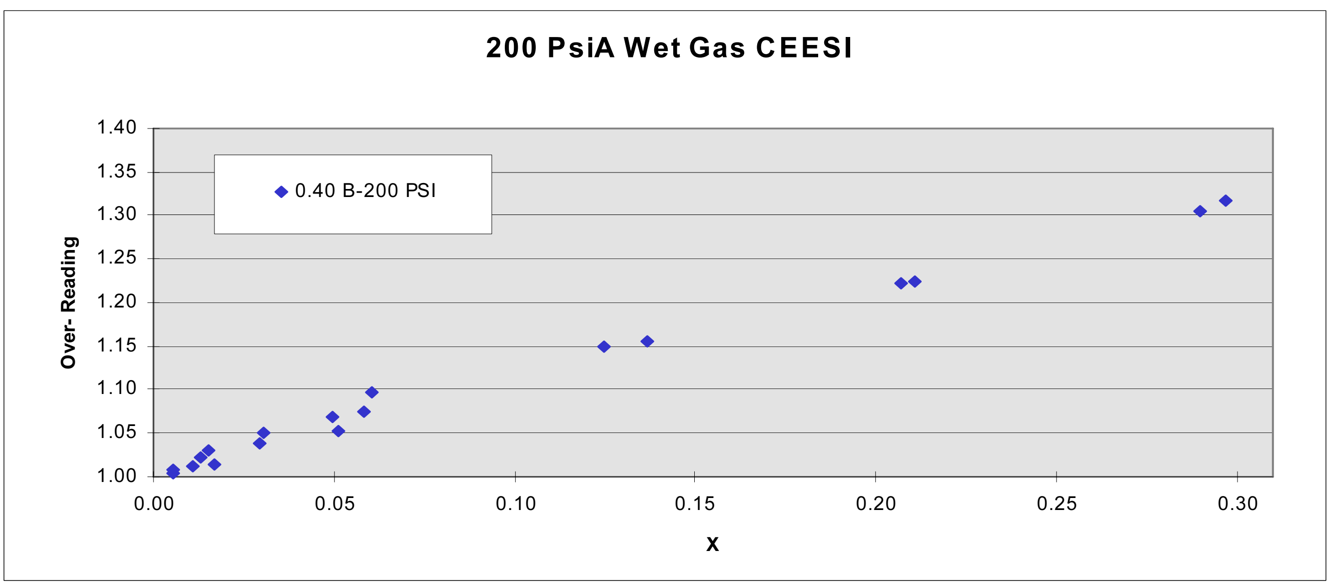


Table 3-3. 3” Rosemount 1595 0.40 Beta 200PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH$_2$0	lb/sec	Gas	C_c	C_d	%
1	69.1	20.6	256.0	16.2	0.0111	0.8831	1041.026	2.6394	1,766,747	0.5974	0.5999	0.412
2	68.1	20.1	233.6	15.8	0.0110	0.8042	647.578	2.0177	1,355,021	0.5987	0.6000	0.204
3	68.7	20.4	223.8	15.7	0.0110	0.7681	499.329	1.7433	1,171,610	0.5995	0.6000	0.088
4	70.2	21.2	214.3	15.6	0.0110	0.7322	332.108	1.3977	939,423	0.5995	0.6001	0.103
5	69.5	20.9	204.7	15.5	0.0110	0.6992	159.701	0.9567	643,936	0.6009	0.6003	-0.096
6	68.0	20.0	201.2	15.4	0.0110	0.6888	96.944	0.7451	502,227	0.6034	0.6004	-0.491
7	66.4	19.1	197.6	15.3	0.0110	0.6785	55.653	0.5601	378,028	0.6019	0.6006	-0.218

Table 3-4. 3" Rosemount 1595 0.40 Beta 200PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH$_2$0	lb/ft^3		lb/sec	lb/sec	Gas	C_d	X	%
1	66.6	19.2	277.4	19.1	0.0111	1300.693	0.9834	46.0522	2.8164	1.1656	1,883,085	0.543	0.060	1.098
2	69.9	21.1	270.7	18.7	0.0111	1208.647	0.9514	45.9757	2.7986	0.5959	1,868,821	0.568	0.031	1.050
3	72.0	22.2	266.4	18.4	0.0111	1126.780	0.9313	45.9275	2.7556	0.2519	1,838,565	0.584	0.013	1.021
4	72.2	22.3	265.2	18.3	0.0111	1112.637	0.9267	45.9254	2.7705	0.1076	1,848,561	0.592	0.006	1.007
5	72.3	22.4	261.5	18.0	0.0111	1064.019	0.9128	45.9301	2.7175	0.0218	1,813,923	0.597	0.001	0.998
6	63.3	17.4	234.6	16.2	0.0110	607.365	0.8306	46.2251	1.8504	0.8023	1,246,124	0.556	0.058	1.076
7	65.2	18.4	231.5	16.0	0.0110	565.211	0.8157	46.1787	1.8366	0.4098	1,235,897	0.576	0.030	1.038
8	65.4	18.5	228.6	15.8	0.0110	527.198	0.8046	46.1795	1.8094	0.1510	1,217,900	0.591	0.011	1.012
9	65.1	18.4	227.8	15.7	0.0110	520.606	0.8023	46.1896	1.8110	0.0739	1,219,256	0.596	0.005	1.003
10	64.6	18.1	227.2	15.7	0.0110	517.339	0.8011	46.2046	1.8122	0.0166	1,220,538	0.599	0.001	0.999
11	56.9	13.8	212.2	14.6	0.0110	302.138	0.7579	46.4453	1.0331	2.4024	699,835	0.455	0.297	1.318
12	60.2	15.7	209.8	14.5	0.0110	272.074	0.7432	46.3588	1.0480	1.7124	708,942	0.491	0.207	1.222
13	63.2	17.3	207.5	14.3	0.0110	234.292	0.7301	46.2813	1.0225	1.1113	690,688	0.520	0.137	1.155
14	66.8	19.3	204.9	14.1	0.0110	197.941	0.7151	46.1863	1.0216	0.4187	688,801	0.570	0.051	1.053
15	69.9	21.0	204.1	14.1	0.0110	188.402	0.7075	46.1014	1.0306	0.1385	693,555	0.592	0.017	1.013
16	57.1	13.9	201.2	13.9	0.0109	101.620	0.7162	46.4631	0.5954	1.3905	403,737	0.461	0.290	1.304
17	57.3	14.1	200.2	13.8	0.0109	90.285	0.7119	46.4583	0.5964	1.0169	404,432	0.491	0.211	1.224
18	59.1	15.0	199.3	13.7	0.0109	78.676	0.7059	46.4111	0.5906	0.5987	400,201	0.523	0.125	1.150
19	61.0	16.1	198.6	13.7	0.0109	69.082	0.7004	46.3595	0.5939	0.2394	402,066	0.563	0.050	1.068
20	63.0	17.2	198.3	13.7	0.0110	64.862	0.6961	46.3045	0.5948	0.0734	402,258	0.584	0.015	1.030

Figure 3-5.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/15/04

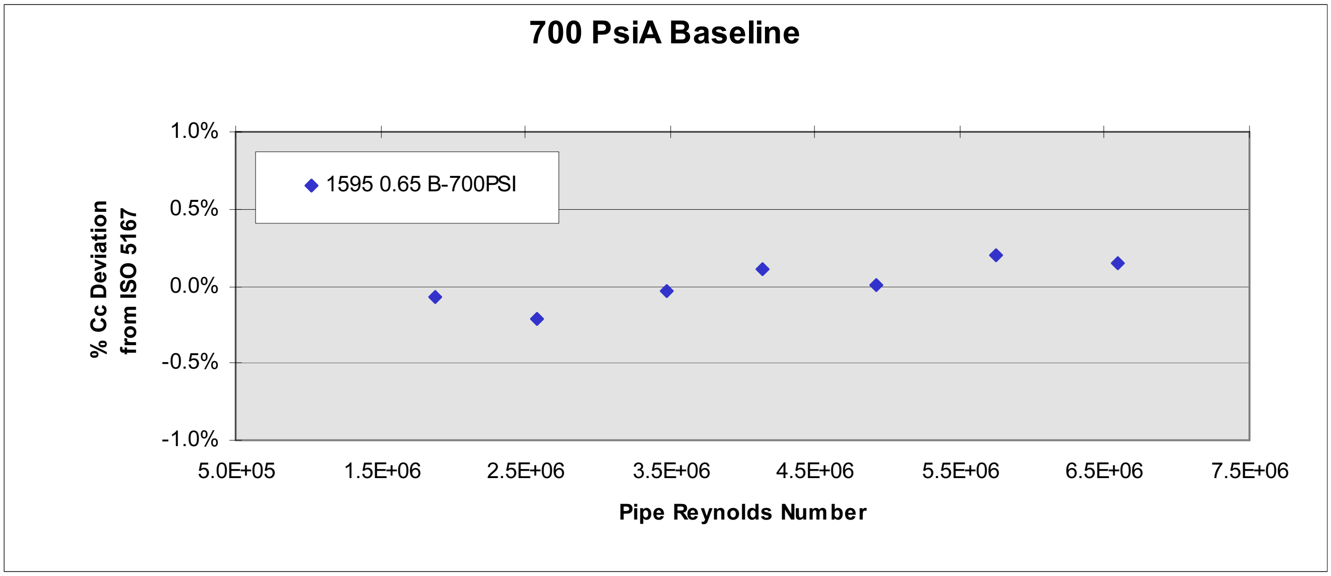


Figure 3-6.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/19/04

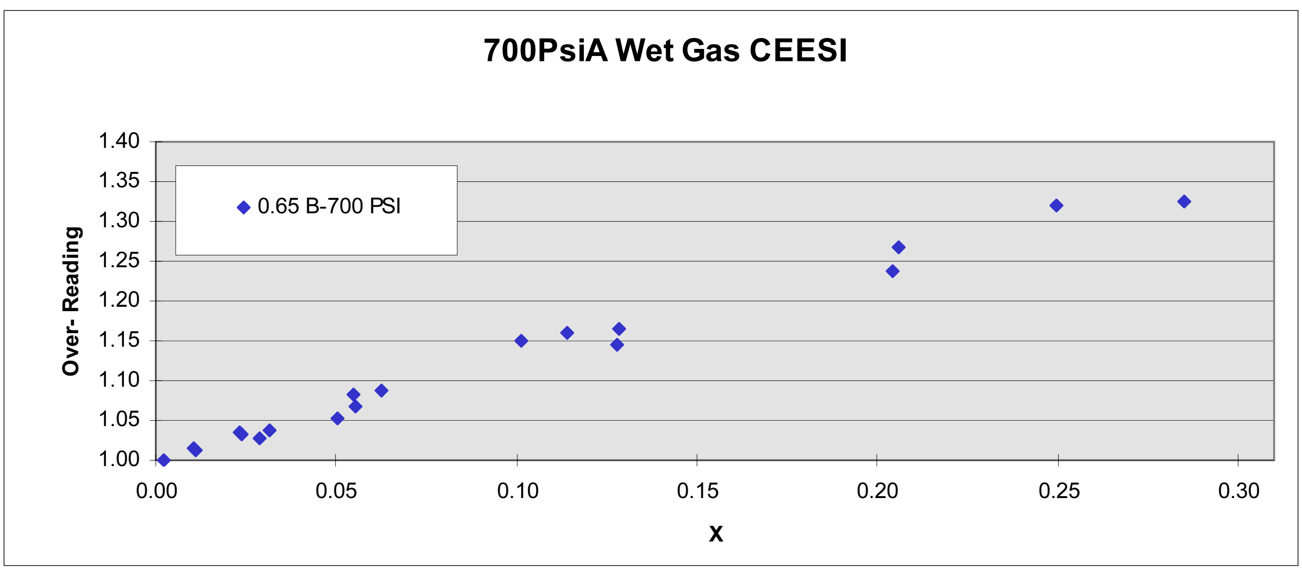


Table 3-5. 3" Rosemount 1595 0.65 Beta 700PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft³	inH20	lb/sec	Gas	C_c	C_d	%
1	84.1	28.9	710.9	49.0	0.0122	2.4871	713.649	10.8476	6,596,205	0.6042	0.6051	0.148
2	85.2	29.5	706.5	48.7	0.0122	2.4632	545.520	9.4613	5,754,535	0.6040	0.6052	0.201
3	85.3	29.6	702.6	48.4	0.0122	2.4472	398.461	8.0966	4,928,799	0.6053	0.6053	0.010
4	85.1	29.5	698.6	48.2	0.0122	2.4332	281.653	6.7956	4,141,419	0.6048	0.6055	0.114
5	83.3	28.5	691.0	47.6	0.0121	2.4151	198.013	5.6946	3,481,690	0.6059	0.6056	-0.035
6	79.2	26.2	684.7	47.2	0.0121	2.4173	107.248	4.2090	2,585,171	0.6073	0.6060	-0.214
7	76.8	24.9	679.4	46.8	0.0120	2.4117	56.303	3.0464	1,876,532	0.6068	0.6063	-0.074

Table 3-6. 3" Rosemount 1595 0.65 Beta 700PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH20	lb/ft³		lb/sec	lb/sec	Gas	C_d	X	%
1	74.7	23.7	739.4	51.0	0.0122	990.260	2.6451	45.0028	11.4156	4.7571	6,938,589	0.518	0.101	1.150
2	77.6	25.4	735.3	50.7	0.0122	858.095	2.6071	44.9504	11.2203	2.5464	6,813,684	0.550	0.055	1.083
3	79.3	26.3	734.2	50.6	0.0122	796.699	2.5911	44.9188	11.3023	1.0862	6,857,482	0.576	0.023	1.034
4	80.2	26.8	733.6	50.6	0.0122	770.867	2.5821	44.9009	11.3092	0.5044	6,858,156	0.587	0.011	1.015
5	81.4	27.4	733.7	50.6	0.0122	754.264	2.5744	44.8763	11.3400	0.0987	6,870,587	0.595	0.002	1.000
6	76.5	24.7	725.1	50.0	0.0122	567.829	2.5766	44.9922	8.5192	4.0513	5,190,748	0.514	0.114	1.159
7	78.3	25.7	722.2	49.8	0.0122	499.554	2.5519	44.9598	8.4844	2.2293	5,166,940	0.548	0.063	1.088
8	78.9	26.0	719.2	49.6	0.0122	433.853	2.5364	44.9534	8.3172	0.8369	5,066,832	0.577	0.024	1.032
9	79.0	26.1	718.1	49.5	0.0122	421.934	2.5313	44.9526	8.3552	0.3969	5,090,871	0.588	0.011	1.013
10	79.6	26.4	717.6	49.5	0.0122	415.896	2.5253	44.9419	8.4114	0.0762	5,123,738	0.597	0.002	0.997
11	73.7	23.2	711.4	49.1	0.0121	359.356	2.5396	45.0730	5.9442	6.2517	3,640,777	0.452	0.250	1.320
12	73.7	23.2	707.7	48.8	0.0121	314.990	2.5251	45.0810	5.7871	5.0418	3,547,999	0.471	0.206	1.267
13	72.9	22.7	703.8	48.5	0.0121	275.001	2.5150	45.1049	5.8765	3.1939	3,608,197	0.513	0.128	1.164
14	72.5	22.5	700.6	48.3	0.0121	226.868	2.5048	45.1177	5.8128	1.3685	3,572,631	0.559	0.055	1.067
15	73.2	22.9	699.5	48.2	0.0121	216.408	2.4958	45.1055	5.8298	0.7773	3,582,438	0.575	0.031	1.038
16	71.0	21.7	691.8	47.7	0.0120	104.499	2.4795	45.1662	3.1719	3.8566	1,955,553	0.451	0.285	1.326
17	71.6	22.0	690.7	47.6	0.0120	92.661	2.4710	45.1561	3.1971	2.7895	1,970,954	0.484	0.204	1.237
18	71.6	22.0	689.8	47.6	0.0120	80.828	2.4674	45.1574	3.2240	1.7635	1,987,913	0.522	0.128	1.145
19	71.8	22.1	689.1	47.5	0.0120	69.534	2.4630	45.1536	3.2538	0.7037	2,006,373	0.569	0.051	1.051
20	71.6	22.0	688.4	47.5	0.0120	65.147	2.4614	45.1592	3.2244	0.4014	1,988,849	0.583	0.029	1.027

Figure 3-7.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/20/04

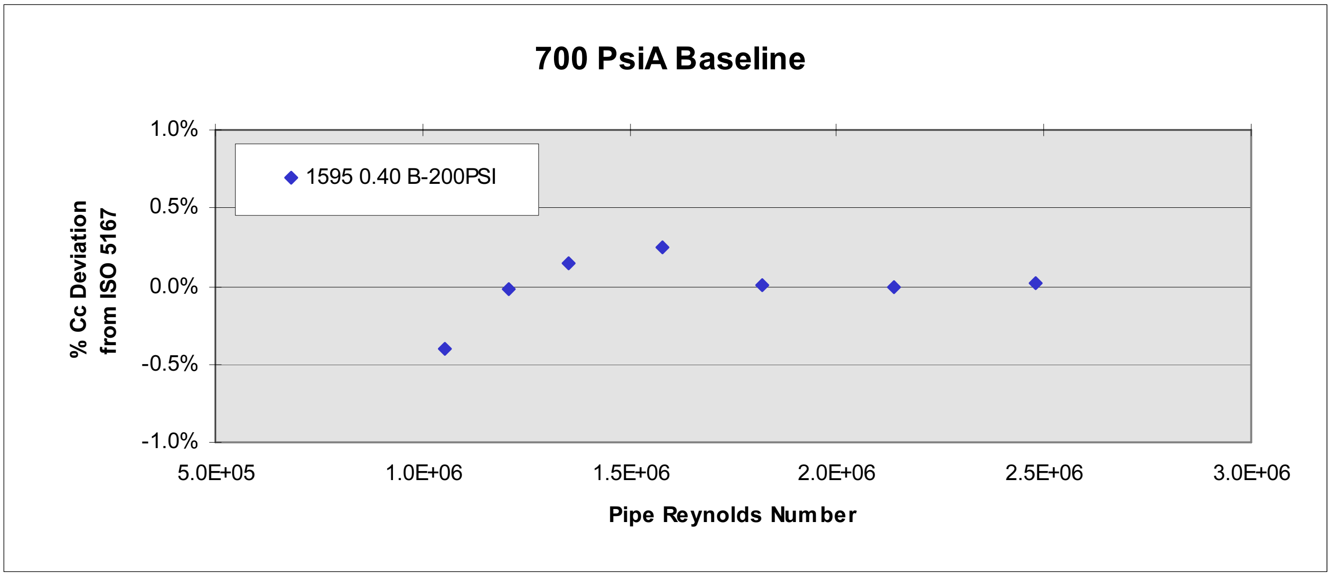


Figure 3-8.

Test Laboratory: CEESI, Colorado	
Model: 1595	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/20/04

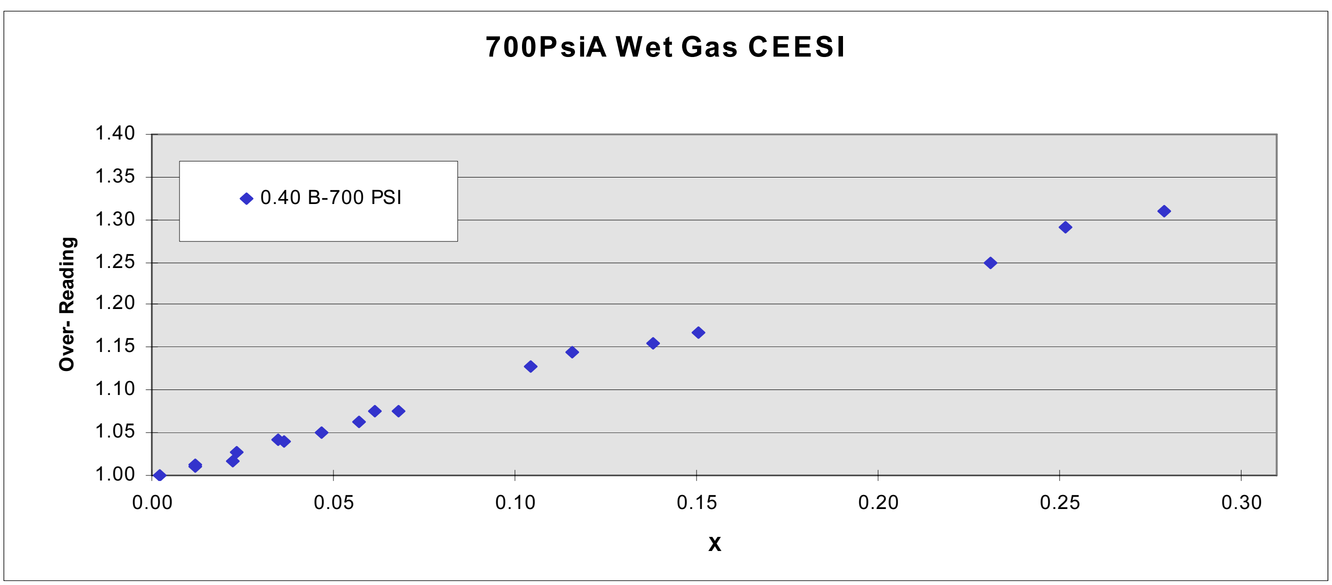


Table 3-7. 3" Rosemount 1595 0.40 Beta 700PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH_20	lb/sec	Gas	C_c	C_d	%
1	76.8	24.9	740.6	51.1	0.0122	2.6310	776.945	4.0827	2,477,386	0.5996	0.5998	0.024
2	77.3	25.2	730.2	50.3	0.0122	2.5862	582.730	3.5156	2,138,105	0.5998	0.5998	-0.003
3	77.2	25.1	723.6	49.9	0.0122	2.5608	423.540	2.9886	1,820,766	0.5998	0.5999	0.009
4	76.8	24.9	716.2	49.4	0.0121	2.5344	321.574	2.5882	1,580,148	0.5984	0.5999	0.251
5	74.9	23.8	710.4	49.0	0.0121	2.5247	233.402	2.2060	1,350,469	0.5991	0.6000	0.144
6	73.8	23.2	707.2	48.8	0.0121	2.5197	185.544	1.9696	1,207,598	0.6001	0.6000	-0.023
7	73.7	23.2	705.6	48.6	0.0121	2.5136	140.726	1.7210	1,055,644	0.6025	0.6001	-0.402

Table 3-8. 3" Rosemount 1595 0.40 Beta 700PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH_20	lb/ft^3		lb/sec	lb/sec	Gas	C_d	X	%
1	69.5	20.9	764.2	52.7	0.0122	1291.446	2.7828	45.0607	4.7198	1.9817	2,859,708	0.526	0.104	1.128
2	72.2	22.3	760.4	52.4	0.0122	1205.072	2.7462	45.0149	4.8526	0.9228	2,938,396	0.563	0.047	1.050
3	73.1	22.8	758.4	52.3	0.0122	1162.222	2.7307	45.0005	4.9070	0.4443	2,971,220	0.581	0.022	1.016
4	74.3	23.5	747.8	51.6	0.0122	947.886	2.6792	44.9962	4.4735	0.2227	2,714,098	0.591	0.012	1.010
5	74.3	23.5	746.9	51.5	0.0122	934.475	2.6758	44.9982	4.4990	0.0415	2,730,236	0.599	0.002	0.996
6	71.2	21.8	742.4	51.2	0.0122	832.267	2.6812	45.0688	3.7261	1.7665	2,268,203	0.524	0.116	1.145
7	72.3	22.4	735.3	50.7	0.0122	705.549	2.6443	45.0593	3.6343	0.9254	2,214,828	0.558	0.062	1.075
8	73.0	22.8	730.7	50.4	0.0122	623.285	2.6207	45.0538	3.5639	0.3422	2,173,517	0.585	0.023	1.027
9	73.7	23.2	730.7	50.4	0.0122	615.740	2.6153	45.0394	3.5897	0.1755	2,188,283	0.593	0.012	1.013
10	73.9	23.3	730.5	50.4	0.0122	609.320	2.6126	45.0344	3.6133	0.0319	2,202,430	0.600	0.002	1.000
11	70.0	21.1	726.7	50.1	0.0121	545.518	2.6261	45.1216	2.4726	3.3832	1,512,265	0.433	0.330	1.384
12	70.7	21.5	722.8	49.8	0.0121	492.848	2.6052	45.1146	2.5128	2.6346	1,537,703	0.464	0.252	1.290
13	70.7	21.5	718.5	49.5	0.0121	428.321	2.5881	45.1236	2.5817	1.6253	1,581,607	0.513	0.151	1.168
14	70.9	21.6	715.7	49.3	0.0121	382.330	2.5747	45.1229	2.6455	0.7552	1,621,521	0.557	0.068	1.075
15	70.9	21.6	714.2	49.2	0.0121	363.614	2.5691	45.1269	2.6646	0.4039	1,633,924	0.576	0.036	1.040
16	69.5	20.9	713.2	49.2	0.0121	364.015	2.5736	45.1566	2.1213	2.4814	1,302,153	0.458	0.279	1.309
17	69.5	20.8	710.4	49.0	0.0121	323.586	2.5624	45.1624	2.0917	2.0285	1,284,926	0.480	0.231	1.250
18	69.3	20.7	707.7	48.8	0.0121	286.448	2.5533	45.1727	2.1256	1.2372	1,306,805	0.519	0.138	1.156
19	68.4	20.2	704.7	48.6	0.0120	252.511	2.5480	45.1969	2.1672	0.5212	1,334,061	0.564	0.057	1.063
20	67.8	19.9	702.3	48.4	0.0120	228.208	2.5424	45.2136	2.1009	0.3078	1,294,452	0.575	0.035	1.043

Figure 3-9.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/12/04

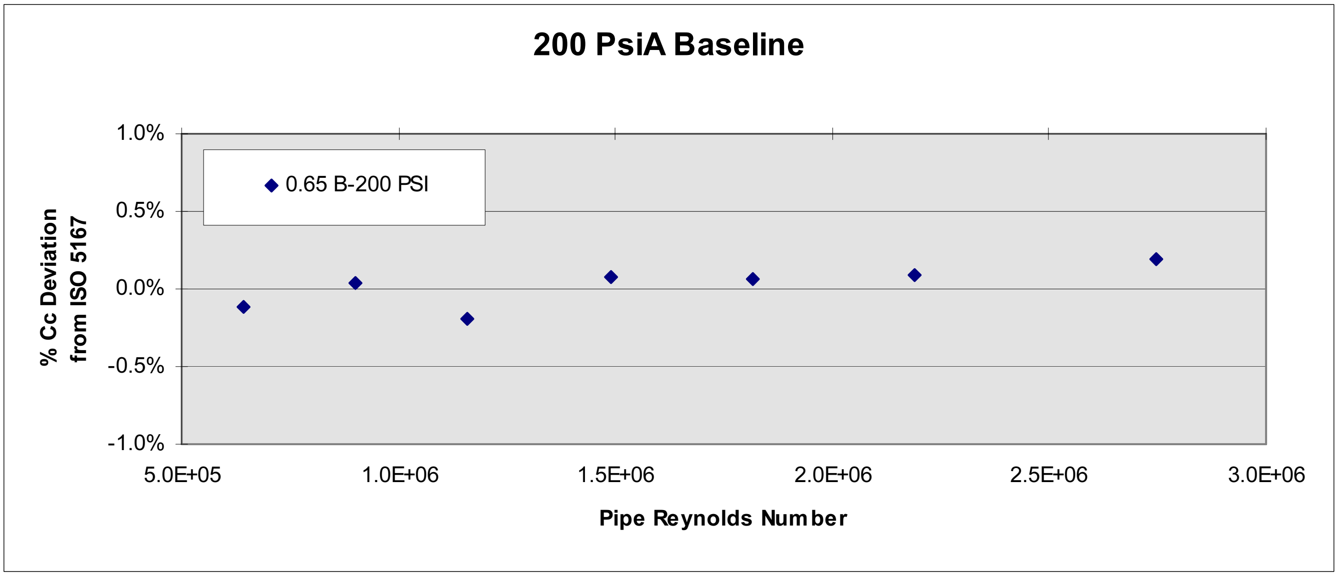


Figure 3-10.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/14/04

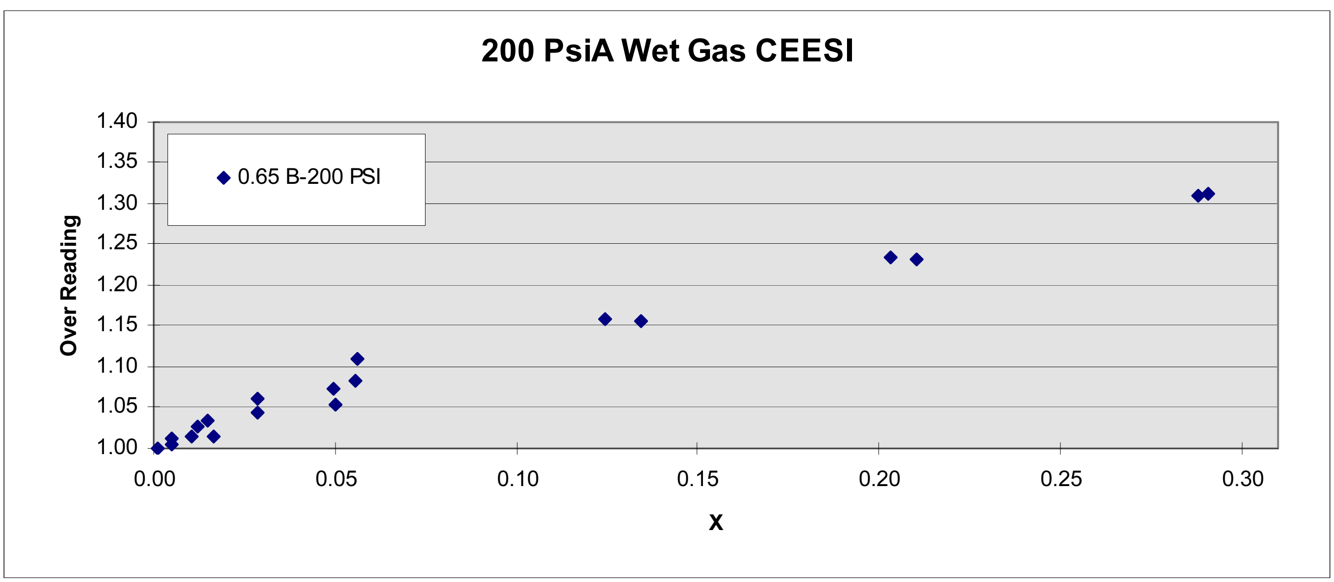


Table 3-9. 3" Rosemount 405 0.65 Beta 200PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH$_2$0	lb/sec	Gas	C_c	C_d	%
1	72.6	22.6	227.9	15.7	0.0111	0.7751	339.6704	4.2332	2,744,776	0.6014	0.6035	0.348
2	75.8	24.3	225.3	15.5	0.0111	0.7607	212.1040	3.3430	2,189,921	0.6027	0.6038	0.178
3	77.4	25.2	224.8	15.5	0.0111	0.7565	143.8084	2.7563	1,814,998	0.6030	0.6040	0.171
4	79.3	26.3	224.2	15.5	0.0111	0.7512	96.2317	2.2559	1,491,008	0.6039	0.6043	0.058
5	79.6	26.4	224.0	15.4	0.0111	0.7499	57.6104	1.7493	1,160,478	0.6045	0.6046	0.013
6	79.6	26.4	223.1	15.4	0.0111	0.7469	34.5996	1.3583	902,656	0.6062	0.6050	-0.198
7	78.5	25.8	222.1	15.3	0.0111	0.7454	17.3174	0.9648	642,356	0.6087	0.6056	-0.509

Table 3-10. 3" Rosemount 405C 0.65 Beta 200PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH$_2$0	lb/ft^3		lb/sec	lb/sec	Gas	C_d	X	%
1	69.9	21.1	211.4	14.6	0.0110	335.241	0.7089	46.0873	3.6243	1.7346	2,340,823	0.548	0.059	1.110
2	76.8	24.9	211.3	14.6	0.0111	310.459	0.6983	45.8976	3.6757	0.8496	2,373,565	0.581	0.029	1.047
3	82.2	27.9	211.5	14.6	0.0111	297.604	0.6912	45.7478	3.7110	0.3336	2,390,373	0.601	0.011	1.011
4	85.0	29.5	212.0	14.6	0.0111	293.826	0.6887	45.6676	3.7203	0.1762	2,392,882	0.608	0.006	1.000
5	85.6	29.8	212.0	14.6	0.0112	291.060	0.6881	45.6511	3.7352	0.0418	2,403,151	0.613	0.001	0.991
6	75.4	24.1	210.5	14.5	0.0111	154.235	0.6976	45.9359	2.5253	1.1183	1,659,923	0.561	0.055	1.085
7	77.8	25.5	209.7	14.5	0.0111	144.533	0.6916	45.8708	2.5455	0.5834	1,673,575	0.587	0.028	1.038
8	80.0	26.7	209.1	14.4	0.0111	127.876	0.6864	45.8120	2.4602	0.2514	1,617,051	0.605	0.013	1.007
9	81.0	27.2	209.0	14.4	0.0111	126.392	0.6847	45.7836	2.4681	0.1173	1,622,944	0.611	0.006	0.997
10	82.3	28.0	209.1	14.4	0.0111	126.813	0.6833	45.7469	2.4852	0.0263	1,632,187	0.615	0.001	0.991
11	74.1	23.4	209.5	14.4	0.0111	113.880	0.6963	45.9749	1.7247	3.8203	1,138,188	0.446	0.273	1.370
12	78.2	25.7	207.8	14.3	0.0111	81.072	0.6845	45.8624	1.6529	1.9085	1,093,118	0.510	0.141	1.198
13	80.1	26.7	208.1	14.3	0.0111	69.769	0.6829	45.8105	1.6476	1.0801	1,090,223	0.548	0.080	1.115
14	81.9	27.7	207.3	14.3	0.0111	59.984	0.6780	45.7629	1.6301	0.3862	1,079,423	0.586	0.029	1.042
15	84.4	29.1	207.6	14.3	0.0111	54.255	0.6752	45.6907	1.5871	0.2091	1,048,733	0.601	0.016	1.016
16	77.6	25.3	207.5	14.3	0.0111	28.535	0.6850	45.8801	0.8752	2.1386	582,636	0.453	0.299	1.357
17	79.5	26.4	207.4	14.3	0.0111	21.214	0.6820	45.8280	0.8758	0.9223	582,998	0.527	0.128	1.167
18	80.9	27.1	206.9	14.3	0.0111	18.920	0.6784	45.7911	0.8760	0.5997	582,969	0.560	0.083	1.099
19	81.2	27.3	206.8	14.3	0.0111	16.985	0.6774	45.7822	0.8775	0.2208	583,875	0.592	0.031	1.039
20	81.5	27.5	206.6	14.2	0.0111	16.393	0.6764	45.7746	0.8780	0.1327	584,327	0.603	0.018	1.019

Figure 3-11.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/21/04

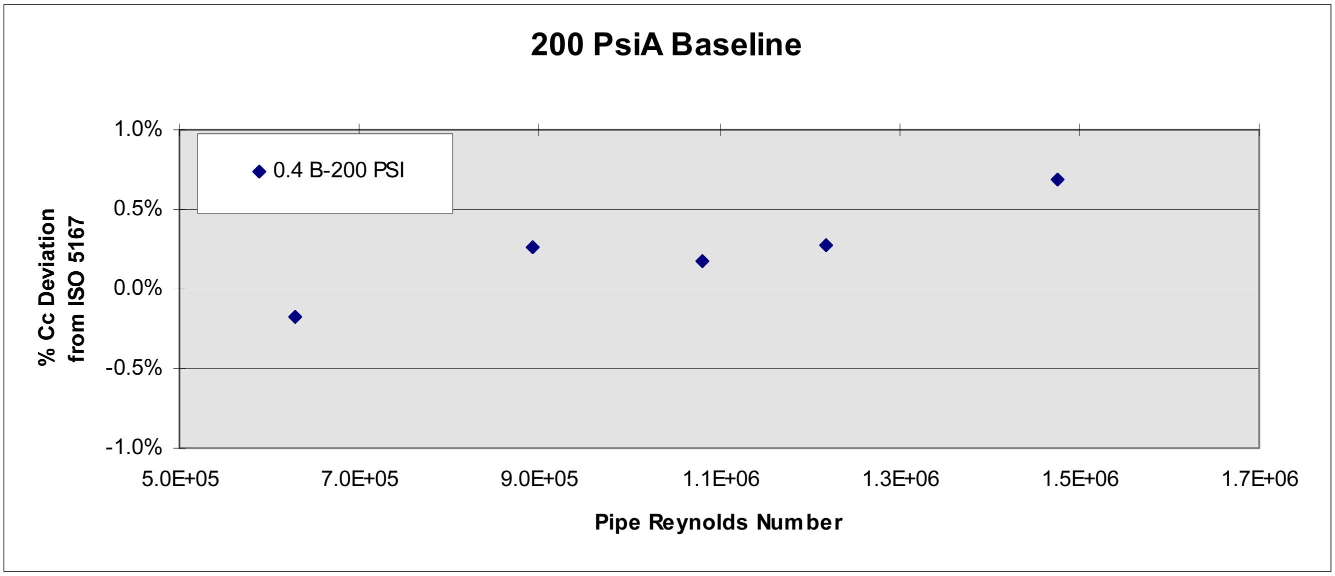


Figure 3-12.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/21/04

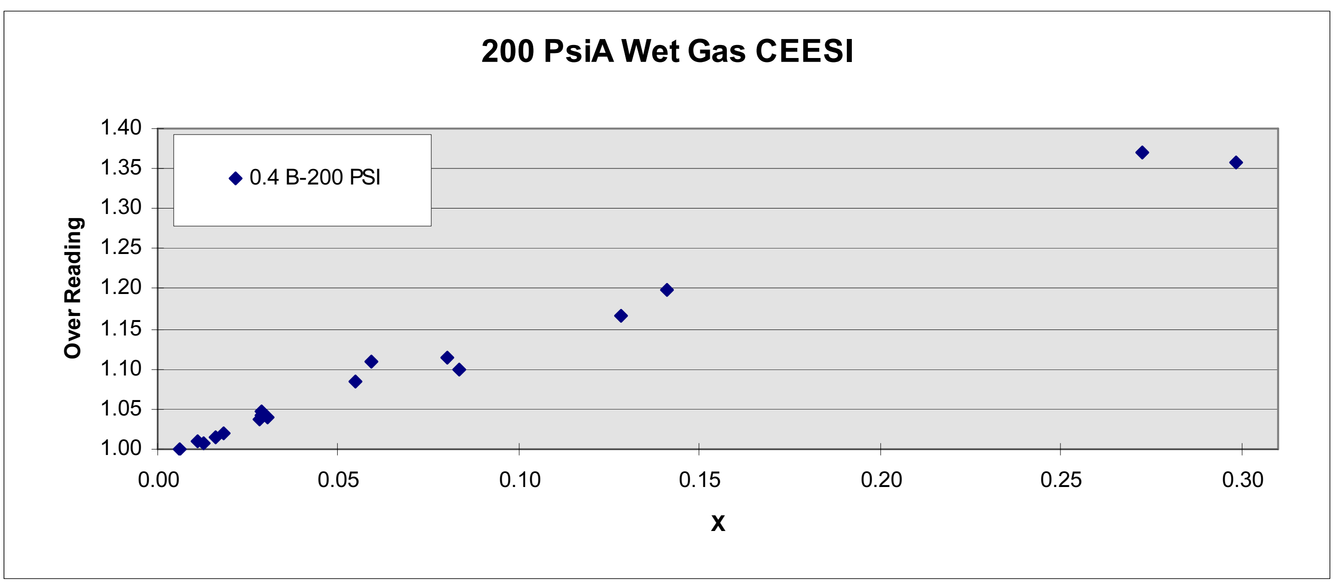


Table 3-11. 3" Rosemount 405C 0.40 Beta 200PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH_20	lb/sec		C_c	C_d	%
1	66.2	19.0	225.6	15.6	0.0110	0.7788	1230.4707	2.6394	1,476,941	0.5969	0.6010	0.690
2	66.2	19.0	214.9	14.8	0.0110	0.7405	717.7253	2.0177	1,218,765	0.5994	0.6011	0.281
3	67.0	19.4	209.6	14.4	0.0110	0.7203	541.1293	1.7433	1,080,858	0.6001	0.6011	0.178
4	68.8	20.4	205.2	14.1	0.0110	0.7018	351.1974	1.3977	891,541	0.5997	0.6012	0.258
5	68.6	20.3	200.5	13.8	0.0110	0.6854	163.9384	0.9567	628,302	0.6025	0.6014	-0.175
6	67.2	19.5	198.9	13.7	0.0110	0.6819	98.0659	0.7451	494,440	0.6063	0.6015	-0.795
7	65.6	18.7	196.6	13.6	0.0110	0.6760	56.0606	0.5601	374,813	0.6041	0.6017	-0.402

Table 3-12. 3" Rosemount 405C 0.40 Beta 200PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH_20	lb/ft^3		lb/sec	lb/sec		C_d	X	%
1	63.2	17.3	238.7	16.5	0.0110	1631.268	0.8465	46.2192	2.8164	1.1656	1,494,063	0.535	0.056	1.109
2	66.5	19.2	234.9	16.2	0.0110	1495.351	0.8262	46.1356	2.7986	0.5959	1,510,136	0.559	0.028	1.061
3	68.8	20.4	233.2	16.1	0.0110	1362.922	0.8159	46.0778	2.7556	0.2519	1,515,889	0.577	0.012	1.028
4	68.8	20.4	232.4	16.0	0.0110	1336.433	0.8130	46.0778	2.7705	0.1076	1,529,867	0.586	0.005	1.011
5	69.0	20.6	230.3	15.9	0.0110	1262.452	0.8052	46.0764	2.7175	0.0218	1,514,697	0.593	0.001	1.000
6	61.5	16.4	216.9	15.0	0.0110	678.168	0.7682	46.3081	1.8504	0.8023	1,127,987	0.550	0.056	1.082
7	63.4	17.4	215.2	14.8	0.0110	627.896	0.7588	46.2598	1.8366	0.4098	1,126,926	0.570	0.029	1.045
8	63.5	17.5	213.4	14.7	0.0110	577.203	0.7521	46.2598	1.8094	0.1510	1,118,157	0.587	0.011	1.014
9	63.2	17.4	213.0	14.7	0.0110	567.019	0.7509	46.2688	1.8110	0.0739	1,120,675	0.593	0.005	1.004
10	62.7	17.1	212.5	14.7	0.0110	560.907	0.7501	46.2840	1.8122	0.0166	1,122,750	0.596	0.001	0.998
11	56.0	13.3	203.6	14.0	0.0109	314.092	0.7273	46.4885	1.0331	2.4024	663,407	0.456	0.291	1.311
12	59.2	15.1	201.9	13.9	0.0109	289.990	0.7157	46.4026	1.0480	1.7124	677,678	0.485	0.203	1.233
13	62.2	16.8	201.0	13.9	0.0110	244.249	0.7080	46.3209	1.0225	1.1113	665,144	0.517	0.134	1.157
14	65.4	18.5	199.5	13.8	0.0110	204.934	0.6978	46.2350	1.0216	0.4187	668,520	0.567	0.050	1.055
15	68.2	20.1	199.2	13.7	0.0110	194.539	0.6923	46.1567	1.0306	0.1385	674,105	0.589	0.016	1.015
16	56.6	13.7	198.7	13.7	0.0109	103.964	0.7077	46.4814	0.5954	1.3905	396,410	0.459	0.288	1.310
17	56.6	13.6	198.2	13.7	0.0109	92.375	0.7056	46.4838	0.5964	1.0169	398,312	0.488	0.210	1.231
18	58.1	14.5	197.6	13.6	0.0109	80.507	0.7012	46.4414	0.5906	0.5987	395,436	0.519	0.125	1.158
19	59.7	15.4	197.1	13.6	0.0109	70.177	0.6969	46.3987	0.5939	0.2394	398,430	0.560	0.049	1.072
20	61.4	16.4	197.0	13.6	0.0109	65.666	0.6940	46.3497	0.5948	0.0734	398,462	0.581	0.015	1.034

Figure 3-13.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/15/04

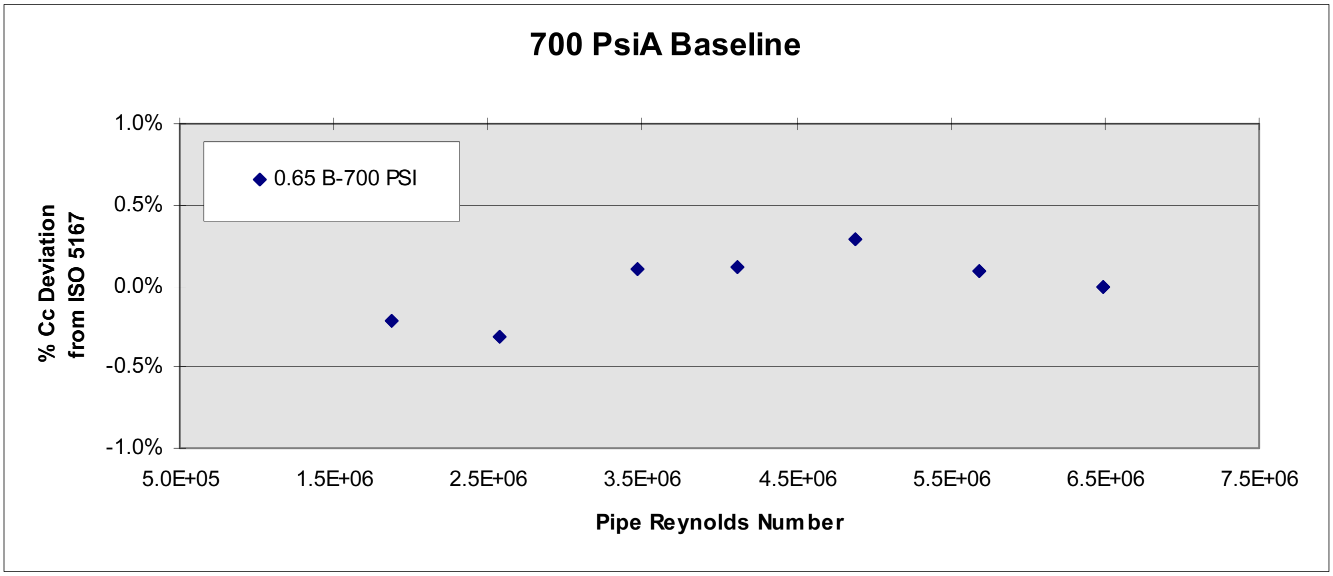


Figure 3-14.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.65	Test Date: 4/19/04

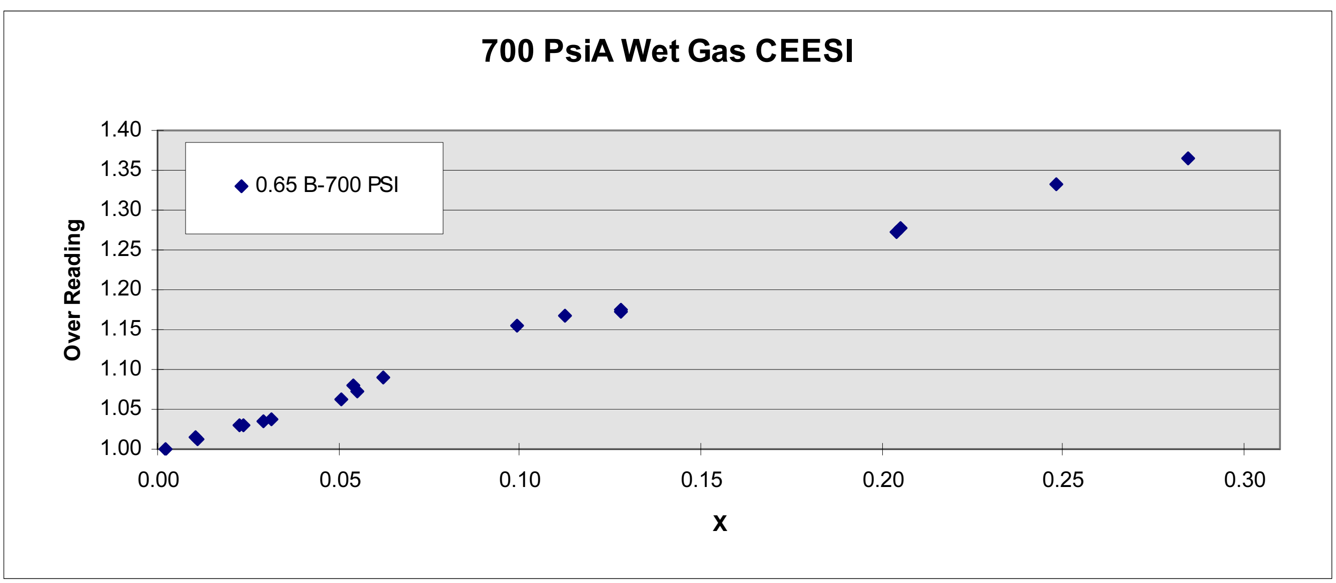


Table 3-13. 3" Rosemount 405C 0.65 Beta 700PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH_20	lb/sec	Gas	C_c	C_d	%
1	82.8	28.2	695.5	48.0	0.0121	2.4358	696.9868	10.8476	6,489,485	0.6027	0.6027	-0.002
2	84.1	29.0	694.9	47.9	0.0121	2.4250	530.3233	9.4613	5,683,026	0.6023	0.6028	0.089
3	84.4	29.1	694.2	47.9	0.0121	2.4205	388.6274	8.0966	4,883,455	0.6012	0.6030	0.292
4	84.4	29.1	692.9	47.8	0.0121	2.4154	272.1513	6.7956	4,114,062	0.6024	0.6031	0.116
5	82.8	28.2	687.0	47.4	0.0121	2.4031	191.3980	5.6946	3,464,484	0.6027	0.6033	0.100
6	78.8	26.0	682.9	47.1	0.0121	2.4125	102.8875	4.2090	2,576,362	0.6055	0.6036	-0.308
7	76.5	24.7	678.8	46.8	0.0120	2.4112	53.8707	3.0464	1,872,312	0.6053	0.6040	-0.217

Table 3-14. 3" Rosemount 405C 0.65 Beta 700PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH_20	lb/ft^3		lb/sec	lb/sec	Gas	C_d	X	%
1	73.4	23.0	717.4	49.5	0.0121	971.467	2.5667	45.0700	11.4156	4.7571	6,777,195	0.531	0.099	1.149
2	76.4	24.7	716.3	49.4	0.0121	833.578	2.5409	45.0097	11.2203	2.5464	6,678,455	0.565	0.054	1.079
3	78.0	25.6	716.6	49.4	0.0121	775.964	2.5307	44.9758	11.3023	1.0862	6,732,539	0.591	0.023	1.033
4	79.0	26.1	716.5	49.4	0.0122	753.553	2.5239	44.9559	11.3092	0.5044	6,737,467	0.600	0.011	1.016
5	80.1	26.7	717.0	49.4	0.0122	736.745	2.5178	44.9313	11.3400	0.0987	6,753,918	0.609	0.002	1.001
6	75.6	24.2	712.7	49.1	0.0121	550.015	2.5333	45.0325	8.5192	4.0513	5,118,810	0.526	0.113	1.154
7	77.4	25.2	711.3	49.0	0.0121	481.883	2.5152	44.9971	8.4844	2.2293	5,103,817	0.562	0.062	1.082
8	78.0	25.6	709.9	48.9	0.0121	415.915	2.5055	44.9869	8.3172	0.8369	5,013,019	0.593	0.024	1.025
9	78.1	25.6	709.1	48.9	0.0121	406.456	2.5020	44.9865	8.3552	0.3969	5,038,188	0.603	0.011	1.008
10	78.7	26.0	708.7	48.9	0.0121	400.117	2.4963	44.9745	8.4114	0.0762	5,072,856	0.612	0.002	0.992
11	73.2	22.9	703.3	48.5	0.0121	345.595	2.5113	45.0997	5.9442	6.2517	3,607,406	0.464	0.248	1.313
12	73.2	22.9	700.8	48.3	0.0121	303.059	2.5015	45.1044	5.7871	5.0418	3,518,623	0.483	0.205	1.262
13	72.3	22.4	698.1	48.1	0.0120	265.737	2.4961	45.1264	5.8765	3.1939	3,580,558	0.524	0.128	1.163
14	72.0	22.2	696.1	48.0	0.0120	217.785	2.4904	45.1371	5.8128	1.3685	3,549,544	0.573	0.055	1.064
15	72.7	22.6	695.2	47.9	0.0120	205.545	2.4824	45.1248	5.8298	0.7773	3,560,435	0.592	0.031	1.029
16	70.7	21.5	689.9	47.6	0.0120	101.779	2.4739	45.1768	3.1719	3.8566	1,947,881	0.458	0.285	1.337
17	71.2	21.8	689.3	47.5	0.0120	90.207	2.4677	45.1657	3.1971	2.7895	1,963,654	0.491	0.204	1.247
18	71.2	21.8	688.6	47.5	0.0120	79.137	2.4650	45.1669	3.2240	1.7635	1,981,489	0.528	0.128	1.158
19	71.5	21.9	688.4	47.5	0.0120	66.699	2.4622	45.1619	3.2538	0.7037	2,000,300	0.581	0.050	1.053
20	71.3	21.8	687.7	47.4	0.0120	62.415	2.4612	45.1676	3.2244	0.4014	1,982,979	0.595	0.029	1.028

Figure 3-15.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/20/04

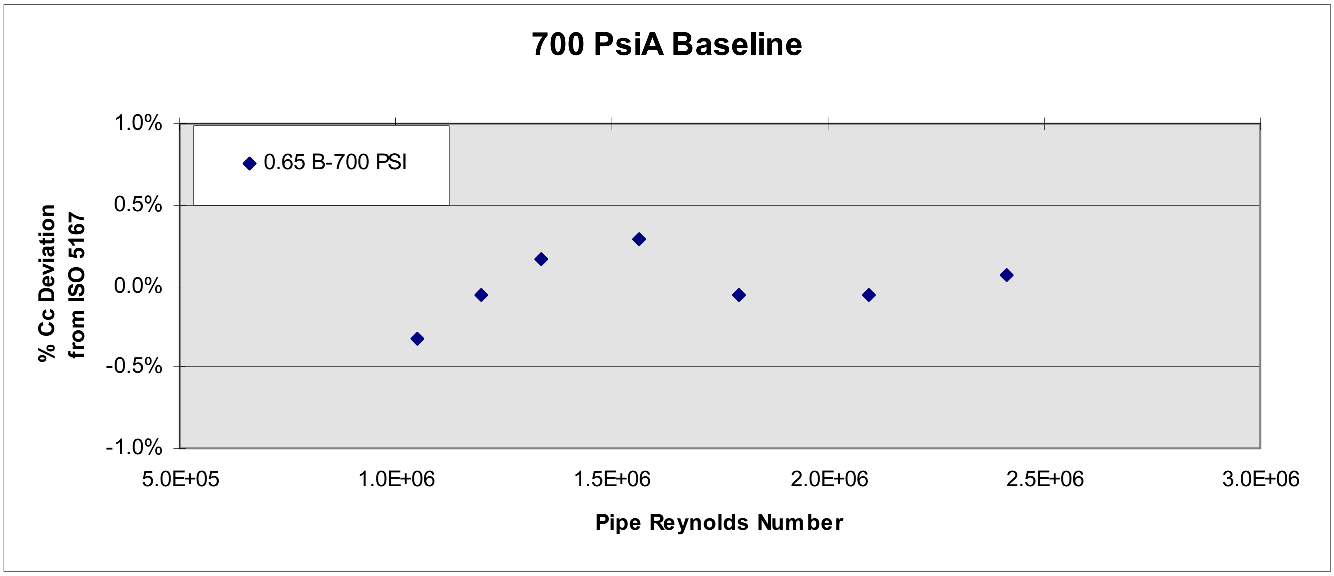


Figure 3-16.

Test Laboratory: CEESI, Colorado	
Model: 405C	Pipe Size: 3-in. (76.2 mm) Schedule 40
Fluid: Decane & Natural Gas	Pipe I.D.: 3.068
Beta Ratio: 0.40	Test Date: 4/20/04

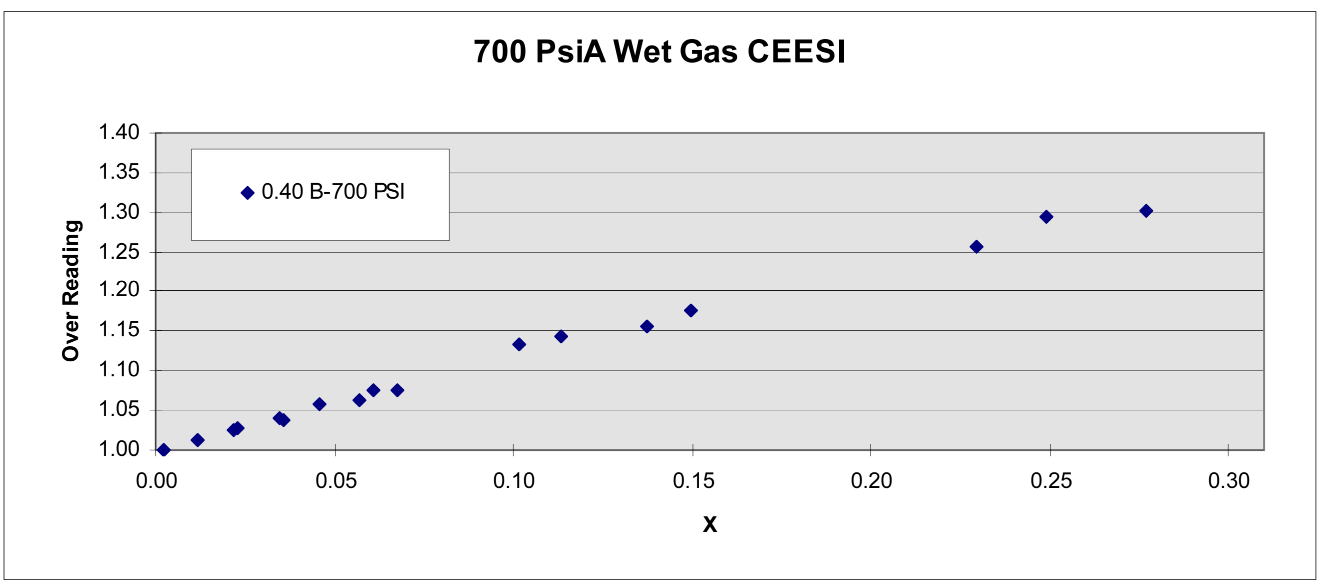


Table 3-15. 3" Rosemount 405C 0.40 Beta 700PsiA Baseline

Data Point	Temperature		Pressure		Viscosity	Density	Differential Pressure	Flow Rate	Pipe Reynolds #	Discharge Coefficient	Iso 5167 Calculation	Deviation from ISO
	°F	°C	PsiA	Bar	cp	lb/ft^3	inH_20	lb/sec		C_c	C_d	%
1	74.9	23.9	718.3	49.5	0.0121	2.5557	804.9056	4.0827	2,411,774	0.6005	0.6009	0.065
2	75.8	24.4	713.8	49.2	0.0121	2.5313	597.5934	3.5156	2,095,867	0.6013	0.6009	-0.060
3	76.0	24.5	711.9	49.1	0.0121	2.5225	431.3033	2.9886	1,794,104	0.6013	0.6010	-0.060
4	75.9	24.4	707.5	48.8	0.0121	2.5064	326.8300	2.5882	1,562,303	0.5993	0.6010	0.289
5	74.1	23.4	704.4	48.6	0.0121	2.5059	236.2645	2.2060	1,338,555	0.6001	0.6011	0.167
6	73.1	22.8	702.6	48.4	0.0121	2.5061	187.1933	1.9696	1,199,105	0.6015	0.6011	-0.061
7	73.1	22.8	702.2	48.4	0.0121	2.5045	142.0302	1.7210	1,049,779	0.6031	0.6012	-0.331

Table 3-16. 3" Rosemount 405C 0.40 Beta 700PsiA Wet Gas

Data Point	Temperature		Pressure		Viscosity	Differential Pressure	Gas Density	Liquid Density	Flow Rate (Gas)	Flow Rate (Liquid)	Pipe Reynolds #	Discharge Coefficient	Lockhart Martinelli #	Over-Reading
	°F	°C	PsiA	Bar	cp	inH_20	lb/ft^3		lb/sec	lb/sec		C_d	X	%
1	67.4	19.6	726.3	50.1	0.0121	1373.564	2.6439	45.1765	4.7198	1.9817	2,731,246	0.525	0.102	1.129
2	69.9	21.1	725.2	50.0	0.0121	1277.305	2.6207	45.1265	4.8526	0.9228	2,815,685	0.561	0.046	1.051
3	70.7	21.5	724.5	49.9	0.0121	1231.277	2.6115	45.1110	4.9070	0.4443	2,851,927	0.579	0.022	1.017
4	72.3	22.4	720.2	49.7	0.0121	993.307	2.5830	45.0872	4.4735	0.2227	2,625,577	0.589	0.012	1.011
5	72.2	22.4	720.0	49.6	0.0121	975.638	2.5825	45.0882	4.4990	0.0415	2,642,028	0.597	0.002	0.996
6	69.8	21.0	718.2	49.5	0.0121	868.366	2.5936	45.1422	3.7261	1.7665	2,202,197	0.522	0.114	1.147
7	70.9	21.6	715.1	49.3	0.0121	731.683	2.5728	45.1242	3.6343	0.9254	2,160,206	0.556	0.061	1.078
8	71.6	22.0	713.0	49.2	0.0121	644.692	2.5593	45.1138	3.5639	0.3422	2,125,665	0.582	0.023	1.030
9	72.3	22.4	713.2	49.2	0.0121	634.941	2.5551	45.0992	3.5897	0.1755	2,140,745	0.591	0.012	1.014
10	72.6	22.5	713.4	49.2	0.0121	626.484	2.5541	45.0937	3.6133	0.0319	2,155,008	0.599	0.002	1.001
11	69.3	20.7	711.5	49.1	0.0121	553.375	2.5697	45.1656	2.4726	3.3832	1,481,957	0.434	0.326	1.376
12	69.9	21.1	708.9	48.9	0.0121	504.182	2.5547	45.1567	2.5128	2.6346	1,510,071	0.464	0.249	1.289
13	69.9	21.0	706.5	48.7	0.0121	443.360	2.5454	45.1623	2.5817	1.6253	1,556,720	0.508	0.149	1.176
14	70.1	21.2	705.3	48.6	0.0121	392.405	2.5386	45.1589	2.6455	0.7552	1,598,562	0.554	0.068	1.079
15	70.1	21.1	704.3	48.6	0.0120	371.766	2.5350	45.1625	2.6646	0.4039	1,612,134	0.574	0.036	1.042
16	68.9	20.5	703.3	48.5	0.0120	374.158	2.5380	45.1879	2.1213	2.4814	1,284,354	0.455	0.277	1.315
17	68.9	20.5	701.6	48.4	0.0120	331.426	2.5315	45.1917	2.0917	2.0285	1,268,898	0.477	0.230	1.255
18	68.6	20.3	700.1	48.3	0.0120	295.143	2.5273	45.2008	2.1256	1.2372	1,292,296	0.514	0.138	1.164
19	67.7	19.8	698.2	48.1	0.0120	256.282	2.5259	45.2227	2.1672	0.5212	1,320,982	0.562	0.057	1.064
20	67.2	19.5	696.5	48.0	0.0120	231.057	2.5231	45.2377	2.1009	0.3078	1,282,956	0.574	0.035	1.043

Section 4 Flow Calculations

The Rosemount 405C and 1595 primary flow elements are sized using the Instrument Toolkit sizing program. This program provides accurate flow calculations using installation details and fluid properties for the flowmeter and presents this on a calculation data sheet or specification sheet. The following section provides the supporting equations and theory that are used in the Toolkit sizing program

ROSEMOUNT 405C AND 1595 CONDITIONING ORIFICE PLATE

Calculated Values and Variables Designations

C =	Discharge Coefficient
C_C =	Discharge Coefficient corrected by calibration factor
d =	Bore Diameter corrected for thermal expansion [inches [US units], mm [SI units]]
d_c =	Calculated Bore Diameter inches [[US units], mm [SI units]]
d_{meas} =	Measured typical orifice bore diameter (assumed to be 68 °F). See Table 1 or 2. [inches [US units], mm [SI units]
F_C =	Calibration factor (0.750 < F_c < 1.250)
F_S =	Pipe schedule adjustment factor
h_w =	Differential pressure (inwc [US units], Pa [SI units])
ΔP =	Differential pressure (inwc [US units], Pa [SI units])
M_{ID} =	Meter internal diameter corrected for thermal expansion (inches [US units], mm [SI units])
$M_{ID_{meas}}$ =	Meter internal ID (assumed to be 68 °F) See Table 1. (inches [US units], mm [SI units])
OR =	Over-Reading
P_{ID} =.	Pipe internal diameter corrected for thermal expansion (inches [US units], mm [SI units])
$P_{ID_{meas}}$=	Measured ID (assumed to be 68 °F) (inches [US units], mm [SI units])
P_1 =	Upstream static pressure (PSI [US units], Pa [SI units])
P_2 =	Downstream static pressure (PSI [US units], Pa [SI units])
q_m =	Mass flow rate (in lbm/s [US units] or kg/s [SI units], a conversion factor must be applied to other units)
R_D =	Pipe reynolds number
t =	Process temperature (°F [US units], °C [SI units])
t_{meas} =	Temperature at bore / pipe ID measurement (assumed to be 68 °F) (°F [US units], °C [SI units])
Y_1 =	Gas expansion factor
X =	Lockhart-Martinelli
α_P =	Thermal expansion factor of the pipe (in./in./°F [US units], m/m/°C [SI units])
α_{PE} =	Thermal expansion factor of the primary element (in./in./°F [US units], m/m/°C [SI units])
β_c =	Beta ratio using calculated bore diameter
ε_1 =	Gas expansion factor
κ =	Isentropic exponent
μ =	Viscosity (cP [US units], Pa-s [SI units])
ρ =	Density (lbm/ft^3 [US units])
ρ_{F_1} =	Density (kg/m^3 [SI units])

Equations

Flow Rate Equations (ASME MFC-3M and ISO-5167)

Equation 1

US units

$$q_m = 0.09970190 C_c Y_1 d_c^2 \quad \text{OR} \quad \sqrt{\frac{h_w \rho}{1-\beta_c^4}}$$

SI units

$$q_m = \frac{\pi}{4} C_c \varepsilon_1 d_c^2 \quad \text{OR} \quad \sqrt{\frac{2\Delta p \rho_{f_1}}{1-\beta_c^4}}$$

Reynolds Number Equation

Equation 2

US units

$$R_D = \frac{22737.47 q_m}{\mu P_{ID}}$$

SI units

$$R_D = \frac{q_m}{\frac{\pi}{4}\mu P_{ID}}$$

Beta is calculated using the meter internal diameter and calculated bore diameter.

Equation 3

$$\beta_c = \frac{d_c}{M_{ID}}$$

Thermal Expansion Corrections

$$d = [1 + \alpha_{PE}(t - t_{meas})]d_{meas}$$

$$M_{ID} = [1 + \alpha_{PE}(t - t_{meas})]M_{ID_{meas}}$$

$$P_{ID} = [1 + \alpha_P(t - t_{meas})]P_{ID_{meas}}$$

Discharge Coefficient Equations (ISO-5167)

Rosemount 405C Compact Conditioning Orifice Plate, Line Sizes 2 to 8-in (50.8 to 203 mm)

Equation 4

$$C = 0.5961 + 0.0261 B_c^2 - 0.216 B_c^8 + 0.000521\left(\frac{10^6 B_c}{R_D}\right)^{0.7} + \left(0.0188 + 0.0063\left(\frac{19000 B_c}{R_D}\right)^{0.8}\right) B_c^{3.5}\left(\frac{10^6}{R_D}\right)^{0.3}$$

For 2-in. models, add this additional term when calculating C:

US units

$$+ 0.011(0.75 - B_c)(2.8 - M_{ID})$$

SI units

$$+ 0.011(0.75 - B_c)\left(2.8 - \frac{M_{ID}}{25.4}\right)$$

Rosemount 1595 Conditioning Orifice Plate
Line Sizes 2 to 24-in. (50.8 to 610 mm), Flange Taps

Equation 5

$$C = 0.5961 + 0.0261B_c^2 - 0.216B_c^8 + 0.000521\left(\frac{10^6 B_c}{R_D}\right)^{0.7} +$$
$$\left(0.0188 + 0.0063\left(\frac{19000B_c}{R_D}\right)^{0.8}\right)B_c^{3.5}\left(\frac{10^6}{R_D}\right)^{0.3} +$$
$$\left(0.043 + 0.080e^{-10L_1} - 0.123e^{-7L_1}\right)\left(1 - 0.11\left(\frac{1900B_c}{R_D}\right)^{0.8}\right)\left(\frac{B_c^4}{1 - B_c^4}\right) -$$
$$0.031(M_2' - 0.8M_2'^{1.1})B_c^{1.3}$$

Where:

US units

$$L_1 = L_2' = \left(\frac{1}{P_{ID}}\right)$$

$$M_2' = \left(\frac{2L_2'}{1 - B_c}\right)$$

SI units

$$L_1 = L_2' = \left(\frac{25.4}{P_{ID}}\right)$$

If the 2-in. model or pipe ID is less than 2.8-in. (71.12 mm), add this additional term when calculating C:

US units

$$+ 0.011(0.75 - B_c)(2.8 - P_{ID})$$

SI units

$$+ 0.011(0.75 - B_c)\left(2.8 - \frac{P_{ID}}{25.4}\right)$$

Beta is calculated using the pipe diameter and calculated bore diameter.

Equation 6

$$\beta_c = \frac{d_c}{P_{ID}}$$

Discharge Coefficient Calibration Factory Adjustment

Equation 7 (for 405C)

$$C_c = CF_cF_s$$

Equation 8 (for 1595)

$$C_c = CF_c$$

Gas Expansion Factor (ISO-5167) Equation

Equation 9

US units

$$Y_1 = 1 - (0.351 + 0.256B_c^4 + 0.93B_c^8)\left[1 - \left(1 - \frac{h_w}{27.73P_1}\right)^{\frac{1}{k}}\right]$$

SI units

$$\varepsilon_1 = 1 - (0.351 + 0.256B_c^4 + 0.93B_c^8)\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}}\right]$$

Calculated Bore Size

The calculated bore size is two times the typical hole size (size of one of the four holes)

Equation 10

$$d_c = 2d$$

Lockhart Martinelli Number

The maximum Lockhart-Martinelli value, (X) was 0.3 where pressure and beta would permit.

Equation 11

$$X = \frac{\dot{m}_l}{\dot{m}_g} \cdot \sqrt{\frac{\rho_g}{\rho_l}}$$

Where:
$\dot{m}_l$ = Mass flow of liquid
$\dot{m}_g$ = Mass flow of gas
p_l = Density of liquid
p_g = Density of gas

Over-Reading

Equation 12

$$OverReading = \sqrt{\frac{\Delta P_{tp}}{\Delta P_g}}$$

Where:

ΔP_{tp} = Total DP reading of wet gas

ΔP_g = The DP of gas only

The ΔP_g is calculated using the dry gas calibration data and measured gas flow rate and density.

$$\Delta P_g = \left(\frac{Q_{m,\,ref}}{0.09970190 \cdot C_{d,\,calc} \cdot Y_1 \cdot D_c^2 \cdot E \cdot \sqrt{\rho}} \right)^2$$

Where:
$Q_{m,ref}$ = Gas mass flow read by the reference turbine meter
$C_{d,calc}$ = Calculated discharge coefficient based on dry gas run and Re_{ref}
Re_{ref} = Reynolds number based on gas reference flow

For the 405C Compact Conditioning Orifice Plate and 1595 Rosemount Conditioning Orifice Plate, select the equation below for the specific beta:

Equation for Rosemount 1595 0.40 beta

$$OR = 1.0998 \cdot X + 1.0331$$

Equation for Rosemount 1595 0.65 beta

$$OR = 1.2306 \cdot X + 0.9999$$

Equation for Rosemount 405C 0.40 beta

$$OR = 1.1062 \cdot X + 1.0071$$

Equation for Rosemount 405C 0.65 beta

$$OR = 1.2684 \cdot X + 0.9999$$

Where:

OR = Over-Reading
X = Lockhart Martinelli Number

FLOW CALCULATION TABLES

Table 4-1. Rosemount 405C Nominal Meter Inside Diameter and Typical Orifice Hole Size

Line Size	Beta Ratio (β)	Meter ID	Typical Orifice Hole Size
2-in. (50.8 mm)	0.40	2.067-in. (52.5 mm)	0.413-in. (10.5 mm)
	0.60	2.067-in. (52.5 mm)	0.620-in. (15.7 mm)
3-in. (76.2 mm)	0.40	3.068-in. (77.9 mm)	0.614-in. (15.6 mm)
	0.65	3.068-in. (77.9 mm)	0.997-in. (25.3 mm)
4-in. (101.6 mm)	0.40	4.026-in. (102.3 mm)	0.805-in. (20.4 mm)
	0.65	4.026-in. (102.3 mm)	1.309-in. (33.2 mm)
6-in. (152.4 mm)	0.40	6.065-in. (103.3 mm)	1.213-in. (30.8 mm)
	0.65	6.065-in. (103.3 mm)	1.971-in. (50.0 mm)
8-in. (203.2 mm)	0.40	7.981-in. (202.7 mm)	1.596-in. (40.5 mm)
	0.65	7.981-in. (202.7 mm)	2.594-in. (65.9 mm)

Table 4-2. Rosemount 1595 Typical Orifice Hole Size

Line Size	Beta Ratio (β)	Typical Orifice Hole Size
2-in. (50.8 mm)	0.40	0.413-in. (10.5 mm)
	0.60	0.620-in. (15.7 mm)
3-in. (76.2 mm)	0.40	0.614-in. (15.6 mm)
	0.65	0.997-in. (25.3 mm)
4-in. (101.6 mm)	0.40	0.805-in. (20.4 mm)
	0.65	1.309-in. (33.2 mm)
6-in. (152.4 mm)	0.40	1.213-in. (30.8 mm)
	0.65	1.971-in. (50.0 mm)
8-in. (203.2 mm)	0.40	1.596-in. (40.5 mm)
	0.65	2.594-in. (65.9 mm)
10-in. (145.0 mm)	0.40	2.004-in. (50.9 mm)
	0.65	3.257-in. (82.7 mm)
12-in. (304.8 mm)	0.40	2.400-in. (60.9 mm)
	0.65	3.900-in. (99.0 mm)
14-in. (355.6 mm)	0.40	2.625-in. (66.7 mm)
	0.65	4.265-in. (108.3 mm)
16-in. (406.4 mm)	0.40	3.000-in. (76.2 mm)
	0.65	4.875-in. (123.8 mm)
18-in. (457.2 mm)	0.40	3.375-in. (85.7 mm)
	0.65	5.485-in. (139.3 mm)
20-in. (508.0 mm)	0.40	3.762-in. (95.6 mm)
	0.65	6.114-in. (155.3 mm)
24-in. (609.6 mm)	0.40	4.525-in. (114.9 mm)
	0.65	7.353-in. (186.8 mm)

Table 4-3. 405C Pipe Adjustment Factors

Pipe Size	Beta Ratio (β)	Schedule 10 (F_s)	Schedule 40 (F_s)	Schedule 80 (F_s)
2-in. (50.8 mm)	0.40	0.9985	1.0000	1.0077
	0.60	0.9950	1.0000	1.0165
3-in. (76.2 mm)	0.40	1.0000	1.0000	1.0000
	0.65	0.9927	1.0000	1.0033
4-in. (101.6 mm)	0.40	1.0018	1.0000	1.0063
	0.65	0.9945	1.0000	1.0052
6-in. (152.4 mm)	0.40	0.9981	1.0000	1.0011
	0.65	0.9873	1.0000	1.0054
8-in. (203.2 mm)	0.40	0.9983	1.0000	1.0020
	0.65	0.9834	1.0000	1.0015

Appendix A

The below paragraphs are representations of how well the curve fit matched the actual data. The product specifications (See page 1-2) were determined from these graphs.

Figure A-1. Rosemount 1595 Calculated offset from measured versus Lockhart-Martinelli Number

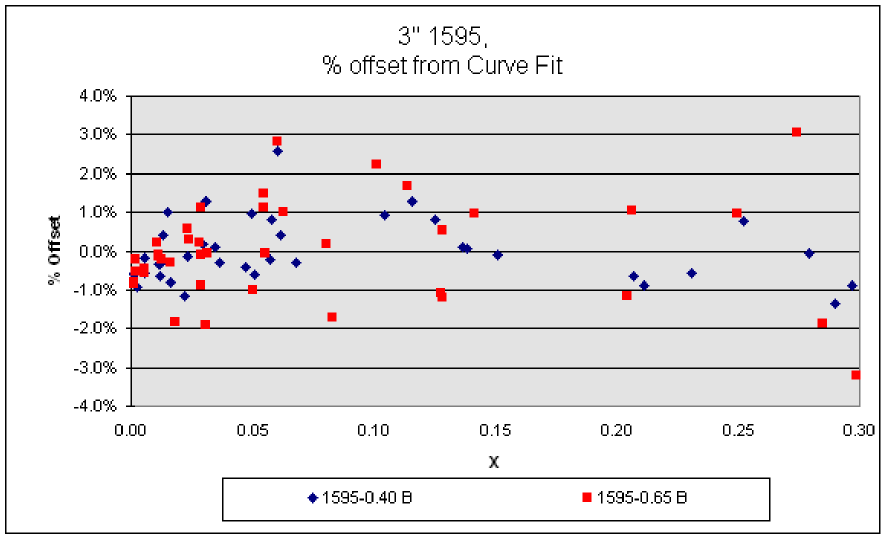
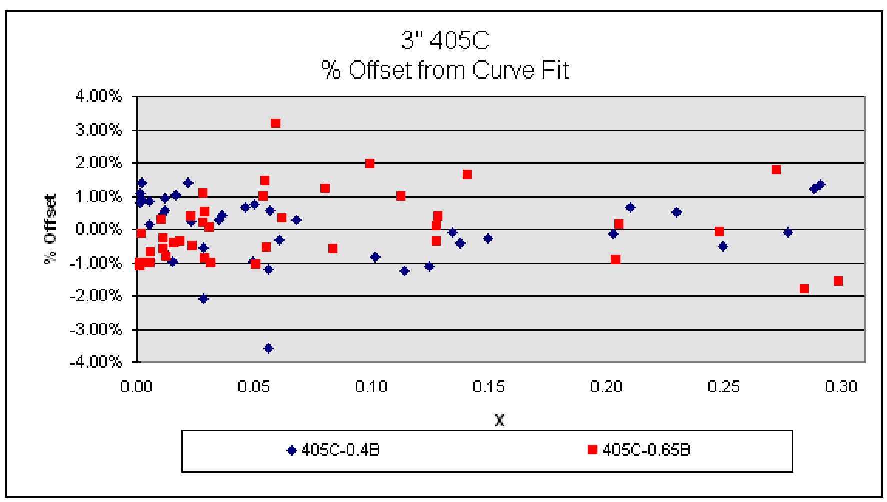


Figure A-2. Rosemount 405C Calculated offset from measured versus Lockhart-Martinelli Number



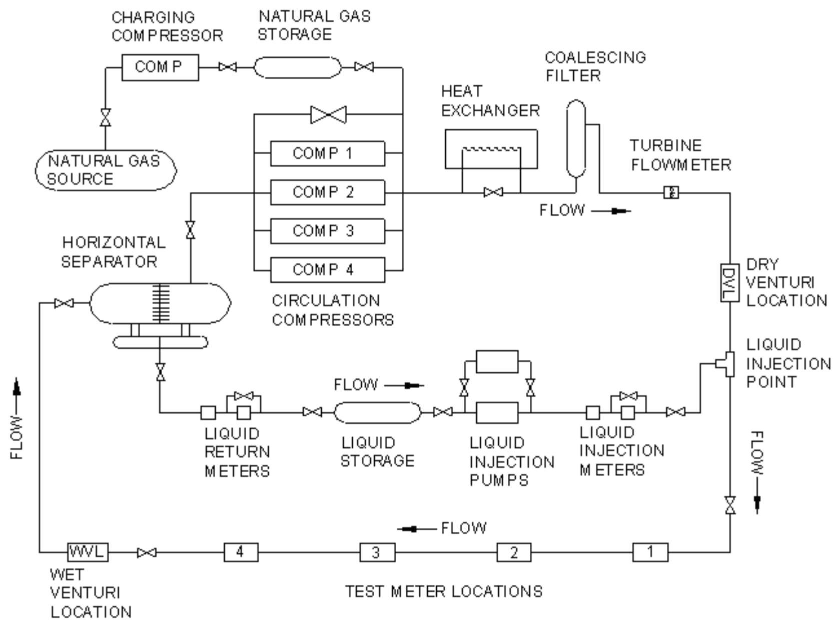


Figure A-3. CEESI Facility Diagram

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