Accurate Low Flow Rate Measurement Using a Specially Designed Differential Pressure Type Flowmeter

By: Bruce Brigg
Source: Primary Flow Signal, Inc.

All flow measurement technologies have inherent limitations on the level of accuracy they provide based on a number of application conditions such as range, viscosity, density, ambient conditions, process temperature, process pressure, and others.

One technology to carefully consider is differential pressure in the form of a specially designed Venturi tube. Venturi tube accuracy is always expressed as a plus/minus (+/-) value down to a calculated pipe Reynolds (Rd) number, which becomes its low flow limit for its basic accuracy performance. Other technologies, such as magnetic and ultrasonic meters, have similar low flow limits as a function of a minimum line velocity requirement although the components of the low Reynolds number calculation are a bit more complex compared to a single line velocity calculation.

From a Reynolds number performance point-of-view, Venturi tubes have been categorized by the type or internal design of the meter. Designs such as the ISO 5167, classical long form and modified short form designs each have different performance limitations and advantages. For example, the ISO5167 and ASME Classical type meters have a minimum pipe Reynolds number limitation (for constant discharge coefficient accuracy) of 200,000, while modified short form Venturi meters have a limitation of 75,000 in the case of the PFS-HVT design.

In order to put these values into perspective, 200,000 pipe Rd would represent approximately 720 gallons per minute flowing in a 10.0” pipe; while 75,000 pipe Rd represents approximately 270 gallons per minute in that same 10.0” line, but using the modified short form PFS-HVT venturi meter. Therefore, the accuracy statement for the ISO5167 and ASME classical type meters would be +/-1.0% of actual rate of flow (in the case of a machined convergent design) down to 720 gallons per minute, while the modified short form meter design of the PFS-HVT statement of +/-0.5% of actual rate of flow down to 270 gallons per minute.

Note that both the ISO5167/ASME classical and modified short form HVT meters can operate at less than their stated minimum pipe Rd values, but with a modified accuracy statement. As an example, if the minimum flow rate dropped to 500 gallons per minute for the classical type meter, the adjusted accuracy statement would be approximately +3.0/-1.7% of actual rate of flow because a bias error develops below about 295,000 the impact of which is reflected in a modified accuracy statement.

PRIMARY FLOW SIGNAL, INC.

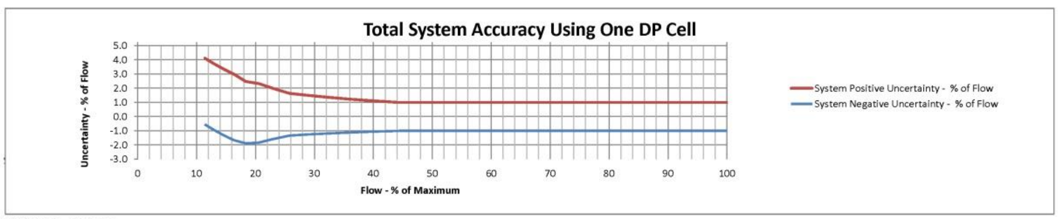
800 Wellington Avenue, Cranston,RI USA 02910 Ph (401)-461-6366 Fax (401)-461-4450

Accuracy of the Flow Metering System

Customer:	0	Line Size:	6		Max. Flow	1750	GPM
Project:	0	Pipe ID:	6		Min. Flow	200	GPM
PFS Quote No.:	0	Throat Dia:	4.2		DP @ Max. Flow:	235.38	IN H2O
Serial No.:		Beta:	0.70000		DP @ Min. Flow:	3.074	IN H2O
Tag:	FIGURE 1	Meter Type:	ISO5167/ASME		Max. Reynolds No. x 10^{-3}	822.832	
		Model:	MACH'D ENT & CONV				

SINGLE DP CELL			
MODEL	Emerson's Rosemount Model 3051S Ultra for Flow		
URL	250	IN H2O	
BASIC UNCERTAINTY =	0.04	% OF RDG	
SECONDARY UNCERTAINTY =	0.04	+ A % OF RDG	
A =	0.0023	x URL/RDG	
INVOKE SECONDARY @ URL/RDG =		8	
SPAN	235.38		IN H2O
URL/SPAN	1.062		
MAX DP	235.38		IN H2O

% OF MAX FLOW	FLOW GPM	DP IN H2O	DP UNCERT % OF SPAN +/-	DP UNCERT % OF RDG +/-	DP UNCERT IN H2O +/-	DP CELL POS UNCERT % OF FLOW	DP CELL NEG UNCERT % OF FLOW	PRIMARY ELEMENT CD UNCERT +/- %	REYNOLDS NUMBER x 10^{-3}	REYNOLDS NO. BIAS % OF FLOW	REYNOLDS NO,. RANDOM UNCERT +/-%	UPSTREAM DISTURBER BIAS % OF FLOW	SYSTEM UNCERT + % OF FLOW	SYSTEM UNCERT - % OF FLOW
100	1750.000	235.380	n/a	0.040	0.094	0.020	-0.020	1.000	823	0.000	0.000	0.000	1.000	-1.000
74.315	1300.517	129.995	n/a	0.040	0.052	0.020	-0.020	1.000	611	0.000	0.000	0.000	1.000	-1.000
54.728	957.745	70.501	n/a	0.040	0.028	0.020	-0.020	1.000	450	0.000	0.000	0.000	1.000	-1.000
35.850	627.372	30.251	n/a	0.059	0.018	0.029	-0.030	1.000	295	0.060	0.180	0.000	1.240	-1.120
28.815	504.270	19.544	n/a	0.069	0.014	0.035	-0.035	1.000	237	0.120	0.380	0.000	1.500	-1.260
23.049	403.351	12.504	n/a	0.086	0.011	0.043	-0.043	1.000	190	0.200	0.780	0.000	1.981	-1.581
18.342	320.987	7.919	n/a	0.113	0.009	0.056	-0.056	1.000	151	0.300	1.180	0.000	2.481	-1.881
16.330	285.777	6.277	n/a	0.132	0.008	0.066	-0.066	1.000	134	0.670	1.330	0.000	3.001	-1.661
14.519	254.082	4.962	n/a	0.156	0.008	0.078	-0.078	1.000	119	1.040	1.330	0.000	3.371	-1.291
12.891	225.586	3.911	n/a	0.187	0.007	0.093	-0.094	1.000	106	1.410	1.330	0.000	3.742	-0.922
11.429	200.000	3.074	n/a	0.227	0.007	0.113	-0.114	1.000	94	1.780	1.330	0.000	4.113	-0.553
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**



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(FIGURE 1)

Figure 1 is an example of a complete metering system comprised of a 6.0" classical Venturi meter as the primary flow element and an Emerson's Rosemount* 3051S Ultra for Flow smart DP transmitter as the secondary instrument element. Note the following:

a. Assuming the MFC-3M type venturi meter is used (MFC-3M includes the ISO5167 and ASME type classical venturi meters), the basic accuracy of the venturi meter is +/-1.0% of rate but, as you will note in column# 10, the Reynolds number is dropping as a function of the flow rate and a plus and minus bias error begins developing at approximately 295,000 pipe Reynolds number and increases as the flow rate continues to drop. As noted from columns 14 and 15, the result of the integrated system accuracy analysis is +/-1.0% of actual rate of flow at the maximum rate of 1750 GPM and +4.113/-0.553% of actual rate of flow at the minimum flow of 200 GPM.

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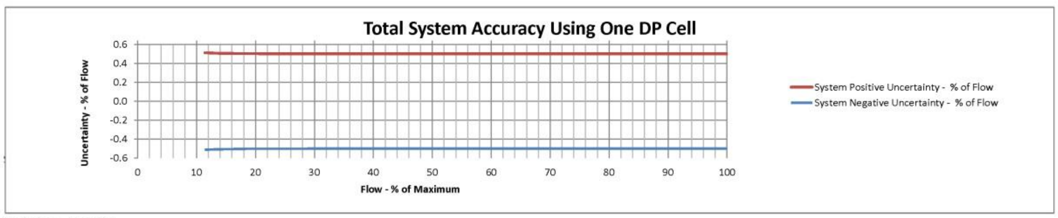
Accuracy of the Flow Metering System

Customer:	0	Line Size:	6	Max. Flow	1750	GPM
Project:	0	Pipe ID:	6	Min. Flow	200	GPM
PFS Quote No.:	0	Throat Dia:	4.2	DP @ Max. Flow:	237.76	IN H2O
Serial No.:		Beta:	0.70000	DP @ Min. Flow:	3.105	IN H2O
Tag:	FIGURE 2	Meter Type:	PFS-HVT SERIES	Max. Reynolds No. x 10^{-3}	822.832	
		Model:	HVT-FV			

SINGLE DP CELL			
MODEL	Emerson's Rosemount Model 3051S Ultra for Flow		
URL	250	IN H2O	
BASIC UNCERTAINTY =	0.04	% OF RDG	
SECONDARY UNCERTAINTY =	0.04	+ A % OF RDG	
A =	0.0023	x URL/RDG	
INVOKE SECONDARY @ URL/RDG =		8	
SPAN	237.76		IN H2O
URL/SPAN	1.051		
MAX DP	237.76		IN H2O

% OF MAX FLOW	FLOW GPM	DP IN H2O	DP UNCERT % OF SPAN +/-	DP UNCERT % OF RDG +/-	DP UNCERT IN H2O +/-	DP CELL POS UNCERT % OF FLOW	DP CELL NEG UNCERT % OF FLOW	PRIMARY ELEMENT CD UNCERT +/- %	REYNOLDS NUMBER x 10^{-3}	REYNOLDS NO. BIAS % OF FLOW	REYNOLDS NO,. RANDOM UNCERT +/-%	UPSTREAM DISTURBER BIAS % OF FLOW	SYSTEM UNCERT + % OF FLOW	SYSTEM UNCERT - % OF FLOW
100	1750.000	237.760	n/a	0.040	0.095	0.020	-0.020	0.500	823	0.000	0.000	0.000	0.500	-0.500
74.315	1300.517	131.309	n/a	0.040	0.053	0.020	-0.020	0.500	611	0.000	0.000	0.000	0.500	-0.500
54.728	957.745	71.213	n/a	0.040	0.028	0.020	-0.020	0.500	450	0.000	0.000	0.000	0.500	-0.500
49.318	863.062	57.829	n/a	0.040	0.023	0.020	-0.020	0.500	406	0.000	0.000	0.000	0.500	-0.500
35.850	627.372	30.557	n/a	0.059	0.018	0.029	-0.029	0.500	295	0.000	0.000	0.000	0.501	-0.501
28.815	504.270	19.742	n/a	0.069	0.014	0.035	-0.035	0.500	237	0.000	0.000	0.000	0.501	-0.501
23.049	403.351	12.631	n/a	0.086	0.011	0.043	-0.043	0.500	190	0.000	0.000	0.000	0.502	-0.502
18.342	320.987	7.999	n/a	0.112	0.009	0.056	-0.056	0.500	151	0.000	0.000	0.000	0.503	-0.503
16.330	285.777	6.340	n/a	0.131	0.008	0.065	-0.065	0.500	134	0.000	0.000	0.000	0.504	-0.504
14.519	254.082	5.012	n/a	0.155	0.008	0.077	-0.077	0.500	119	0.000	0.000	0.000	0.506	-0.506
12.891	225.586	3.951	n/a	0.186	0.007	0.093	-0.093	0.500	106	0.000	0.000	0.000	0.509	-0.509
11.429	200.000	3.105	n/a	0.225	0.007	0.113	-0.113	0.500	94	0.000	0.000	0.000	0.513	-0.513
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15



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(FIGURE 2)

Figure 2 shows what the system accuracy performance would be with a modified short form type Venturi meter (a refinement of the classical Venturi meter design that includes improved accuracy, lower minimum pipe Reynolds number requirement, and lower headloss among a number of advantages). The basic accuracy of the Venturi meter is maintained down to a much lower flow rate compared to Figure 1. While the classical Venturi meter in Figure 1 has a +/-1.0% accuracy, the modified short form design in Figure 2 is based on +/-0.5% of rate standard accuracy.

The pipe Reynolds number may be a potential limiting factor when applying differential pressure technology in a flow metering design, depending on what the minimum flow rate pipe Rd. As a practical matter, there is generally no upper end Reynolds number requirement with certain types of differential producers, some of which are used for very high Reynolds number applications in the 35 to 50 million Rd range.

Recognizing this low pipe Rd limitation, Primary Flow Signal Inc. has developed a modified Venturi meter design that eliminates the 75,000 pipe Rd limitation and allows for a laboratory calibrated accuracy of +/-0.25% down to as low as 6,000 pipe Reynolds number. The benefit of this design is clear when taking into account the system accuracy performance in Figure 3.

(FIGURE 3)

PRIMARY FLOW SIGNAL, INC.

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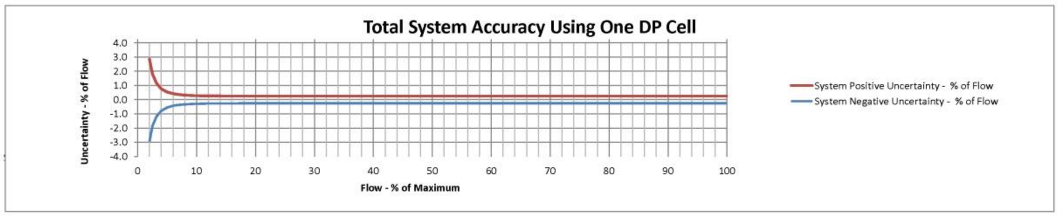
Accuracy of the Flow Metering System

Customer:	0	Line Size:	6		Max. Flow	745	GPM
Project:	0	Pipe ID:	6		Min. Flow	15	GPM
PFS Quote No.:	0	Throat Dia:	3.17		DP @ Max. Flow:	246.74	IN H2O
Serial No.:		Beta:	0.52833		DP @ Min. Flow:	0.100	IN H2O
Tag:	FIGURE 3	Meter Type:	PFS FVFLF (HBX-1)		Max. Reynolds No. x 10^{-3}	350.291	
		Model:	PFS-FVFLF				

SINGLE DP CELL			
MODEL	Emerson's Rosemount Model 3051S Ultra for Flow		
URL	250	IN H2O	
BASIC UNCERTAINTY =	0.04	% OF RDG	
SECONDARY UNCERTAINTY =	0.04	+ A % OF RDG	
A =	0.0023	x URL/RDG	
INVOKE SECONDARY @ URL/RDG =		8	
SPAN	246.74	IN H2O	
URL/SPAN	1.013		
MAX DP	246.74	IN H2O	

% OF MAX FLOW	FLOW GPM	DP IN H2O	DP UNCERT % OF SPAN +/-	DP UNCERT % OF RDG +/-	DP UNCERT IN H2O +/-	DP CELL POS UNCERT % OF FLOW	DP CELL NEG UNCERT % OF FLOW	PRIMARY ELEMENT CD UNCERT +/- %	REYNOLDS NUMBER x 10^{-3}	REYNOLDS NO. BIAS % OF FLOW	REYNOLDS NO,. RANDOM UNCERT +/-%	UPSTREAM DISTURBER BIAS % OF FLOW	SYSTEM UNCERT + % OF FLOW	SYSTEM UNCERT - % OF FLOW
100	745.000	246.740	n/a	0.040	0.099	0.020	-0.020	0.250	350	0.000	0.000	0.000	0.251	-0.251
60.829	453.173	91.297	n/a	0.040	0.037	0.020	-0.020	0.250	213	0.000	0.000	0.000	0.251	-0.251
36.051	268.581	32.069	n/a	0.040	0.013	0.020	-0.020	0.250	126	0.000	0.000	0.000	0.251	-0.251
17.149	127.761	7.256	n/a	0.119	0.009	0.060	-0.060	0.250	60	0.000	0.000	0.000	0.257	-0.257
11.573	86.219	3.305	n/a	0.214	0.007	0.107	-0.107	0.250	41	0.000	0.000	0.000	0.272	-0.272
7.685	57.255	1.457	n/a	0.435	0.006	0.217	-0.218	0.250	27	0.000	0.000	0.000	0.331	-0.331
5.015	37.362	0.621	n/a	0.967	0.006	0.482	-0.484	0.250	18	0.000	0.000	0.000	0.543	-0.545
4.023	29.970	0.399	n/a	1.480	0.006	0.737	-0.743	0.250	14	0.000	0.000	0.000	0.779	-0.784
3.211	23.921	0.254	n/a	2.300	0.006	1.144	-1.157	0.250	11	0.000	0.000	0.000	1.171	-1.184
2.550	18.994	0.160	n/a	3.625	0.006	1.796	-1.829	0.250	9	0.000	0.000	0.000	1.814	-1.846
2.013	15.000	0.100	n/a	5.789	0.006	2.854	-2.937	0.250	7	0.000	0.000	0.000	2.864	-2.948
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15



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While Figures 1 and 2 were based on a minimum to maximum flow rate range of 8:1, Figure 3 expands that range to 50:1 but continues to utilize (1) Emerson's Rosemount* 3051S Ultra for Flow model DP transmitter. One other element in analyzing the system accuracy performance of any Venturi tube is the magnitude of the differential produced by the Venturi meter at the minimum flow rate since the secondary instrumentation that is typically used with a Venturi meter is a differential pressure transmitter. As the performance capabilities of differential pressure transmitters have improved over the years as the result of the transmitter manufacturers changing from analog to digital signal processing. Additionally, there have been significant improvements in the pressure sensing cell and method of signal processing elements of the transmitter. Where the analog type transmitter required 1.0" of differential at the minimum flow rate, today's smart digital transmitter can process an input differential as low as 0.10" of water depending on line conditions including maintaining low acoustic noise to produced pressure ratios.

Figure 4 is the same meter as depicted in Figure 3 but designed around a split range (stacked transmitter) system and changing the model of the DP transmitter to the Emerson's Rosemount* 3051S Ultra.

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Total System Accuracy Using Two

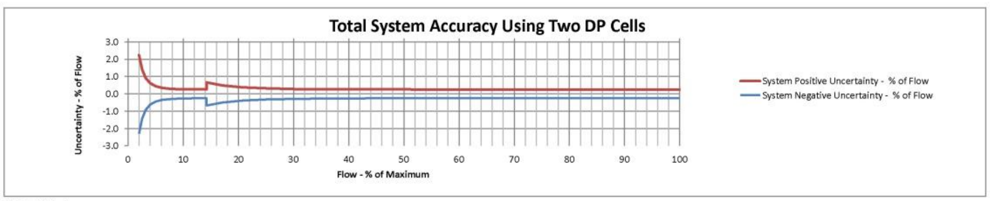
Accuracy of the Flow Metering System

Customer:	0	Line Size:	6		Max. Flow	745	GPM
Project:	0	Pipe ID:	6		Min. Flow	15	GPM
PFS Quote No.:	0	Throat Dia:	3.17		DP @ Max. Flow:	246.74	IN H2O
Serial No.:		Beta:	0.52833		DP @ Min. Flow:	0.100	IN H2O
Tag:	FIGURE 4	Meter Type:	PFS-FVFLF (HBX-1)		Max. Reynolds No. x 10^{-3}	350.291	
		Model:	PFS-FVFLF				

DP CELL 1		
MODEL	Emerson's Rosemount Model 3051S Ultra	
URL	250	IN H2O
BASIC UNCERTAINTY =	0.025	% OF SPAN
SECONDARY UNCERTAINTY =	0.005	+ A % OF SPAN
A =	0.0035	x URL/SPAN
INVOKE SECONDARY @ URL/SPAN =	10	
SPAN	246.74	IN H2O
URL/SPAN	1.013	
MAX DP	246.74	IN H2O

DP CELL 2		
MODEL	Emerson's Rosemount Model 3051S Ultra	
URL	25	IN H2O
BASIC UNCERTAINTY =	0.09	% OF SPAN
SECONDARY UNCERTAINTY =	0.015	+ A % OF SPAN
A =	0.005	x URL/SPAN
INVOKE SECONDARY @ URL/SPAN =	15	
SPAN	5	IN H2O
URL/SPAN	5.000	
XOVER FLOW	106	GPM

% OF MAX FLOW	FLOW GPM	DP IN H2O	DP UNCERT % OF SPAN +/-	DP UNCERT % OF RDG +/-	DP UNCERT IN H2O +/-	DP CELL POS UNCERT % OF FLOW	DP CELL NEG UNCERT % OF FLOW	PRIMARY ELEMENT CD UNCERT +/- %	REYNOLDS NUMBER x 10^{-3}	REYNOLDS NO. BIAS % OF FLOW	REYNOLDS NO,. RANDOM UNCERT +/-%	UPSTREAM DISTURBER BIAS % OF FLOW	SYSTEM UNCERT + % OF FLOW	SYSTEM UNCERT - % OF FLOW
100	745.000	246.740	0.025	n/a	0.062	0.012	-0.013	0.250	350	0.000	0.000	0.000	0.250	-0.250
60.829	453.173	91.297	0.025	n/a	0.062	0.034	-0.034	0.250	213	0.000	0.000	0.000	0.252	-0.252
36.051	268.581	32.069	0.025	n/a	0.062	0.096	-0.096	0.250	126	0.000	0.000	0.000	0.268	-0.268
17.149	127.761	7.256	0.025	n/a	0.062	0.424	-0.426	0.250	60	0.000	0.000	0.000	0.492	-0.494
11.573	86.219	3.305	0.090	n/a	0.005	0.068	-0.068	0.250	41	0.000	0.000	0.000	0.259	-0.259
7.685	57.255	1.457	0.090	n/a	0.005	0.154	-0.155	0.250	27	0.000	0.000	0.000	0.294	-0.294
5.015	37.362	0.621	0.090	n/a	0.005	0.362	-0.363	0.250	18	0.000	0.000	0.000	0.440	-0.441
4.023	29.970	0.399	0.090	n/a	0.005	0.562	-0.565	0.250	14	0.000	0.000	0.000	0.615	-0.618
3.211	23.921	0.254	0.090	n/a	0.005	0.881	-0.888	0.250	11	0.000	0.000	0.000	0.915	-0.923
2.550	18.994	0.160	0.090	n/a	0.005	1.393	-1.413	0.250	9	0.000	0.000	0.000	1.415	-1.435
2.013	15.000	0.100	0.090	n/a	0.005	2.225	-2.275	0.250	7	0.000	0.000	0.000	2.239	-2.289
14.228	106.001	4.995	0.025	n/a	0.062	0.616	-0.619	0.250	50	0.000	0.000	0.000	0.664	-0.668
14.227	105.990	4.994	0.090	n/a	0.005	0.045	-0.045	0.250	50	0.000	0.000	0.000	0.254	-0.254
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**



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(FIGURE 4)

Note in Figure 4 that crossover point between the high and low range DP transmitters is 14.228% of full scale and the 50:1 integrated system accuracy noted in the (2) far right columns as +/- 0.25% of actual rate of flow at max flow of 745 GPM and +2.239/-2.289% of actual rate of flow at the minimum rate of 15 GPM.

There is no question that the opportunity to effectively design a highly accurate flow metering system using a Venturi meter primary element is primarily due to the result of significant advances in differential pressure transmitter design and performance.
Conclusions:

1. Accurate and reliable system accuracy performance can be assured using a low Reynolds number Venturi meter like the PFS-HBX-1 and a smart differential pressure transmitter on low and ultra-low flow applications where other flow measurement technologies, such as magnetic and ultrasonic meters, suffer from poor accuracy performance due to low line velocity conditions.
2. Wide range flow metering can now be accomplished by selecting the right differential pressure transmitter, including multiple transmitters for wide range applications.

*The performance data for the Rosemount brand differential pressure transmitters used in all of the system accuracy figures was provided courtesy of Rosemount Inc.