Analysis of Pressure Effects on Rotary PD Meter Performance and Calibration

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ABSTRACT

Rotary Positive Displacement Meters (RPD Meters) are being extensively used in Custody Transfer application of Industrial Gases for the past several years. The wide popularity of PD meters attributed to its high level of metering accuracy in tantalization and improved confidence level offered in batch rate monitoring.

Generally these meters are supplied with calibration at a single operating condition, mostly using Air at a pressure and temperature close to atmosphere. In practice, they are required to perform at different pressure and density condition within its declared specifications and range.

It is interesting and worthwhile to understand the behavior of the PD meters over a wide variety of operating conditions. Only specific and extensive laboratory experimentation can throw light on such aspects.

In this paper the influence of pressure effects are detailed based on actual calibration performed under varying conditions of pressure.

Key words: Rotary PD meter, Pressure effects, Performance, Calibration.

1. INTRODUCTION

Rotary type gas PD meters are widely used in City Gas Distribution networks. The flow measurement is by trapping the fluid between the impellers that rotates in opposite directions. The bottom of impeller turns anticlockwise, there by trapping the gas to the space between the impeller and the casing. As the impeller reaches the horizontal position the gas is holding between the impeller and the case walls shown in Fig. 1. As the impeller continues to rotate, the trapped gas escape through the outlet.

The PD meter requires fluid energy to physically or mechanically rotate the rotor of the meter to measure the volume; therefore, it achieves volumetric flow. The rotor speed is proportional to the fluid volume transferred. The rotor speed is converted to volume through mechanical gear trains. This volume can be read out from the integral counters or through a frequency out. The frequency output may be in HF or

LF format. The pressure drop across the meter depends on the rotor speed and fluid properties at flowing condition. A typical construction of PD meter is shown in Fig. 2.

However, in many applications, rotary PD meters are used to infer mass flow even though they measure the volumetric flow. This is achieved by using additional parameters like pressure, temperature and gas physical properties.

1.1 Advantages

The rotary PD meter is recognized for its high accuracy over a wide flow range and is widely used in utility billing and batch metering. Over the years, comparatively less accurate diaphragm meters are being replaced, particularly in the larger commercial and industrial sized meters, with a better and smaller rotary PD meter.

1.2 Limitations

The main disadvantage of these meters is their sensitivity to gas flow rate and to the change of the gas pressure and viscosity. The moving parts and close tolerances restrict them to use in clean and dry gases environment. Since the meter measures only volumetric flow, it also requires pressure and temperature compensation to obtain corrected gas flow to a standard or base conditions.

2. FLOW REGISTRATION

Increasing the operating pressure of the gas will cause the flow meter body to expand and cause it to under-register.

Increasing the temperature of the gas will cause both the gas and the meter body to expand. These effects will balance each other if the expansion of gas and meter body by the same amount. This is generally not happen and hence the measurement will register an error which dependent upon the difference in the expansion rates. Gas will often expand more than the flow meter body so the flow measurement will tend to over-register.

PD flow meters have physical tolerances among its rotors and the body that allow some gas to leak through the flow meter. This leak is called slippage and typically tends the PD meters to under-register. Increasing the temperature of the gas will tend to decrease its viscosity. Decreasing viscosity tends to increase the slippage. This will allow more unmeasured fluid to pass through the flow meter there by the measurement can under-register.

3. ACCURACY

The overall accuracy of a PD meter is defined as the degree to which a meter correctly measures the volume of gas passing through it. Accuracy is determined by comparing the volume registered by the meter with a known volume registered by a reference device.

The accuracy of a rotary PD meter is built-in through the machining tolerances of its rotors and body parts and cannot be adjusted once it is assembled. Since the volume of the measurement chamber does not change at a given pressure and temperature of the gas, the only factor that can affect accuracy is an increase in internal friction within the meter, which allows gas to slip through the clearances. The Maximum permissible errors of gas meters based on the accuracy class, as per OIML R137 [1], is shown in Fig. 3.

However in varying operating conditions, the rotary PD meter performance depends on the tolerance between its parts, fluid type, pressure, viscosity, pressure drop across the meter and the rotor speed that is related to the flow rate and a few other parameters. Increasing demands for improved measurement accuracy require deeper knowledge on influencing dynamic factors and gas physical properties to determine the meters' error pattern.

The K-Factor shift of a PD meter in response to gas pressure variation is yet to be established in a broad way. Because of the nature of measuring the flow quantity, the error related to operating gas pressure variations is to be established through a calibration.

Expensive and complex procedures and equipment are required for calibration, assigning the value for the K-factor and to ensure the measurement accuracy in their wide operating conditions. Calibration in operating medium such as Natural gas, may make the process more expensive and risky, but selecting an Air medium provides an economy. Hence as an initial step, it is relevant to establish the measurement accuracy of these meters under various pressure conditions using Air medium.

Once the effect of pressure is established in Air medium, studies can be done in other variables later.

4. EXPERIMENTAL PROGRAM

As a startup, Rotary PD meters of sizes up to 80mm available at FCRI were used. The meter lot comprises of sizes40mm, 50mm and 80mm from five different manufacturers. Each manufacturer is coded from A to E in order to keep the confidentiality. One 40mm and one 50 mm size meters were selected from manufacturer A. One 50mm and one 80mm meters were selected from manufacturer B. One 50mm was selected from manufacturer C. Two 80mm meters were selected from manufacturer D. One 80mm meter was selected from manufacturer E. The size and flow ranges of the PD meters are given in Table 1.

These meters were calibrated at four or five different pressure ranges from 1 bar to 20 bar. Critical Flow Venturi Nozzles (Sonic nozzles) and Turbine meters were used for reference flow measurement depending on the flow rate to be covered during calibration.

5. EXPERIMENTAL FACILITY

The 20 bar Air Test Facility of FCRI is equipped with Critical Flow Venturi Nozzles and Turbine meters as references. The facility can operate between 1 to 20 bar pressures.

5.1 Critical Flow Venturi Nozzles (Sonic Nozzles).

There are eight numbers of Critical Flow Venturi Nozzles (Sonic Nozzles)with flow rate ranges from 0.8 to 50 m³/h actual. They works in an open loop system. The PD meter under calibration is mounted at upstream of the selected nozzle. Different nozzles are used to cover the flow meter range. The set up operates at ambient conditions. The calibration uncertainty is about 0.15% reading. ISO 9300 describes the design and requirements of critical flow venturi nozzles [2].The schematic of the set-up is given in Fig. 4.The critical flow venturi nozzles are shown in Plate 1.

Plate 1 Critical Flow Venturi Nozzles

5.2 Turbine meters.

The Turbine meters are having flow rate ranges from 10 to 400 m³/h. They are operating in a closed loop system. Air temperature is maintained at about 25 °C using a counter flow type heat exchanger. The calibration uncertainty is about 0.30% reading. ISO 9951 describes the design and requirements of Turbine meters [3]. The Closed Loop System's instrument is traceable to National standards and accredited to NABL [3].The schematic of the set-up is given in Fig. 5.The facility is shown in Plate 2.

Plate 2 Closed Loop Air Test Facility

Traceability of the reference critical flow venture nozzles and turbine meters was maintained by calibrating them with Primary Standard Gravimetric System with an uncertainty of 0.1%.The system's instrument is traceable to National standards and accredited to NABL [4]. The schematic set-up is shown in Fig. 6. The setup is shown in Plate 3

6. CALIBRATION

The PD meters having maximum flow rates up to 65 m³/h (G40) was calibrated against Critical Flow venture Nozzles in the Open Loop System. A typical data is shown in Table. 2. The PD meters having maximum flow rate above 65 m³/h and up to 400 m³/h were calibrated against Turbine meters in the Closed Loop System. A typical data is shown in Table. 3.

The static Pressures were measured using Multifunctional Pressure Indicators and temperatures were measured using Digital Temperature indicators with PT 100 RTD probes. The High frequency output signal is used in all cases. Pressure measurement uncertainty is about 0.025% and temperature uncertainty is less than 0.1 °C. All the secondary instruments used are traceable to National Standards.

Plate 3 Primary Standard Gravimetric System

6.1 Calibration procedure

The rotary PD meter is connected at upstream of the critical venture nozzles whereas it is mounted at downstream in the case of Turbine meter as reference. Flow is established through the system. Pressure and temperature from the reference and PD meter are recorded electronically. Pulse from PD meter over a pre-determined period was recorded. For each meter Air flow rate varied in the range specified by the meter manufacturer. Error is calculated from the actual estimated volume flow rate and that from the PD meter using the manufacturer's K-factor given along with the meter.

The results of meter' errors variation were analyzed. In all cases, the influence of the temperature and viscosity in the measurement results were not considered.

7. ANALYSIS OF RESULTS

The experimental results of errors dependence on Flow rate at different pressures are shown in Figures7.1through 7.8.Since PD meters have different error zone, a higher value below Qt and a lower value above Qt, the analysis is focused only with flow rate above Qt. Fig. 7.1 shows the results of PD meters of size 40mm and Fig. 7.2 through Fig. 7.4 shows the results of 50mm meters. Fig. 7.5 through Fig. 7.8 shows the results of 80mm meters.

It can be observed from Fig. 7.1 and Fig. 7.2 that the error pattern fairly remains same in their operating flow and pressure range. In Fig. 1, the error shifted from -0.44% at 1 bar to +0.42% at 20 bar at the maximum flow rate of 25 m³/h which is about 1% absolute. A similar shift is observed at the midrange also. The errors are almost same at flow rate close to Qt. From Fig. 7.2, a similarity in the error shift pattern can be seen compared with Fig. 1. However the shift in the magnitude of error is about 0.5%.Both meters are from the same manufacturer A.

Fig. 7.2, Fig. 7.3 and Fig. 7.4 shows the errors in a 50mm meter from three different manufacturers, A, B and C. All the three have different error patterns. Fig. 7.2 shows the magnitude of error are close over their flow range at different pressures. Whereas Fig. 7.3 and Fig. 7.4 shows a wide variation in the magnitude of errors over their flow range. However in all the above three cases, the error sign marginally moves from -ve to +ve direction with respect to increase in operating pressures. These results indicates the influence of pressure on K-factor or meter performance.

Fig. 7.5 through Fig. 7.8 shows the results of 80mm meters. The meters are from three different manufacturers. Fig. 7.6 and Fig. 7.7 are the meters from the same manufacturer, but having different G number or flow range. The error patterns are different from that observed in 50mm size. In Fig. 7.5, the error values moves from +ve to –ve with increase in pressure. This trend is reverse of that observed in the 50mm meter from the same manufacturer, B. Fig. 7.6 through Fig. 7.8 shows that the errors varies randomly and scattered in magnitude and direction in the case of manufacturer D and E.

The error pattern is different with respect to size from the same manufacturer and different with respect to same size from different manufacturer.

The variation in magnitude and direction of errors increases with increase in meter size.

8. CONCLUSION

1. The analysis indicates the presence of pressure influence on the performance of rotary PD meters.
2. The variation in magnitude of errors increases with increase in line size.
3. The variation in the direction of error sign different with line size and manufacturer.
4. Meters from different manufacturers have different error characteristics.
5. The above conclusions are with limited number of meter sizes and manufacturers.
6. More experiments are suggested with more meter size and many different manufacturers.

9. REFERENCES

1. OIML R 137-1&2, 2012 :
   Part 1: Metrological and technical requirements.
   Part 2: Metrological controls and performance tests.
2. ISO 9300, ‘Measurement of gas flow by means of critical flow Venturi nozzles’.
3. ISO 9951, ‘Measurement of gas flow in closed conduits – Turbine meters’.
4. R. Mascomani, C.B. Suresh et all, Traceability, Uncertainty and Accreditation of 20 bar CLATF of

FCRI, International Conference on Hydrocarbon Flow Measurement, FCRI India, Sep 22-24 : 2003.

5. C. B. Suresh et all, "20 bar Air Test Facilities – Up gradation and Validation", Global Conference and Exhibition on Towards Intelligent Flow measurement and Control System, FCRI India, Sep 26-28: 2007.

Sl. NO.	Size Inch	Manufacturer Code	G No.	Flow range, m³/h Min.	Max.
1	1½	A	G16	0.5	25
2	2	A	G40	0.8	65
3	2	B	G40	3.2	65
4	2	C	G16	1.0	25
5	3	B	G100	8.0	160
6	3	D	G160	2.5	250
7	3	D	G250	4.0	400
8	3	E	G160	2.6	250

Table1 Rotary PD meter Details

Sl. No.	Reference nozzle			Item under calibration			
	Nozzle No.	Pressure P_r	Temperature T_r	Pressure P_t	Temperature T_t	Pulse F_t	Time taken t_t
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1	SN1	11.1793	31.22	11.2074	30.30	6484	60
2	SN2	11.2530	31.74	11.2685	30.65	4879	60
3	SN2	11.2532	31.58	11.2647	30.64	4878	60
4	SN2	11.2520	31.40	11.2645	30.61	4877	60
5	SN2	11.2523	31.27	11.2640	30.59	4878	60
6	SN2	11.2508	31.15	11.2622	30.57	4878	60
7	SN3	11.3001	31.69	11.3047	30.45	3233	60
8	SN4	11.3234	31.76	11.3244	30.42	1631	60
9	SN5	11.1923	31.39	11.1905	30.72	816	60
10	SN6	11.3548	31.51	11.3526	30.36	1219	180
11	SN8	11.3738	31.93	11.3678	30.33	599	360
12	SN1	19.5018	30.07	19.5664	28.73	6493	60
13	SN2	19.6616	30.32	19.6732	28.87	4881	60
14	SN3	19.8556	30.55	19.8639	29.04	3238	60
15	SN4	20.0851	30.49	20.0839	29.50	3271	120
16	SN5	20.1532	30.51	20.1530	29.46	1634	120
17	SN6	20.1785	31.20	20.1759	29.31	1222	180
18	SN8	20.2048	30.93	20.2018	29.41	504	300
19	SN1	5.0696	30.64	5.0809	29.60	6472	60
20	SN2	5.0975	30.57	5.1006	29.61	4880	60
21	SN3	5.1222	30.53	5.1242	29.61	3232	60
22	SN4	5.0932	30.30	5.0939	29.58	8162	300
23	SN5	5.1530	31.09	5.1523	29.61	4053	300
24	SN6	5.3730	31.12	5.3714	30.15	2037	300
25	SN8	5.3929	31.29	5.3923	30.23	597	300
26	SN1	2.1993	31.31	2.2037	30.32	6477	60
27	SN2	2.2265	31.22	2.2283	30.37	4882	60
28	SN3	2.2375	31.43	2.2383	30.40	3233	60
29	SN4	2.2537	31.23	2.2528	30.43	1629	60
30	SN5	2.2679	31.38	2.2667	30.49	1620	120
31	SN6	2.2998	31.34	2.2977	30.60	1212	180
32	SN8	2.3104	31.38	2.3093	30.63	498	300

Compressed Air Relative humidity , % **0**

Table 2 Typical Data in the Open Loop System.

Sl. No.	Reference Meter 1				Reference Meter 2				Item under test		
	Pressure P_r bar a	Temperature T_r °C	Pulses F_r -	Time t_r s	Pressure P_r bar a	Temperature T_r °C	Pulses F_r -	Time t_r s	Pressure P_t bar a	Temperature T_t °C	Indicated reading m^3/h
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]
1	17.3513	25.43	104111	60	-	-	-	-	17.1738	26.10	396.0
2	17.4314	25.63	80597	60	-	-	-	-	17.3276	26.08	306.0
3	17.6165	24.72	54236	60	-	-	-	-	17.5725	26.41	204.0
4	17.4743	25.56	53091	60	-	-	-	-	17.4359	26.28	198.0
5	17.4503	25.53	53114	60	-	-	-	-	17.4112	26.28	198.0
6	17.4295	25.51	53100	60	-	-	-	-	17.3902	26.26	198.0
7	17.3979	25.47	53077	60	-	-	-	-	17.3568	26.24	198.0
8	17.3697	25.47	53074	60	-	-	-	-	17.3306	26.21	198.0
9	17.3780	25.51	26959	60	-	-	-	-	17.3731	26.23	102.0
10	16.8367	20.74	13347	60	-	-	-	-	16.8434	26.88	50.4
11	16.8160	21.70	2802	60	-	-	-	-	16.8257	25.24	10.8
12	-	-	-	-	16.2970	29.76	14645	60	16.2916	25.94	9.6
13	-	-	-	-	16.1113	25.58	7492	60	16.1057	26.83	4.8
14	19.6112	25.23	103723	60	-	-	-	-	19.4107	25.64	396.0
15	19.6628	25.52	80326	60	-	-	-	-	19.5458	25.78	306.0
16	19.6901	25.62	52941	60	-	-	-	-	19.6424	26.04	198.0
17	19.6537	25.65	27504	60	-	-	-	-	19.6490	26.04	102.0
18	19.2292	24.60	13379	60	-	-	-	-	19.2349	25.68	50.4
19	-	-	-	-	18.9060	27.24	15312	60	18.8999	25.82	9.6
20	-	-	-	-	18.7923	25.71	7167	60	18.7840	26.02	4.8
21	-	-	-	-	18.9696	25.55	15124	60	18.9615	26.08	9.6
22	19.6901	25.66	27499	60	-	-	-	-	19.6836	26.01	102.0
23	19.7269	25.64	52940	60	-	-	-	-	19.6810	25.98	198.0
24	19.7024	25.45	80336	60	-	-	-	-	19.5838	25.70	306.0
25	19.6243	25.15	102932	60	-	-	-	-	19.4266	25.37	390.0
26	10.9239	24.03	104452	60	-	-	-	-	10.8131	25.40	396.0
27	11.0093	24.96	79777	60	-	-	-	-	10.9486	25.49	300.0
28	11.0601	24.99	53071	60	-	-	-	-	11.0383	25.68	198.0
29	11.0734	24.99	26745	60	-	-	-	-	11.0736	25.82	102.0
30	11.0212	24.39	13677	60	-	-	-	-	11.0272	25.93	51.6
31	-	-	-	-	10.7366	24.99	15414	60	10.7326	26.91	9.6
32	-	-	-	-	10.7169	26.31	7161	60	10.7134	27.31	4.8
33	6.0779	23.65	104570	60	-	-	-	-	6.0183	26.26	402.0
34	6.1284	24.74	80485	60	-	-	-	-	6.0974	25.84	306.0
35	6.1580	24.79	53151	60	-	-	-	-	6.1495	25.91	198.0
36	6.1585	24.67	27896	60	-	-	-	-	6.1631	26.37	102.0
37	6.1365	24.26	13563	60	-	-	-	-	6.1446	26.57	51.6
38	-	-	-	-	5.9776	25.92	15426	60	5.9769	27.69	9.6
39	-	-	-	-	5.9670	25.76	7610	60	5.9669	27.76	4.8
40	2.9932	22.36	103559	60	-	-	-	-	2.9680	24.90	396.0
41	3.0235	24.11	80041	60	-	-	-	-	3.0116	24.91	300.0
42	3.0402	25.40	53659	60	-	-	-	-	3.0391	25.52	198.0
43	3.0400	24.26	26667	60	-	-	-	-	3.0458	25.95	102.0
44	3.0402	24.18	13488	60	-	-	-	-	3.0473	26.09	50.4
45	-	-	-	-	3.0289	27.32	15194	60	3.0295	26.86	9.6
46	-	-	-	-	3.0299	27.26	7378	60	3.0304	27.02	4.8

Table 3 Typical Data in the Closed LoopSystem.

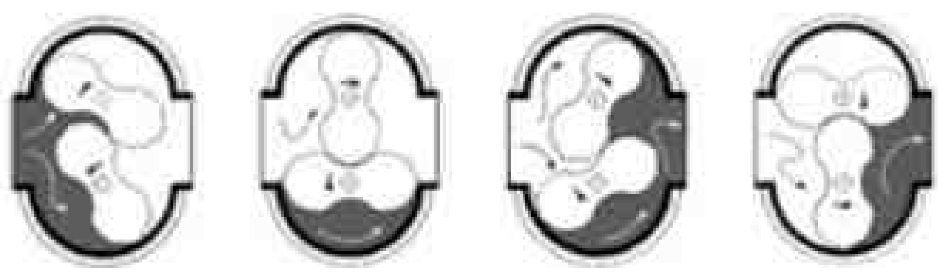


Fig. 1 Flow through a Rotary PD meter

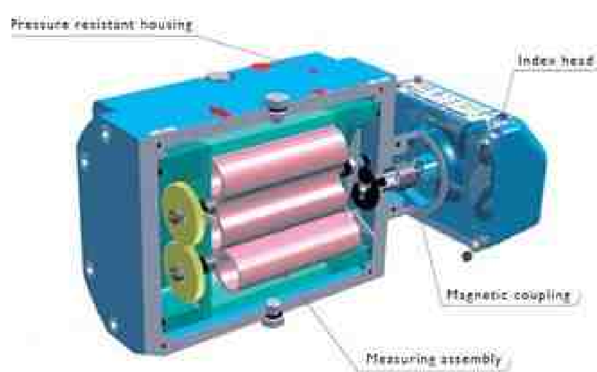


Fig. 2 Typical PD meter construction

Flow rate	Type approval and initial verification Accuracy class			In service* Accuracy class		
	0.5	1	1.5	0.5	1	1.5
$Q_{min} < Q < Q_t$	±1	±2	±3	±2	±4	±6
$Q_t < Q < Q_{max}$	±0.5	±1	±1.5	±1	±2	±3

Fig. 3 Typical PD meter accuracy limit (OIML R137, 2012)

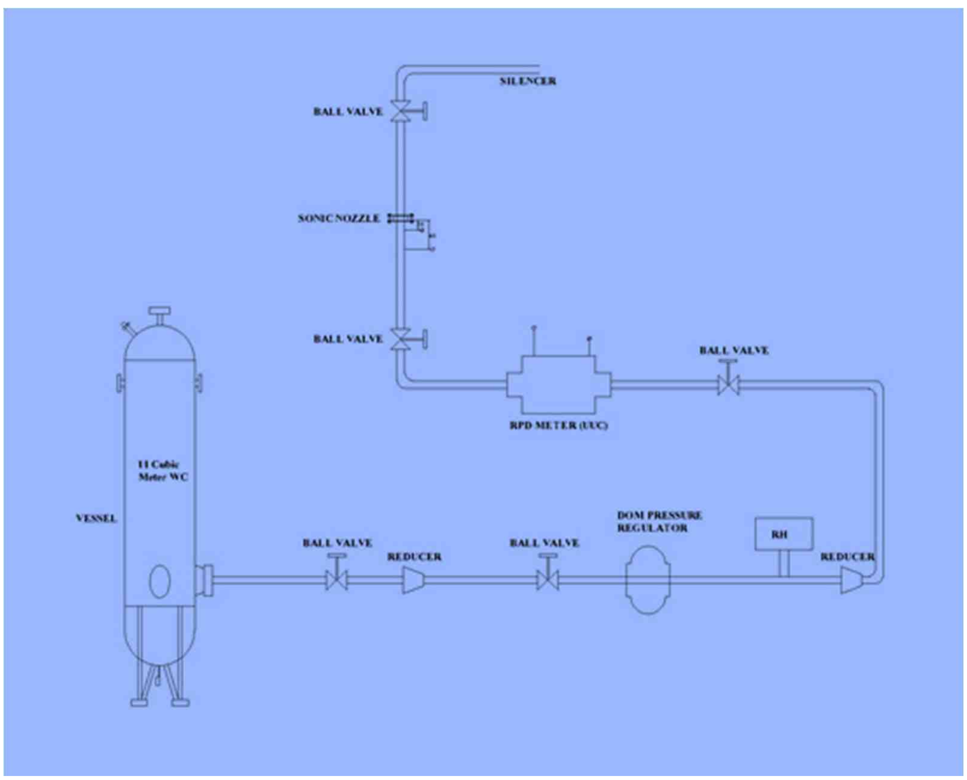


Fig. 4 Schematic of Open Loop System

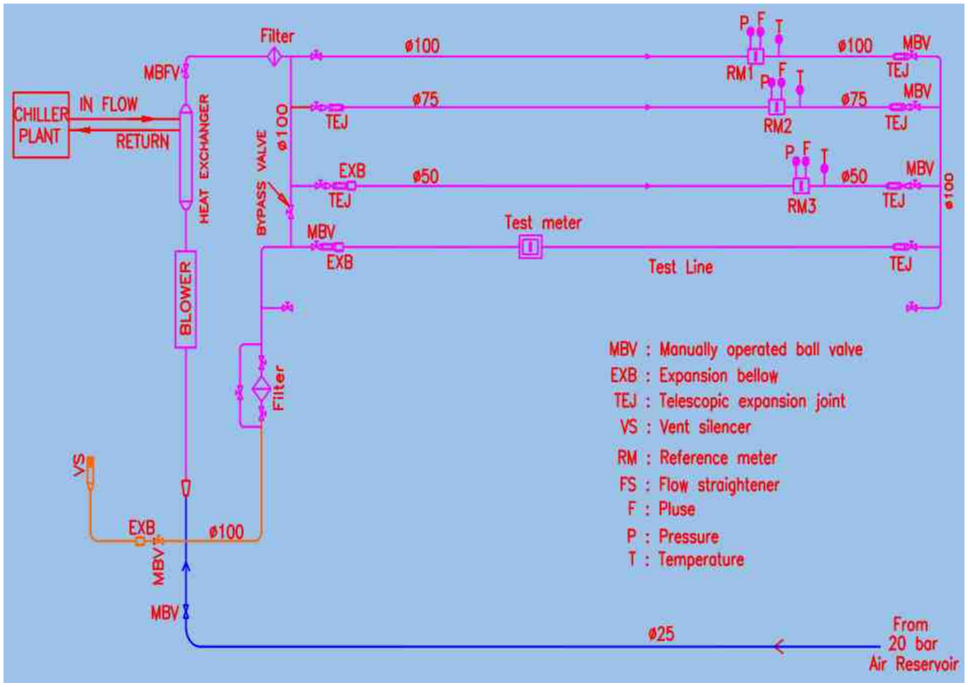
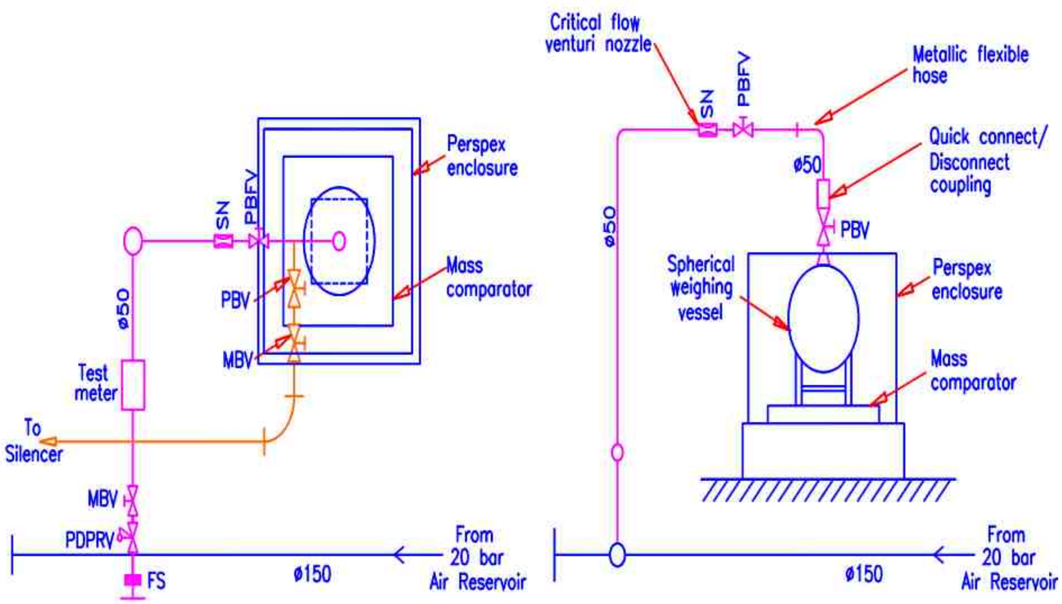


Fig. 5 Schematic of Closed Loop System



MBV : Manually operated ball valve, PDPRV : Power dome pressure regulator valve, PBV : Pneumatically operated Ball valve, PBFV : Pneumatically operated butterfly valve, FS : Flow straightener, SN : Sonic nozzle(CFVN).

Fig. 6 Schematic of Primary Standard Gravimetric System

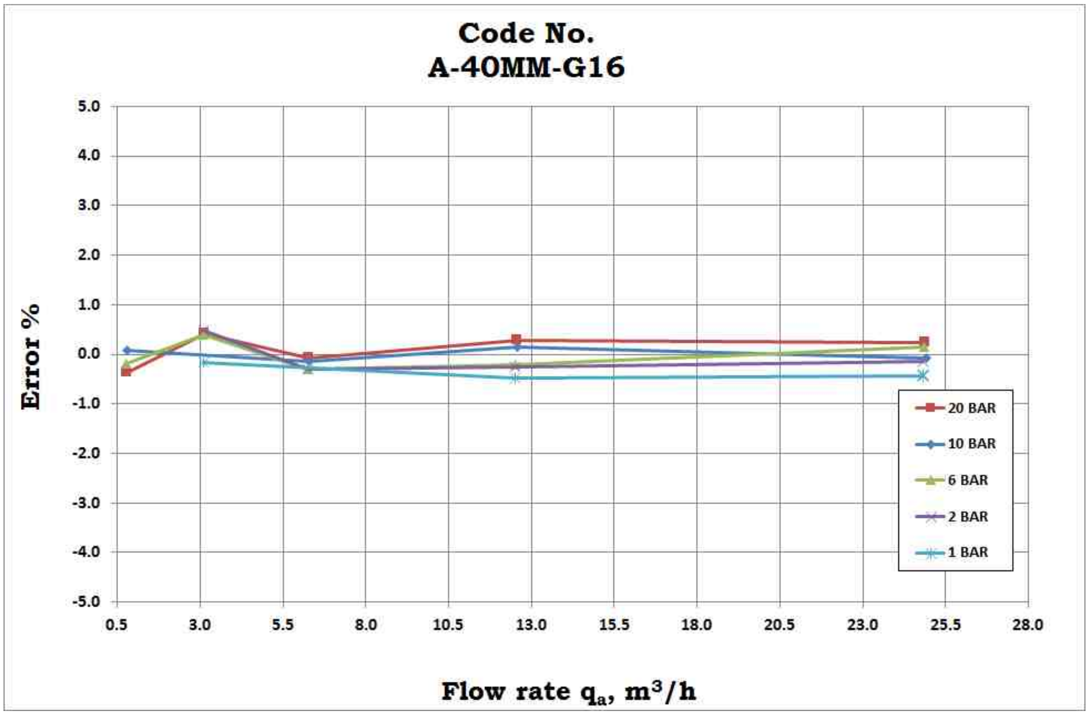

Code No.
A-40MM-G16
Error %
Flow rate q_a, m^3/h
20 BAR
10 BAR
6 BAR
2 BAR
1 BAR
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
0.5
3.0
5.5
8.0
10.5
13.0
15.5
18.0
20.5
23.0
25.5
28.0

Fig. 7.1

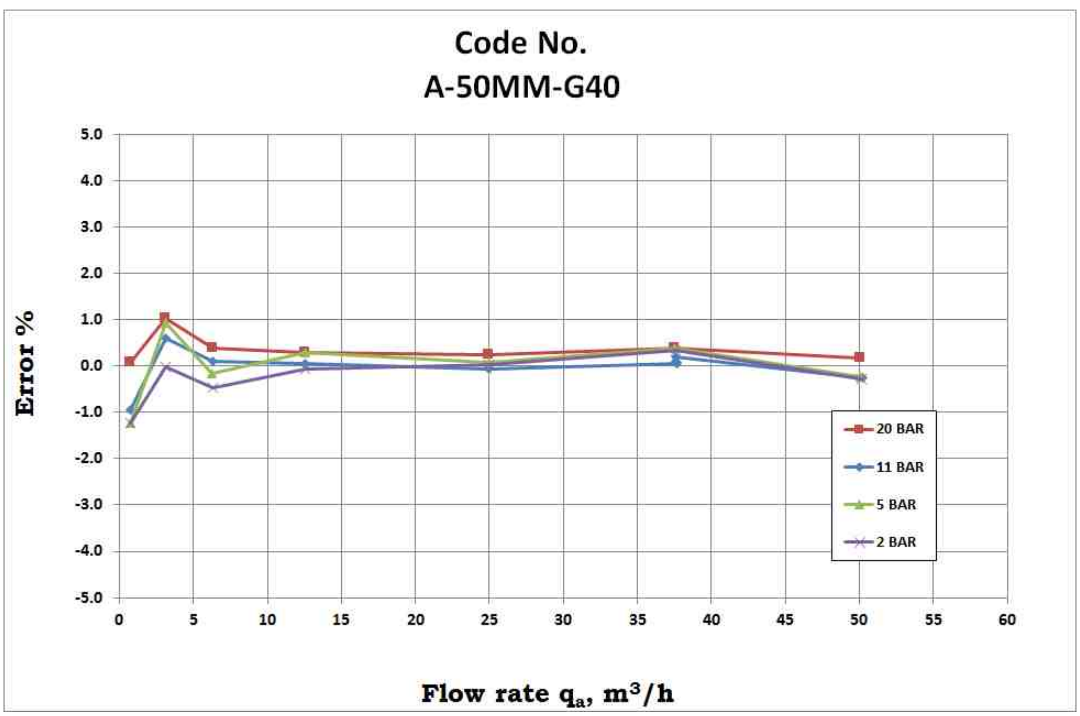

Code No.
A-50MM-G40
Error %
Flow rate q_a, m^3/h
20 BAR
11 BAR
5 BAR
2 BAR
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
0
5
10
15
20
25
30
35
40
45
50
55
60

Fig. 7.2

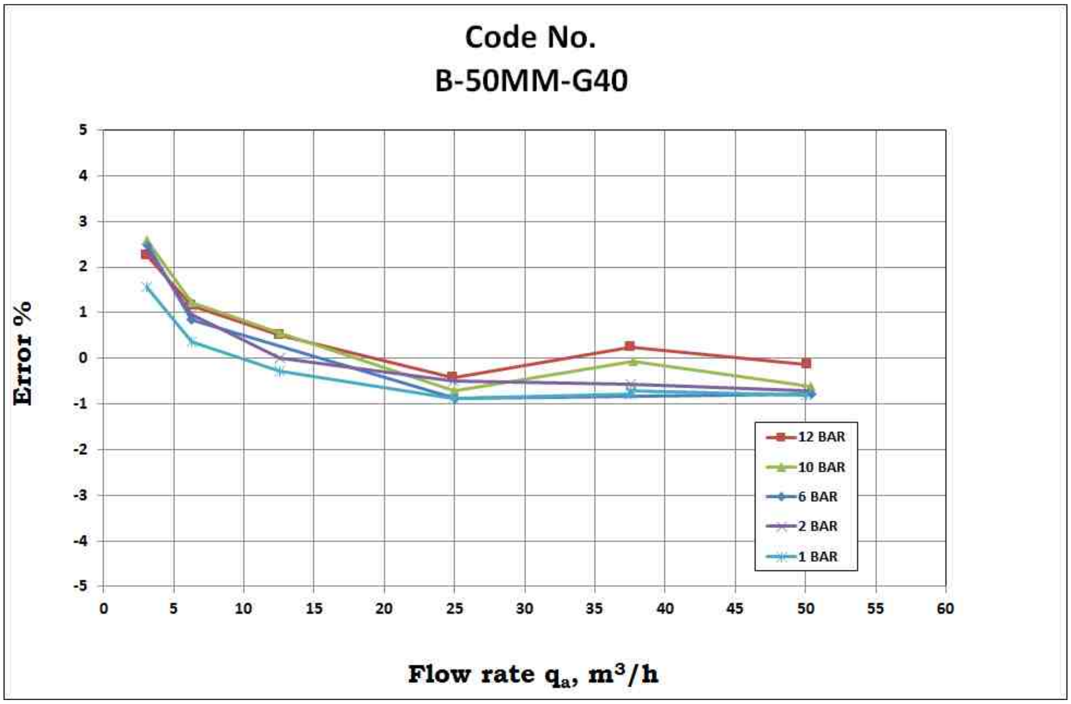

Code No.
B-50MM-G40
Error %
Flow rate q_a, m^3/h
12 BAR
10 BAR
6 BAR
2 BAR
1 BAR
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
5
10
15
20
25
30
35
40
45
50
55
60

Fig. 7.3

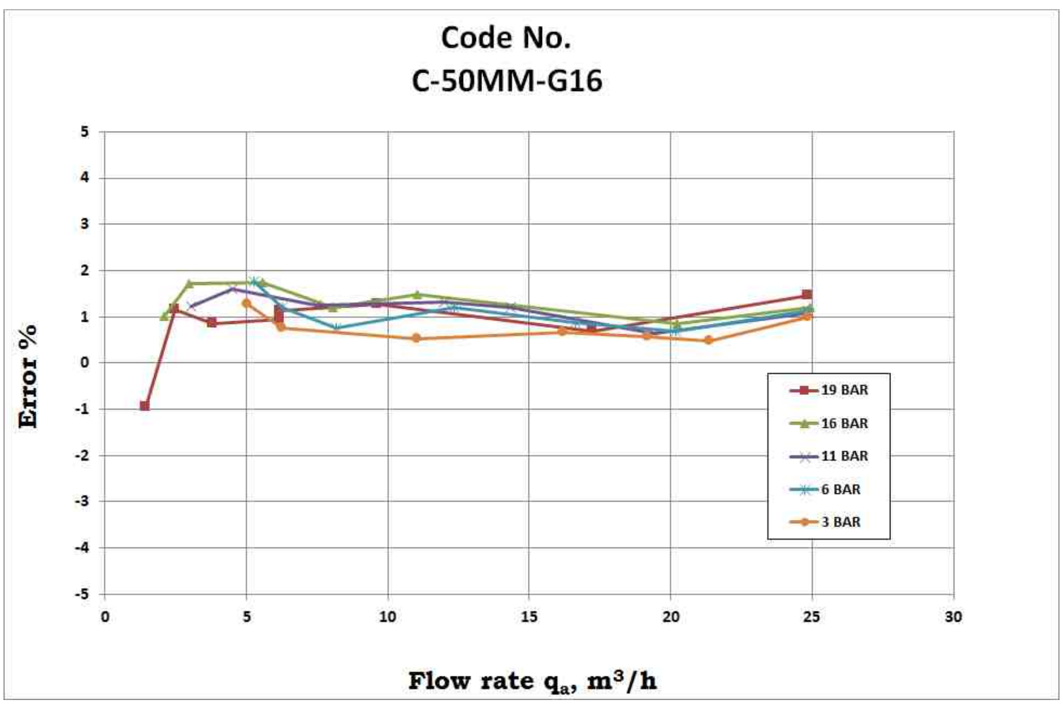

Code No.
C-50MM-G16
Error %
Flow rate q_a, m^3/h
19 BAR
16 BAR
11 BAR
6 BAR
3 BAR
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
5
10
15
20
25
30

Fig. 7.4

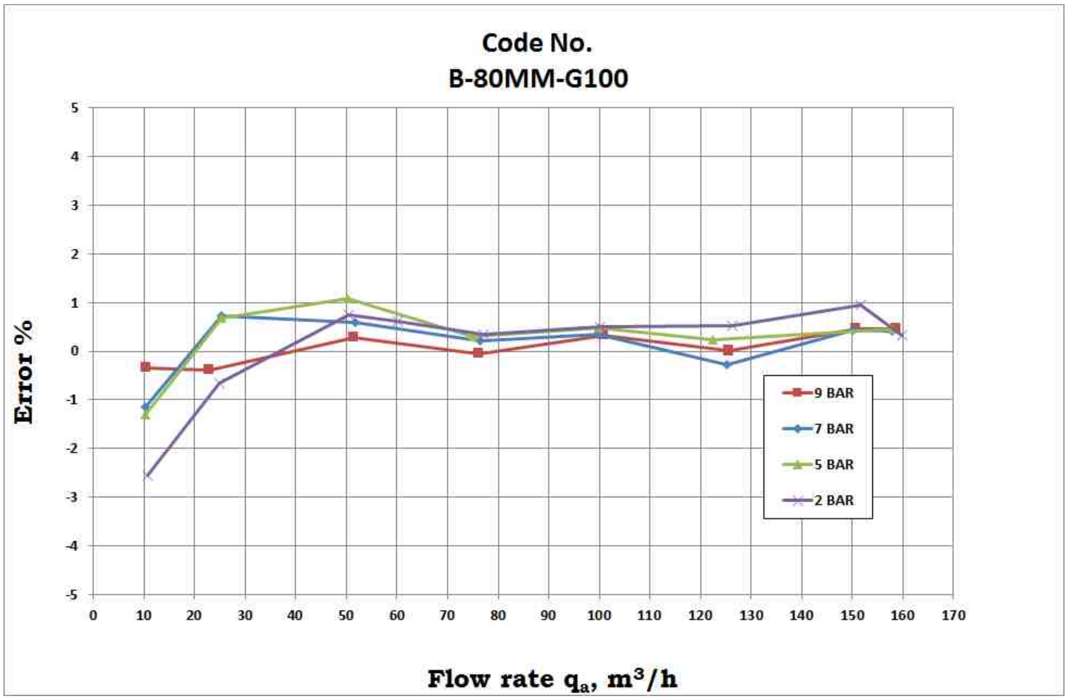

Code No.
B-80MM-G100
Error %
Flow rate q_a, m^3/h
9 BAR
7 BAR
5 BAR
2 BAR
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170

Fig. 7.5

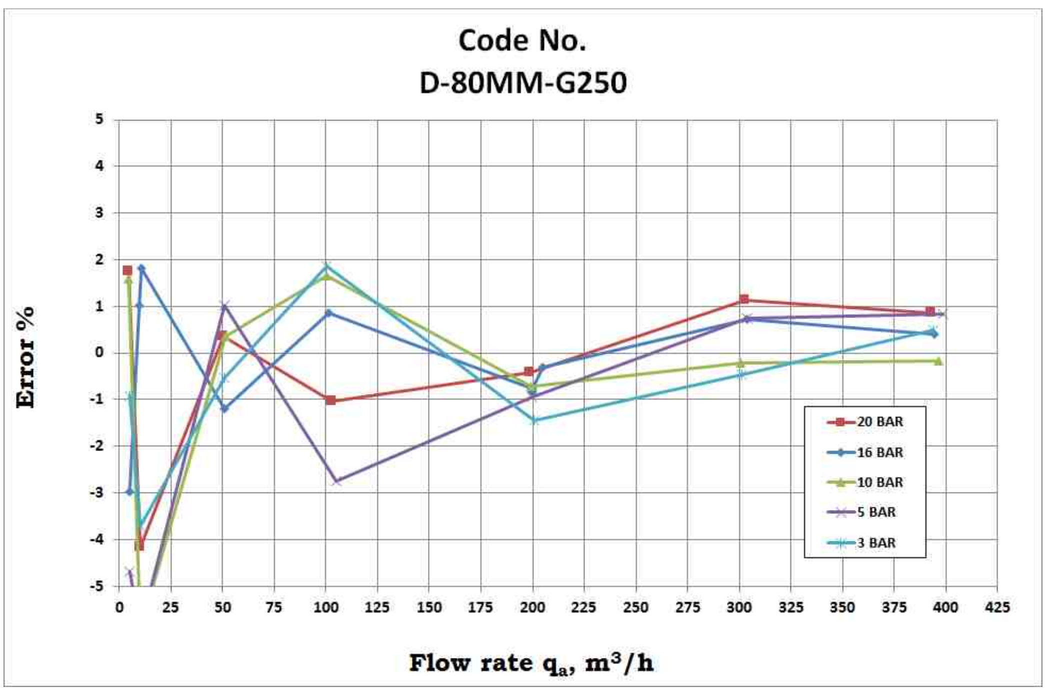

Code No.
D-80MM-G250
Error %
Flow rate q_a, m^3/h
20 BAR
16 BAR
10 BAR
5 BAR
3 BAR
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
400
425

Fig. 7.6


Code No.
D-80MM-G160
Error %
Flow rate q_a, m^3/h
20 BAR
15 BAR
11 BAR
3 BAR

Fig. 7.7

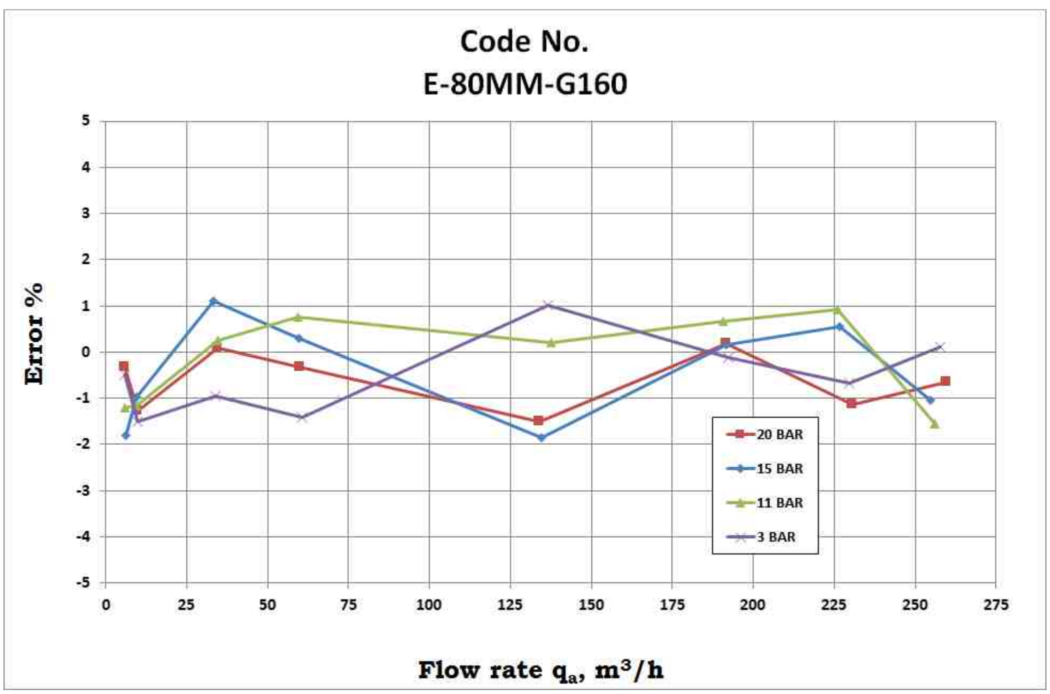

Code No.
E-80MM-G160
Error %
Flow rate q_a, m^3/h
20 BAR
15 BAR
11 BAR
3 BAR

Fig. 7.8

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