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Significance of Air Flow Measurement for Leak Test in Air Handling Units of Air-Conditioning System

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Abstract

Flow measurement is an essential part of process industry like chemical, cement, pharmaceutical, oil and gas industry etc. It’s also plays important role if Air conditioning system.
Most important to measure leakages of conditioned air. The leakage of conditioned air cause of waste of conditioned air from a costly system. In this stems the need for accurate, economical measurement for leakages is essential in Air flow system measurement to control the quality and quantity of air properties also. Orifice metering satisfies most flow measurement applications and is the most common flow meter in use today. In this paper test results of orifice plate recorded with precise instruments to find out significance of using orifice plate for air flow leakage measurement.

Keywords- Air, Flow, Measurement, Air-Conditioning System, Leakage.

1. Introduction

The orifice meter is a type of obstacle measurement, sometimes called the head loss flow meter, is chosen most frequently because of its long history of use in many applications, versatility, and low cost, as compared to other flow meter available.

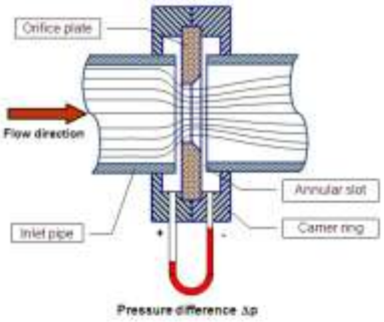


Fig. 1: Orifice Plat

An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena contracta point as shown in fig. 1. As it does so, the velocity and the pressure changes. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation.

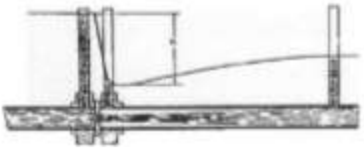


Fig. 2: Pressure Taps

The differential pressure is measured through pressure taps located on each side of the orifice plate. Pressure taps can be positioned at a variety of different locations.

1.1 Flange Taps

Flange taps located 1” upstream and downstream for the face of the orifice plate. This is the most common tap configuration and is recognized by the latest AGA specifications.

Corner taps located at the face of the orifice plate normally used in the line sizes smaller than 2".

1.2 Pipe Taps

Pipe taps located 2.5 times of pipe diameters upstream of differential pressure at the point the orifice plate and 8 times of pipe diameters downstream of the orifice plate. Measures differ of full pressure recovery.

1.3 Vena Contracta Taps

Vena Contracta taps located 1 times of pipe diameter upstream of the orifice plate and at the vena contracts on the downstream side of the orifice plate. Not recommended when a variety of orifice bore sizes are required to meet flow requirements.

1.4 Radius Taps

Radius tap located 1 pipe diameter upstream of the orifice plate and 1/2 times of pipe diameter downstream of the orifice plate.

2. Flow Rate Computation

The fundamental flow equation is:

Oh= C' hw Pf

Where:

Oh = Flow rate at base conditions,

C' = Orifice flow coefficient,

hw = Differential pressure,

Pf = Absolute static pressure.

The orifice flow coefficient is calculated using other constants that identify diameter of the pipe, orifice bore diameter, base pressure and temperature with variables that relate to the physical properties of the fluid such as temperature, specific gravity, density, viscosity, and compressibility. Any change in the diameter of the orifice bore fluid composition or temperature will change the coefficient, thus, changing the rate of flow.

3. Meter Tube Lengths

The flow of fluid through elbows, tees, and valves will cause turbulence, which adversely effects the fluid measurement. For accurate flow measurement, the fluid should enter the orifice plate free from swirls and cross currents. In order to achieve the desired flow profile, adequate upstream and downstream straight pipe is required and / or flow conditioners such as straightening vanes. The use of flow conditioners (straightening vanes) will also reduce turbulence within the meter tube while allowing shorter lengths of straight pipe.

Research continues on straightening vanes in regard to effect location and relationship to meter tube lengths.

Minimum lengths of straight pipe preceding and following the orifice plates shown in the figure 7.

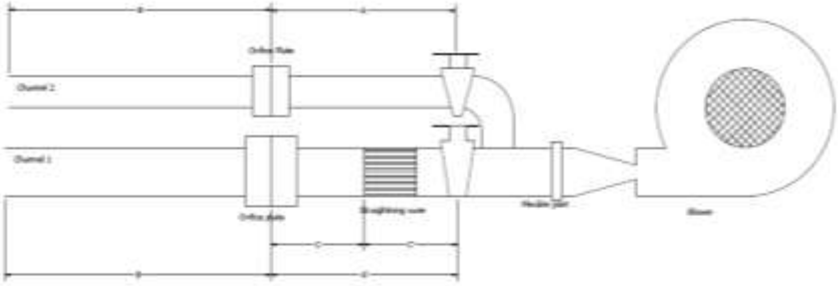


Fig. 3: Test Set up Arrangement

There are to be no pipe connections within the minimum amount of straight pipe with the exception of the pressure taps, temperature probes, and/or straightening vane attachments. There is considerable research being conducted regarding minimum lengths of meter tube pipe required. Meter Tube Inspection and Calibration Upon completion of fabrication, the meter tube shall be checked for compliance with standards and documents.

4. Test Set Up

The test rig fabricated as per design the prevailing standard in vogue and ISO 5167 as shown in fig. 1, and arrangement made as Fig. 3. Globe valves were used for flow control in two channels. Channel 1 is high flow rate channel where channel 2 is for low flow rates. Diameter of channel 1 is 102.3 and for channel 2 it is 62.7 mm and β values are 0.636 and 0.51 respectively. Since the calibration is carried out on the actual setup, small deviations are unlikely to affect the general performance.

The Highest flow rate that could be obtained with the blower fan was found to be 100 l/s through channel 1, which implies that the total system pressure drop is 250 mm of water column (wc) based on the performance characteristic of fan. The pressure drop across the orifice plate at this flow rate was about 86 mm of wc. The pressure drop of the meter itself would be about 50 mm of WC. Thus it is implied that the pressure drop between discharge ends of the fan to the stream state pressure drop would be around 200 mm of wc. This could have been be contributed by the gradual expansion at the discharge of the fan, the vibration isolator, the dividing T and the flow regulating valve.

The fluid in the inclined tube manometer has a specific gravity of about 0.8 but the scale has been marked in mm wc. However, it was found that at differential pressures above 60 mm of wc the inclined tube manometer was not confirming to the reading of the U-tube manometer. Hence a calibration of the inclined tube manometer obtained against the U-tube manometer. Calibration chart shown in curve 1 below.

The least squares fit of the data yields the following equation with a regression coefficient of 99.95%.

$$\Delta p_{\text{U tube}} = 0.97\Delta p_{\text{inclined tube}} + 0.37 \quad \text{--------------} \quad (1)$$

With the pressure units in mm water column.

5. Test Procedure

The test performed in two stages:

(1) Decreasing and increasing flow rate for channel 1,
(2) Same for channel 2.

The free ends of the both channels were allowed to discharge into the ambient with no obstructions for a substantial length such that no back pressure present. Flow rate from minimum to maximum were obtained by using the valve alone in channel 1. In the case of channel 2 for low flow rates first the valve in this section alone was used. However, at high flow rates the disturbances were too large to obtain a steady flow. Hence the valve in channel 1 was used as a bypass to stabilize the flow rate.

Four different types of velocity probes were used to measure the velocity at the center of the pipe section:

- A vane anemometer,
- Pitot tube. The dynamic pressure was transformed to velocity using a differential pressure transducer,
- Hotwire anemometer,
- Pitot tube along with the differential pressure input to TSI instrument.

The pressure drop across the orifice plate was measured with a water U-tube manometer and an inclined tube manometer. The differential pressure across the orifice plates as measured by the U-tube manometer was also used to cross check the accuracy of the TSI differential pressure measurement. It was found that they are all commensurate with each other with in the specified precision of each instrument.

Velocities are measured at the center of the pipe. Since the Reynolds numbers of flow were above 10000 in both the channels for the range of flows proposed to be measured by the test rig (namely 8.5 l/s and above) and the diameters of both channels are small it is assumed that this represents the average velocity. However, near the wall it may not be true. Thus, the leakage rates measured by the test rig will be pessimistic.

The range of calibration is about 100-28 l/s for channel 1 and 28-8 l/s for channel 2.

6. Test Data

Test data shown in the table 1 and plot on flow vs pressure drop for channel 1. Table 2 and plot show the same for channel 2. For these tables the inclined tube manometer used after appropriate correction using the equation 1. The flow rate was fitted as a function of measured pressure drop across the orifice plate through a 6th order polynomial of the form given below:

$$Q\ (\mathrm{l/s}) = A_6\Delta p^6 + A_5\Delta p^5 + A_4\Delta p^4 + A_3\Delta p^3 + A_2\Delta p^2 + A_1\Delta p + A_0 \quad \text{....(2)}$$

Δp is mm of water column.

The coefficients are listed in table 3 below. The error distributions for the two channels are shown in the curves. Here the error is defined as the [measured flow rate – calculated flow rate from equation 2] / measured flow rate X 100%. The overall uncertainty of the leak rate measurement is expected to be less than about 5% which is contributed by uncertainties in differential pressure measurements and the fact that only velocity at the axis has been considered for all flow calculations.

Table 3 shows the Coefficient of discharge. The data generated during calibration were also used for evaluating the coefficient of discharge (Cd) of each of the flow channels. They are depicted in curves shown. It may be observed that Cd values are 0.64 and 0.71 for channels 1 and 2 respectively. These values are commensurate with those expected.

For the testing two typical air handling housings were tested for leak.

Very low flow calibration

For flow lower than 8.5 l/s, the channel 2 can still be used, but the calibration equation (2) with coefficients in table 3 will yield large uncertainties. Hence, a separate calibration is provided for this range taking the data points at differential pressures below 30 mm of water column. The calibration equation is given below.

$$Q\ (l/s) = -3.7 \times 10^{-5}\,\Delta p^4 + 3.24 \times 10^{-3}\,\Delta p^3 - 0.09851\,\Delta p^2 + 1.458\,\Delta p + 0.1013 \quad .....(3)$$

In the above equation again Δp is mm of wc. The difference between measured and calculated values will be about 0.6 l/s in the range.

7. Test Parameters

The flow measuring setup can be used for detecting leaks in the air handling unit housings from about 8 l/s to 100 l/s. Depending on the class of manufacture of the unit and surface area, it will be possible to guess the magnitude of possible leak. Based on this value choose channel 1 if likely leakage is > 28 l/s and channel 2 if < 28 l/s, multiply l/s by 3.6 to obtain m^3/hr.

Operating instructions:

1. If the leak rate is not known always use the channel 1 and the U-tube manometer or the TSI differential pressure transducer for measuring the differential pressure across the orifice plate. If TSI instruments is used, whose display is in Pa, multiply the displayed value with 0.102 to obtain the pressure differential in mm of wc. The constants in Table 3 are applicable only when differential pressure is in mm of water column.
2. Ensure that there are no leaks between the upstream of the orifice plate and the connection to the air handling unit housing.
3. If the leak rates are below 28 l/s change over to channel 2 because at or below this flow rate the differential pressure across the orifice plate in channel 1 will be quite small.
4. For leak rates above about 20 l/s (equivalent to a differential pressure across orifice plate of about 80 mm of water column) when channel 2 is being used, It is possible that the differential pressure might fluctuate causing

difficulties in getting a precise measurement. When this happens, bypass some amount of flow through channel 1 and open the flow regulation valve in channel 2 till the differential pressure stabilizes.

5. For leakage rates below 8 l/s use equation (3) for converting the differential pressure across the orifice plate of channel 2 in flow rates.

Table 1
Experiment Data for Channel 1

Pressure						Velocity				
U-tube	Inclined	TSI	Testo	Solomat	Average	TSI	TSI	Vane	Average	Discharge
						Hotwire	Pitot			
mm wc	mm wc	Pa	mm wc	Pa	mm wc	m/s	m/s	m/s	m/s	l/s
86		836	86	837	86	11		10.5	10.67	94.13
76					76	10	10.05	9.6	9.88	87.22
66				620	66	9.2	9.35	9.2	9.24	81.52
57				530	57	8.5	8.55	8.3	8.45	74.57
45				410	45	7.6	7.65	7.5	7.58	66.92
35.5				320	35.5	6.75	6.85	6.7	6.77	59.71
25			24.13		25	5.75	5.7	5.8	5.75	50.74
15					15	4.33	4.4	4.45	4.39	38.77
8			7.1		8	3.05	3.2	3.2	3.15	27.8
Ascending										
	15				15	4.47	4.47	4.5	4.51	39.8
	25				25	5.7	5.8	5.6	5.68	50.08
	35				35	6.75	6.75	6.7	6.73	59.35
	45				45	7.5	7.45	7.4	7.44	65.63
	55				55	8.45	8.2	8.1	8.21	72.47
	65				65	9.15	9.1	8.9	9.04	79.75
	75				75	9.65	9.55	9.3	9.48	83.61
	85				85	10.25	10.2	9.9	10.09	89.02
	5				5	2.63	3.14	2.6	2.79	24.62

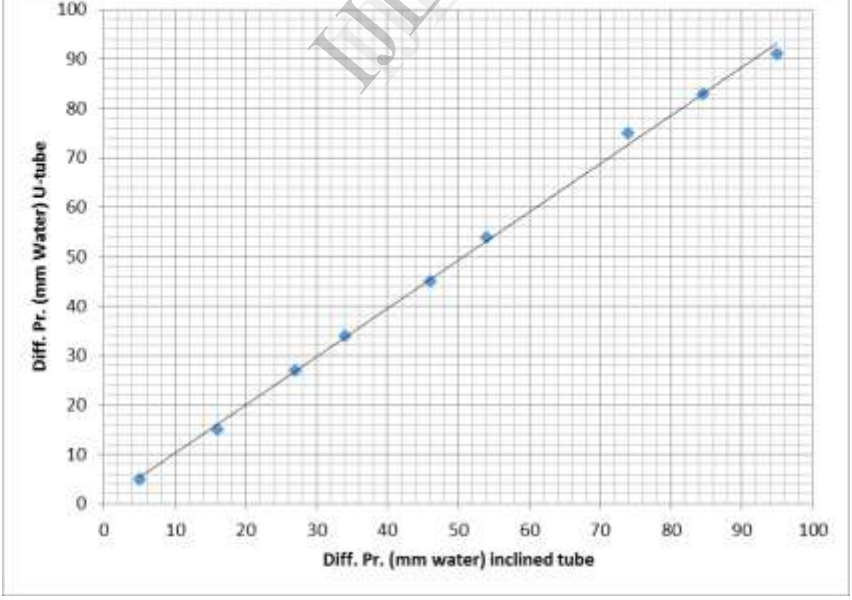
Table 2
Experiment Data for Channel 2

Pressure					Velocity					
U Tube	Inclined	TSI	Testo	Average	TSI	TSI	TESTO	TESTO		
	mm wc	Pa	mm wc	mm wc	HOTWIRE	Pitot	Pitot	vane	Average	Discharge
					m/s	m/s	m/s	m/s	m/s	I/s
Ascending										
										0
	2.5			3	1.35	1.45		1.3	1.37	3.99
	10			10	2.77	2.86		2.7	2.78	8.11
	20			20	3.41	3.5		3.2	3.37	9.85
	30			30	4.21	4.37	4.3	4.1	4.25	12.41
	40			39	4.8	4.75	4.7	4.6	4.71	13.77
	50			49	5.65	5.5	5.3	5.3	5.44	15.89
	60			59	6	5.95	5.6	5.8	5.84	17.06
	70			68	6.45	6.1	6.1	6.2	6.21	18.16
	80			78	6.8	6.85	6.8		6.82	19.92
	90			88	7.55	7	7.1	6.9	7.14	20.86
	100			98	7.65	7.6	7.5		7.55	22.16
		1067	108.8	108.8	8.2		8	7.8	8	23.38
		1168	119.1	119.1	8.65		8.4	8.2	8.42	24.6
		1337	136.3	136.3	9.2	8.95	8.6	8.6	8.84	25.83
		1532	156.2	156.2	9.9		9.7	9.1	9.57	27.96
Descending										
		1440		146.8	9.5		9.2	8.8	9.17	26.79
		1270		129.5	9.05		8.9	8.7	8.88	25.96
		1100		112.1	8.45		8.3	8	8.25	24.11
		1000		101.9	8.05		7.8	7.7	7.85	22.94
		930		94.8	7.65		7.6		7.63	22.28
91	94.5	91		91	7.4	7.3	7.3		7.33	21.43
83	84.5	83		83	7.05	6.8	6.7	6.5	6.76	19.76
74	74.5	74		74	6.7	6.35	6.2	6.1	6.34	18.52
63	65	63		63	6.25	6.05	6.1	5.9	6.08	17.75
53	54	53		53	5.7	5.35	5.5	5.3	5.46	15.96
45	45	45		45	5.3	5.25	5	5	5.14	15.01
33	34	33		33	4.6	4.55	4.55	4.3	4.5	13.15
25	25	25		25	3.81	3.87	4.1	3.9	3.92	11.46
15	15	15		15	3.09	2.98		2.8	2.96	8.64
5	5	5		5	1.67	1.58		1.55	1.6	4.68

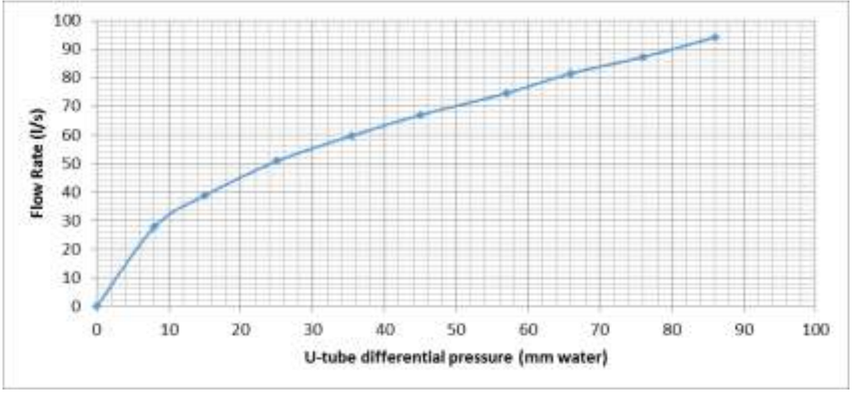
Table 3
Coefficient of Discharge

Coefficient	Channel 1	Channel 2
A_6	-5.313×10^{-10}	-2.514×10^{-11}
A_5	2.884×10^{-7}	1.468×10^{-8}
A_4	-5.092×10^{-5}	-3.365×10^{-6}
A_3	4.158×10^{-3}	3.817×10^{-4}
A_2	-0.1749	-0.02251
A_1	4.484	0.798
A_0	0.2265	1.024
Regression Coefficient	99.89%	99.64%
Root mean square	1.40%	2.20%
deviation		

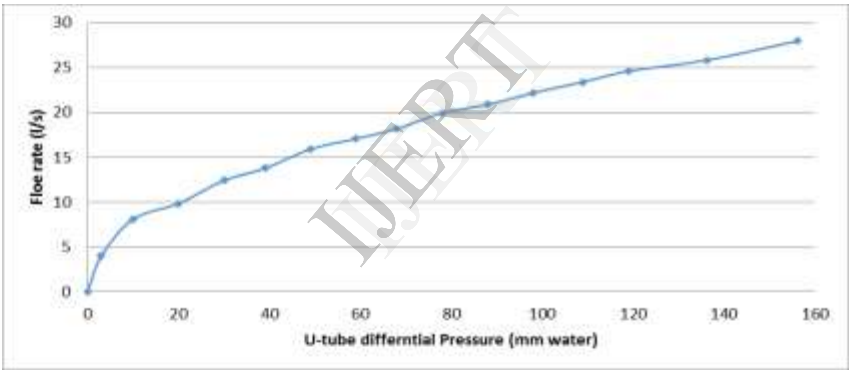
Curve 1
Calibration of the Inclined Tube Manometer



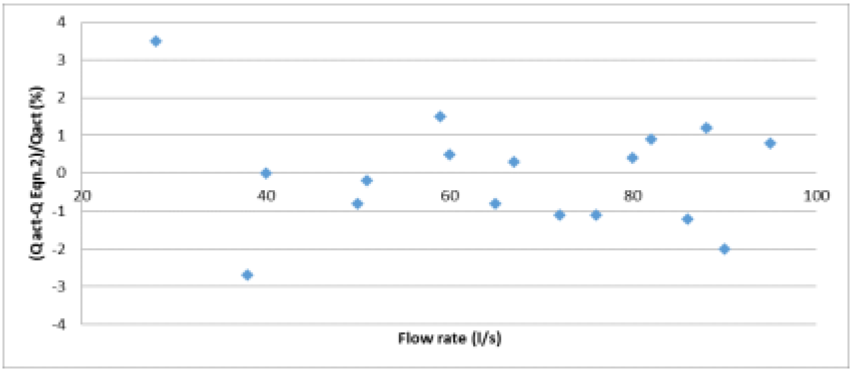
Curve 2
Readings for Channel 1



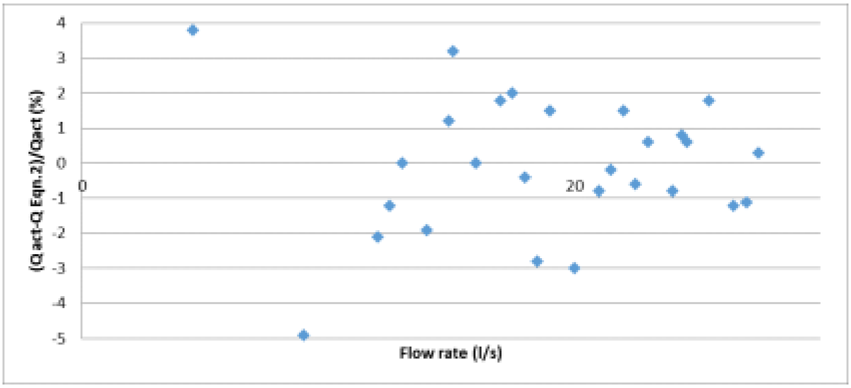
Curve 3
Readings for Channel 2



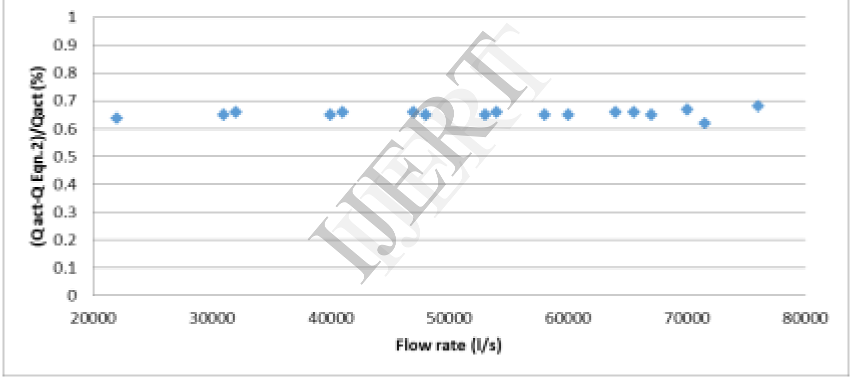
Curve 4
Error Distribution for Channel 1



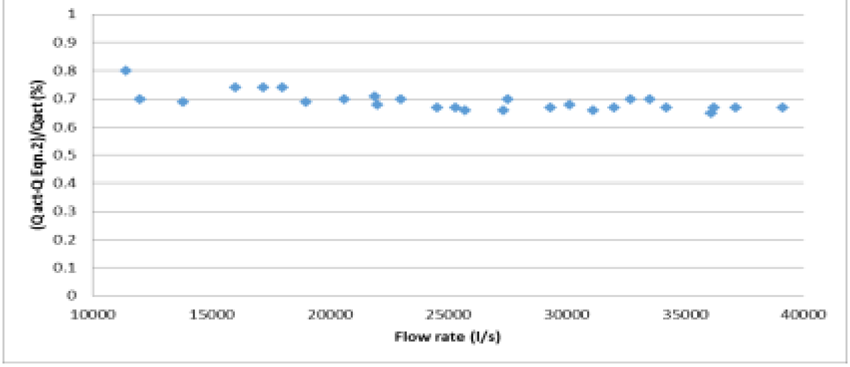
Curve 5
Error Distribution for Channel 2



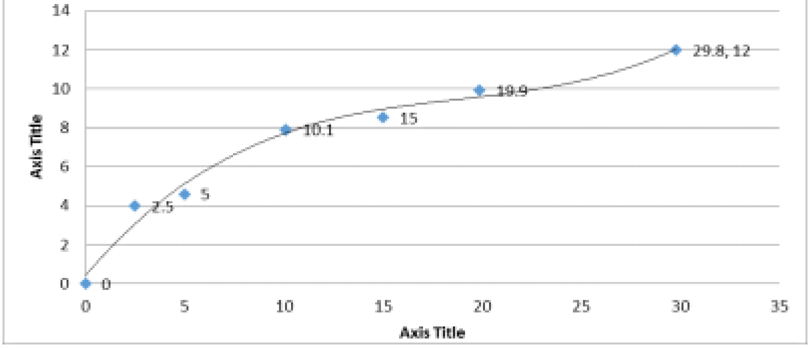
Curve 6
Coefficient of Discharge Distribution for Channel 1



Curve 7
Coefficient of Discharge Distribution for Channel 2



Curve 8
Very Low Flow Measurement Channel 2



8. Conclusion

The wide variety of applications available today demands dependable, accurate measurement. Recently, significant improvements in metering standards and secondary equipment have enhanced the overall quality and efficiency of orifice metering. Given the proper design considerations, orifice metering satisfies the measurement requirements for a variety of applications.

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