Proceedings of the
International Conference on Mechanical Engineering 2011
(ICME2011) 18-20 December 2011, Dhaka, Bangladesh

ICME 11-RT-042

COMPARATIVE STUDY ON ORIFICE VERSUS TURBINE METERS FOR GAS FLOW MEASUREMENT

Mohammad Sohrab Hossain[1], Golam Faroque[2] and Mahbubur Rahman[1]

[1] PMRE Department, BUET, Dhaka
[2] Manager, Titas Gas Transmission and Distribution Limited, Dhaka

ABSTRACT

Orifice and Turbine type meters are commonly used in Titas Gas Transmission and Distribution Company Limited (TGTDCL) to meter the gas prior receiving it from production companies and distributing it to the customers respectively. Basic metering principles, operation and calibration procedures and standards of Orifice and Turbine meters, error and uncertainties in flow measurements are discussed in this paper. The comparison of flow measurements between Orifice and Turbine meters had been made by measured data, which were collected in fields over 15 months where two meters were installed in series. Calibration method of Orifice meter and Turbine meter with secondary device had been studied and analyzed the calibration results to determine what affect the accuracy of gas flow measurement. Two orifice meters installed in series under same flow condition in TGTDCL were analyzed and yielded a significant difference in their measurements. Rate dependency in measuring accuracy was observed in two meters. The causes of discrepancy of the results were explained. Application and performance of these meters were suggested in this study.

Keywords: Gas Metering, Metering Calibration, and Error and Uncertainty Analysis

1. INTRODUCTION

Titas Gas Transmission and Distribution Company Limited (TGTDCL) is the largest distribution company under Petrobanlga in Bangladesh. It holds around 73.3% of natural gas distribution business comprises from bulk customers like power plants, fertilizer factories; non bulk customers like garments industries, ceramic, pharmaceuticals, CNG stations and other industries and domestic customers like domestic households, apartment complexes etc in Bangladesh. TGTDCL purchases 1300 MMSCFD gas from the production companies and sells it to different customers after metering it. In TGTDCL, Orifice and Turbine type meters are commonly used depending on the gas flow rate, quantity and specification of the gas.

TGTDCL divides gas measuring installations within Bangladesh into five categories which are Intake Metering Station (IMS), City Gate Station (CGS), Town Bordering Station (TBS), Regulating and Metering Station (RMS) and District Regulating Station (DRS).The meters are installed in the above mentioned stations are known as custody transfer meter. For high capacity power plants and fertilizer factory are required high pressure and flow rate, therefore Orifice meters are used. For industrial customers and small quick rental power plants, Turbine meters are usually used in TGTDCL. Moreover in most of the TBS, DRS, CGS Turbine meters are used for input gas measurements. In these metering stations wide variety of flow conditions exist like ideal flow, non-ideal flow (i.e swirl effect, flow transients, high or low flow rates and quality of the gas - dry or wet) and Reynolds number below 1000000 etc. These conditions cause measuring inaccuracy and uncertainty in measurement.

2. BASIC PRINCIPLE OF FLOW MEASUREMENTS

An Orifice meter is a fluid measuring device that produces a differential pressure to infer flow rate. When fluid is flowing within a closed conduit (a pipe) and passing through Orifice plate, a pressure drop is developed. This pressure drop and the operating condition at which the Orifice is operated are main input parameters to measure the flow rate of the fluid. In an Orifice meter, the measured variables are the differential pressure, flowing gas temperature and static pressure. These variables are recorded on a circular chart by a mechanical chart recorder, then interpreted the chart parameters to find flow rate.

Since the Orifice plate has been used for flow measurement applications for about 100 years, therefore considerable data has been collected on its performance and applications. A number of variants have been developed where the profile of the plate and the location of the differential taps can be significantly different. The Orifice plate meter is designed for unidirectional flow. Should reverse flow occur, or the plate installed in reverse, a substantial flow error in the order of 20% may be observed as reported in the literature. [1].

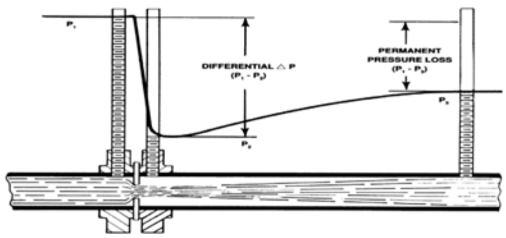

Fig 1. Simple view of an Orifice meter

Modern Orifice meter installations calculate flow using computers rather than charts. Orifice meter can be installed with multiple differential pressure transducers for higher and lower range which give electrical signal to the flow computer. Differential pressure transducer do not give accurate value in a temperature uncontrolled environment, so controlled environment need to be ensured when differential pressure transducer is used.

The Turbine meter is classified as a rotary inferential meter. Turbine meters were first used in Europe for low pressure gas flow measurement applications. After a decade of research and field testing, Rockwell international introduced its improved design to the United States in 1963 for high pressure gas flow measurements. A Turbine meter works on the principle, a flowing gas stream turns a turbine rotor at a speed directly proportional to gas flow rate. A revolution counter geared to the rotor, shows the meter's volumetric throughput at operating condition, so the meter reading must be corrected to standard condition.

At early time, various questions were raised about Turbine meter, after extensive research and development improve it's the accuracy, rangeability and reliability for gas flow measurement. Turbine meters are individually calibrated and resulted accuracy level within ±1% over a wide range of both pressure and flow rate. They are capable of ±0.25% accurate over a specified flow range if individually calibrated near line operating conditions. If Turbine meters are calibrated once, they can maintain high accuracy level for a period of two years[2].

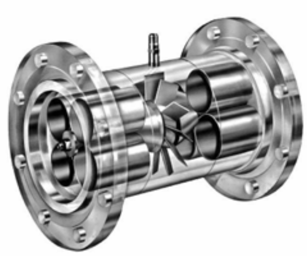

Fig 2. Simple view of a Turbine meter

3. INSTALLATION AND PERFORMANCE OF METERS

Performance of meters depends on installation, flow condition, operation and maintenance. A fully developed and swirl free flow condition are prerequisite for accurate measurement for the meters. As per recommendation of AGA 3 and ISO 5167, if the flow is not swirl free, a flow conditioner is recommended in the upstream of the flow. For Orifice meter, 10D distance between primary device (Orifice meter) and inlet valve and 5D distance between flow conditioner (straightner vanes) and primary device are recommended by AGA 3. For ISO 5167 these distances are to be 42 D and 22D respectively [3]

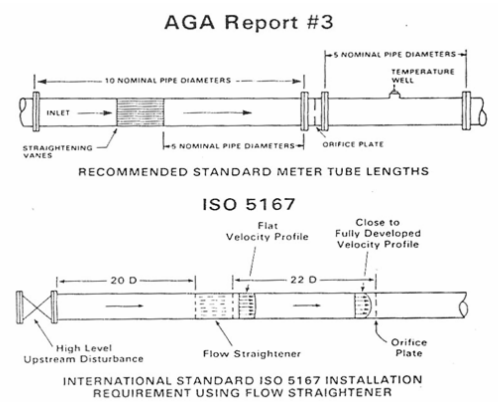

Fig 3. Schematic view of flow straightener position in Orifice meter

According to AGA report 7, minimum straight line distance between valve and primary device (meter) and distance between flow conditioner and turbine meter are recommended 10D and 5D respectively. Both inlet and outlet pipe should be of the same nominal size as the meter. [4]

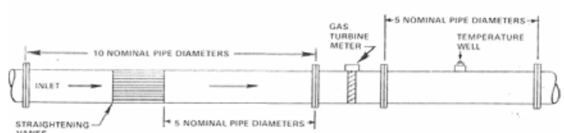

Fig 4. Schematic view of flow straightener position in Turbine meter

Certain flow conditions must be met, if fluid to be measured with reasonable degree of accuracy. Velocity profile, Reynolds number, swirl, composition, foreign particle and condensing or flashing during the measurements are among those important criterions. The Reynolds number characterizes the velocity profile and flow patterns. Non ideal flow pattern occurs in the Laminar flow region where the velocity profile is parabolic i.e. mean stream velocity is much higher than the pipe wall velocity. Ideal or near ideal flow profile is the fluid in the turbulent region where pipe wall has a greater influence on the velocity profile. Center line velocity and pipe wall velocity difference is not very significant.

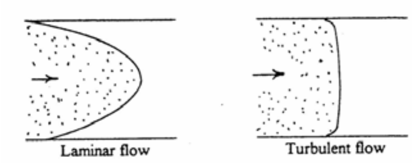

Fig 5. Velocity profile of a Newtonian fluid

Upstream and downstream pipe length, the location of bends, valves, reciprocating plant, changes in pipe diameter and general conditions of the internal pipe walls within the immediate and general proximity of the orifice plate, can result in non-ideal flow conditions such as swirl, transients flow and profile distortion or jetting. These non-ideal flow conditions can produce errors which magnitude is higher than the basic uncertainty in the orifice meter co-efficient

Since the orifice plate can deteriorate with usage over time, therefore, periodic inspection and cleaning of an orifice plate is required to maintain initial equipment condition. Secondary instruments such as the differential pressure transmitter should be regularly calibrated against a standard. Standards would have demonstrated traceability to an International Standard held within a recognized laboratory or metrology institution

Turbine meter should be operated within its specified flow range. Over speeding of meter must be avoided to protect the rotor from damage. Generally turbine meters are capable of operating at modest overloads for short period of time, but continued overloading must be avoided by proper meter sizing. Like all other meters, turbine meters should be pressured and placed in service slowly. Shock loading by opening valves quickly, will result in rotor damage usually. Regular lubrication, with manufacturer's specified lubricating oils, is also required. The frequency of lubrication depends on the operating conditions

Moreover static pressure, base temperature, density or specific gravity, pulsation created by the flow control valves, regulators and piping configuration cause significant error in measurement accuracy. [5]

4. CALIBRATION OF METERS

Orifice and Turbine meters require periodic intervention to assure accurate measurement. In this case, Calibration is done by the means of comparison is made between an instrument and a reference standard for the purpose of adjusting the instrument characteristics to provide agreement with the reference standard.

The orifice meters with three pen recorders are used in different locations (purchase point & counter check meters, bulk Customers of power, fertilizer, captive power, TBS, CGS, DRS) in TGTDCL.

The measurement error in Orifice metering system is determined mostly by verifying the measured variable from auxiliary devices which integrated with Orifice meter. During flowing of gas through Orifice meter differential pressure (dp), flowing gas pressure, and temperature to be checked for determination of error in volumetric flow calculation. Orifice meters with secondary devices were calibrated and found error on differential pressure and static pressure in some magnitudes that are shown in Table 1 and 1A. These calibration programs have been conducted by TGTDCL in different times. The probable causes for deviation of measured variables are not following precautions during chart changes by operator and not purging the accumulated condensate from the meter manifold piping regularly and in some cases it may be occurred for malfunctioning of measuring devices. When deviation of different values in differential pressure and static pressure has been found then what happens to volume calculation in Orifice meter are shown as follows:

Table 1: Calibration of pressure measurement devices and flow differences (pressure deviation in inch of water column from standard value and flow difference)

SL. No	Differential pressure at operation (w.c)	For 2"w.c deviation			For 1"w.c deviation		
		Gas flow at operation, P=172psig & T=66°F (MSCFD)	Flow during calibration (MSCFD)	Flow difference (%)	Gas flow at operation, P=171psig &T=84°F (MSCFD)	Flow during calibration (MSCFD)	Flow difference (%)
1	23.042	31699.476	30275.936	4.701	31129.646	30412.372	2.375
2	33.504	38528.674	37358.792	3.131	37709.878	37143.172	1.574
3	41.414	42362.055	41324.786	2.509	41939.654	41409.922	1.259
4	52.935	47612.843	46707.155	1.938	47024.723	46581.300	0.970
5	62.265	51943.793	51104.192	1.642	50940.819	50532.624	0.857
6	71.928	55780.927	55003.302	1.413	54847.705	54468.697	0.706
7	82.768	59626.641	58905.623	1.224	59023.466	58669.787	0.610
8	93.229	63287.922	62609.595	1.083	62533.630	62221.528	0.539

Table 1a: Calibration of pressure measurement devices and flow differences

SL. No	Differential pressure at operation (w.c)	For 0.6"w.c deviation			For 0.4"w.c deviation		
		Gas flow at operation, P=172psig & T=82°F (MSCFD)	Flow during calibration (MSCFD)	Flow difference (%)	Gas flow at operation, P=171psig & T=77°F (MSCFD)	Flow during calibration (MSCFD)	Flow difference (%)
1	23.042	31369.009	30954.882	1.429	31207.935	30934.636	0.953
2	33.504	38020.451	37679.759	0.945	37705.870	37477.522	0.628
3	41.414	41896.835	41992.670	0.755	41882.594	41681.900	0.501
4	52.935	47201.129	46935.928	0.581	47254.491	47069.463	0.385
5	62.265	50841.427	50598.829	0.491	51430.380	51268.120	0.325
6	71.928	54416.229	54192.471	0.421	54970.914	54825.399	0.279
7	82.768	58431.726	58223.556	0.364	59712.154	59571.826	0.240
8	93.229	63408.587	63210.042	0.321			

The high pressure calibration unit consists of turbine reference meter and meter under tested. In the calibration unit one turbine meter can be tested at a time. One reference meter and the Meter Under Test (MUT) will be connected in series. The flow rate measured through the MUT is compared with the flow rate measured by the reference meter. The reference meter is part of the high pressure calibration equipment, whereas the MUT is the meter to be checked.

In general, the line conditions for the MUT and the reference meters are not the same. The temperature and pressure are measured at both the reference meter and the MUT. A correction for pressure, temperature and compressibility is used to calculate the flow rate measured by the reference meter and MUT at line conditions making an accurate calibration possible. Turbine meter calibration values were not reported on the project works.

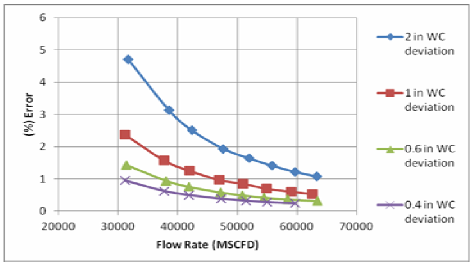

Fig 6. Differential pressure deviation and error percentage for orifice meters

5. UNCERTAINTY ANALYSES OF ORIFICE AND TURBINE METERS

The uncertainty is an estimate of the interval width that contains the true value being measured. For example, the statement "100 ± 1psi" means the true value is estimated to be between 99 and 101 psi. The equation for flow measurement by Orifice meter is

$$q = c_f \times A_o \times \sqrt{\frac{2\Delta P}{\rho}} \qquad (1)$$

Where Ao is the area of the orifice, P is the pressure, ρ is the density and Cf is the flow coefficients found from the experiments or supplied by the manufactures. The quantities in this equation are not independent from each other. Therefore to define the uncertainty with reasonable accuracy, one needs to separate the independent variables. The flow coefficient (Cf) is dependent of β ratio, Reynolds number (Re) and δCf. B is the ratio of the orifice dia to pipe dia. These diameters are dependent on the temperature and diameter varies with the temperature with the correlation

$$D = D_{to} \times \left[1 + \gamma_D \times (t_r - t_o)\right] \qquad (2)$$

Where D is the diameter of pipe or orifice, γ_D is the expansion coefficient of pipe or orifice material, t_r is reference temperature and t_o is operating temperature. From detail uncertainty analysis, maximum uncertainty was found about 1.5%.

At a basic level the data reduction equation for turbine meter is:

$$V_b = V_f \times \left(\frac{P_f}{P_b}\right) \times \left(\frac{T_b}{T_f}\right) \times \left(\frac{Z_b}{Z_f}\right) \qquad (3)$$

Where V stands for volume, P for pressure, T for temperature and Z for compressibility factor, b and f are base and flow condition respectively. The uncertainties associated with volume flow measurement by Turbine meter is specified by the AGA 7 and AGA 9 standards. For instance Turbine meter operating at higher flow rates gives uncertainty about ±1% i.e. u = 0.58%. Details of uncertainty can be found in reference [6].

6. RESULTS

Titas Gas system has few numbers of Counter Metering Stations (CMS) at gas purchase points in which two Orifice meters are installed and the gas taken from field is measured continuously through these two meters at the same time. One of the meters is operated by Titas Gas Company and another is operated by gas production Company. Counter measuring data were collected for one month period of time at Narshindhi metering station which was mentioned in Table 2 and figure 7. Most of the cases upstream meters predict higher values but in some cases it gave lower values as well. Overall average error was 1.51%.

Table 2: Comparison of flow measurements by two Orifice meters in series at Narshindhi CMS

No of Days	Gas Flow Rate (MMSCFD)		% Error
	Gas Field Meter (upstream)	TGTDCL Meter (downstream)	
1	17.85	17.54	1.81
2	17.82	17.36	2.65
3	17.85	17.27	3.39
4	17.84	17.40	2.59
5	17.71	17.28	2.51
6	17.77	17.32	2.59
7	16.24	15.94	1.90
8	16.20	15.83	2.35
9	17.38	17.22	0.98
10	17.91	17.54	2.07
11	17.95	17.87	0.41
12	17.28	17.31	-0.18
13	17.98	17.80	1.03
14	17.56	17.52	0.24
15	16.75	16.67	0.45
16	17.24	17.09	0.89
17	17.75	17.53	1.26
18	17.97	17.77	1.07
19	17.81	17.66	0.85
20	18.81	17.81	5.65
21	17.98	18.01	-0.17
22	17.84	17.73	0.60
23	17.93	17.91	0.10
24	16.77	17.05	-1.65
25	12.57	12.42	1.25
26	10.57	10.77	-1.88
27	12.86	12.80	0.50
28	13.70	13.46	1.75
29	14.30	13.86	3.14
30	14.73	14.70	0.35
Total	**500,900**	**494,379**	**1.51**

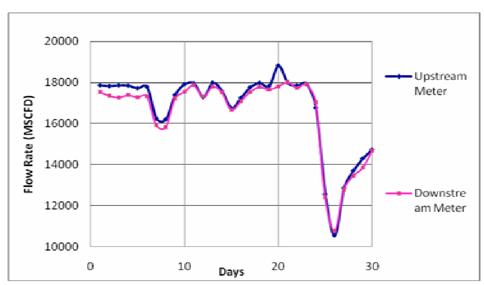

Fig 7. Flow difference between two orifice meters installed in series

In Titas location 3, another set of Orifice meters in series type assembly is available. Measured data for a month were collected and reported in the Table 3 and Figure 8.

Like the pervious case upstream meter gave higher reading than the downstream one. But the overall average error was 0.53%. This small error has a greater impact for high value measurement.

Table 3: Comparison of flow measurements by two Orifice meters in series at Titas location 3

No of Days	Gas Flow Rate (MMSCFD)		% Error
	Gas Field Meter (upstream)	TGTDCL Meter (downstream)	
1	130.07	131.06	-0.76
2	130.02	130.64	-0.47
3	113.34	114.31	-0.84
4	110.70	110.10	0.54
5	112.46	113.20	-0.65
6	117.50	118.03	-0.44
7	108.02	107.46	0.514
8	105.40	104.58	0.77
9	105.55	104.75	0.77
10	102.01	100.43	1.57
11	102.19	101.65	0.53
12	93.16	900.15	3.50
13	117.08	115.96	0.97
14	118.71	118.19	0.44
15	114.18	112.49	1.51
16	115.41	115.45	-0.04
17	110.55	108.23	2.14
18	119.11	117.83	1.09
19	121.82	121.26	0.46
20	123.61	124.06	-0.37
21	125.46	126.26	-0.63
22	127.22	127.07	0.12
23	128.11	125.90	1.76
24	109.44	109.67	-0.21
25	117.97	115.47	2.16
26	119.96	121.27	-1.08
27	121.59	120.06	1.27
28	125.31	125.61	-0.24
29	101.27	98.34	2.98
30	122.36	121.99	0.29
Total	**3469.58**	**3451.340**	**0.53**

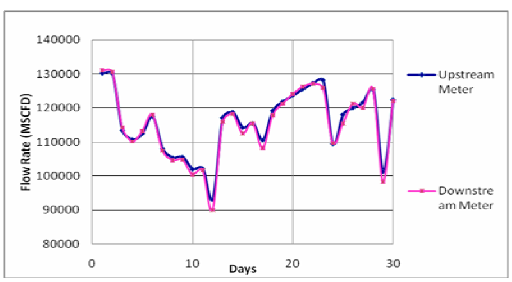

Fig 8. Flow difference between two orifice meters installed in series

Orifice and Turbine meter were installed in series in Titas franchise locations at the RMS of Ashuganj and Ghorasal power plants. Here Orifice meter was in the upstream and Turbine meter was in the downstream side. In Orifice metering system -differential pressure, flowing pressure and flowing temperature were taken from hourly chart reading. Turbine meter pressure and temperature readings were measured on daily average from hourly readings and total gas flow reading were taken from meter counter once per day. In Ashuganj RMS, operating pressure is 495 psia, Temperature 85°F and average flow rate was almost 90 MMSCFD and data were taken over fifteen months time. In the Table 4 shows monthly average readings for Ashuganj RMS meters.

Table 4: Comparison of Orifice and Turbine meter readings at Ashuganj power station RMS

Month	Orifice Meter			Turbine Meter			% Diff
	P avg (psig)	T avg (°F)	Flow MMSCFD	P avg (psig)	T avg (°F)	Flow MMSCFD	
1	499.3	89.12	84.67	485.5	78.75	87.02	2.7
2	498.5	88.75	88.80	486.9	78.43	92.34	3.8
3	496.2	92.68	65.63	480.2	82.97	65.05	-0.9
4	499.5	89.5	88.79	486.6	75.94	91.26	2.4
5	495.8	90.26	67.24	480.3	80.77	66.27	-1.4
6	498.7	89	80.85	483.2	79.23	82.01	1.4
7	496.8	92.39	63.52	483.2	80	63.08	-0.7
8	499	89.16	75.83	487.4	77.52	78.62	3.5
9	498.3	89.74	46.05	491.7	79.42	47.17	2.4
10	497.8	90.44	79.18	485	80.29	81.02	2.3
11	495.5	92.6	78.05	483.2	77.45	80.1	2.5
12	497	92.45	70.90	487.5	78.83	72.87	2.7
13	496.1	89.21	74.98	483.1	78.42	78.08	3.9
14	497.8	89.29	83.93	483.8	80.17	84.74	0.9
15	498	88.67	90.56	481.6	79.55	92.30	1.8
						AVG	**1.84**

Above Table 4 and Figure 9.showed that Turbine meter always gave higher reading than the orifice meter with same flow conditions and 1.84 % of over reading had been reported.

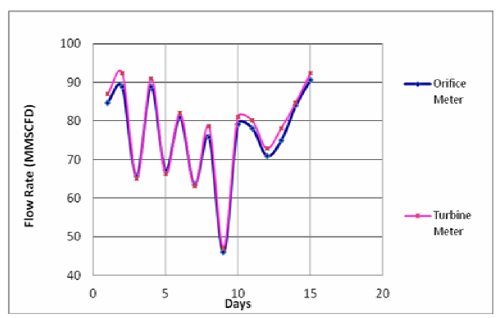

Fig 9. Comparison of Orifice vs. Turbine meter reading at Ashuganj Power Station RMS

Ghorashal RMS Orifice and Turbine meter data were compared and plotted in the Table 5 and Fig 10. This data were taken on an arbitary month and found that turbine meter reading was higher. Over here almost 1% of over reading was recorded by the Turbine meter. Though these reading were not compared with reference meter online, but operating conditions and standard calibration techinques suggested that Turbine meter was the most accurate in this location

Table 5: Comparison of Orifice and Turbine meter readings at Ghorashal power station RMS

Days	Orifice Meter			Turbine Meter			% Diff
	P avg (psia)	T Avg (°F)	Flow (MMSCFD)	P avg (psia)	T Avg (°F)	Flow (MMSCFD)	
1	500	88.5	32.1	493	78	34.4	7.3
2	498	87.9	30.1	492	79	33.2	10.3
3	498.2	87.9	43.9	490	78	48.2	9.6
4	495.4	92.5	63.9	486	79	63.9	0.1
5	495.5	90.7	68.9	482	77	68.7	-0.3
6	495.2	90.4	67.9	481	82	66.4	-2.4
7	495	89.6	71.3	481	80	70.4	-1.4
8	495.4	90.9	68.9	481	80	69.1	0.2
9	495.2	91	67.7	481	81	66.1	-2.4
10	495.83	89.7	64.5	482	82	66.8	3.7
11	495	89.2	67.7	481	81	66.9	-1.3
12	495	89.9	69.6	480	80	66.6	-4.4
13	495	89.8	71.4	480	81	66.5	-6.8
14	495	88.9	69.5	484	81	67.3	-3.3
15	495	90.4	66.9	484	80	67.5	0.84
16	500	89.2	77.7	487	80	76.7	-1.2
17	495.5	88.2	77.4	489	76	79.2	2.3
18	496.2	89.2	78.7	486	75	80.9	2.8
19	495.2	90.3	90.3	485	77	93.7	3.8
20	495.1	91.3	89.3	483	79	90.6	1.5
21	497	91.2	85.9	484	80	87.1	1.3
22	495	91.8	92.3	483	79	95.2	3.1
23	494.8	91.9	86.4	480	80	86.5	0.1
24	495	91.7	69.8	481	79	68.7	-1.6
25	496.9	89.5	63.8	487	79	62.2	-2.5
26	496.5	89.1	61.7	487	77	61.1	-0.9
27	495.5	91.5	63.4	488	76	67.3	6.2
28	496.2	90.3	61.2	485	76	63.3	3.4
29	496.5	89.8	73.4	487	77	78.6	7.1
30	498.3	89.9	80.7	491	76	84.1	4.2
Total			**2076.7**			**2097.2**	**0.98**

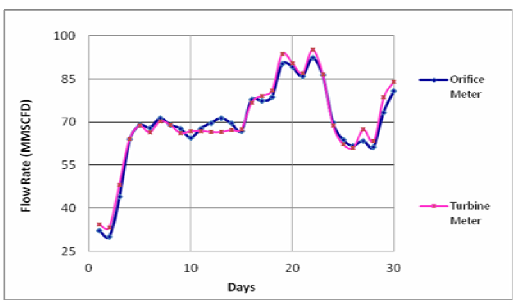

Fig 10. Comparison of orifice vs. Turbine meter reading at Ghorashal Power Station RMS

7. CONCLUSIONS

Calibration of Orifice meter has great influence on measurements. At low flow rate it has more impact than higher flow rates. For 2 inch water column difference in differential pressure measurement caused 5% error at the flow of 20 MSCFD and for 80 MSCFD flow the error was 1%. This shows that turbulent flow is desirable for Orifice meter measurements.

For low flow rates, turbine meter readings are more accurate than the orifice meters. Orifice meter has some limitation in laminar flow region. When two orifice meters were in series, upstream meter gave higher readings. This happens due to loss in pressure in the first meter is irrecoverable in the pipeline. The gas stream cools down at the downstream of first orifice due to expansion of gas. This expansion is isenthalpic or isentropic yet to de determine by the scientist.

8. REFERENCES

1. Redenhall, Anthill Farnhouse, "Introduction to gas metering published by BMW Projects", Norfolk 1P209HP, Copy right 1988, Training Module GM1
2. Rockwell International Report No. 1, "A look at Meter accuracy; Turbo-meter VS. Orifice meter comparison".
3. AGA Report no. 03, "Orifice metering of natural gas and other related hydrocarbon fluids", Part 3 Natural gas application third editions, August 1992.
4. AGA Report no. 07, "Measurement of fuel gas by Turbine Meters"
5. Appalachian, U.S.A, "Fifty ninth Annual Short course on Gas Measurement"
6. Faroque,Golam, Hossain, M. Sohrab, Rahman, Mahbubur, and Chowdhury, Zaved "Comparative study on Orifice versus. Turbine meter for Gas flow measurement",M. Engg Project, PMRE, BUET, June 2009.

9. NOMENCLATURE

Symbol	Meaning	Unit
T	Temperature	(C)
P	Pressure	(Psi)
D	Diameter	(in)
Q	Flowrate	(SCF)
ρ	Density	(lbm/ft^3)
MM	Million	10^6

10. UNIT CONVERSION

FPS Unit	SI Unit
1 Psi	6.89 kPa
1 °F	5/9(F-32) C
1 Ft^3	0.0283 m^3
1 Lbm/ft^3	0.01602 g/cm^3