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# PERFORMANCE EVALUATION OF CLAMP-ON ULTRASONIC FLOW METER

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**ABSTRACT**:

Clamp on Ultrasonic flow meters are widely used in the field due to easy transportation and installation requirements. However performance of these meters may vary in different diameter pipes and under non ideal conditions wherein sufficient minimum straight length as prescribed by the manufacturer may not be available at site. In this context detailed study conducted in-house on clamp on ultrasonic flowmeter to assess the performance.
The above studies have been conducted at Water flow laboratory, Centre for water management laboratory and Large water flow laboratory of FCRI, in different diameter pipes and in non ideal conditions.
This paper discuss about the method of experiment, data evaluation and analysis of results.

## KEYWORDS:

Actual flow, Indicated flow, Transit time, Upstream straight length , down stream straight length.

## INTRODUCTION:

Fluid Control Research Institute (FCRI), an autonomous institute was established in 1987 with active assistance and participation from UNDP and UNIDO under the ministry of industry (govt. of India). At FCRI we have full-fledged NABL accredited laboratories for the calibration of flow meters in water, oil and air medium. The flow laboratories at FCRI are on par with similar laboratories in Europe, as have been proved through an inter laboratory comparison programme with national engineering laboratory UK, Delft hydraulic laboratory and Denmark TECH institute.

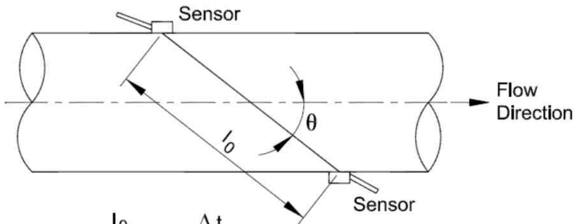
As a premier lab in south east Asia that caters to different sectors of industries viz, refineries, power, process industries, defence, flow product manufactures etc. major companies viz, ONGC, IPCL-nagothanae, BPCL, HPCL, IOCL, GAIL, indraprastha gas ltd., FMC sanmar, RIL, Teltec and various water supply boards have been taking advantage of our services because of the high reliability and accuracy of our systems.

## ULTRASONIC FLOW METER

Ultrasonic flowmeters have gained a lot of attention over the past five years, primarily because of their ability for measuring custody transfer of natural gas. They are replacing differential pressure (DP) and turbine meters in many natural gas applications. But ultrasonic flowmeters are also widely used to measure liquids. And they are not limited to clean liquids either; a special type of ultrasonic flowmeter can also accurately measure the flow of slurries and liquids with many impurities.

## WORKING PRINCIPLE

The difference between the apparent speed of sound in a moving liquid and the speed of sound in the same liquid at rest is directly proportional to the liquid's instantaneous velocity.




$$V = \frac{l_0}{2\cos\theta} \times \frac{\Delta t}{t_{up} \times t_{dn}}$$

Where V- velocity of flow in m/sec

lo – transit length in meters

ϴ – angle of ultrasound path with flow direction

$\Delta$t – difference of u/s and d/s transit times in sec

tup – u/s transit time in sec

tdn - d/s transit time in sec

Ultrasonic flowmeters are one of distinctive types of meters used to measure flow in pipes. The most common variety, transit time, contains both a sending and a receiving transducer. Both sending and receiving transducers are mounted on either side of the flowmeter, or on the pipe wall. The sending transducer sends an ultrasonic signal at an angle from one side of the pipe to the other and back. Some ultrasonic flowmeters send more than one signal and have more than one pair of transducers. The flowmeter measures the time it takes the ultrasonic signal to travel across the pipe and how long it takes the signal to travel back the other way. When the signal travels with the flow, it travels more quickly than it would in conditions of no flow. On the other hand, when the signal travels against the flow, it slows down. The difference between the "transit times" of the two signals is proportional to flowrate. Transit time flowmeters work best with clean fluids. However, much progress has been made in adapting transit time flowmeters to fluids that contain some impurities. Refering to the figure 'V' is the velocity of flow, 'lo' is the length of travel of the sound wave, '$\Delta$t' the difference in the time taken by the wave to travel upstream and down stream, ' tup' and 'tdn' time of travel upstream and down stream respectively and 'ϴ' the angle of sound wave with flow direction.

Doppler based meters, for example, actually require impurities in the liquid to operate properly. Doppler flowmeters send an ultrasonic signal across a pipe, but the signal goes only part way. Instead of sending the signal to the other side of the pipe, a Doppler flowmeter relies on having the signal reflected by particles in the flowstream. These particles travel at the same speed as the flow. As the signal is reflected, its frequency changes in proportion to the flowrate. The reflected signal is detected by a receiver, which measures its frequency. The meter calculates flow by comparing the frequencies of the transmitted and reflected signals. Doppler ultrasonic flowmeters are used with dirty liquids or slurries. They are not used to measure gas flow.

Some ultrasonic flowmeters, called hybrids, incorporate both transit time and Doppler technology. Which technology is used depends on the flowstream. Hybrid meters are used to handle varying application conditions, including both clean and dirty liquids.

## ADVANTAGES OF ULTRASONIC FLOWMETER

General advantages of ultrasonic flowmeters are,

- Simplicity in handling and operation
- High turn down ratio
- Bi Directionality
- Non intrusive models available
- No pressure loss on flow
- No moving parts and hence wear and tear of instrument is minimal
- Can measure the flow of nonconductive liquids, gases, and steam.

## DISADVANTAGES OF ULTRASONIC FLOWMETER

The main disadvantages of ultrasonic flow meters are

- Complex metering technology
- Very sensitivity to installation conditions
- Sensitivity to ultrasound noise

## ANALYSIS

The performance of the meter was evaluated in SS pipes of different diameters. More than 10D straight length in the upstream and 5D straight length in the downstream of the meter were provided during testing. The meter factor was set to 1.0 and was not changed during the measurement in all pipe sizes. It was observed that the error of the meter varies with pipe diameter for the same meter factor. The error of the meter in different line sizes are tabulated in table 1 to 6.

The effect of upstream and downstream straight length on meter performance was also studied in 6" diameter pipe. Various upstream and downstream straight lengths were provided and the performance of the meter was analysed. The performance of the meter for different straight lengths is tabulated in table 7 to 9.

The specification of clamp-on flow meter used for this study is given below:

| Description | Details |
|---|---|
| Type | Clamp on Ultrasonic flow meter |
| Flow measurement method | Transit Time method |
| Accuracy | ± 2% of reading |
| Channel Options | Single channel |

- **Experimental Data In Different Pipe Diameters**

| Pipe size: 4 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 199.218 | 200.50 | 0.64 |
| 2 | 165.128 | 166.73 | 0.97 |
| 3 | 121.724 | 123.07 | 1.11 |
| 4 | 73.501 | 74.38 | 1.20 |
| | | Average Error | 0.98 |

Table 1 . Test result in 4" line.

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 459.135 | 460.62 | 0.32 |
| 2 | 425.716 | 426.52 | 0.19 |
| 3 | 422.300 | 422.89 | 0.14 |
| 4 | 416.987 | 417.47 | 0.12 |
| 5 | 403.900 | 403.82 | -0.02 |
| 6 | 369.500 | 368.66 | -0.23 |
| 7 | 349.480 | 349.29 | -0.06 |
| 9 | 271.510 | 268.55 | -1.09 |
| 10 | 224.058 | 221.49 | -0.15 |
| 11 | 198.910 | 196.48 | -1.22 |
| 12 | 147.948 | 147.48 | -0.31 |
| 14 | 67.622 | 67.42 | -0.29 |
| 15 | 45.367 | 45.55 | 0.41 |
| | | Average Error | -0.17 |

Table 2. Test result in 6" line.

| Pipe size: 8 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate Qa (m3/hr) | Error % |
| 1 | 217.847 | 216.95 | -0.41 |
| 2 | 505.736 | 503.84 | -0.37 |
| 3 | 601.636 | 599.00 | -0.44 |
| 4 | 779.712 | 774.25 | -0.70 |
| 5 | 898.360 | 891.80 | -0.73 |
| | | Average Error | -0.53 |

Table 3. Test result in 8" line.

| Pipe size: 12 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 1357.669 | 1318.74 | -2.87 |
| 2 | 1194.680 | 1161.33 | -2.79 |
| 3 | 992.07 | 967.24 | -2.50 |
| 4 | 799.416 | 776.79 | -2.83 |
| 5 | 597.641 | 580.05 | -2.94 |
| 6 | 397.031 | 384.21 | -3.23 |
| | | Average Error | -2.79 |

Table 4. Test result in 12" line.

| Pipe size: 20 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 501.800 | 480.03 | -4.34 |
| 2 | 897.620 | 855.40 | -4.70 |
| 3 | 1984.500 | 1896.45 | -4.44 |
| | | Average Error | -4.49 |

Table 5. Test result in 20" line.

| Pipe size: 48 inch | | | |
|---|---|---|---|
| Meter factor: 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 6549.3 | 6228.10 | -4.90 |
| 2 | 4797.5 | 4560 | -4.95 |
| 3 | 3057.8 | 2907.1 | -4.93 |
| 4 | 2033.3 | 1932 | -4.98 |
| | | Average Error | -4.94 |

Table 6. Test result in 48" line.

- **Experimental data of meter with flow straightener at different upstream positions.**

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Configuration: Flow straightner at 2D upstream | | | |
| Upstream straight length: | | | 2 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr | |
| 1 | 147.600 | 141.07 | -4.42 |
| 2 | 100.300 | 95.64 | -4.64 |
| 3 | 67.150 | 63.79 | -5.00 |
| | | Average Error | -4.69 |

Table 7. Meter performance with flow straightener at 2D upstream of the meter

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Configuration: Flow straightener at 5D upstream | | | |
| Upstream straight length: | | | 5 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 149.070 | 153.05 | 2.67 |
| 2 | 101.670 | 104.38 | 2.67 |
| 3 | 63.760 | 65.12 | 2.13 |
| | | Average Error | 2.49 |

Table 8. Meter performance with flow straightener at 5D upstream of the meter

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Configuration: Flow straightener at 7D upstream | | | |
| Upstream straight length: | | | 7 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 64.720 | 65.72 | 1.55 |
| 2 | 102.300 | 103.34 | 1.02 |
| 3 | 150.100 | 154.23 | 2.75 |
| | | Average Error | 1.77 |

Table 9. Meter performance with flow straightener at 7D upstream of the meter

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Configuration: Flow straightener at 10D upstream | | | |
| Upstream straight length: | | | 10 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 63.400 | 63.56 | 0.25 |
| 2 | 89.200 | 89.87 | 0.75 |
| 3 | 128.020 | 129.52 | 1.17 |
| 4 | 151.310 | 153.28 | 1.30 |
| | | Average Error | 0.86 |

Table 10. Meter performance with flow straightener at 10D upstream of the meter

- **Experimental data of meter with a reducer at different upstream positions.**

| Pipe size: 4 inch | | | |
|---|---|---|---|
| Configuration: Reducer at 2D upstream | | | |
| Upstream straight length: | | | 2 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No : | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 197.484 | 194.96 | -1.28 |
| 2 | 157.681 | 155.33 | -1.49 |
| 3 | 121.819 | 119.59 | -1.83 |
| 4 | 73.053 | 71.37 | -2.30 |
| | | Average error | -1.73 |

Table 11. Meter performance with reducer at 2D upstream of the meter

| Pipe size: 4 inch | | | |
|---|---|---|---|
| Configuration: Reducer at 5D upstream | | | |
| Upstream straight length: | | | 5 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate(m3/hr) | Error % |
| 1 | 203.969 | 201.40 | -1.26 |
| 2 | 164.337 | 162.53 | -1.10 |
| 3 | 141.952 | 140.67 | -0.90 |
| 4 | 77.683 | 76.42 | -1.63 |
| | | Average Error | -1.22 |

Table 12. Meter performance with reducer at 5D upstream of the meter

| Pipe size: 4 inch | | | |
|---|---|---|---|
| Configuration: Reducer at 5D upstream | | | |
| Upstream straight length: | | | 10 D |
| Downstream straight length: | | | >5 D |
| Meter Factor | | | 1.000 |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 199.218 | 200.50 | 0.64 |
| 2 | 165.128 | 166.73 | 0.97 |
| 3 | 121.724 | 123.07 | 1.11 |
| 4 | 73.501 | 74.38 | 1.20 |
| | | Average Error | 0.98 |

Table 13. Meter performance with reducer at 10D upstream of the meter

- **Experimental data of meter with NRV at different upstream positions.**

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Upstream straight length: 5D | | | |
| Downstream straight length: >5D | | | |
| Meter Factor : 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 220 | 203.3 | -7.59 |
| 2 | 198 | 184.75 | -6.69 |
| 3 | 148 | 138.92 | -6.14 |
| 4 | 107.8 | 101.3 | -6.03 |
| 5 | 69.5 | 65.68 | -5.5 |
| 6 | 43.6 | 41.19 | -5.52 |
| | | Average Error | -6.25 |

Table 14. Meter performance with NRV at 5D upstream of the meter

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Upstream straight length: 10D | | | |
| Downstream straight length: >5D | | | |
| Meter Factor : 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 320.978 | 322.96 | 0.62 |
| 2 | 301.97 | 298.34 | -1.2 |
| 3 | 267.739 | 268.31 | 0.21 |
| 4 | 226.516 | 225.34 | -0.52 |
| 5 | 200.296 | 198.95 | -0.67 |
| 6 | 147.387 | 146 | -0.94 |
| 7 | 104.36 | 103.03 | -1.27 |
| 8 | 68.36 | 68.33 | -0.05 |
| 9 | 44.9 | 45.43 | 1.17 |
| | | Average Error | -0.29 |

Table 15. Meter performance with NRV at 10D upstream of the meter

| Pipe size: 6 inch | | | |
|---|---|---|---|
| Upstream straight length: 7D | | | |
| Downstream straight length: > 5D | | | |
| Meter Factor : 1.000 | | | |
| Sl.No: | Actual flow rate Qa (m3/hr) | Mean Indicated flow rate (m3/hr) | Error % |
| 1 | 320.275 | 311.66 | -2.69 |
| 2 | 301.456 | 293.26 | -2.72 |
| 3 | 268.455 | 261.07 | -2.75 |
| 4 | 225.478 | 219.41 | -2.69 |
| 5 | 199.987 | 194.59 | -2.70 |
| 6 | 150.150 | 145.81 | -2.89 |
| | | Average Error | -2.75 |

Table 16. Meter performance with NRV at 7D upstream of the meter

## RESULTS

- **Varying pipe diameters**

From the measurement data it was observed that the accuracy of the meter changes with respect to varying pipe sizes for a particular meter factor. From figure 1 it is evident that pipe diameter has significant effect on the accuracy of clamp-on ultrasonic flow meter for same velocity range. It is observed that the % error in reading shifted towards positive side with decrease in pipe diameter. However it was observed that the variation in meter performance is less in large pipe sizes. From the results it is evident that pre calibrating the instrument in almost same pipe sizes at which the instrument is going to be used is necessary for ensuring correct measurement.

- **Non-ideal upstream conditions**

The meter was tested with different upstream disturbances by providing different flow elements, like flow straightener, pipe reducer and non-return valve (NRV), at the upstream side. Test was conducted by providing different up-stream straight lengths for all flow elements. The performance of the meter in 150 mm pipe line for different up-stream configurations are given in figure 2. By plotting the upstream distance vs error for flow straightener, reducer and NRV, we can observe that the error is within 1 % only when 10 D upstream straight length is provided.

## CONCLUSION

From this study we could establish that pipe line diameter has significant effect on the accuracy of clamp-on ultrasonic flow meter for same velocity range in pipe size less than 500 mm. The effect of up-stream straight length on the meter performance is also evaluated for various up-stream configurations. It is observed that decrease in the upstream length less than 10D will increase the error in the flow measurement. Hence a straight length of 10 times the pipe diameter shall be provided for measurement accuracy of ± 1 %. Further analysis with multiple meters also has to be performed to strengthen the evaluation.

Pre calibration of the instrument at laboratory has to be carried out at required velocity range in almost same pipe size which is under consideration at the site.

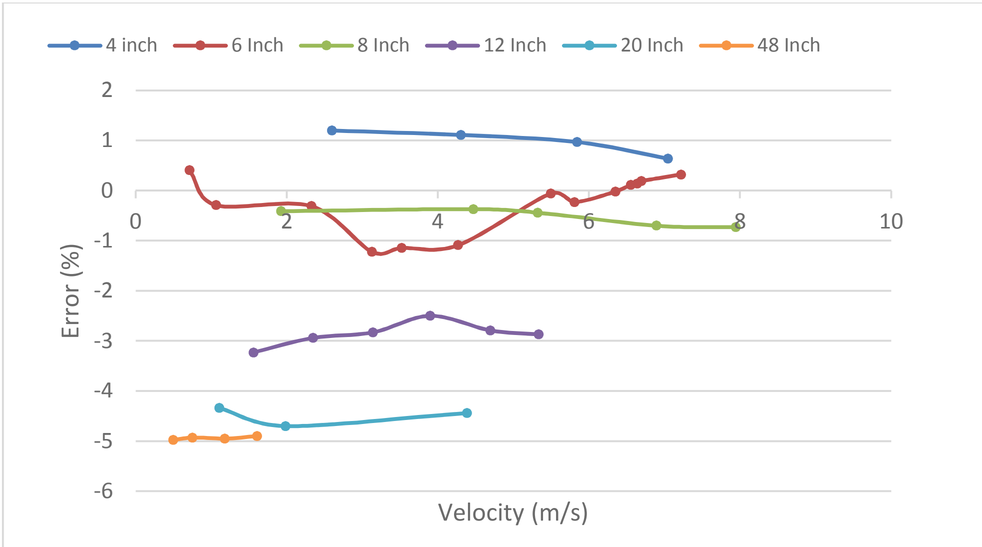



**Fig 1: Graph for Varying Pipe Diameter**

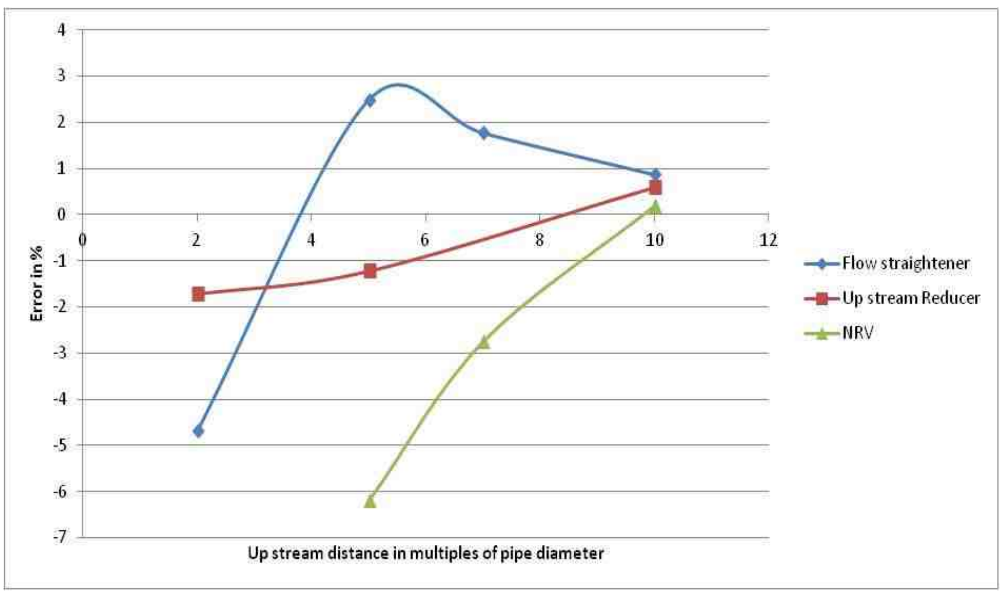



**Fig 2: Graph for Non-ideal Upstream conditions**

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