

*Full Research Paper*

## **Study on a Concentric Tube Bulb Manometer and its Performance Compared to U-shaped Manometer**

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**Abstract:** This paper presents comparative study of a new type of manometer called concentric tube bulb (C.T.B) manometer. Its performance of measuring differential height is studied against conventional U-shaped manometer. Pressure drops and mass flow rates are calculated by taking various systems comprising of different flow measuring devices such as orifice and venturimeters using both U- shaped and C.T.B manometers. Comparison between the physically measured values of differential pressure drops and mass flow rates with the calculated values based on theoretical equations is also made. Experiments are carried out using mercury and CCl<sub>4</sub> in these manometers as sensing fluids. Water is used as flowing fluid for mass flow rate and pressure drop measurements, whereas in gauge pressure measurements air is used.

**Keywords:** Comparative study, Differential height, Concentric tube bulb manometer, Mass flow rates, Sensing fluids.

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### **1. Introduction**

In 1661 Dutch physicist and astronomer Christian Huygens invented the U tube manometer, which was a modification of Torricelli's barometer for determining gas pressure differences. Although the manometer is one of the earliest pressure measuring instruments, it is still widely used because of

inherent accuracy and simplicity of operation. It is an important device used for measuring low pressure differences and gauge pressures by balancing the pressure against the weight of a column of fluid on laboratory and industrial scale [1]. According to hydrostatics, a change in elevation of a liquid is equivalent to a change in pressure thus a static column of one or more fluids is used to measure pressure differences between two points [2].

Different types of manometers used in laboratory as well as on industrial scale are U-shaped, well type, inclined, inverted, two liquids and multi-tube manometers [3]. The general classification of manometers is based on whether they have an open end or sealed end or have both the ends open [4].

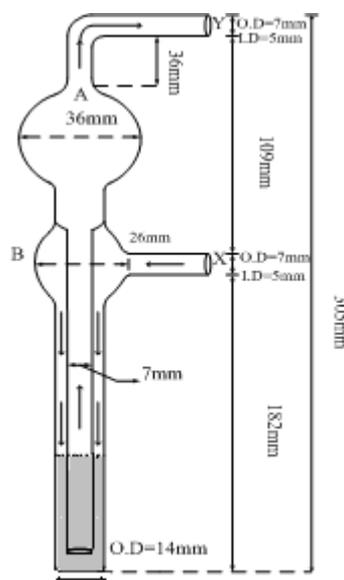
Holley et al. [5] showed that manometers are a passive form of instrument which can be left unattended to monitor fluid loads. Modern day use of these conventional and modified manometers involves a wide variety of applications for example; Webster [6] developed a less expensive, reliable and easily maintained tensiometer for determining the water in soil under growing plants. Patin [7] used manometers for frosting control. In some cases these can be used in less accessible places like nuclear industry. Manometers made for commercial purpose are available in different shapes and ranges depending upon the nature of use; one of the commercial usages is McLeod manometer developed by Jansen et al. [8] for measurement of low gas pressures up to  $5 \times 10^{-5}$  mm Hg without changing the composition of the gas. In medical field, measurement of carotid artery back pressure is also done by manometer. This device can measure arterial pressures less than 60 torr [9]. Poiseuille [10] introduced mercury hydrodynamometer for pressure measurement which than later developed for different pressure measuring processes.

Much of the research work accounts for the use of pressure measuring devices and thus modern day use of these manometers involve different areas as Brunold and et al. [11] used U-shaped manometers to study oscillatory flow in geometries that contained sharp edges. Another type of manometer named vapor pressure manometer have its edge in measuring water activity of saturated salt solutions as done by Lewicki [12]. Nielson et al. [13] incorporated combined use of manometers with tube-transducer systems for coastal water level and wave measurements. Salcudean et al. [14] investigated the pressure drops due to flow obstructions in horizontal air-water systems. Axial pressure distributions along a 25.4 mm inside diameter tube, with and without flow obstructions were measured using multi-tube manometers. Obstructions of various shapes and sizes were investigated to determine the kinetic energy and momentum of flow for different radial void distribution measurements.

Most of the manometers which are in use have inherent disadvantage in their design. If there is a sudden surge in the flow of fluid; the manometer fluid jumps out of manometer tubing and comes out in either the main fluid line whose pressure is been measured or in the container connected to the other end of the manometer. Some times mercury is used as sensing fluid and its spillage can cause hazardous problems. In addition, pressure fluctuations during low or high fluid flow causes erroneous evaluation of actual results. Thus, there is a pressing need to develop a manometer for such applications which can overcome the above difficulties and be as accurate as that of the conventional U-shaped manometer. Another additional advantage includes compactness of C.T.B manometer, occupying less space as compared to conventional U-shaped manometer. The design presented in the present paper is inspired by two reservoir manometer design.

A new type of manometer is designed whose basic working principle is same as that of other conventional manometer but differs in its stable construction and shape. C.T.B manometer shown in Figure 1, comprise mainly of two glass bulbs spherical in shape and two glass tubes which are concentric. Total length of the C.T.B manometer is 305 mm and the diameter of the outer tube is 14mm. The outer diameters of both the bulbs A and B are 36mm and 26mm respectively. Outer diameter of the inside tube is 7 mm and wall thickness of glass is 1 mm.

Two limbs X and Y, 109mm apart, extended from lower and upper spheres respectively are used as pressure tappings. Out of which the lower tapping X is connected to a point of high pressure and tapping Y to relatively lower pressure enabling C.T.B to measure differential pressure. For gauge pressure measurement tapping Y has to be left open to atmosphere. Volumes of the bulb A and bulb B are  $20.6 \text{ cm}^3$  and  $7.24 \text{ cm}^3$  respectively. Bulb A is at distance of 36 mm from Y.

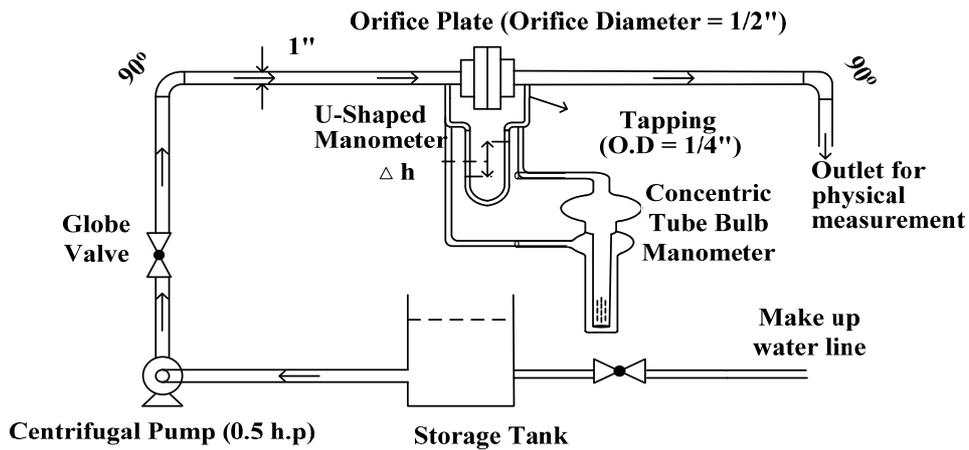


**Figure 1.** Diagram of the concentric tube bulb manometer.

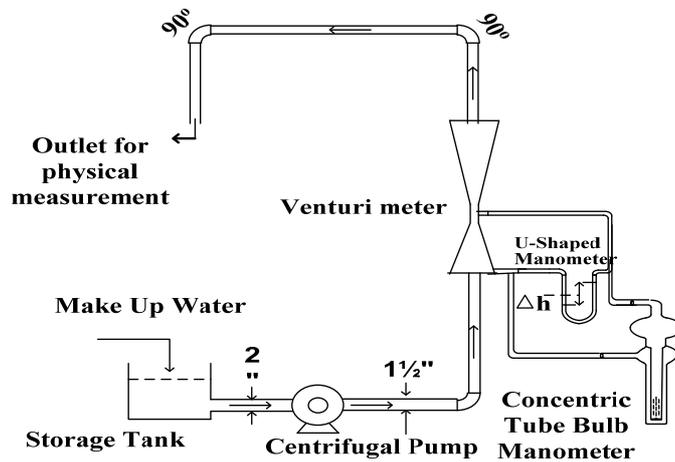
## 2. Experimental Section

Series of experiments were performed on the C.T.B manometer in comparison with conventional U-shaped manometer by taking mercury and carbon tetra chloride as sensing fluids separately.

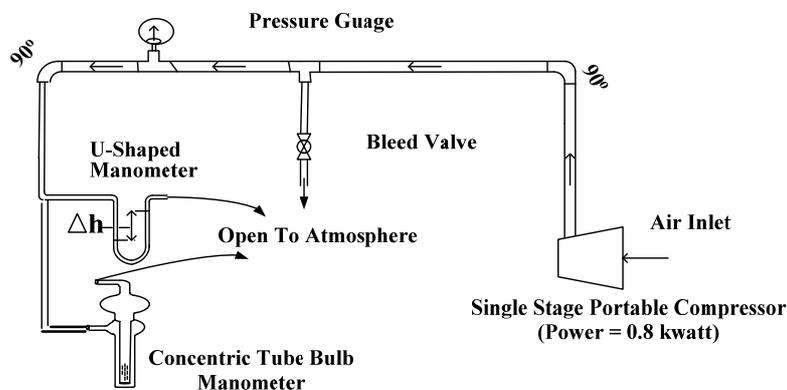
Experimental setups are shown in the Figures 2 to 4. Experimental rig in Figure 2 was employed to study variation of mass flow rates of water on difference in heights of sensing fluids i.e.; mercury and carbon tetra chloride alternatively for both C.T.B and U-shaped manometers. Differential pressure was created by introducing a 12.7mm I.D, 316L stainless steel concentric type standard orifice plate across the flanges. Whereas, an arrangement for C.T.B and U-shaped manometer with a vertically installed (316L stainless steel,  $15^\circ$  angle of convergence and  $7^\circ$  angle of divergence) venturimeter is shown in Figure 3. Venturimeter having a throat diameter of 25.4mm and vertical distance of 113mm between pressure tapping was used.



**Figure 2.** Experimental rig for studying the impact of variation of mass flow rates on difference in heights alternatively for both U-shaped and C.T.B manometers installed across orifice meter.



**Figure 3.** Experimental rig for studying the impact of variation of mass flow rates on difference in heights alternatively for both U-shaped and C.T.B manometers installed across venturimeter.



**Figure 4.** Setup to study the variation of gauge pressure of compressed air on the differential pressure readings using both U-shaped and C.T.B manometers.

Mass flow rates of water were calculated on the basis of changes in head for both orifice and venturimeters with help of Equations 1 and 2 respectively. Calculated mass flow rates were obtained for both types of manometers using mercury and carbon tetra chloride separately and analyzed later.

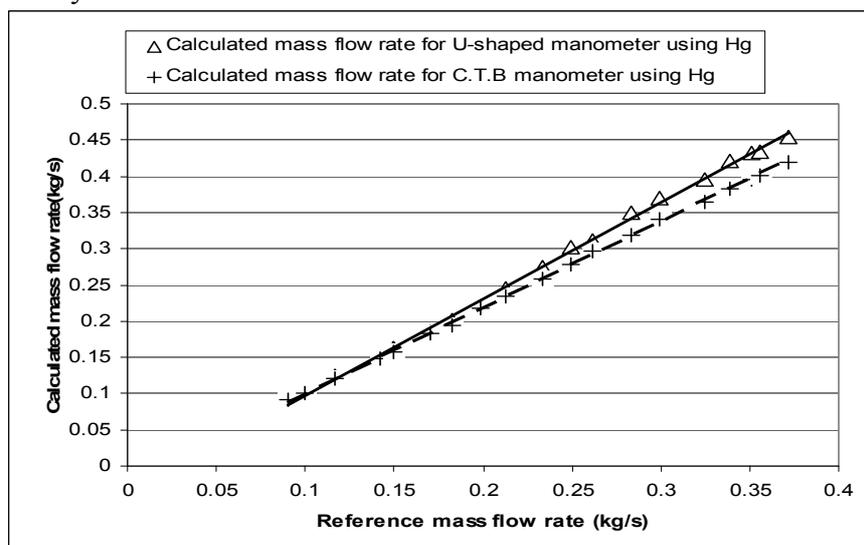
$$G = C_D A_O \rho \sqrt{2gh_o} \quad (1)$$

$$G = C_D \rho \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}} \sqrt{2gh_v} \quad (2)$$

$C_D$  for venturimeter varied within range of 0.843 to 0.957 for different flow rates, whereas for orifice meter the variation was from 0.31 to 0.54. Another experimental setup shown in Figure 4 involved the study of variation of gauge pressure readings on gauge differential pressure measurements. This also included the two manometers with only mercury as sensing fluid. In this set of experiment a calibrated bourdon tube gauge of 63.5 mm dial was used. Selection of a calibrated bourdon gauge as reference is made to include air as flowing medium unlike water taken in previous experiments.

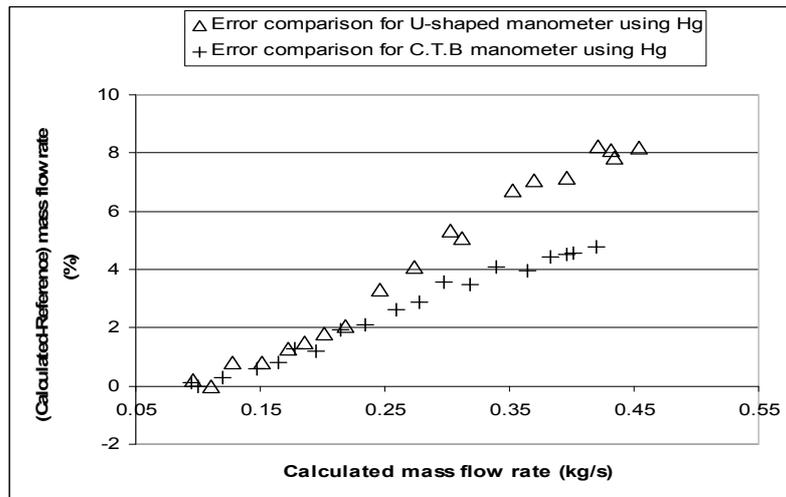
### 3. Results and Discussion

Initially a comparison between physical (reference) and calculated mass flow rate measurements was made on the basis of change in head across orifice meter. Reference measurements of mass flow rate during fixed interval of time were taken with the help of liquid level fitted calibrated tank. Figure 5 shows the profiles between calculated and reference mass flow rates for both manometers while using mercury (Hg) as sensing fluid. Data distribution points were consistent to each other for initial flow rate range of 90-183g/s. However after 207g/s, plotted data points start to apart from each other. Slope analysis revealed that a close agreement of linear relationship between reference and calculated mass flow rates existed in case of C.T.B manometer. Whereas in case of U-shaped manometer the slope of the calculated flow rate points was found to be higher than that of C.T.B manometer. The angles of data fitted lines with reference mass flow rate axis are  $49^\circ$  and  $53^\circ$  for C.T.B and U-shaped manometer respectively.



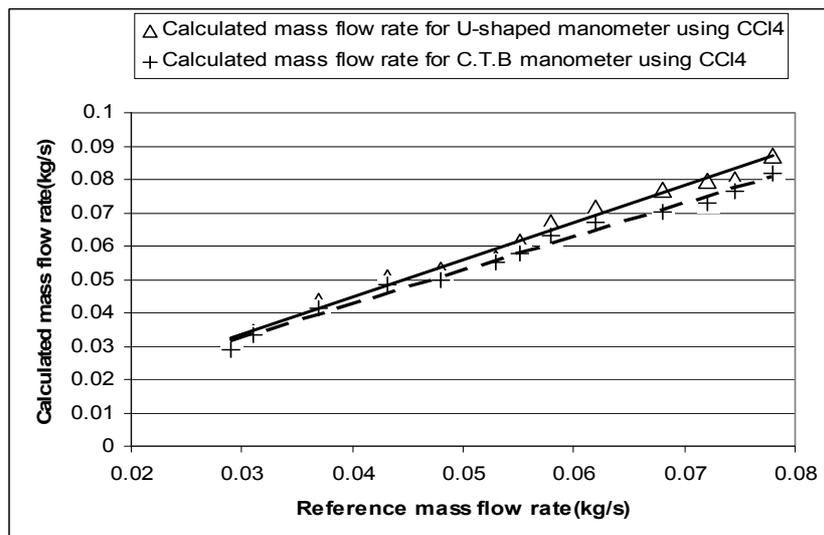
**Figure 5.** Comparison between reference and calculated mass flow rates in case of orifice meter using Hg as manometer fluid.

Figure 6 shows error difference in percentage between calculated and reference mass flow rates plotted against respective calculated mass flow rates. Fixed error difference of about  $\pm 0.4\%$  was observed for both the manometers within initial range of mass flow rate, however for later flow ranges the average error difference increased to 3.8% and 7% for C.T.B and U-shaped manometer respectively. Additionally in case of C.T.B it is apparent that error peaks for higher distribution points were of less value compared to error peaks of U-shaped manometer. It was also observed that error percentage in case of U-shaped manometer increased as step function compared to C.T.B. The reason for this seemed to be due to the pressure fluctuations during mass flow rate changeovers which were dampened because of increased wetted perimeter of concentric tubes and greater areas of spherical bulbs of C.T.B manometer.



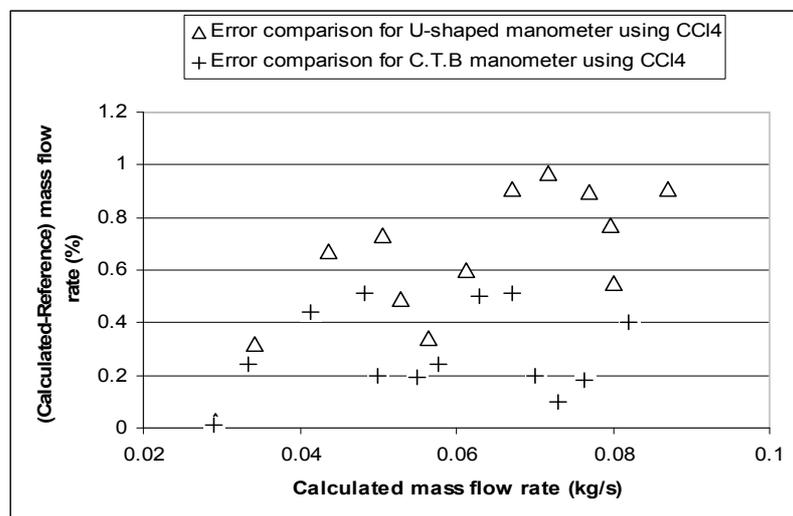
**Figure 6.** Error analysis comparison between mass flow rates in case of orifice meter while using Hg as sensing fluid.

Similar set of experiments were carried out using carbon tetra chloride as sensing fluid. Plotted data points shown in Figure 7 for C.T.B and U-shaped manometer gave different slope angles of  $45^\circ$  and  $48^\circ$  respectively.

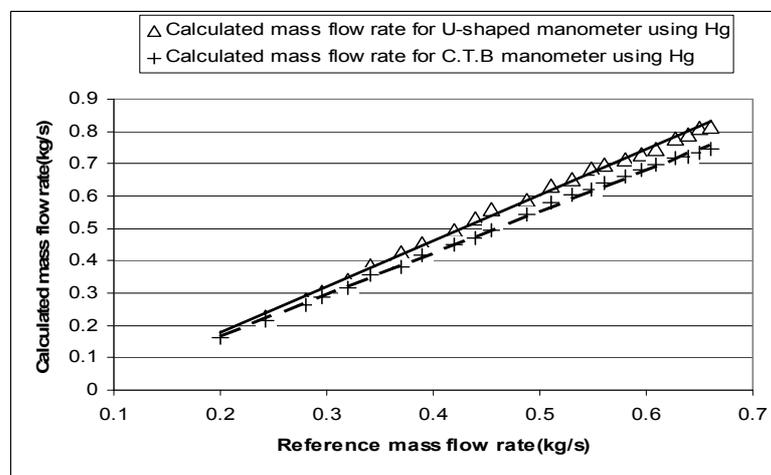


**Figure 7.** Comparison between reference and calculated mass flow rates in case of orifice meter using  $\text{CCl}_4$  as manometer fluid.

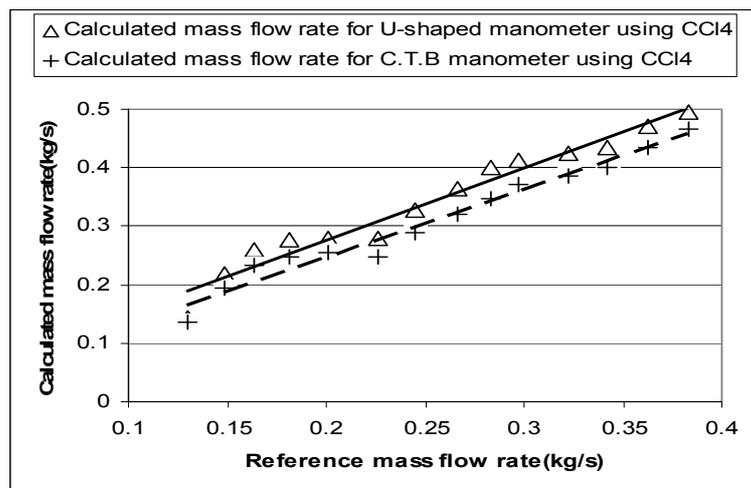
This behaviour is again in conjunction with observations of Hg when used as sensing fluid. However, data distribution points show a slight shift among various values of reference mass flow rates which relates to lesser density and surface tension of  $\text{CCl}_4$  as compared to Hg. Adequate number of repeatable reference flow rates were practically impossible for  $\text{CCl}_4$  because of the same limitation of lower density and surface tension. Despite this, both the manometers results in error difference (Figure 8), which propagates over to a sinusoidal function. Results of this nature show that  $\text{CCl}_4$  is more prone to instability during mass flow rate changeovers. However, for the studied flow rates, overall percentage average error was not more than 0.2% in case of C.T.B compared to 0.6% for U-shaped manometer because of dampened behavior of C.T.B manometer. The effect of irregular mass flow rate changeovers resulting in pressure transients is another salient feature which is under experimentation for another study of stability response comparison between both the manometers. This will also include development of performance equation along with study of capillary effect in C.T.B manometer.



**Figure 8.** Error analysis comparison between mass flow rates in case of orifice meter while using  $\text{CCl}_4$  as sensing fluid.

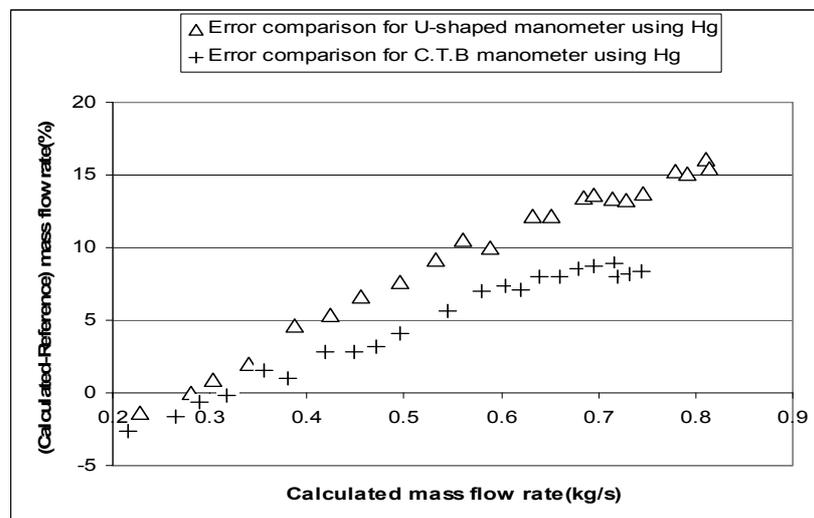


**Figure 9.** Comparison between reference and calculated mass flow rates in case of venturimeter using Hg as manometer fluid.



**Figure 10.** Comparison between reference and calculated mass flow rates in case of venturimeter using  $\text{CCl}_4$  as manometer fluid.

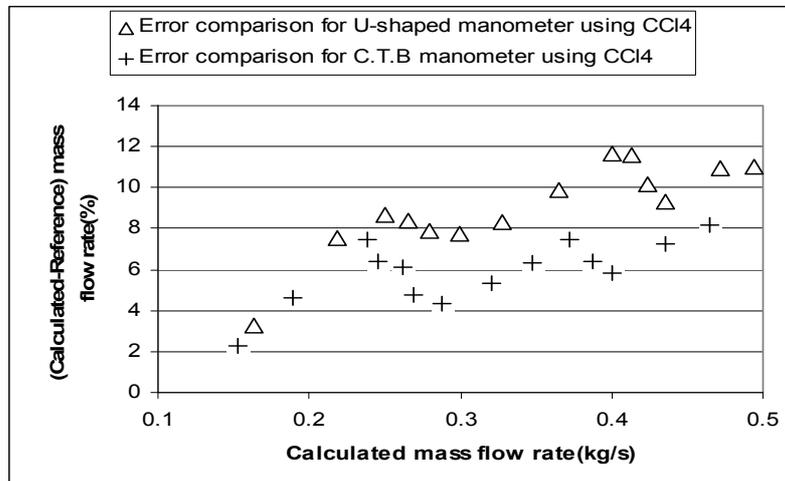
Another set of experiments are carried out across venturimeter for both manometers using the same set of sensing fluids. Mass flow rates are compared in the same manner as done for orifice meter. The graphs between reference and calculated mass flow rates are shown in Figure 9 and 10 for mercury and  $\text{CCl}_4$  respectively, whereas, error percentage for the said combination is plotted in Figure 11 and 12.



**Figure 11.** Error analysis comparison between mass flow rates in case of venturimeter while using Hg as sensing fluid.

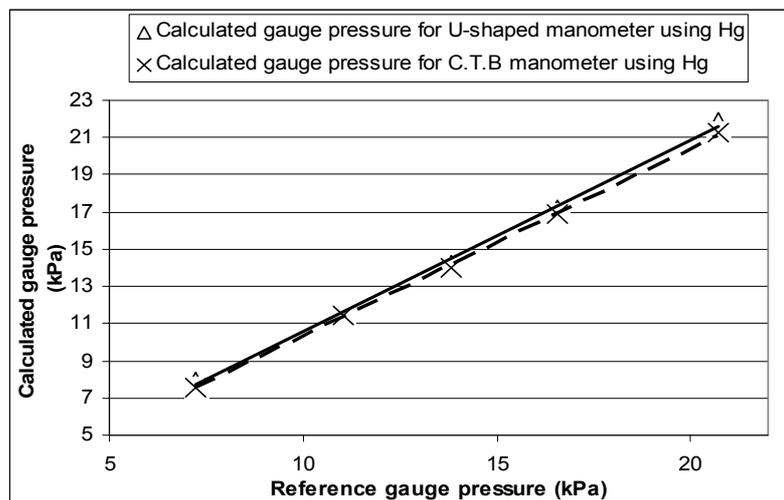
Profiles plotted in Figure 9 & 10 again reiterate a linear relation agreement in case of C.T.B as previously observed in Figure 5 & 7. Slope angles of  $52^\circ$  and  $48^\circ$  are determined for C.T.B in comparison to  $55^\circ$  and  $50^\circ$  for U-shaped manometer in case of Hg and  $\text{CCl}_4$  respectively. Error distribution points for the above combination are also found to be similar as that shown in Figure 6 and 8. Error profile of Figure 11 like Figure 6 shows a step rise function in case of U-shaped manometer as compared to steady dampened profile of C.T.B manometer. Step rise error function of U-shaped manometer is due to its sensitivity towards pressure fluctuations. Whereas the steady dampened profile

of C.T.B manometer makes it appropriate for changing flow applications due to its fluctuation compensating bulbs. On the other hand Figure 12 like Figure 8 results in the same sinusoidal function of error distribution. Reason associated with this is lesser density and surface tension of  $\text{CCl}_4$ . In this case, values of the error percentage are again found to be less for C.T.B manometer.



**Figure 12.** Error analysis comparison between mass flow rates in case of venturimeter while using  $\text{CCl}_4$  as sensing fluid.

The third phase of study involved comparison between calculated and measured gauge pressures using C.T.B and U-shaped manometers. The resultant profiles shown in Figure 13 represented C.T.B manometer gauge pressure readings more concordant with the actual gauge pressure readings.



**Figure 13.** Comparison of measured gauge pressure with calculated gauge pressures using Hg.

#### 4. Conclusions

Performance comparison of C.T.B manometer with U-shaped manometer is studied by measuring mass flow rates and pressure drops. Pressure differentials across the constriction of orifice and venturimeters are obtained using both U-shaped and C.T.B manometers. Reference and calculated mass flow rates based on changes in head of flowing fluid are compared. Slope analysis of the data

generated lines have shown that mass flow rates obtained by C.T.B manometer are close to linear agreement with reference mass flow rates than U-shaped manometer. Error percentage for U-shaped manometer is found to increase as step rise function which is due to its sensitivity towards pressure fluctuations. In case of C.T.B manometer, pressure fluctuations during mass flow rate changeovers were dampened due to increased wetted perimeter of concentric tubes and greater areas of spherical bulbs, thus resulting in stable error peaks. On the other hand sinusoidal error behavior for both manometers, while using  $\text{CCl}_4$  as sensing fluid, is due to its lesser density and surface tension. Experimental results performed across venturimeter also fall under the domain of profiles taken for orifice meter.

Gauge pressure values are also calculated for U-shaped and C.T.B manometer taking dead weight tested standardized bourdon tube gauge. These calculated gauge pressure readings from experiments are compared with bourdon gauge readings. It is observed that gauge pressure values obtained from C.T.B manometer are closer to linearity with bourdon tube gauge pressure reading. Further experimentations are underway to study the capillary effects, pressure transients against mass flow rate changeovers along with calculation of characteristic time and process gain values.

### Acknowledgements

The valuable discussions and suggestions given by Mr. Liaqat Mahmood regarding the design of C.T.B manometer are highly appreciated.

### Nomenclature

G	= Mass flow rate	[g/s]
$C_D$	= Coefficient of Discharge	
$\rho$	= Density of the fluid	[g/cm <sup>3</sup> ]
$A_0$	= Area of orifice	[cm <sup>2</sup> ]
$A_1$	= Area of pipe	[cm <sup>2</sup> ]
$A_2$	= Area of throat of venturi	[cm <sup>2</sup> ]
g	= Acceleration due to gravity	[cm/s <sup>2</sup> ]
$h_v$	= Change in head over converging cone of venturimeter converted in terms of flowing fluid	[cm]
$h_o$	= Change in head over orifice meter converted in terms of flowing fluid	[cm]

### References and Notes

- McCabe, W. L.; Smith, J. C. *Unit Operations of Chemical Engineering*, 7<sup>th</sup> Ed; McGraw-Hill Professional: New York, 2006 (international edition).
- Felder, R. M.; Rousseau, R. W. *Elementary Principles of Chemical Processes*, 3<sup>rd</sup> Ed; John Wiley & Sons Inc.: Hoboken, NJ, 2000.
- Coulson, J. M.; Richardson, J. F. *Chemical Engineering*, Vol. 1, 6<sup>th</sup> Ed. Butterworth Heinemann: London, UK, 2000 and reference therein.
- White, F. M. *Fluid Mechanics*, 4<sup>th</sup> ed., WCB / McGraw-Hill Publishers: New York, 1999 and references therein.
- Holley, W. L.; Banister, J. R. Use of dynamically responding manometers to monitor structural wind pressure loads. *Journal of Wind Engineering and Industrial Aerodynamics* **1975**, *1*, 139.

6. Webster, R. The measurement of soil water tension in the field. *New Phytologist* **1966**, *65*(2), 249.
7. Patin, A. Optimization of hot gas defrosting in a low temperature room. *International Journal of Refrigeration* **1990**, *13*, 325-329.
8. Jansen, C. G. J.; Venema, A. A McLeod manometer with prescribed volumes for use as a standard instrument. *Vacuum* **1959**, *9*, 219-230.
9. Archi, J. P. A simple accurate manometer technique for measuring carotid artery back pressure. *The American Journal of Surgery* **1978**, *136*, 643-644.
10. Roguin, A.; Riva-Rocci S. and the men behind the mercury sphygmomanometer, *International Journal of Clinical Practice* **2006**, *60*, 73.
11. Brunold, C. R.; Hunns, J. C. B.; Mackley, M.; Thompson; R. J. W. Experimental observations on flow patterns and energy losses for oscillatory flow in ducts containing sharp edges. *Chemical Engineering Science* **1989**, *44*, 1227-1244.
12. Lewicki, P. P. Measurement of water activity of saturated salt solutions with the vapour pressure manometer. *Journal of Food Engineering* **1989**, *10*, 39-55.
13. Nielsen, P.; Dunn, S. L. Manometer tubes for coastal hydrodynamics investigation. *Coastal Engineering* **1998**, *35*, 73-84.
14. Salcudean, M.; Groeneveld; D. C.; Leung, L. Effect of flow-obstruction geometry on pressure drops in horizontal air-water flow. *International Journal of Multiphase Flow* **1983**, *9*, 73-85.