THE EXPERIMENTAL AND COMPUTATIONAL STUDY OF PRESSURE DROP ACROSS A SINGLE JET WATER METER

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Abstract - *The present work carried out experimental and computational study of pressure drop across the class B - IS 779 standard single jet water meter. The experiment was carried out in a laboratory equipped with state of the art equipment's which facilitates in-house evaluation of flow product. The pressure drop across the water meter and measurement error for different flow rates has been obtained from the experimental results. The water was modeled and analyzed using ANSYS FLUENT software [1]. The standard k-ε model is used for turbulence modelling with standard wall function [2]. The impact of water jet on turbine plates is the basic operating principle of this kind of meters. The pressure drop across a single jet water meter for different flow rates was determined computationally. The pressure drop obtained from CFD analysis was validated through experimental measurements performed on a test rig. The computational pressure drop and experimental pressure drop are found to be in good agreement. The performances of the meter at different flow rates were analyzed and the related change in the measurement error was plotted.*

***Key Words*:** Single Jet Water Meter, Experimental Test Rig, CFD, Measurement Error, Pressure Drop

1. INTRODUCTION

A water meter is a device that measures the volume of water that passes through it [5]. Mechanical, electromagnetic and ultrasonic are the different types of water meters available nowadays. Two common approaches to flow measurement in the mechanical designs are velocity and displacement based approaches. Velocity based designs include single- and multi - jet and turbine meters. Single-jet meters are broadly used for measuring water consumption in industrial, commercial, and domestic applications. Their wide measuring range and notable low-flow receptivity, along with their long-term durability, make single-jet water meters a cost-effective choice for general billing purposes.

Single jet meters use a single flow stream or jet to move the sensor, which involves an impeller / turbine with radial vanes. The speed at which the turbine rotates is expected to be proportional to the flow rate, so that the number of revolutions that the turbine turns is thereby proportional to the water volume delivered through the meter.

Manufacturers provide error curve composed with the pressure drop showing that the meter come across the desires of the applicable standard. The inaccuracy in volume measurements is influenced by the flow rate and its deviation all over the measuring range of the meter is called error curve [3].

Regardless of their simple functioning principle, single-jet meters are hard to theoretically evaluate. Due to the absence of a solid theoretical origin, the design and enhancement of single-jet water meters have been mainly accomplished so far by means of the skill gathered by each industrialist in expensive experimental events. This procedure involves building expensive prototypes and a large number of tests, which are limited to assessing the error and pressure drop curves of the new meter designs. Therefore, improvements in performance obtained with this methodology are often difficult to interpret and are not universally applicable.

Pressure drop is the difference in upstream and downstream pressure across the water meter. There is a limit for pressure drop at each flow rates for the proper working of a water meter. In this work a very simplified theoretical model is used in which it is assumed that the turbine rotates at a strictly constant speed for a given flow rate and that there is no interference between the vanes impacted by the jet. The pressure drop across the water meter has been determined experimentally in a laboratory equipped with state of the art equipment's which facilitates in-house evaluation of flow product. Alternatively; computational fluid dynamics (CFD) technique also has been employed for determining the pressure drop across the water meter.

1.1 Description of the Meter Studied

The single jet water meter used is of class B - IS 779 standard, which is commonly used for residential purposes. The figure 1 shows the single jet water meter which has been used in the study. Its ten-vane turbine is contained in a cylindrical chamber. The turbine is mounted on a pivot bearing and it has a magneto transmit the number of revolutions by a magnetic coupling to the mechanical register located in a water tighten closure. Both inlet and outlet pipes have straight ends that are aligned with the axis of the pipeline. In this case t h e inlet strainer has been removed for simplicity. The measuring range of single-jet water meters in residential applications usually expands from 30l/hto3000l/h.

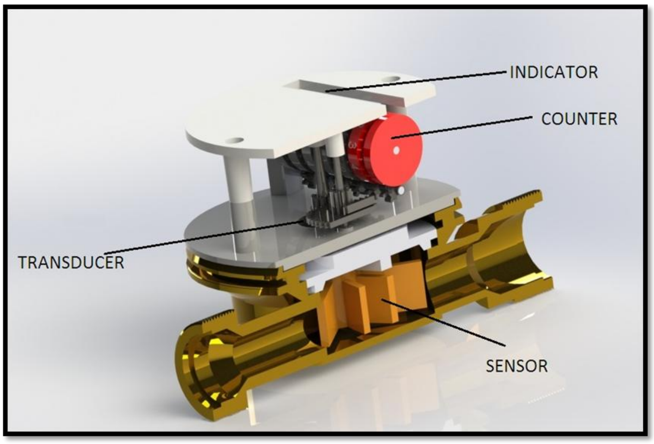

Figure 1:- Components of class B - IS 779 standard Water Meter

2. EXPERIMENTATION

2.1 Test Rig

The experimentation has been carried out in a laboratory equipped with state of the art equipment's which facilitates in-house evaluation of flow product. The accurate measurement of flow in terms of volume is determined by gravimetric system.

The schematic diagram of the experimental set up is as shown in Figure 2. The flow source consists of a constant head tank located at a height of 15m and a centrifugal pump. The water meter to be tested is connected in a pipe of 2 inch size. In order to maintain the water quality, stainless steel pipes and fixtures are used. Air vents are placed at areas where flow increases or decreases to remove the air entrapped. Ball valves are used to control the flow and gate valves are used only to fully open or close the supply. An electromagnetic flow meter is employed to sense the water flow through the pipeline. The weight of water passing through the test line is measured using a weighing balance fitted with a tank, from which the volume of water passing across the water meter is calculated. Pressure gauges are kept across the water meter to measure the upstream and downstream pressures

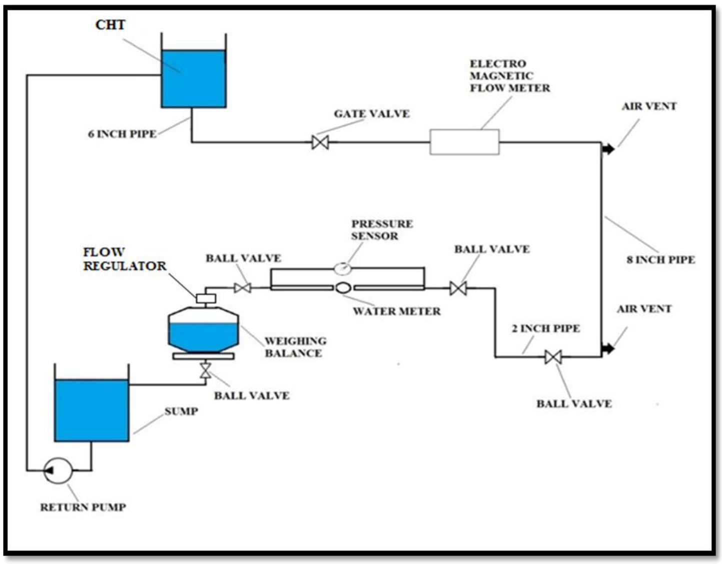

Figure 2:- Experimental Test Rig

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2.2 Procedure

The water is allowed to continuously flow through the pipes and water meter for about ten minutes to make flow region completely filled with the liquid. This is to ensure that all the air from this portion of the meter and pipe is driven out to get uninterrupted supply of liquid from the constant head tank. The flow rate is set using flow regulator which is indicated on the electromagnetic flow meter. As the first step, initial reading of the water meter is taken. After that flow of water from the weighing balance to the sump is closed, and the initial reading of weighing balance is taken. The temperature is also noted to include the variation of density of water with temperature. The final readings are taken after the weighing balance acquires the required weight for the corresponding flow rate which is standardized at the calibration lab. The values of upstream and downstream pressure across the water meter are also noted from the pressure gauges.

3. COMPUTATIONAL DETAILS

3.1 Physical Model

The water meter considered has a 120mm span, 52mm breadth and 30mm height. But only the flow domain is considered for the simulation. The flow domain has a hydraulic diameter of 18mm at the inlet and 19mm at the outlet. The central section contains a cylindrical domain of diameter 48mm but the space for impeller is kept hollow because only the flow domain is considered. The flow domain is shown in figure 3.

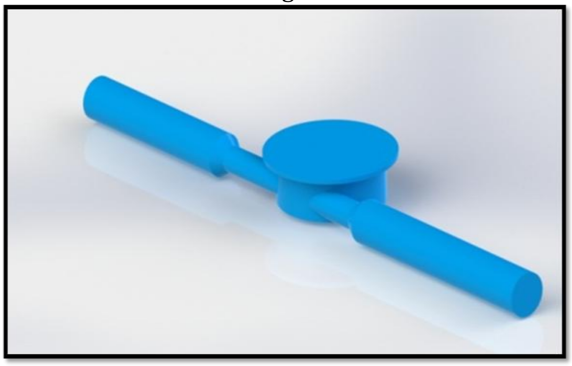

Figure 3:- Flow Domain

3.2 Governing Equations

The standard k-ε model is used for turbulence modelling with standard wall function [7]. Convergence criteria for mass, momentum and turbulence parameters were set to 10^{-4}. Pure water is taken as working fluid. Number of iteration used for the simulation of analysis is 1000.All the numerical simulations are carried out using the ANSYS FLUENT Software.

3.3 Computational Grid

A three-dimensional structured tetrahedral grid has been generated using GAMBIT. The generated computational grid on symmetry plane is shown in Figure 4.the grid was clustered in the region where the upstream (at a distance of five times the diameter of pipe from inlet) and downstream (at a distance of ten times the diameter of pipe from outlet) pressure was taken.

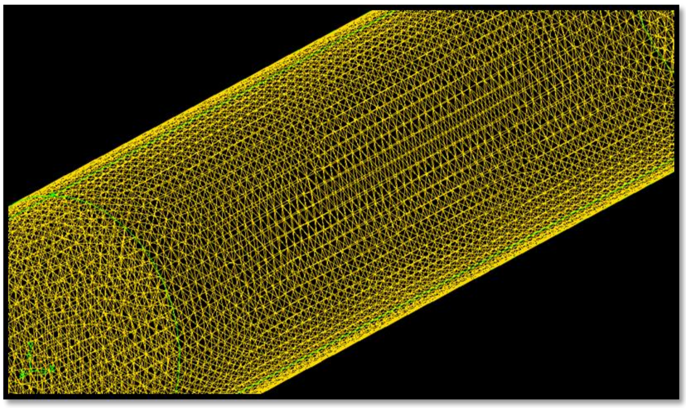

Figure 4:- A Meshed View of Inlet section of pipe

3.4 Boundary Conditions

At the inlet of the pipe section of the water meter, the water flow velocity and flow rate are specified. At the turbine section of the water meter the speed of impeller and angular velocity of the impeller are specified.Rotating faces of impeller was considered as wall .The inlet, impeller passages, outlet, top and bottom interface were considered as fluid zone.The water meter inlet flow rate was varied as 1125l/hr, 1500l/hr and 3000l/hr. The corresponding values of water meter impeller speed were 625.02 rpm, 833.3 and 1666.67.

4. EXPERIMENTAL RESULTS

4.1 Pressure Drop

The experimental pressure drop obtained for different flow rates are shown in the Table 1. From the table it can be understood that the pressure drop is getting increased with the increase in flow rate.

Table 1:- Experimental pressure drop across water meter for different flow rates

Flow rate (l/h)	Experimental pressure drop(bar)
1125	0.11
1500	0.18
3000	0.71

4.2 Error Curve

The error curve of the water meter has been obtained by performing test at seven different flow rates. The measuring error of the water meter is calculated from the equation as given below.

$$\%\text{Error} = \left\{\frac{(V_{actual} - V_{theoretical})}{V_{actual}}\right\} \times 100$$

Where :

V_{actual} =Water volume flown through the meter, measured in the weighing balance

$V_{theoretical}$= Water volume flown through the meter, measured on the meters counter

% Error = Error in meter reading in case of steady flow

The error curve of the water is shown in Chart 1. The curve is plotted with flow rate on x-axis and percentage error on y-axis.

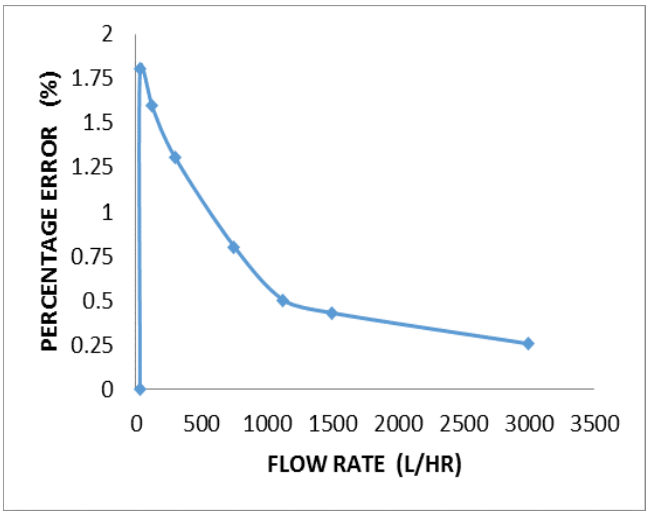

Chart 1:- Error Curve of the water meter

5. COMPUTATIONAL RESULTS

5.1 Pressure Contours

The properties of internal flow of the single jet water meter are analyzed by using pressure contours [6]. Study of the pressure contours help in understanding of energy conversion taking place in different parts of the water meter. The static pressure contours are varying with span. The static pressure contour for three different flow rates is shown in Figure 5, Figure 6 and Figure 7.

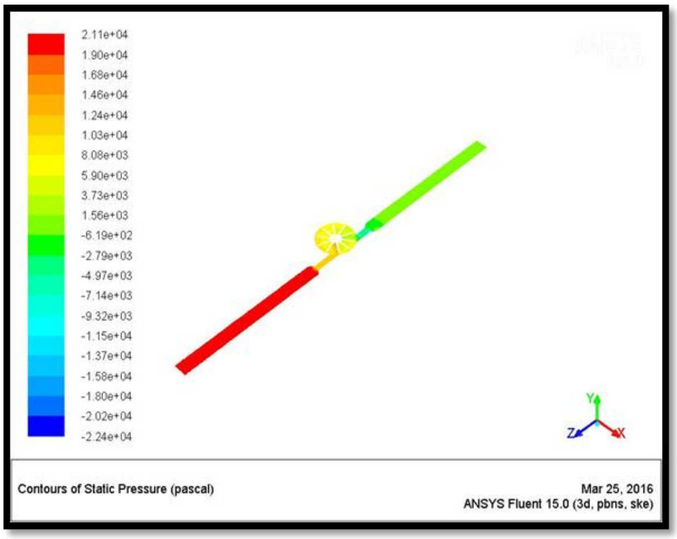

Figure 5:- Pressure contour at a flow rate of 1125 l/hr

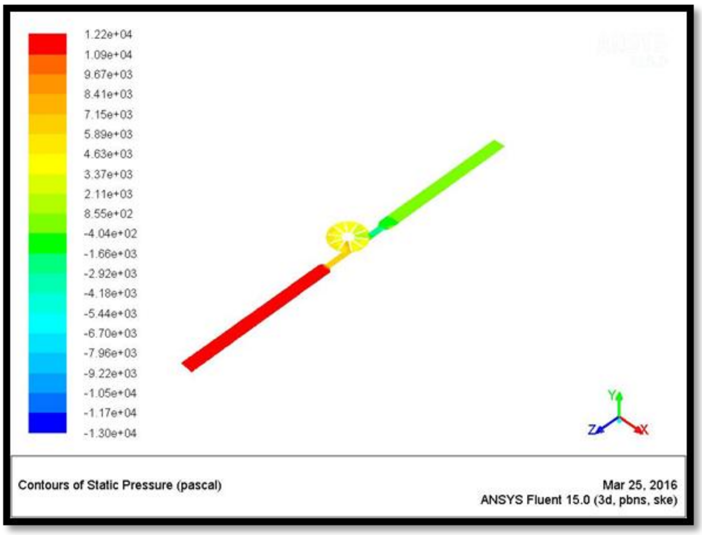

Figure 6:- Pressure contour at a flow rate of 1500 l/hr

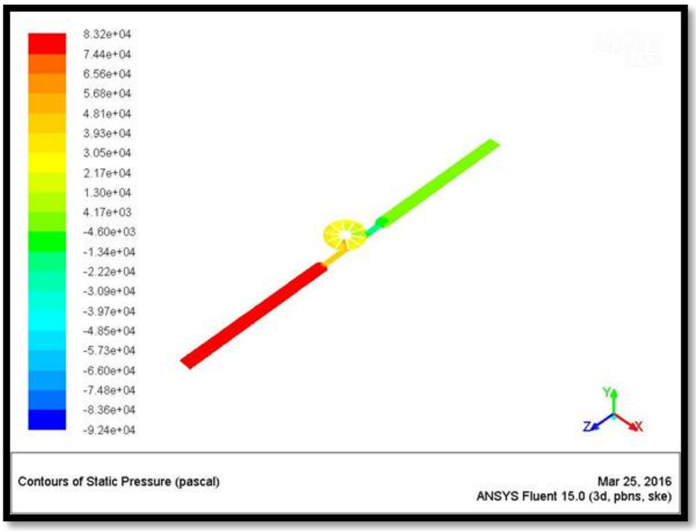

Figure 7: Pressure contour at a flow rate of 3000 l/hr

5.2 Velocity contours

Study of the velocity contours gives idea about the kinetic energy and dynamic pressure acting in the different parts [6]. Study of velocity vectors helps in identifying the direction of fluid particles flowing through the different components. It helps to identify directional motion of fluid particles in the flow domain. The internal circulation and separation zones in flow region can be understood from the velocity contours. The velocity contours for different flow rates are shown in the figure 8, figure 9 and figure 10.

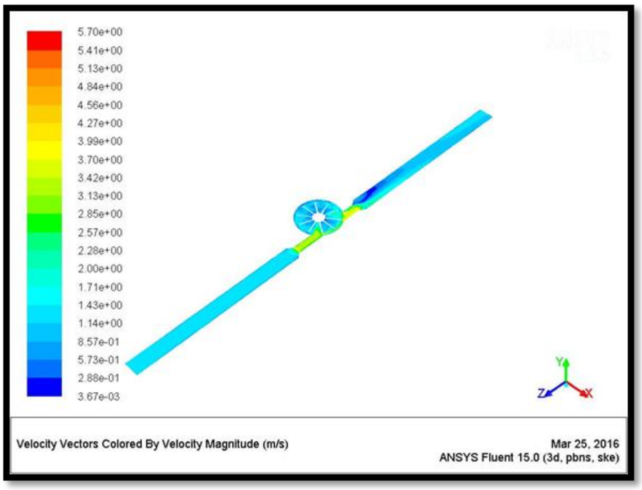

Figure 8:- Velocity contour at flow rate of 1125 l/hr

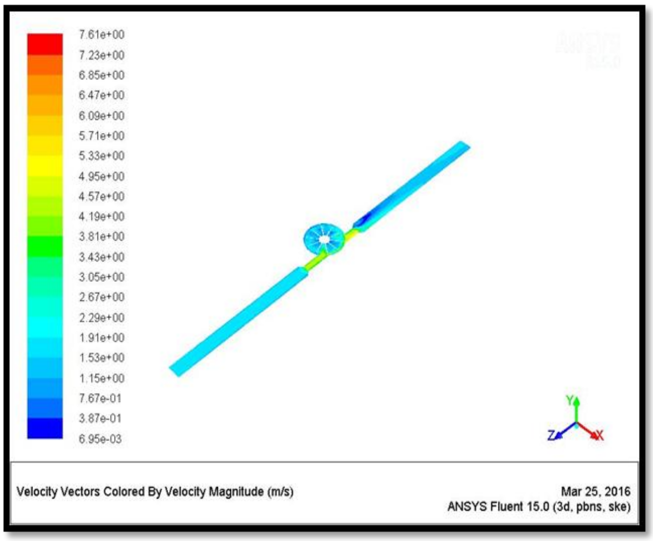

Figure 9: Velocity contour for flow rate of 1500 l/hr

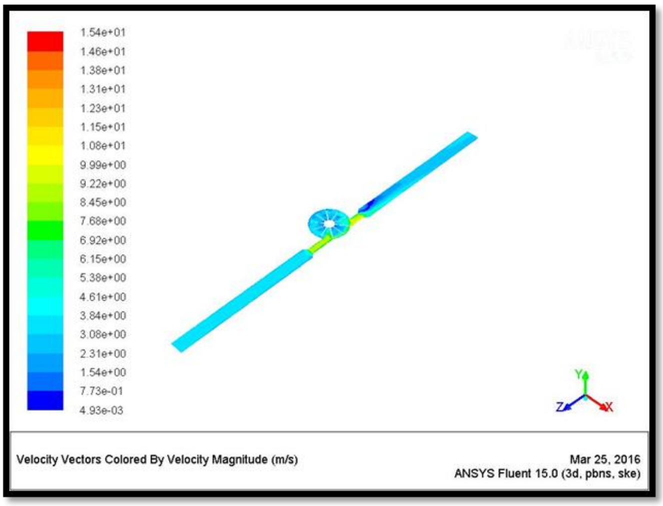

Figure 10: Velocity contour for flow rate of 3000 l/hr

5.3 Computational Pressure Drop

The pressure drop across the water meter obtained from the computational analysis is shown in Table 2. The behavior of pressure drop is such that it is getting increased with the increase in flow rate.

Table 2: Computational pressure drop across water meter for different flow rates

FLOW RATE (l/h)	Computational pressure drop (bar)
1125	0.11784
1500	0.20507
3000	0.785655

6. DISCUSSION

The error of a water meter is a function of the circulating flow rate [4]. Therefore the ability of that instrument to accurately measure water consumption strongly depends on the flow water. The error curve of the tested water meter is shown in figure. It can be seen from the curve that the % error is high at low flow rate and low at high flow rate. Also it is found that the average error between the flow rate 30 l/h and 3000 l/h remained inside the 2% error band. That means the meter was capable of maintaining its accuracy curve below the maximum permissible error specified for a domestic Class B meter.

One of the factors that were identified as having great influence on the meters error was the water quality. Calcium depositions inside the meter body, the turbine bearings and the entrance and exit nozzles caused severe damaged to the instruments, especially at low flows. This caused an increase of drag which has a significant effect on the error.

The numerical simulation of the flow within the single-jet water meter with different flow rates has allowed a detailed analysis of the interaction between the flow and the turbine. Figure7 to figure 12 shows the pressure contour and velocity contour obtained from the simulation of a flow rate of 1125 l/h, 1500l/h and 3000l /h. It is important to note that the pressure difference between the inlet and the outlet of the meter is not constant but varies with the flow rate the simulation was carried out for flow rate of 1125 l/h, 1500l/h and 3000l /h. Computational results shows that at a mass flow rate of 3000 l/h, the pressure drop is 0.785bar, at 1500 l/h the pressure drop is 0.205bar and at 1125l/h pressure drop is about 0.117 bar. The experimental pressure drop across the water meter are 0.11bar, 0.18 bar and 0.71 bar for flow rates of 1125 l/h, 1500l/h and 3000l /h respectively. The computational pressure drop and experimental pressure drop are showing good agreement. From the velocity contour the variation of velocity in different regions of the flow domain under study can be understood.

The error curve from experimentally obtained reading was plotted. The curves plotted where the accuracy requirements of the ISO 4064 standard are indicated. The fact that some values of the measurement error do not conform to these requirements is of no importance since the meter studied is a noncommercial prototype. The experimental error curve in the range between 30 l /h and 3000 l /h, but deviates from it at lower and higher flow rates. The deviation to more positive errors such that more volume registered observed in the case of lower flow rates is consistent with the fact that mechanical friction has not been considered.

6.1 Validation of the Numerical Model

The computational model has been validated by comparing the results of the computational pressure drop obtained, error in pressure drop with the experimental measurements obtained in the test rig. The percentage error in the results is shown in Table 3 and it is found that the values are within the acceptable range.

Table 3:-Comparison of computational and experimental pressure drop across the water meter.

FLOW RATE (l/h)	PRESSURE DIFFERENCE (bar)		PERCENTAGE ERROR
	COMPUTATIONAL	EXPERIMENTAL	
1125	0.11784	0.11	7.127584
1500	0.20507	0.18	13.92759
3000	0.785655	0.71	10.65566

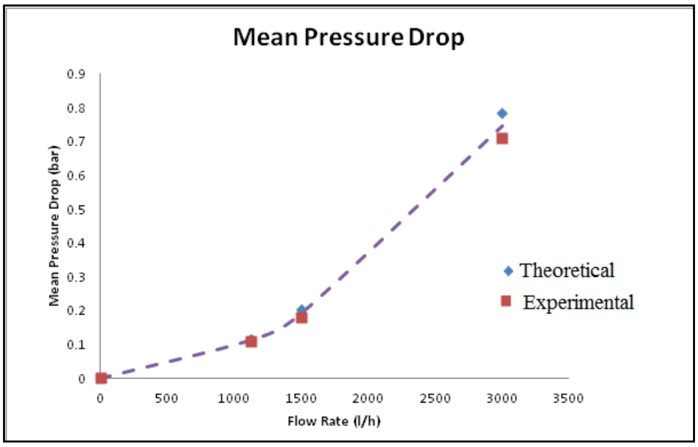

Chart -2:-Comparison of computational and experimental pressure drop

As shown in Figure. 13, the computational model very accurately reproduces the shape of the experimental error curve in the range between 1125 l/h and 3000 l/h. The deviation from the measurements might be due to the combination of two causes. On the one hand, the computational mesh is probably not fine enough to accurately calculate the thinner boundary layers found in such high flow rates. On the other hand, the rotation speed of the turbine may be so important at these high flow rates that the centrifugal forces to which the flow is subjected in the chamber might have a significant impact on turbulence. Therefore, some differences between the calculated and the actual flows and, ultimately, between the computational and the experimental measurement errors may be expected if the mentioned rotation effects are significant. Nevertheless, these differences seem to be minor in light of the comparison between the calculated and the measured values.

3. CONCLUSIONS

Based on the experimental and analytical study carried out on single jet water meters, the following observations are found.

1. The measurement error is found to be within the acceptable range and for low flowrate the errors are larger and more sensitive to external variables and at medium and high flows remain relatively stable throughout the working life of the instrument. The errors of single jet meters, especially for low flows, are sensitive to any increment of the drag torque on the sensor element. Consequently, many are the variables that can affect the accuracy of these meters.

2. The pressure drops across the water meter is high at higher flow rate at its getting decreased as the flow rate decreases.

3. The simulated values of pressure drop have been compared with the experimental values and have been found to be in good agreement. The small variations are may be due to the various assumptions considered in numerical procedure and modeling.

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