



24th COBEM - 2017



24th ABCM International Congress of Mechanical Engineering
December 3-8, 2017, Curitiba, PR, Brazil

COBEM-2017-2421

UNCERTAINTY ANALYSIS OF AIR-WATER FLOW IN RESIDENTIAL WATER METERS

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Abstract. *The water is a fundamental resource for the maintenance of life on the planet and of the various activities undertaken by man, however the quantity intended to supply the large urban centers is small in comparison to its total volume, this way is necessary to have a rational use and preservation of this resource. The water intended to supply the large urban centers is called treated and, the responsibility for its distribution is of the company of sanitation that use on a large scale the counters of water tachometric to estimate the water consumption. There is mistrust on the part of consumers that this instrument can assess the air present in the distribution network by increasing the value of the accounts of water. In this context, this work presents a study on the behavior of this equipment when submitted to two-phase flow using the Theory of errors to treat the data obtained experimentally. The main objective of the study is to validate experimentally that the amount of air measured by water meters can interfere substantially in total volume registered, for both was used a hypothetical example to demonstrate the super measurement of equipment in terms of monetary values.*

Keywords: *counters of water tachometric, admeasurement, two-phase flow.*

1. INTRODUCTION

Turbine type water meters usually called water meters speedometer are widely used by sanitation companies in Brazil to estimate water consumption. Under normal supplies conditions the amount of air present in the public water supply can be considered negligible, but in extraordinary situations may occur a significant amount of inflow of air into the system (MELLO, 2001).

The issue is how the air is incorporated into the supply system and how it can interfere with real water consumption recorded by the meters. The air may be incorporated or withdrawn into the system both accidentally and deliberately. Interference of this air consumption recorded by the water meter is a task difficult to solve both from the operational and strategic point of view by the sanitation companies.

The water intended for human consumption can be classified as treated or potable water, the first case is suitable for washing food, bathing and cleaning in general; the second case refers to water for human consumption in accordance to the potability patterns, which are suitable amounts of minerals, acidity and free of microorganisms. The treated water is distributed by the water supply system, which is made up of infrastructure and services to produce and distribute this input to a given location (SAMAE, 2009). The supply system is divided basically into 5 stages: collection, treatment, reservation, supply and distribution (Gularte, 2005).

Distribution is the crux of this work, specifically in building connections in which where are installed water meters. They are the main instruments of micro measurement which is the set of actions aimed on the knowledge of the actual consumption of water in a supply system (Gularte , 2005).

The preservation of water and its rational use are essential for the maintenance of life and various activities carried out by humanity, because it is a scarce and non-renewable resource. In the sense of rational use, distribution systems are directly responsible for residential water supply, industrial and service sector, consequently waste and irregularities in consumption can be assessed by micro measurement. Therefore, further study on the operating conditions and reliability of flowmeters is extremely necessary both from an ecological point of view as an economic one.

The objective of this work is a experimental measurement analysis of a speedometer Single-jet water meter Class C when subjected to two-phase flow, as well as apply the Error Theory on the statistical analysis of the measurements obtained by the water meter when subjected to two-phase flow.

2. TWO PHASE FLOW

The two-phase flow is found in a wide variety of industrial processes and mineral extraction (PEREIRA, 2006). These can occur because of project definition, own flow characteristics or accidentally (VENZON, 1996). The most common cases of such flows are those involving a component such as water and steam, or with two components such as water and air, with a gaseous phase and a liquid phase.

2.1 Basics concepts

Next will be treated the main concepts in the context of two-phase flow, more precisely on the basic equations governing this kind of phenomenon.

2.1.1 Mass flow

In a flow with two phases which coexist simultaneously, the total mass flow rate “ m ” is given by the sum of the flow rates of the gas phase “ m_g ” and liquid, “ m_l ” (Pereira, 2006).

$$m = m_g + m_l \quad (1)$$

The mass flow rate of the gas phase is given by:

$$m_g = \rho_g V_g A_g \quad (2)$$

The mass flow rate of the liquid phase is given by:

$$m_l = \rho_l V_l A_l \quad (3)$$

Being ρ_g and ρ_l the specific mass of gas and fluid, V_g e V_l the average velocities of gas and liquid, and A_g e A_l he areas of cross-section occupied by the gas phase and the liquid phase. The terms $V_g A_g$ e $V_l A_l$ are called gas volumetric flow and liquid volumetric flow, usually expressed in flowmeters by volume ratio drained over time.

2.1.2 Vapour quality

The ratio between the mass of gas and the total mass of the mixture (VENZON, 1996), in terms of mass flow rate, it is given by:

$$x = \frac{m_g}{m_g + m_l} \quad (4)$$

2.1.3 Surperficial velocity

The superficial velocity, “ j ” is a parameter that defines the flow rate that each phase has separately (COLLIER et al, 1994), the surface speeds for the gas phase “ j_g ” and liquid phase “ j_l ” are given by:

$$j_g = \frac{V_g A_g}{A} \quad (5)$$

$$j_l = \frac{V_l A_l}{A} \quad (6)$$

2.1.4 Void Fraction

The void fraction, “ α ” is the ratio of the pipe cross sectional area occupied by the gas phase and the total area of the pipe’s transverse section, which is the sum of the areas occupied by the gas phase and the liquid phase (COLLIER et al 1994).

$$\alpha = \frac{A_g}{A} = \frac{A_g}{A_g + A_l} \quad (7)$$

or in terms of volumetric flow “ Q ”:

$$\alpha = \frac{Q_g}{Q_g + Q_l} \quad (8)$$

2.1.5 Slip factor

This parameter is represented by symbol “ S ” and is the ratio between the velocities of the gaseous and liquid phases:

$$S = \frac{v_g}{v_l} \quad (9)$$

In terms of vapour quality and void fraction, the slip factor can be expressed by (COLLIER et al, 1994):

$$S = \left(\frac{x}{1-x} \right) \left(\frac{\rho_l}{\rho_g} \right) \left(\frac{1-\alpha}{\alpha} \right) \quad (10)$$

3. FLOW RATE

The water meters are dimensioned according to their flow rate. The correct dimensioning of these meters is very important for a better measurement of the consumed water volume, so a detailed study of the conditions in which this flow reaches the consumer is essential to the particular locality sanitation project.

Permissible flow rates, expressed in [m³ / h] on a water meter are classified as follows (INMETRO et al, 2000):

- Maximum flow rate (Q_{max}): It is the largest workflow in which a water meter can operate in a short period of time and cannot exceed their maximum permissible errors and should maintain its metrological performance when back down to normal working conditions.
- Nominal flow rate (Q_n): Known as the normal flow or designation of a water meter, equivalent to 50% of maximum flow. Higher flow conditions of use in a water meter is required to operate strictly satisfactorily.
- Transitional flow rate (Q_t): Taking into account the uniform flow, it is the one that marks the separation between the upper and lower fields of measurement, known as separator flow. Typically, it corresponds to 5% of the maximum flow rate.
- Minimum flow rate (Q_{min}): It is the smallest workflow rate of the water meter, in other words, the smaller flow which the instrument provides indications.

4. THE EXPERIMENTAL APPARATUS

The water meter calibration bench was assembled from the two-phase flow analysis bench shown in Figure 1 already present in the Steam Laboratory of the Universidade Federal do Pará, whose main objective is to provide a continuous flow of water and / or air preconditions established.

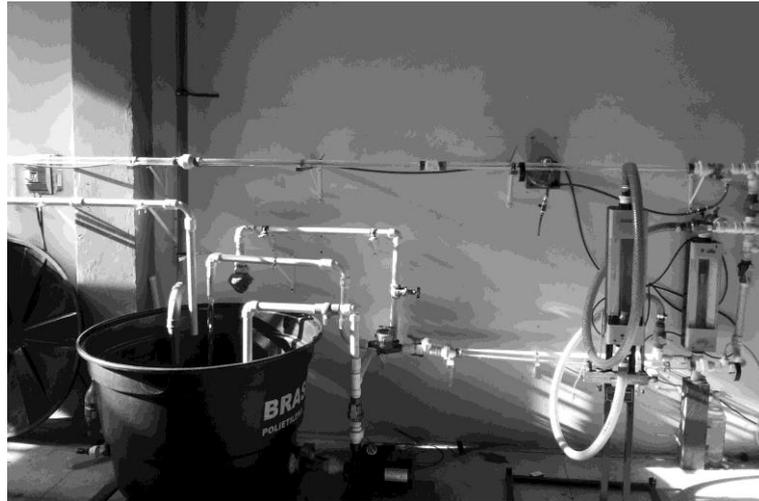


Figure 1. Partial view of the two-phase flow analysis bench

The water runs in a closed circuit, while the air is supplied by an air compressor and is rejected to the atmosphere in the water storage tank when the phase separation occurs. The water meter calibration bench scheme is shown below (Figure 2). The water contained in the storage tank (1) passes through the control valve (2) and is suctioned by the centrifugal pump (3), the water pass through the second control valve (2) before being measured by the water flow meter (4) and then have its volume measured by the meter (9). The air supplied by the air compressor (5) pass through the control valve pressure (6), and then through the air flowmeter, which measures the flow rate that will be released by the control valve (8). On a point of the pipe before the hydrometer (9) air is injected through a porous aspect ball in order to uniform the flow of air bubbles and avoid the formation of vortices.

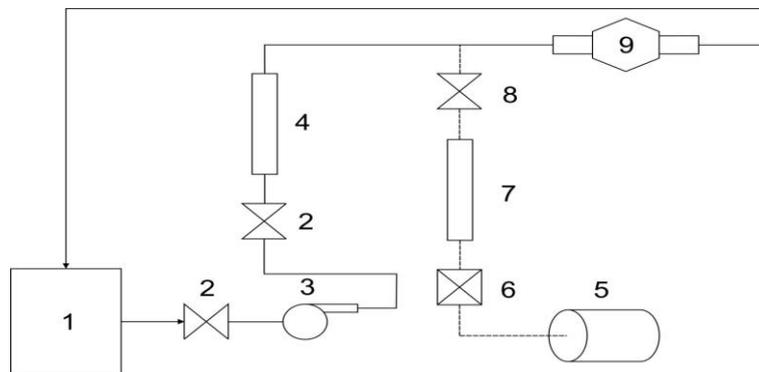


Figure 2. Calibration bench

For the experiment was used distilled water stored in a water tank water with 210 liter capacity, the water operates in a closed circuit composed of a PVC pipe which the diameter is equal to 0.5 in. The responsible for moving water in this system is a centrifugal pump with 1 hp with maximum flow rate of 11.6 m³ / h.

The volume was set to be measured by the meter at 100 liters and a stopwatch was used to measure the time that the hydrometer expands to register this value, making it possible to calculate the value of its flow. With the aid of the frequency inverter, the centrifugal pump can maintain a constant water flow in the flowmeter and thus use it to calibrate the meter.

The hydrometer was submitted to the nominal flow rates of the flowmeter of 5, 10, 15, 20, 25 and 30 l/min. 10 samples were collected for each of these points.

5. RESULTS

Using the theory of errors to process the data obtained by the experimental procedure was possible to estimate parameters which were the most representative value of a quantity that is presented in terms of flow recorded by the hydrometer (Q_r) and the standard uncertainty (σ_p). The nominal uncertainty hydrometer's flow rate cannot be obtained directly, but we can use the nominal uncertainty related to volume manufacturer that is $\pm 2\%$ in the top field of flow and

nominal uncertainty of the chronometer that is $\pm 0.5\%$. The % Deviation was adopted instead of % Error, since it refers to the difference between the most representative value of a quantity and value of an experimental measurement.

The first point to be considered is when the water meter class "c" is subjected to a flow only with water, the equipment tends to record flow values lower than expected, this fact can be best viewed in Fig. 4, in which the flow of the hydrometer and flow meter are compared. It can be seen an almost linear trend of the hydrometer that indicates values below the flowmeter, except for the flow of 25 l/min at which the meter registers slightly higher values than the flowmeter. This fact can be explained by a transition region in the curve hydrometer error, this flow is exactly at the point where measurement errors are no longer negative and become positive.

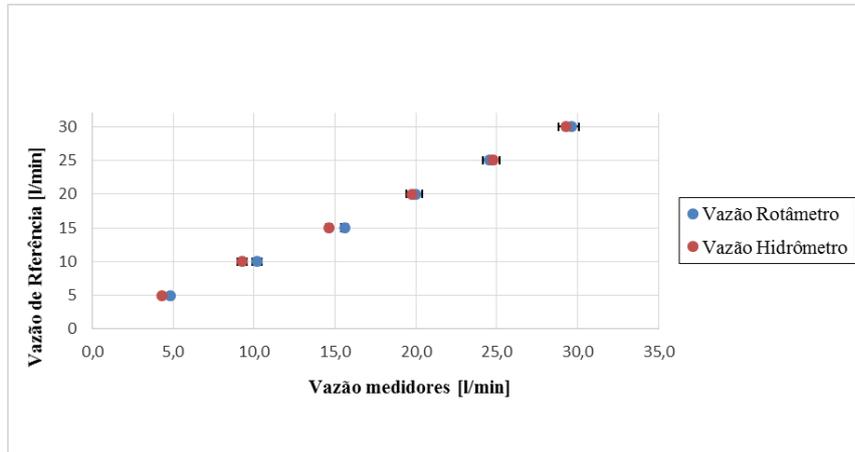


Figure 3. Measurement of hydrometer and flow meter when subjected to a one-phase flow

The second point to be considered is when the hydrometer is subjected to two-phase flow, in which can be observed the predictable behavior the hydrometer acquires in relation to the increase in water flow with increasing air flow. This fact can be easily verified in graphic reference flow according to the flow shown in Fig. 4. It can be inferred that the water meters have a constant increase in the volume of the value recorded as a function of an increased amount of air present in the pipes of the distribution of drinking water.

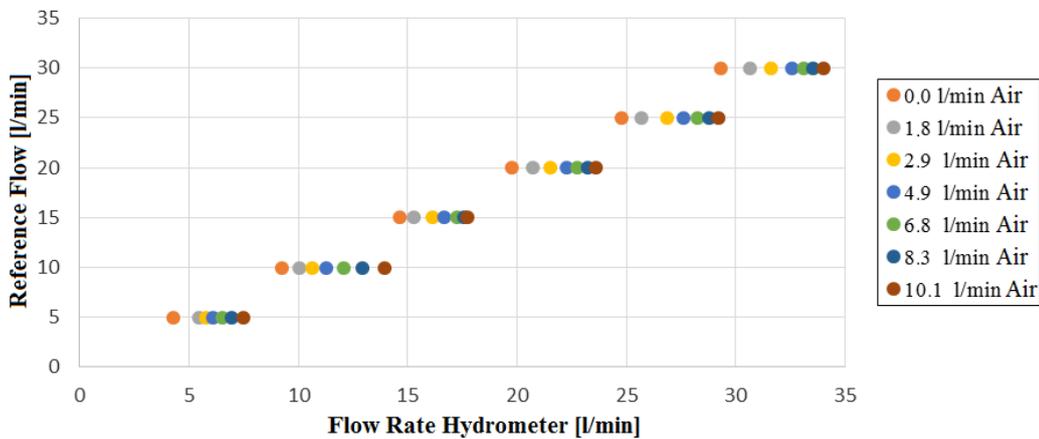


Figure 4. Calibration of the hydrometer when subjected to one-phase and two-phase flows

The void fraction can be represented by the ratio of the volume of gas flow by the total volume flow. This parameter was calculated for each of combinations of two-phase flow, presented in Tab. 1, the % deviation from the graph as a function of void fraction, Figure 5, it is apparent that with an increasing deviation of the values of the flow rate of the flowmeter and of the hydrometer is also an increase in the void fraction.

Table 1. Void fraction for the combinations air and water flow.

Q_c water [l/min] \ Q_c air [l/min]	4.82	10.2	15.57	20	24.52	29.6
1.8	0.272	0.150	0.104	0.083	0.068	0.057
2.9	0.376	0.221	0.157	0.127	0.106	0.089
4.9	0.504	0.324	0.239	0.197	0.167	0.142
6.8	0.585	0.400	0.304	0.254	0.217	0.187
8.3	0.633	0.449	0.348	0.293	0.253	0.219
10.1	0.677	0.497	0.393	0.336	0.292	0.254

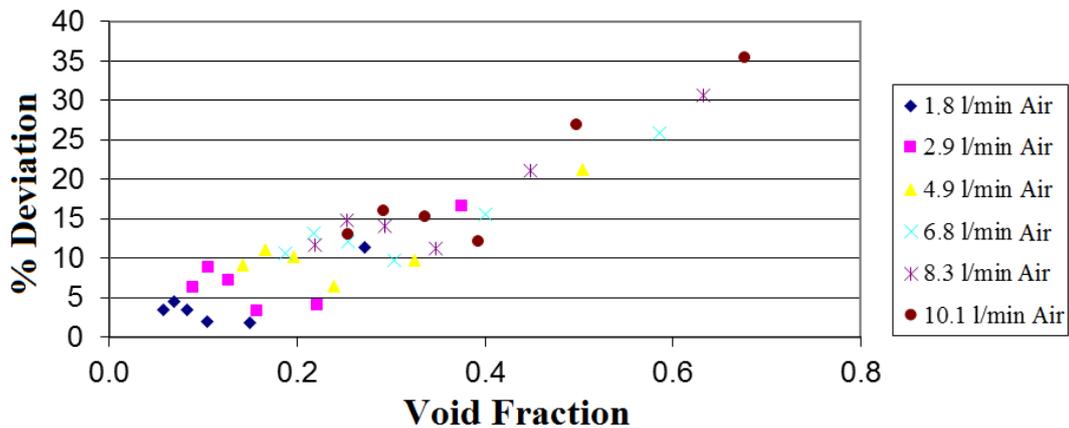


Figure 5. Discrepancy measures between flowmeter and hydrometer due to the void fraction.

The superficial velocity is estimated separately for each phase using the equations (2) and (3) replacing the terms with the calibrated volumetric air flow and the volumetric flow of the water using 0.5 in diameter. The surface velocities were organized in the table below and was identified by the area hatched, the region at the flow of Mandhane, shown in Fig. 6, representing all possible biphasic flow settings in this work.

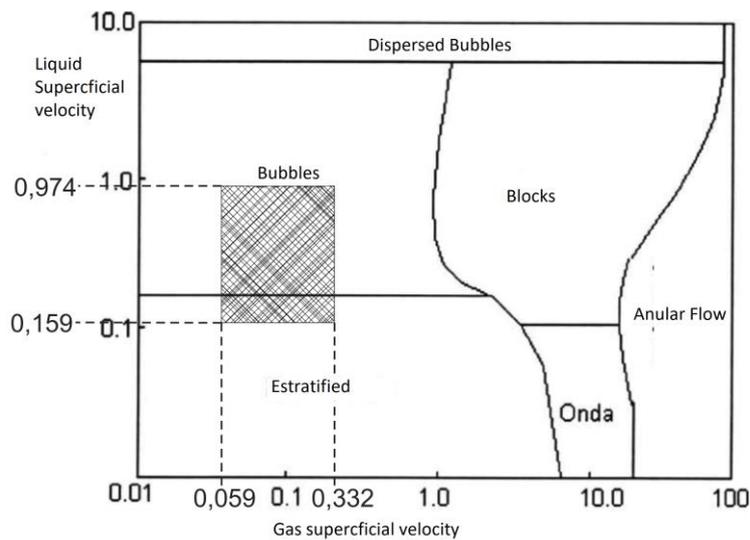


Figure 6. Two-phase flow patterns (Venzon, 1996).

Table 2. Surface speeds for the volumetric flow rates of air and water.

$Q_{c,air}$ [l/min]	j_g [m/s]	$Q_{c,water}$ [l/min]	j_l [m/s]
1.81	0.059	4.82	0.159
2.99	0.095	10.20	0.335
4.96	0.161	15.57	0.512
6.86	0.224	20.00	0.658
8.32	0.273	24.52	0.807
10.17	0.332	29.60	0.974

6. CONCLUSIONS

The results show that the residential flow "C" type meters present errors when are submitted to two phase flows. The flow measurement systems need evaluated to improve flow measurements. Measurement techniques in two phase flow can be implemented. The results indicate that the measuring systems only work only ranges specific measuring.

Acknowledgements

This work was supported by own resources.

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