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DESIGN OF A LARGE SCALE FLOW-METER TEST AND CALIBRATION FACILITY

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ABSTRACT

The design and set up of a large-scale flowmeter calibration and test facility is presented. The facility was designed to handle flowmeters with diameters between 6” and 14”, flow rates up to 0.3 m^3/s and to give results less than 1% accurate. The calibration methodology consisted firstly in calibrating the pattern flowmeters, using volume and time primary measurements, and secondly, comparing the pattern to the flowmeters needing calibration. The design and calculation of the primary calibration device is addressed, including numerical simulations of the outflow manifold and the comparison to experimental data. The calibration facility proved to be accurate and reliable in producing renewed calibration data for various tested flowmeters.

INTRODUCTION

This paper describes the design and performance of the Universidad Simón Bolívar (Venezuela) large-scale Flowmeter Calibration Facility (USB-FCF). The USB-FCF performance was evaluated through the calibration of a 12”-Venturi flowmeter.

The USB-FCF is based on a primary volumetric system and also permits the calibration of flowmeters by contrasting against a calibrated unit.

The following sections describe the main components and instrumentation associated to the USB-FCF, as well as their function and their connection to the Data Acquisition System (DAS).

It is presented the flow diverting system (associated to the distribution manifold) and its importance regarding to the volumetric analysis and further calculation of the flow through the system.

Calibration plots for the Venturi flowmeter and the degree of accuracy of the discharge coefficient (Cd) are also presented.

Numerical simulation is additionally performed to predict the fluid flow through the manifold as part of the preliminary design.

DESCRIPTION OF THE SYSTEM

The USB-FCF has a 500000-litre underground storage tank, connected to a parallel three-pump station. The water is suctioned from the underground tank and then pumped to an elevated constant-level open tank, as shown in Fig. 1. From the elevated tank, excess water is drained through the return line, while the rest goes into the USB-FCF distribution system.

Fig. 1. Underground and Elevated Open Tanks

The USB-FCF is connected to the elevated open tank by a 14” line, attached to the distribution manifold. The distribution manifold consists in a four-pipeline derivation capable to derive flow to 8”, 10”, 12” and 14” lines (see Fig. 2).

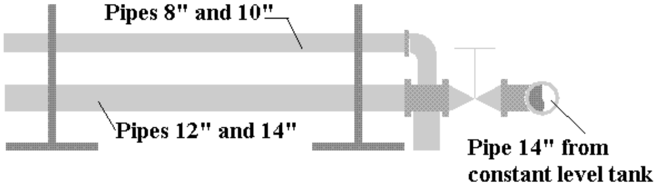

Fig. 2. Distribution Manifold

The main function of the distribution manifold is to conduct the flow either to the calibrated tank or back to the underground tank (see Fig. 3).

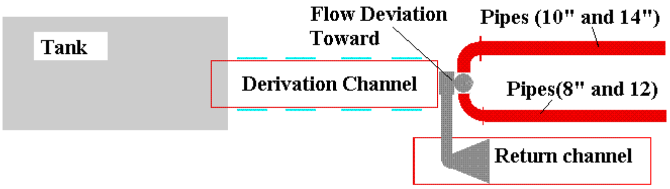

Fig. 3. Diverting and Return Channels

The flow direction is granted through the diverting gate: if the gate is closed, the fluid is derived to the return channel and further to the underground tank, setting up a closed loop. Whereas, if the gate is open, the flow is derived towards a calibrated tank through a 0.6%-slope channel. The gate works pushed-pulled by a pneumatic actuator (see Fig. 4).

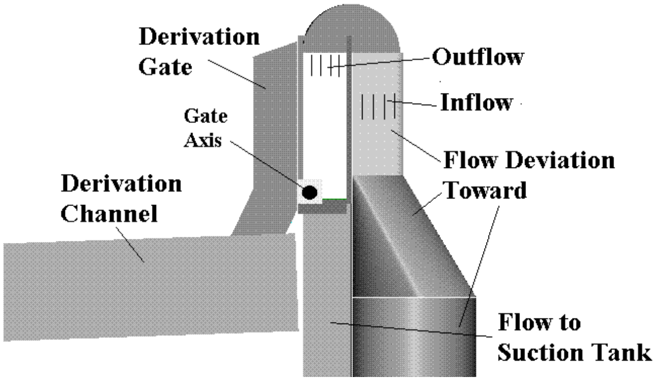

Fig. 4. Diverting gate

The calibrated tank consists in a 20097-litre deposit (see Fig. 5). This tank is internally sub-divided by a wall that creates two tanks within one; i.e., the first tank (named A) is fully loaded with water (18699 lts) after every run, while the excess of water is derived to the second tank (max. capacity of 1398 lts), which refines the volume measurement by using a level-sensor placed within.

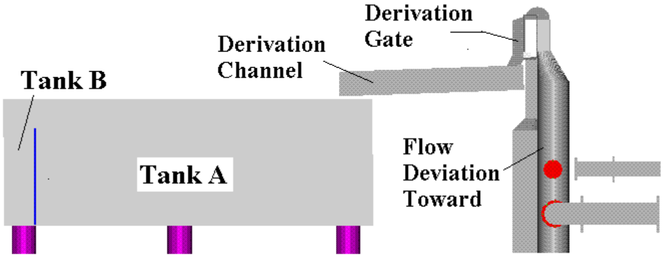

Fig. 5. Schematics of the Calibrated Tank(s)

Once every test ends and the volume is accurately measured, the water in the calibrated tank(s) is drained through an underneath 4”-pipeline that takes the water back to the underground tank.

MEASUREMENT SYSTEM

In order to complete a typical flowmeter calibration procedure, it is necessary to account for a series of parameters to build up the flowmeter calibration curve. For this, a state-of-the-art Data Acquisition System (DAS) is used to input and process in real time the data out of all the instrumentation. Generally speaking, all instrumentation generates a voltage output, which is translated to the respective units through the instrument calibration curve. Next, it is presented a thorough description of the variables included in the calibration process.

- **Temperature**
  A thermocouple is placed in the pipeline where the flowmeter is going to be tested or calibrated.

- **Pressure**
  A differential pressure gage (based on strain gages) is connected to upstream and downstream taps of the

flowmeter. This gage gives a 4-20 mA output and is calibrated for a 1-5 Volts range with a 2.5m water column. The pressure signal is monitored and saved to verify the low deviation from the mean setting and to associate the pressure differential to the measured flow once the test ends.

- **Time**

The time measurement is highly critical, since this parameter along with the volume determine the total flow within the time interval of the test. For time measurement, the following instruments were employed:

- **Optical sensor**

The system is provided by a infrared optical sensor capable to respond in less than two miliseconds under 10-30 Volts. This sensor is connected to detect, through and emitter-receiver assembly, the position of the diverting gate (Fig.6). This sensor allows the definition of opening and closure times of the gate.

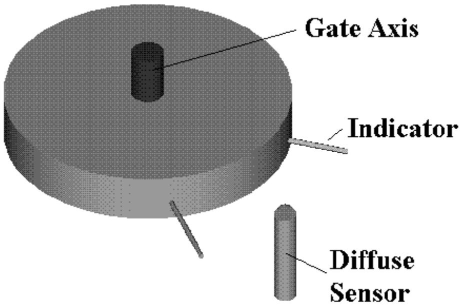

Fig. 6. Optical Sensor Assembly

- **Potentiometer**

The time it takes to run every test and the opening and closure times are measured through a potentiometer coupled to the shaft of the d2-diameter disc (Fig. 7). Such a disc is, at the same time, tangentially adjusted to a bigger d1-diameter disc, that rotates with respect to the gate axis.

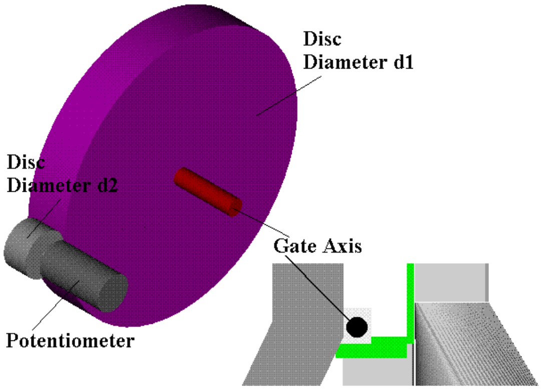

Fig. 7. Schematics of the Potentiometer Assembly

- **Levels and Volumes**

Once the test ends, the level within the calibrated tank(s) is measured using a 0.5mm-graduated ruler. The ruler is also coupled to a level gauge that permits the measurements of the levels within the tanks. A previous systematic and detailed calibration of the tanks is made and a volume vs. height correlation was obtained. The total volume accounted for after the test is the sum of the volumes in tanks A and B (Fig. 5).

CALIBRATION PROCEDURE

The calibration procedure starts after the activation of the pumps to transport the water from the underground to the elevated open tank. When the open tank is at working level, the flow is derived towards the 8”-10”-12”-14” pipeline system. At the same time the control system and the DAS are activated and through the pressure monitoring, it is verified the flow stability for the regulated flow rate.

For what it follows, a Venturi flowmeter was selected to perform the first calibration and further explanations for the procedure, refer to this flowmeter.

The tests are run from lower to higher flow rates, for which the Venturi pressure drop (read at the DAS display) is the reference parameter.

Once the pressure is fixed and stabilized, the diverting gate is activated via the computer console. Then, the gate opens and the flow is derived towards the calibrated tank and simultaneously the computer starts storing all the signals coming out of the USB-FCF instrumentation. When the main calibrated tank (Tank A in Fig. 5) is full, the level sensor within the secondary calibrated tank (Tank B; Fig. 5) orders the closure of the diverting gate. Then, the DAS stops and a file storing temperature, pressure, opening-closure times and the total time it took to fill the calibrated tank(s), is closed. The time measured by the DAS is 1 milisecond accurate.

The volume in the calibrated tank(s) and time determine the actual flow through the flowmeter.

DESCRIPTION OF INPUT-OUTPUT SIGNALS

The data was stored for each performed test. Part of this data is plotted in Fig. 8, corresponding to a flow rate of 183.8 l/s. Plot 1, presents the pressure along the time of testing.

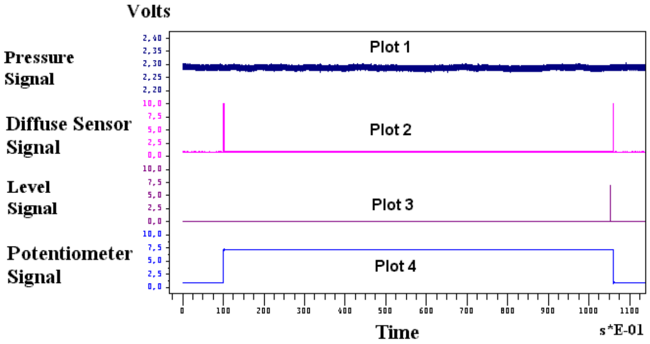

Fig. 8. Signals stored in the DAS

Plot 2 shows, as peaks, the time of gate opening and closing. The time interval between the peaks, represents the test total time-length. Plot 3 depicts the signal out of the level-meter within the secondary calibrated tank (Tank B, Fig. 5). This sensor activates when the main calibrated tank (Tank A, Fig. 5) fills up and simultaneously sends the signal to close the diverting gate through the DAS control software; notice the voltage peak just before the gate starts closing. Plot 4 refers to the initial and final test times (see upward and downward steps, respectively).

During the tests the temperature did not vary appreciably as to be considered within the set of output data. The volume was measured with an absolute error of 0.4 lts out of a total of 20097 lts, which represents a relative error of 0.002%

DISCHARGE COEFFICIENT VS. Re NUMBER

The flowmeter (the Venturi flowmeter in this example) discharge coefficient Cd is determined from the calibration discharge flow (Q_{Actual}) and the pressure head mean values. Cd is usually plotted as a function of the Reynolds number (Re), where the β coefficient, which expresses the ratio between the Venturi throat diameter and the pipe diameter, corresponds to 0.75. Then, Cd is given by:

$$Cd = \frac{Q_{Actual}}{Q_{Theoretical}} = \frac{Q_{Actual}}{Area_{Throat} * \sqrt{2\,g\,\Delta H / (1-(\beta)^4)}}$$

where:

Cd = Discharge coefficient (dimensionless)

Q_{Actual} = Actual flow rate, obtained as the calibrated tank(s) volume divided by test time [m^3/s]

$Q_{Theoretical}$ = Theoretical flow rate, expressed as a function of the pressure head, throat area and β [m^3/s]

$Area_{Throat}$= Throat area (Venturi in 12” line) [m^2]

ΔH = Pressure head [meters of water column]

g = gravity acceleration [m/s^2]

β = Throat diameter / Pipe diameter (dimensionless)

The Re is expressed as:

$$Re = \frac{4}{\pi}\frac{Q_{Actual}}{D\,\upsilon}$$

where :

D = Throat diameter [m]

υ = Kinematic viscosity (μ/ρ) of water [m^2/s]

Figure 9 shows Cd vs. Re for the tested Venturi flowmeter at different flow rates.

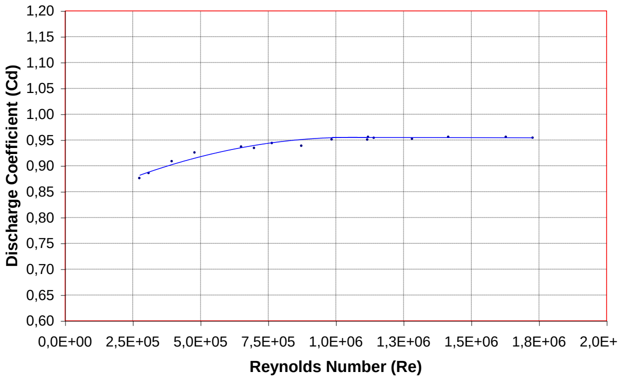

Fig. 10. Cd vs. Re for Venturi Flowmeter

Figure 11 shows the flow rate as a function of the pressure head, depicting the characteristic quadratic dependency between both parameters.

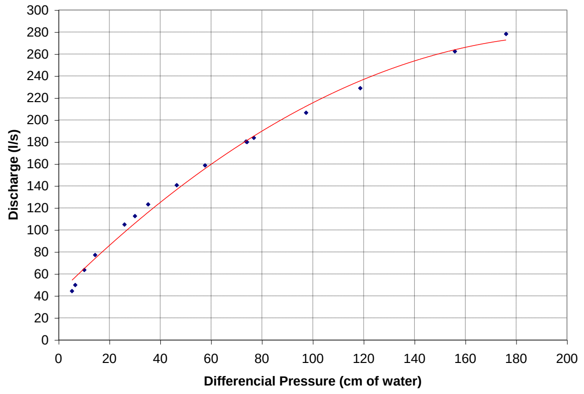

Fig. 11. Flow rate vs. Pressure head for Venturi Flowmeter

ACCURACY OF Cd

The accuracy of the mean Cd, for a pre-selected level of confidence, depends on the standard deviation of the calibration points referred to that mean Cd. The accuracy reflects the precision of the calibration procedure and facility instruments, and the flowmeter properties as well as the number of points taken to determine the mean Cd. The accuracy of the mean value of Cd is calculated from:

$$\text{Accuracy} \pm = \frac{t * \text{Standard Deviation}}{\sqrt{N-1}}$$

where:

t = “students t” selected according to the required confidence level and sample size minus degree of freedom

1 = degree of freedom

N = sample size

$$\text{Standard Deviation} = \sqrt{\frac{\text{Sum of squares of deviations from mean Cd}}{N-1}}$$

Figure 12 presents the calibration points calculated to determine the mean Cd.

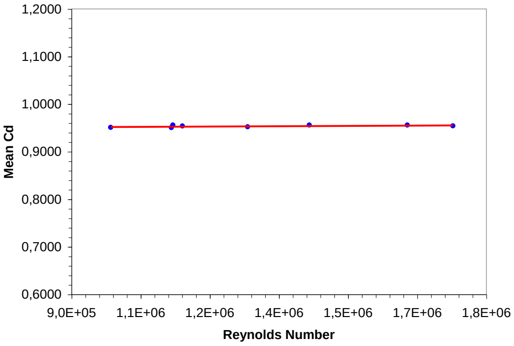

Fig. 12. Mean Cd vs. Re

The “students t” selected according to the required confidence level (99%) and sample size (N=8) minus the degree of freedom (1) is equal to 3.499. The standard deviation of the calibration point at constant Reynolds is ± 0.218 percent.
The tolerance, for 99% confidence, is defined as:

$$\text{Tolerance } \pm = \frac{3.499 * 0.218}{\sqrt{8-1}} = 0.2883\ \%$$

COMPUTATIONAL MODELING OF THE FLOW WITHIN THE DISTRIBUTION MANIFOLD

During the phase of design of the USB-FCF, a computational simulation was performed to study the flow within the distribution manifold and particular emphasis was made at the discharge. The discharge represented a critical section since right there, the flow is either returned or by-passed to the calibrated tank by the diverting gate.
Fig. 13 shows the velocity field around the upper section of the manifold. It is clear the tendency to accelerate the flow towards the outer section of the curved head, due to the centrifugal force. This, as it is also appreciated from experiments, causes a non-uniform discharge of flow through the gate and therefore a natural difference between the flow derived to the calibrated tank during the opening and the closure of the gate.

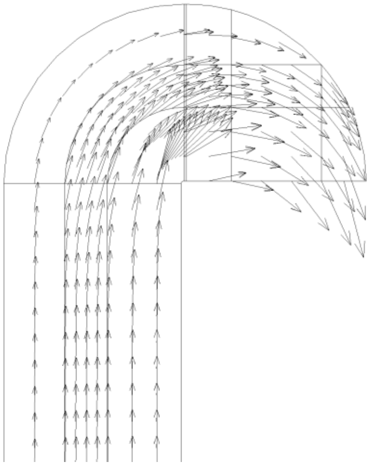

Fig. 13. Velocity Field at the Manifold Head

CONCLUDING REMARKS

The design and test of a large scale flowmeter calibration facility, located at the Universidad Simón Bolívar in Venezuela, is presented.
The facility was tested using a Venturi flowmeter and demonstrated the usefulness of having this type of installation to perform periodic calibrations of field flowmeters. The reliability of the data obtained through the facility was evaluated. The Data Acquisition System attached to the facility permitted to store and calculate in real time the different parameters that constitute the calibration curve for a given flowmeter.
The error associated to the measured volume is around 0.002%, while time is measured with 1 milisecond of accuracy.

BIBLIOGRAPHY

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