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DESIGN OF THE DISTRIBUTION MANIFOLD FOR A LARGE-SCALE FLOWMETER CALIBRATION FACILITY

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ABSTRACT
The design and test of the distribution manifold for a large-scale flowmeter calibration facility is presented. The design was intended to have an air-free flow operation and a free-surface flow-like towards the downstream half-body discharge. Back of the envelope calculations are presented for the estimation of the preliminary dimensions. Numerical simulations of the flow during manifold steady state operation are utilized to refine the manifold design. No air entrapment is noticed in the flow simulation.

INTRODUCTION
The flowmeter calibration is a very important activity in every industry that handles fluids.

The typical flowmeter calibration consists in a flow loop provided by a pumping system, a large water deposit, a constant pressure system, a set of pipelines (where flowmeters are attached), a distribution manifold (to direct the flow to the appropriate pipeline), a diverting gate and a calibrated tank. The facility must be, of course, provided also with all the associated instrumentation for time and volume measurement and data acquisition.

This paper presents the design of the distribution manifold of the Universidad Simón Bolívar Flowmeter Calibration Facility (USB-FCF).

Brief Description of the USB-FCF
The USB-FCF consists of all the essential elements, cited above, typically presented in calibration facilities.

The facility operates in the following way: (a) the pumping system suctions from the main underground tank and discharges into the elevated constant-level open tank, which is provided by a drainage system to recirculate the excess of water. The elevated tank supplies the necessary flow to the pipeline system where the flowmeter (to be calibrated) is placed. Downstream the flowmeter test section, the pipelines converge to a distribution manifold where the head is provided by a diverting gate capable to send the flow towards the recirculation loop or towards the calibrated tank for further measurement. Then, a calibration curve containing the dependency between the flowmeter output (Volts, pressure head, etc) and the actual flow rate is built. The distribution manifold represents a very critical part of the facility since it must guarantee the open channel flow like at the outflow, and must be free of air accumulation.

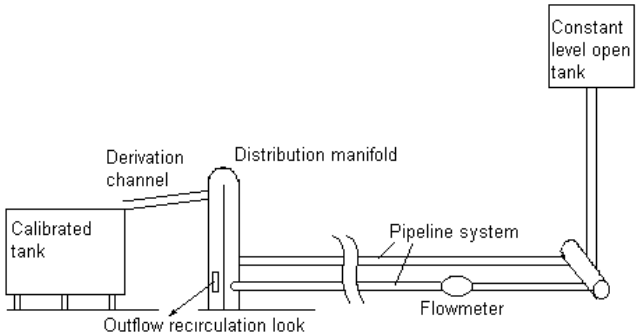

Fig. 1. Schematics of the USB-FCF

DESIGN OF THE MANIFOLD

The manifold must be able to accomplish its distribution purpose without generating upstream perturbations that may affect the flowmeter lecture.

Preliminary design

Due to space constraints, the manifold is designed to be vertical built out of a 20” pipe section coupled to the 8”, 10”, 12” and 14” existent pipelines, as shown in Fig. 2.

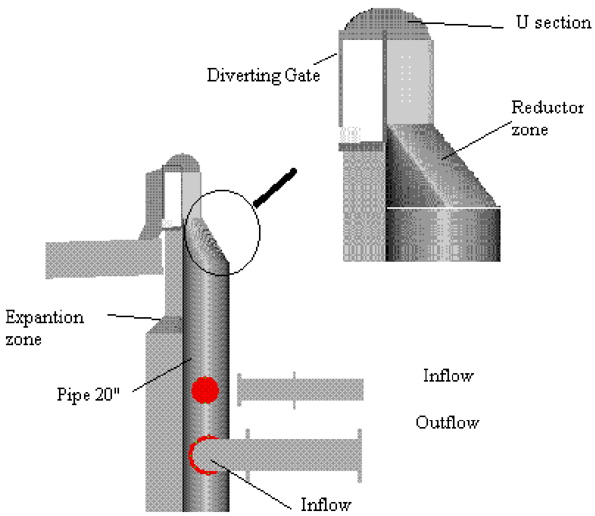

Fig. 2. Proposed Design

Design Constraints

The manifold has to guarantee, as possible, the following flow conditions: (a) uniform flow at the entrance of the diverting gate; and (b) free discharge at the exit in order to avoid upstream perturbations.

Physical and Mathematical Model

The preliminary design of the manifold was subject of a numerical simulation in order to foresee the flow behavior and any flaw in the design. The numerical modeling of the problem considers: three-dimensional geometry, flow characteristics, and the mesh and boundary conditions (for numerical purposes).

Geometry

For computational purposes, the proposed three-dimensional geometry is divided in two sections, A and B, as shown in Fig. 3. Section A corresponds to upward flow, including the U-section (Fig. 3a). Section B corresponds to downward flow (Fig. 3b). Both sections were modeled at their actual scale.

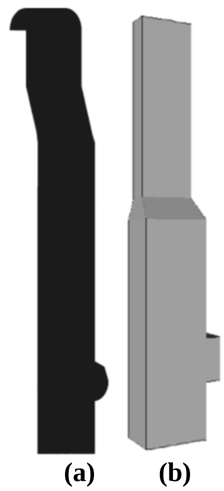

Fig. 3. Manifold Partition (numerical): (a) Section A; (b) Section B

Main Flow Features

Since the operation of the manifold involves a free discharge and a partially air-filled body (Section B), the flow within the manifold will be, at least partially, of two-phase nature. However, for the low speeds, compared to sound speed, both air and water are assumed as incompressible with physical properties at the working temperature (298 K). The flow regime, as verified later, is isothermal.

Boundary Conditions

Figure 4 depicts the boundary conditions established for the mathematical model.

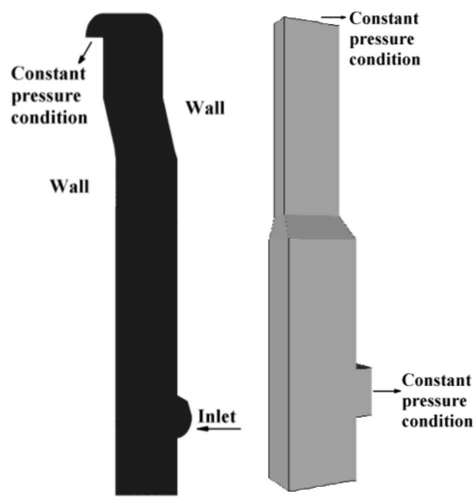

Fig. 4. Boundary Conditions

Meshing
Figures 5 and 6 show a cross-section of the three-dimensional mesh for both sections.

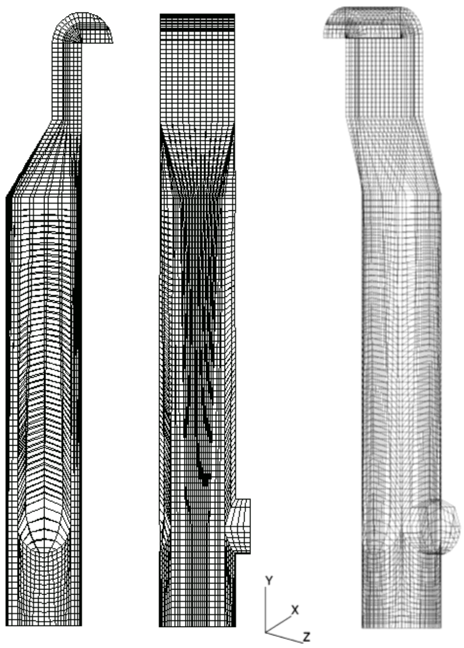

Fig. 5. Meshing in Section A

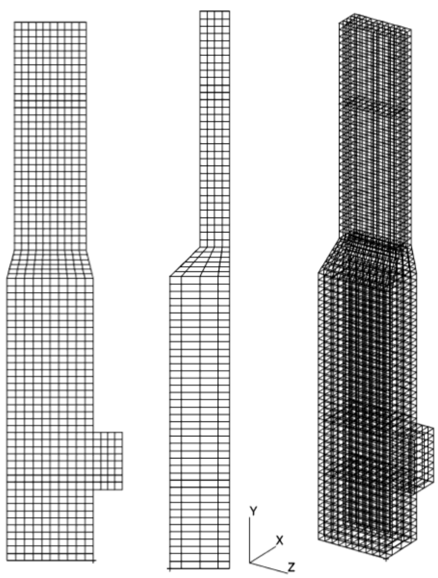

Fig. 6. Meshing in Section B

Numerical Simulation
A finite-volume-based code (CFX4.2) was used to solve the governing equations. The governing equations included mass conservation, linear momentum and k-ε turbulence equations for both phases, including inter-phase exchange parameters.
To handle the phase (air or water) distribution within the manifold, it is necessary to introduce the concept of volumetric fraction of each phase, which represents the ratio between the phase volume and total volume at every computational cell of the flow domain. The computed pressures corresponds to gauge pressures since the incompressibility condition does not require the use of absolute pressures.

Results
The following paragraphs present numerical results pertaining to the simulation of both sections of the manifold.

Section A

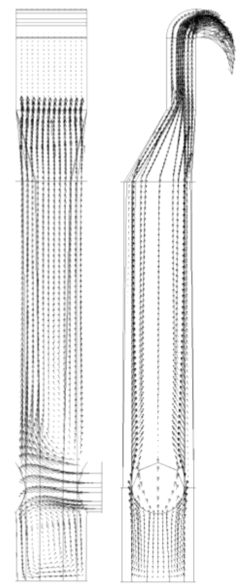

Fig. 7. Velocity field at longitudinal plane in Section A

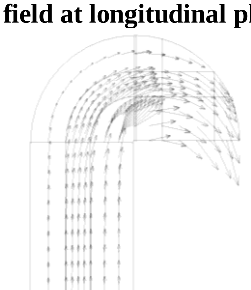

Fig. 8. Detail of velocity field at the exit of Section A (entrance of diverting gate)

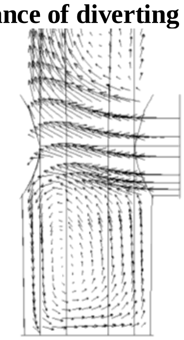

Fig. 9. Details of velocity field at entrance of Section A

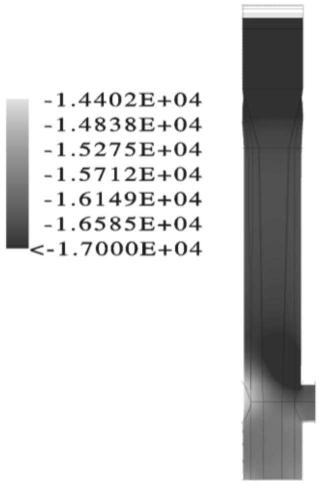

Fig. 10. Pressure field in Section A [Pa]

Section B

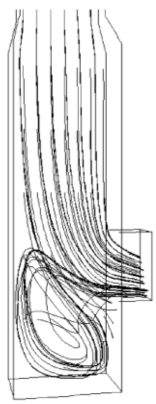

Fig. 11. Streamlines at exit of Section B

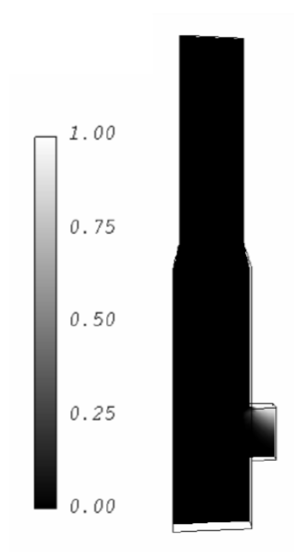

Fig. 12. Air contents (volumetric fraction) within Section B

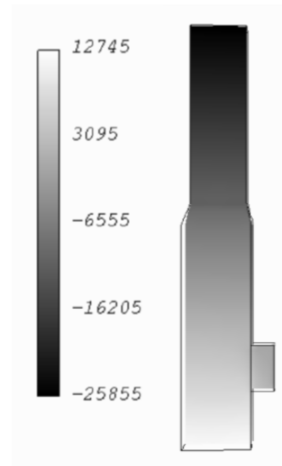

Fig. 13. Pressure field within Section B [Pa]

Analysis of Results

Section A:

Fig. 7 presents the velocity field in steady state regime within Section A using the 14” pipeline inlet. Figure 6a shows the flow asymmetry at the entrance of the section and the progressive re-accommodation as the flow approaches the U-section. A recirculation region is depicted just underneath the entrance, responding to the shear layer caused by the filling stream (see details in Fig. 8).

On the other hand, Fig. 7b, shows the upward flow motion with a convective acceleration towards the upper reduction of the manifold. The velocity profile deforms dramatically as the flow approximates the U-section, due to the centrifugal force, causing larger velocities towards the outer radius of the U-section (see Fig. 9). This result suggests the use of a re-conditioning grill to force the flow to exit closer to uniform.

Figure 10 depicts the pressure distribution, demonstrating larger pressures where velocities are smaller and vice versa, as expected for incompressible flows. In fact, within the recirculation region, the velocity magnitudes are smaller than at the entrance and therefore larger pressures compared to the entrance are also noticed.

Section B:

Figure 11 presents the streamlines at the manifold outlet, where flow is freely discharged. It is also observed a recirculation at the bottom of the Section responding to a shear layer caused for the outflow stream running over the surface of the fluid trapped in the bottom. The pressure is also higher in that section, corresponding to the hydrostatic-like distribution (see Fig. 13).

Fig. 12 depicts the air-water distribution within Section B. From this results it is clear that all the manifold is filled out of water except the discharge section, where it reflects the open channel-like flow at the manifold exit. This is a very important result, since it foresees that the manifold discharge will not control the upstream flow conditions.

Experimental Data Compared to Numerical Results

The numerically studied geometry was built and the Laboratory performance did reflect the same results obtained through simulations; i.e., the Section B outflow was able to discharge the water in an open-channel-like regime. The non-uniformity of the velocity profile was also confirmed through the systematic study of the flow through the diverting gate. In fact, it was shown that the reduction in the flow derivation towards the calibrated tank was not a linear function of the gate position, indicating the non-uniform distribution of velocities, and flow in consequence, at the entrance of the gate (exit of the distribution manifold). The experimental manifold (Fig. 14) was finally provided by a re-uniforming grill to smooth out the differences in the velocity profile. However, it was found that this non-unifornities did not cause significant errors in the operation of the faciility.

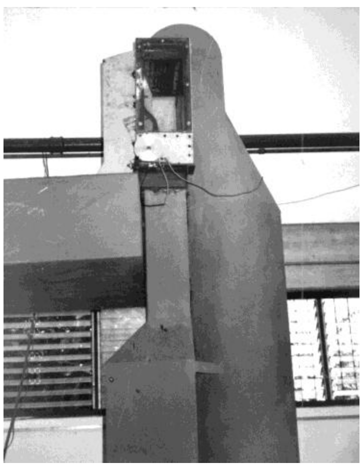

Fig. 14. Manifold and derivation gage

CONCLUSIONS

The design and numerical study of the distribution manifold of the USB-FCF is presented. Experimental data, not shown in this paper, confirmed the numerical results. The analysis allowed to successfully predict important features of the flow, such as recirculation regions and non-uniform distribution of the velocity at the exit of the manifold (entrance of the diverting gate).

The numerical study and the experiments determined the usefulness of a flow reconditioning grill at the exit of the manifold.

REFERENCES

Manual of CFX4 by AEA Technology. England.