µFLU12-89

MICRO FLOW METERS CALIBRATION TEST LOOP AT CETIAT

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KEY WORDS.

Micro flow, Accuracy, Degassing, Temperature control, Viscosity, Specific mass, Scale, Automation, Water treatment.

ABSTRACT.

The increasing need for precise measurements of very low flow rates renders mandatory a reference test loop for calibration of flowmeters. This test loop must be connected to the international standards (S.I.). In order to propose such a solution to manufacturers and users of flowmeters, CETIAT has decided to build a specific test loop with a high level of accuracy. Inauguration has been made in January 31th 2012. The micro flowmeter calibration test loop has the following specifications:

- *Range of flow rates between 1 ml/h and 10 l/h.*
- *Maximum operating pressure: 10 bar,*
- *Range of temperature: between 10°C and 50°C.*
- *Fluid utilised: water.*

The construction of the loop has been finished in 2011.

1. INTRODUCTION.

CETIAT is a French technical centre specialized in characterization of various systems in the field of thermal and aerodynamic industries. Its expertise covers the following applications:

- Boilers and burners
- Radiators
- Air conditioning
- Ventilation, fans
- Transport
- Health
- Industrial process
- Calibration

In this last domain, CETIAT owns 6 calibration laboratories. 3 of these labs (Humidity, Air velocity and Liquid flow) are designated institutes and have the best calibration performances in France. The existing calibration laboratory for water flowmetering covers the range between 8 l/h to 36 m^3/h. (2.2 10^{-6} m^3/s to 10 10^{-3} m^3/s). The test bench uses a vessel at a height of 10 meter to create the flow and the type of measurement is gravimetric. The relative uncertainty is comprised between 5 10^{-4} and 1.6 10^{-3}, depending on flow rates.
The increasing demand of calibration for low flow rates in various fields of industry has led CETIAT to develop a new test bench for much lower flow rates, between 1 ml/h to 10 l/h (2.8 10^{-9} m^3/s to 2.8 10^{-6} m^3/s). The objectives of relative uncertainty are better than 10^{-3}.
CETIAT has asked YLec Consultants to help in the design of the loop and SPRETEC to make the engineering studies and supervise building. End users such as Bronkhorst have been implicated in the design since the beginning.

2. PRINCIPLES.

At the beginning of the project, the weighting method has been retained as the reference. It uses a high precision scale (WZA, Sartorius) and the weight (ΔW) of liquid passing through the flow meter is measured during a period Δt.
The average mass flow rate is readily calculated:

$$w = \frac{\Delta W}{\Delta t}$$

Knowing the specific mass of the liquid, the volumetric flow rate Q can be deduced:

$$Q = \frac{w}{\rho} = \frac{1}{\rho}\frac{\Delta W}{\Delta t}$$

In order to reach a global relative uncertainty lower than 10^{-3}, all these parameters must be measured with an accuracy of 10^{-4} or better.

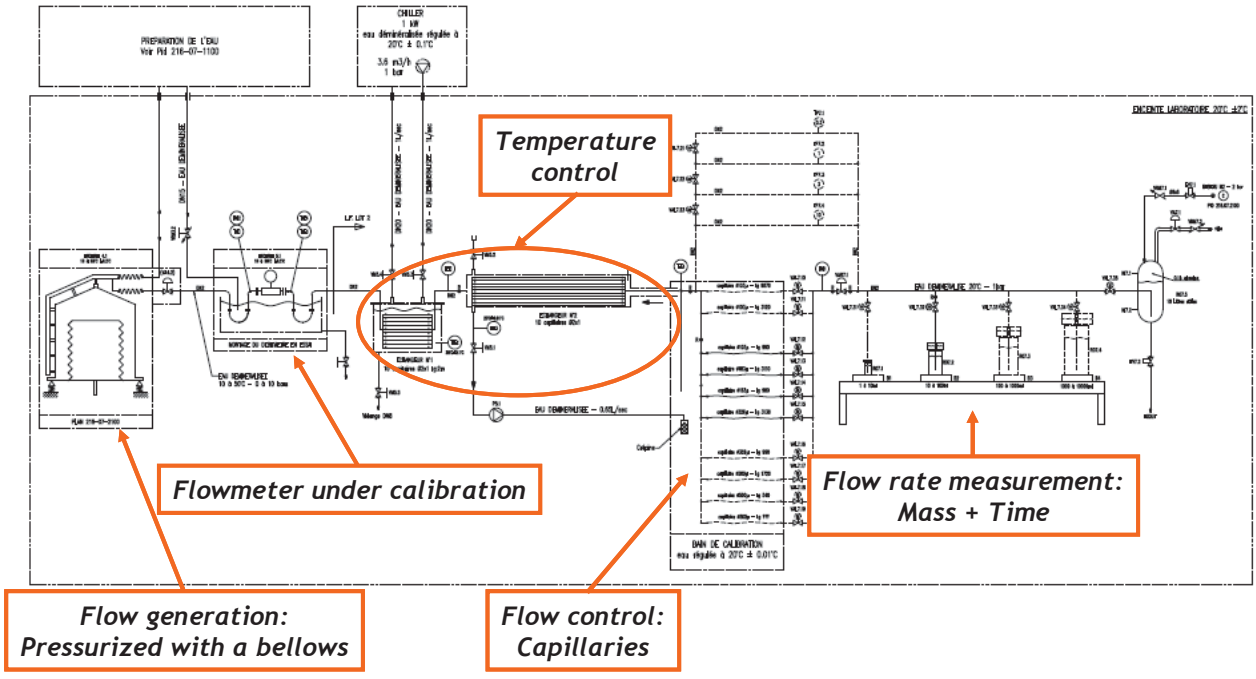

Figure 1. Principles of measurement.

Figure 1 shows the circuit as it has been built. It has been decided to use only water as test fluid.
The reservoir is deformable, thanks to an internal bellow. It is filled with clean and degassed water at a precisely controlled temperature. Its internal pressure is measured by a set of high accuracy pressure gages and regulated by means of compressed air.

The flow meter under test is fed with the water flow. The flow rate imposed by an adjustable pressure drop which work at a perfectly constant flow rate in the range of specifications. A high speed valve is used to open and close the circuit at known dates.
Finally, the water enters the finals reservoirs and the mass of liquid flowing (0,5; 5; 50; 500g depending of the scale used) is weighted during the measuring period (3 to 30 minutes).

3. DIFFICULTIES.

3.1 Foreword.

The design of such a test loop implies to respect classical requirements for calibration loops, but some problems arise due to the very low flow rates and volumes concerned.

3.2 Time measurement.

First of all, the measurement of time elapsed between the opening and closing of the high speed valve (3 to 30 minutes) must be known. If one considers that the displacement of valve lasts 5/1000 s, and that the accuracy of measuring duration must be of 10^{-4}, the minimum measuring period must be of 100 seconds or 1.6 minutes.
Time issues and valve technology directly fix the volume of the reservoirs. Balance accuracy determines the number of scales utilised. 4 balances which individually cover a range slightly higher than 10 are used for the CETIAT test loop.

3.3 Constancy of flow.

The flow passing through the flow meter must be maintained perfectly constant during the measurement period. As the range of flow rates is of 10^4, it is not possible to use a unique pressure drop device.
In classical test loops, with high enough flow rates, valves or calibrated diaphragms are used to produce the pressure drop. This pressure drop does not depend much of fluid properties because the flow is turbulent. This is not possible with very low flow rates because such control devices working in laminar flow regime do not exist.

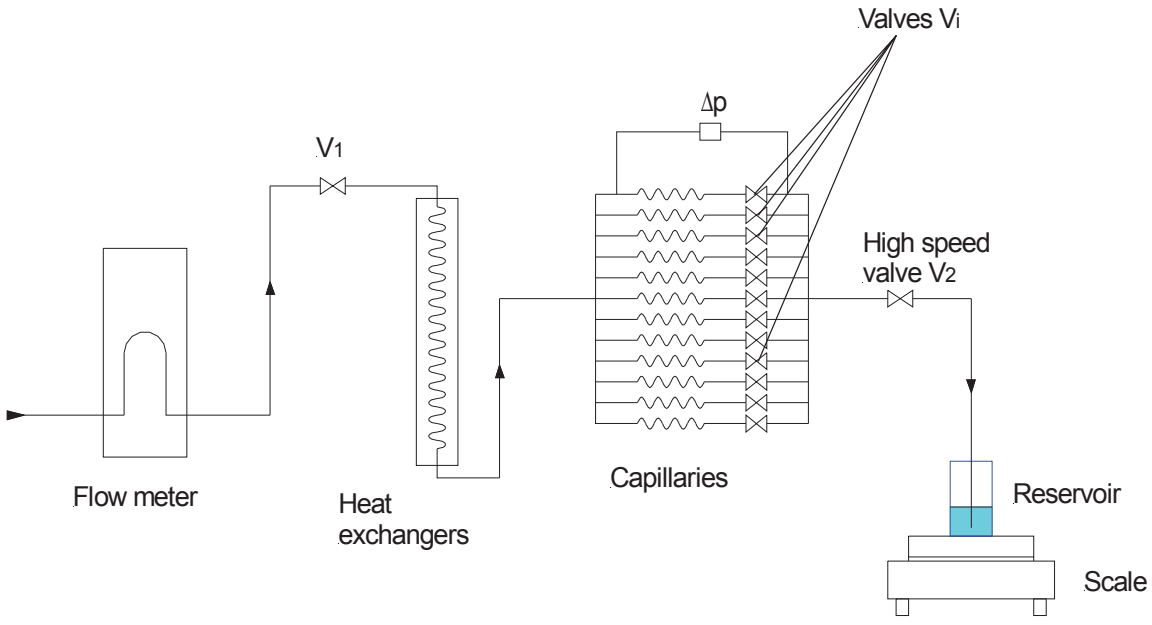

Figure 2. System of capillaries used to control the flow rate.

To attain the specifications, it has been decided to install a set of 8 capillaries working in parallel as shown on figure 2. All these capillaries are made of 316 L stainless steel and they cover the range of flow rates specified. The control of flow rate implies the use of those capillaries and of the upstream pressure in the upstream tank. Each capillary passage can be either open or closed with small valves V_i.
The pressure drop through a capillary of length L and diameter D in laminar flow is given by:

$$\Delta p = \frac{128}{\pi} \frac{\mu L Q}{D^4}$$

In order to precisely measure the volumetric flow rate and to be sure of its constancy during the measuring period, the viscosity μ must be perfectly stabilized. This implies a control of temperature with an accuracy and reproducibility of ± 0.01°C.
The temperature of the flow meter can be adjusted between 10 and 50°C. The temperature in the capillaries is adjusted precisely with a two steps heat exchanger at 20 ± 0.01°C

3.4 Start and stop.

Valve V_2 is a high speed micro electro valve (6650, Burkert). Before any measurement, the valves Vi are open or closed to set the flow rate. After this preparation, the test may begin and V_2 is open. This action creates a sudden pressure change in the circuit and it is mandatory to make sure that there is no compressibility effect which could ruin the measurement accuracy. This means that there must be no air trapped anywhere in the pipes or the flow meter under test. The deformation of all pipes and valves must be negligible.
In the case of the lowest flow rate, a typical measurement lasts 180 s and the mass weighted is of 0.5 g which corresponds to about 500 mm^3. The circuit has been designed in such a way that the sum of all possible deformations under a variation of pressure of 10 bars remains below 0.03 mm^3. This has been made possible by a very high quality of realisation concerning especially welding of tubes, a choice of non deformable valves and the absence of hysteresis during closing and opening of the high speed valve. Moreover, the water utilised is degassed to prevent the formation of bubbles whatever the pressure and temperature.

3.5 The reservoir.

The reservoir used for measurements is a source of potential problems.
At first, it is necessary to have no friction between the pipe and the reservoir. This means that any system using bellows or deformable tight junctions must be avoided. Theoretical studies have been made to take into account such effects have shown that the accuracy of weighting is highly impacted by such liaisons.
In case of a pipe outlet placed over the free surface, pending drops are formed with a typical volume of 40 mm^3. This makes this solution non acceptable because this intermittency is almost impossible to control within the necessary time frame of 0.05 s. Consequently, the outlet of the pipe feeding the reservoir has been immersed.
A detailed study of spurious effects relative to the formation of a meniscus between the pipe and the free surface of the reservoir has been made and practical decisions have been taken to overcome this problem. In the lower range of measurements, the external diameter of the pipe entering the reservoir is of 0.3 mm. Moreover, the outlet of the pipe is at right angle to prevent the creation of vertical forces due to the momentum of the exit jet.

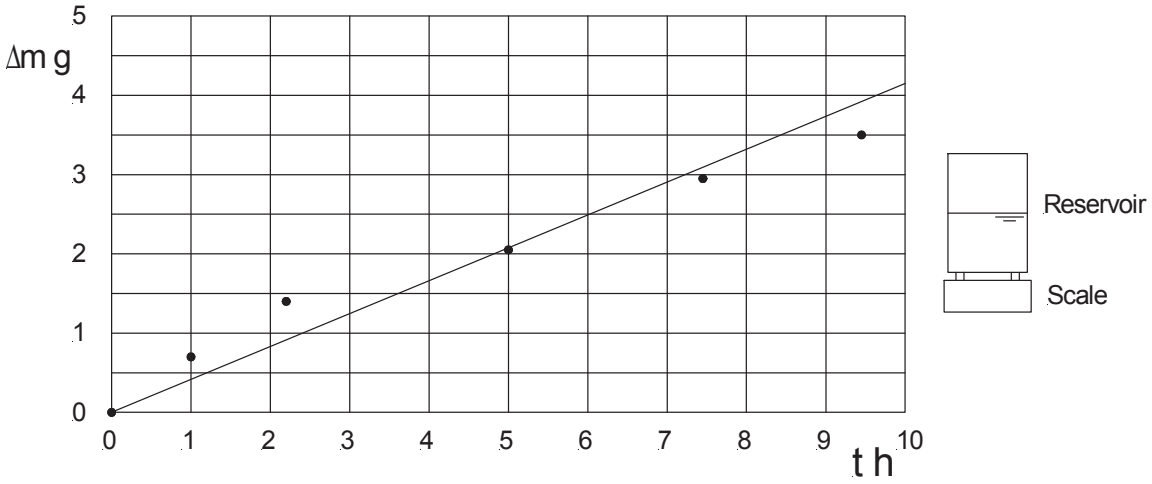

Figure 3: Rate of evaporation over a free surface in still air

Even more important is the fact that the said free surface is in relation with the atmosphere. Evaporation could be a major source of uncertainty. Test have been made with a reservoir of 80 mm in diameter and the rate of evaporation measured was found to be of 0.4 g/h, which is unacceptable, at least for low flow rates.
These results confirm theoretical approaches of evaporation in the natural convection mode.
To prevent this phenomenon, the reservoir has been protected by placing a second reservoir at same temperature and pressure with a direct junction between both free surfaces. This enables to create two saturated atmospheres at same temperature. Liaisons between the two reservoirs and the enclosure have been designed to limit mass transfer by natural convection from the second reservoir. Measurements made with a high precision scale have shown that the evaporation was no more measurable by using this simple system.
Other considerations have concerned the density difference of water saturated air within the reservoir and the air of the laboratory. The measuring system is located in an air conditioned room with temperature control 20 +/- 2°C and humidity control (55%HR +/- 5%HR). All lights and heat sources in the room are switched off. The 4 scales are placed on a table isolated from external vibrations.

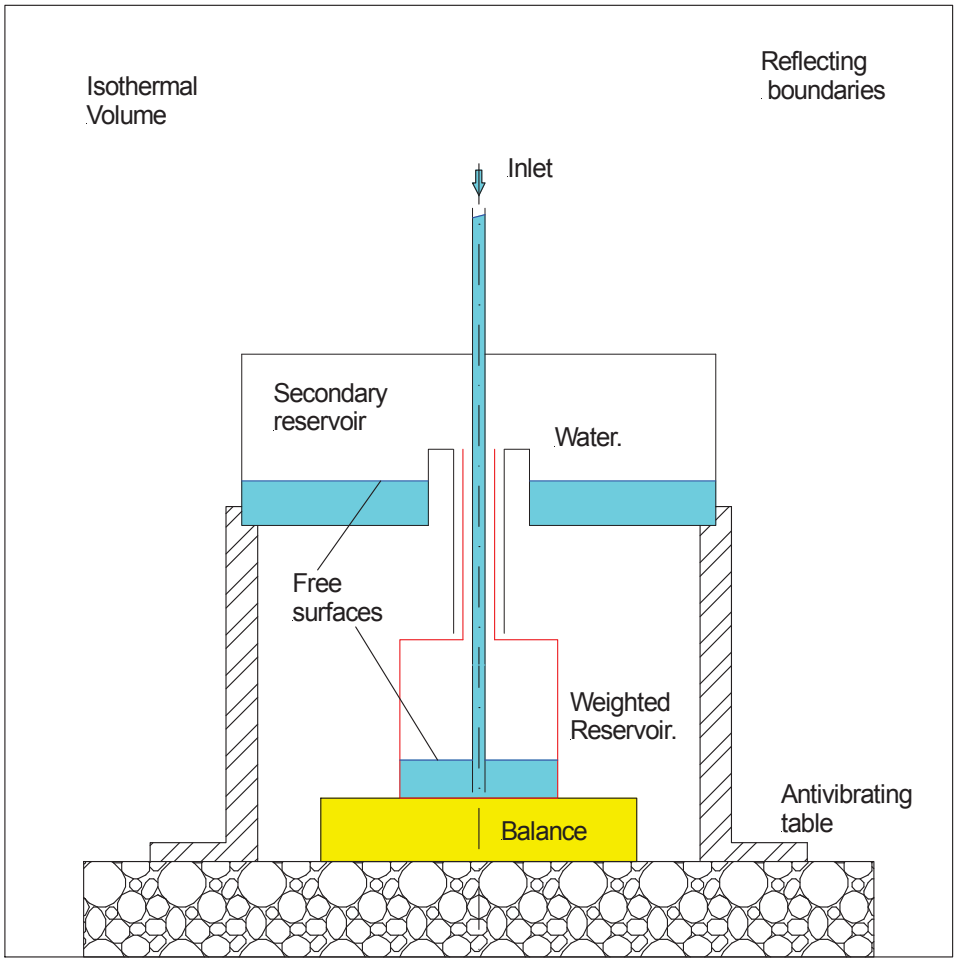

Figure 4: Arrangement of a reservoir on its balance

4. PREPARATION OF WATER.

As already said above, the water entering the upstream tank must be filtered and degassed. Moreover, its temperature must be adjusted between 10°C and 50°C. In order to achieve these requirements, a water treatment plant has been designed and constructed.
Firstly, the water is filtered and deionised. Then it enters an upstream storage tank in which oxygen is removed by stripping with nitrogen bubbles. After this first treatment, it is placed in a second tank to set the temperature at the desired value for the next test. In this reservoir, vacuum is applied to degas the water.
Some degassed water is stored in a second reservoir at 20°C. This water is used to fill the flowmeter before connecting it to the calibration facility. Mounting of flow meters is then done with the hydraulics connectors dived under degassed water to prevent air bubbles going back inside the flowmeter.
The arrangement of the water treatment plant is shown on figure 5.

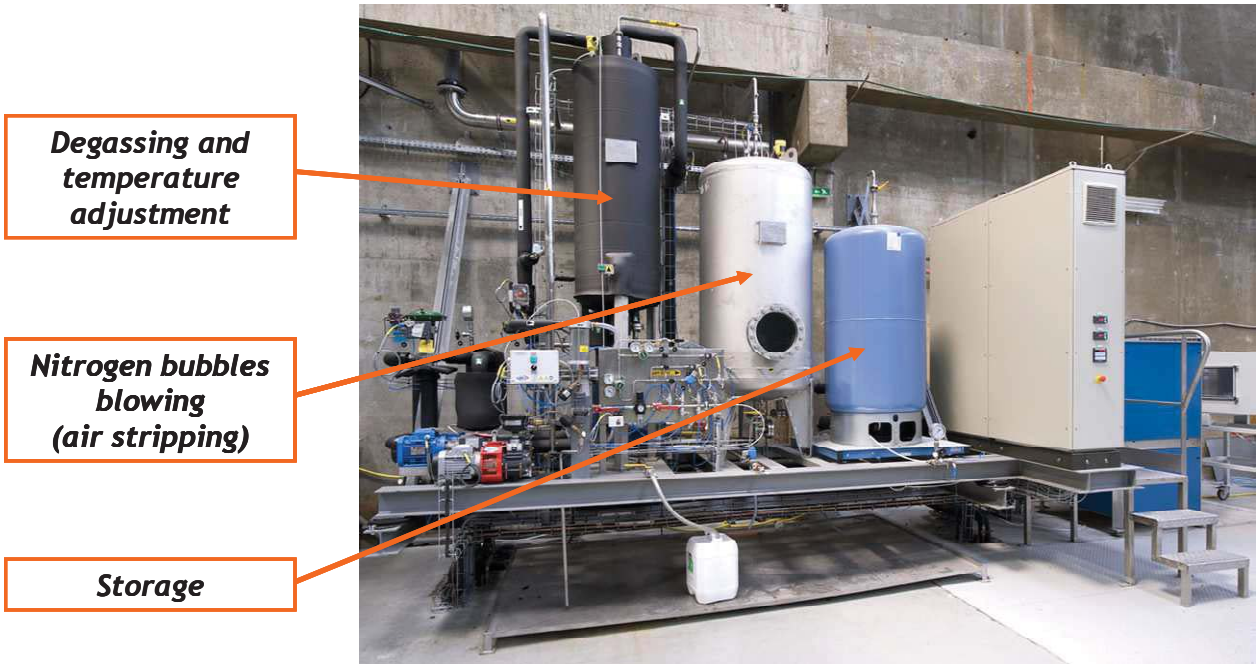

Figure 5: Water treatment plant.

A dedicated procedure using the bellow as a water pump is utilised to fill the upstream reservoir at the desired temperature before test. Its enclosure is air conditioned at the same temperature.

5. TEST PROCEDURE.

The procedure of measurement is totally automated.
First of all, the water is prepared in the degasser. The flowmeter is replaced by a simple capillary tube. Then the circuit is filled with water. At first, a procedure is utilized to fill completely the upstream tank. All the gas contained over the bellow is removed. Then the circuit itself is filled. Owing to the very small size of all capillaries (diameter down to 100µm), the gas in excess is gently pushed downstream to the sewage system, all valves being open. If an air bubble was trapped in some flow line accident, it would be removed by dissolution in water.
Then the balance circuit is chosen and the corresponding reservoir level is set at the desired value. The flow meter is mounted in place of the filling pipe. Specifications have to be respected concerning its cleanliness and absence of trapped air. At the end of the test, the water contained in the reservoir is simply sucked in an intermediate vacuum tank until the desired initial level is reached. In such a test, the only manual procedure is the mounting of the flow meter. All other actions, including the measuring procedure are totally automated. Such an approach permits to optimize the test duration, to obtain all the necessary measurements and this permits a global high quality and traceability.

6. CONCLUSIONS AND FUTURE PLANS.

This paper presents the development of a new test facility dedicated to calibration of flowmeters working in the range of 1 ml/h to 10 l/h. The success of this project is largely due to a tight collaboration between a laboratory, CETIAT, a designer of test facilities, YLec Consultants [i.e.1], an engineering, SPRETEC and the collaboration of end users since the beginning of the project, among whose the Dutch company Bronkhorst High Tech.
The facility represents a breakthrough in the field of low flow rates and is open to all end users.
Next challenge will be to design, build and run a calibration loop for even lower flow rates. Current developments at YLec Consultants concern flow rates of 0.04 ml/h for applications to perfume diffusion [2], 0.01 ml/h in drug delivery systems and even lower values of 0.0001 ml/h to calibrate measuring instruments in pollution applications.

AKNOWLEDGEMENTS.

The authors want to thank the LNE (French national Metrological Institute), the Rhône-Alpes Region, the CETIM (French Technical Center For Mechanical Industries) and BRONKHORST HIGH TECH (NL) for their financial supports.

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