Water Flow Comparison Measurements between Centro Nacional de Metrología (Mexico) and Physikalisch – Technische Bundesanstalt (Germany) by using a CENAM 100 mm Double-Turbine Meter Transfer Standard

Dario Alejandro Loza Guerrero[1], Rainer Engel[2]
[1]Centro Nacional de Metrología – México.
aloza@cenam.mx
km 4,5 Carretera a los Cués, El Marqués, 76900, Querétaro, México
[2]Physikalisch-Technische Bundesanstalt
Bundesallee 100, D-38116 Braunschweig, Germany
rainer.engel@ptb.de

Abstract

This comparison test program 2004 CENAM - PTB was in order to assess the confidence and performance of the Mexican primary standard for liquid flow measurement. This program was an initiative from Centro Nacional de Metrología (CENAM) in Mexico in collaboration with the Physikalisch-Technische Bundesanstalt (PTB) Liquid flow laboratory in Germany.

We expected that the results differences between PTB and CENAM were inside CENAM's uncertainty limits, nevertheless test results from both laboratories, confirm that the measuring capabilities of meter 2 (MTR 2) are insufficient to accomplish the objective brought up above. Moreover, MTR 2 had a negative influence over the fluid velocity profile in configuration 1, causing an awkward response on the downstream turbine meter (MTR 1).

In summary, the outcomes obtained from MTR 1 are the best reference to analyze the agreement in terms of liquid flow measurements between such NMIs and those are showed in the following pages.

1. Introduction

The comparison was initiated by CENAM in 2004 under the flow measurement assurance program with PTB to maintain confidence in the results of the fluid flow measurements processes at the water flow facility in Mexico. A comparison between laboratories was carried out in water, using a two CENAM 100 mm turbine meters in tandem.

Measurement assurance programs are efforts to provide confidence in the results of the liquid flow measurements. To evaluate the systematic errors for CENAM's liquid flow laboratory we used the comparison program, all the procedures, system components and people are evaluated entire.

This package was calibrated at CENAM in Mexico during early November 2004, thereafter at PTB in the last week of November 2004 and finally returned it and re-calibrated at CENAM in December 2004.

The estimated expanded uncertainty U for CENAM volumetric flow rate measurements is nearly constant all through the flow range of 1,5 m^3/h to 720 m^3/h (± 0,04 % with U determined from a combined standard uncertainty and a coverage factor k based on t-distribution for ν degrees of freedom with a level of confidence of approximately 95 percent).

2 Objective

The main objective of this comparison program is to achieve international agreement in liquid flow measurements, i.e.: to establish realistic traceability of liquid flow measurement, to estimate the uncertainty of the laboratory and its routine procedures, identify the systematic differences between laboratories and to build up confidence between Germany and Mexico.
In order to comply with these conditions is necessary to have comparison test programs periodically between NMIs.

3 The participants - National Metrology Institutes (NMIs)

3.1 Centro Nacional de Metrología (CENAM)

The liquid flow facilities at CENAM constitutes Mexico's primary standard for liquid flow measurements. The system is based on the static weighing principle with weighbridges of 1,5 tons and 10 tons (figure 1 and table 1).

This primary fluid flow system not only serves as a basis for the national chain of traceability but also as an important facility for fluid flow research.

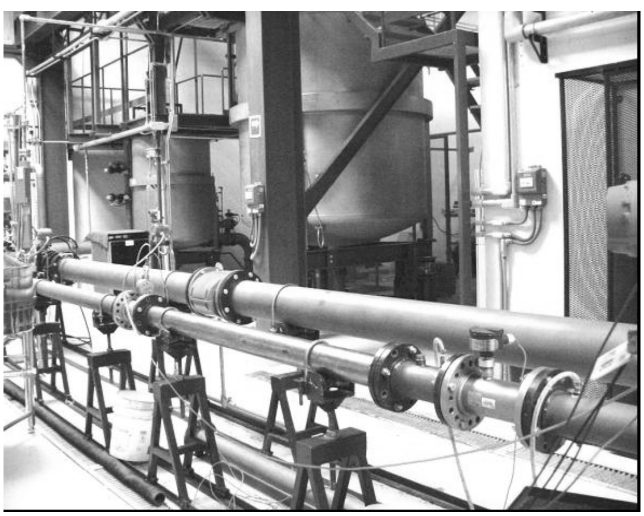

Figure 1. *The liquid flow facilities at the Centro Nacional de Metrología.*

Table 1. *Main features of CENAM water flow standard facility*

Features	Item(s)	Characteristics
Measurands	Volumetric flow rate Mass flow rate Volume (totalized) Mass (totalized)	Flow rate meters and volume and mass flow totalizing meters
Calibrations mode	Flying Start / Finish	Operation control via: Diverter valve
Reference standards	Gravimetric calibration (static weighing) Volumetric calibration	Weigh systems: 10 000 kg and 1 500 kg. Pipe prover and volumetric provers (500 L and 1 000 L)
Operation modes	Pump direct operation	Variable pressure in calibration line (approx: 0,2 MPa, up to 1 MPa)
Meter / pipe sizes (25 mm to 200 mm)	Line A Line B	DN 25 … DN 100 DN150 … DN 200 (Up to DN 250)
Ranges of flow rate	Line A Line B	1,5 m^3/h to 240 m^3/h 36 m^3/h to 720 m^3/h
Expanded measurement uncertainty	± 0,03 %, ± 0,04 to ± 0,05%	mass volume.
Flow straightening section		45 m

All piping and components in contact with the liquid are made of stainless steel.

3.2 Physikalisch-Technische Bundesanstalt

The PTB Hydrodynamic Test Field, which represents a high-accuracy water flow calibration facility, serves as a national primary standard for liquid flow measurements. This system is based upon a static weighing principle which incorporates 3 dual-balance weighing systems: 30 tons, 3 tons and 300 kg. The total expanded measurement uncertainty of ± 0,02 % (figure 2 and table 2) [2].

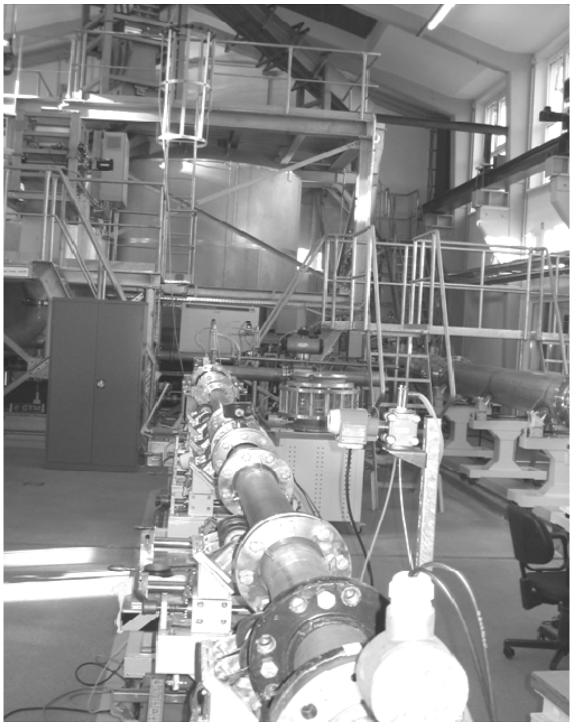

Figure 2. *The liquid flow facility at the Physikalisch-Technische Bundesanstalt.*

Table 2. *Features of the PTB standard facility.*

Plant features	Item(s)	Characteristics
Measurands	Volumetric flow rate Mass flow rate Volume (totalized) Mass (totalized)	Flow rate meters and volume and mass flow totalizing meters
Calibrations modes	flying Start / Finish standing Start / Finish	Operation control via: Diverter On/Off valve
Reference standards	Gravimetric calibration (static weighing) Volumetric calibration	Balances: 30 t, 3 t, and 0,3 t. Pipe prover
Operation modes	Via constant-head tank Pump direct operation	Constant pressure in calibration line (approx: 0,35 MPa) Variable pressure in calibration line (approx: 0,6 MPa)
Meter / pipe sizes	Line A Line B	DN 200 … DN 400 DN20 … DN 150
Ranges of flow rate	Line A Line B	3 m^3/h to 2 100 m^3/h 0,3 m^3/h to 350 m^3/h
Expanded measurement uncertainty	± 0,02 %	(operation via constant-head tank)

4 The Transfer Standard

In each laboratory the 100 mm turbine meters was installed in tandem, configuration 1 as shown in Figure 1, with an additional 100 mm pipework from each laboratory upstream and downstream of the assembly to calibrate the flow meters simultaneously. The flow meters were shifted to configuration 2 to be calibrated under the same conditions.

Table 3. *Turbine meters specifications.*

Turbine meters	MTR 1	MTR 2
Manufacturer	Brooks Instrument	XO Technologies
Model	T04AAA1NA1AAAAA	4-81AF5C2-A
Serial number	9812-37510-1-1	211517
Size (mm)	100	100
Material	Stainless steel	Stainless steel
Range (m^3/h)	29,4 to 294	
Nominal K factor (pulses/ m^3)	6 538,79	12 855,77

The overall length of the “artifact” is 2,90 m. The pipe work has ANSI 150 flanges.

5 Test Measurements

The test program proposed by CENAM consists of:

- An initial set of tests at CENAM (to quantify the performance of the two 100 mm turbine meters),
- A set of tests at PTB, and
- A follow-up set of tests at CENAM to evaluate any changes that may have occurred after the initial test at CENAM.
- Both laboratories were collect data at 3 flow rates: (50, 150, 250) m^3/h.

A test program takes into account:

1. All the results generated from the established calibration *procedures* in each laboratory.

2. The data generated via comparison was analyzed in the following way:
   - The average meter factors will be analyzed for each of the flow rates selected and for each of the meter configurations.
   - E_n number [3].

6 Definitions

Equations of K-factor, mean, repeatability and reproducibility.

The K factor is the number of pulses per unit volume. Repeatability and reproducibility are defined here in accordance with International Vocabulary of basic and General Terms in Metrology published by ISO 1995.
The repeatability is expressed in terms of the dispersion characteristics of the results without changing any parameter during the measurement. The term reproducibility refers to planned changes like time, position of the meters, and installation effects. The reproducibility is expressed in terms of the dispersion characteristics of the results. The figures presented in this report are based on the following definitions:

The common way to present the data of turbine meters is the K-factor as a function of volumetric flow rate or Reynolds number.

The K-factor, $K_{vi}(q_j)$, pulses/m^3, for a single measurement i at the flow rate q_j:

$$K_{vi}(q_j) = \frac{\text{counted pulses from meter}}{\text{volume}} \qquad (1)$$

All of the K-factors, which were produced in CENAM facility, were referenced to the standard temperature selected to be 20 °C, using:

$$K_0 = K\left(1 + 3\alpha\left(T - T_0\right)\right) \qquad (2)$$

where,
K_0 is the meter K-factor in pulses per cubic meter at the reference temperature, T_0.
K is the meter K-factor in pulses per cubic meter at the flowing temperature, T.
α is the linear expansion coefficient for the meter material in °C^{-1}.

In the case of the PTB facility, the temperature is kept around 20 °C during the test.

The K-factor arithmetic mean value $\overline{K}_{vj}(q_j)$, pulses/m^3, for a series at flow rate *j:*

$$\overline{K}_{vj}(q_j) = \frac{1}{n}\sum_{i=1}^{n} K_{vi}(q_j)\,; \qquad n = 5 \qquad (3)$$

where n is the number of measurements at qj flow rate.

The experimental variance $s^2\left(K_{vi}(q_j)\right)$, (pulses/ m^3)^2, of $K_{vi}(q_j)$ from repeated measurements at flow rate q_j:

$$s^2(K_{vi}(q_j)) = \frac{1}{n-1}\sum_{i=1}^{n}\left(K_{vi}(q_j) - \overline{K}_{vj}(q_j)\right)^2; \qquad n = 5 \qquad (4)$$

The K-factor global mean value $\overline{K}$, pulses/ m^3, for K-factor arithmetic mean from the participating laboratories:

$$\overline{K} = \frac{1}{p}\sum_{j=1}^{p}\overline{K}_{vj}(q_j); \qquad p = 4 \qquad (5)$$

where p is the number of the mean K-factors in each laboratory and for each flow rate.

Laboratory reproducibility $s^2(\overline{K}_{vj}(q_j))$, pulses/ m^3, at the same flow rate and the same configuration:

$$s^2\left(\overline{K}_{vj}(q_j)\right) = \frac{1}{p-1}\sum_{j=1}^{p}\left(\overline{K}_{vj}(q_j) - \overline{K}\right)^2;$$

p = 4 (PTB) and p = 8 (CENAM) (6)

Relative error e, %, between K_{PTB} from PTB and K_{CENAM} factor from CENAM is defined by:

$$e = \left(\left[\frac{\overline{K}_{PTB}}{\overline{K}_{CENAM}}\right] - 1\right)\cdot 100 \qquad (7)$$

The deviation E_n normalized [3] in relation to the stated uncertainty is defined by:

$$E_n = \frac{\overline{K}_{CENAM} - \overline{K}_{PTB}}{\sqrt{\left(U_{CENAM}^2 + U_{PTB}^2\right)}} \qquad (8)$$

where $\overline{K}_{CENAM}$ is the measurement result from CENAM as given in its information, $\overline{K}_{PTB}$ is the reference value. U_{CENAM} is the expanded uncertainty of $\overline{K}_{CENAM}$ and U_{PTB} is the expanded uncertainty of $\overline{K}_{PTB}$ in accordance to EAL-P7, Interlaboratory comparisons [3].

The reference values are provided by mean values between PTB and CENAM results, with exception of the E*n* deviation where the reference values are provided by PTB.

7 Data and Results

Now, it should be take into account the measurements values of MTR 1; because the malfunction of MTR 2, during the comparison tests. Also, we found a large variance in the K-factor within different tests, raising the possibility that the meter was altered in some significant way, not letting the rotor spin freely and subsequently damaging the bearings.

This report shows the data summary and test results for MTR 1.

The mean values from the data summary and results from the tests are shown in tables 4 through 10, and plots of such values are shown in figures 3, 4 and 5. The figures and tables also indicate that the mean K-factors were referenced to the standard temperature, 20 °C.

For the results graphed in figures 3 and 4 the mean K-factor values, standard deviations, reproducibility and expanded uncertainty of these means K-factor values are given in tables 4-9.

The results plotted in figure 5 shows that the total spread in these results for MTR 1 in configuration 1 (downstream position) is about 0,12 % from highest to lowest values.

It is concluded from these results that the significant differences between initial and final tests at CENAM for MTR1 in downstream position were due to an anomalous condition of MTR 2 after the initial test at CENAM.

The results shown in figure 4 indicated that, in configuration 2, up stream position (MTR 1) at lower flow, the spread is about 0,05 %. It also noted in figure 5 no significant differences through the flow range occurred.

Table 10 and figure 5 show the deviation E_n normalized with respect to the stated uncertainty. Also, it is concluded from results shown in table 10 that for high and mid-flow rate between final test at CENAM and test at PTB no significant differences occurs.

The results shown in table 10 and figure 5 indicate that, in arrangement 1 at the mid-flow rate and high flow rate, the downstream meter (MTR 1) has a higher error between PTB mean value and CENAM mean value, e = 0,09 % and e = 0,08 % . Table 10, also shows those deviations E_n in these results for MTR 1 are 1,54 in mid-flow and 1,43 in high flow.

It is noted that for the MTR 1 (figure 5) the absolute values of the deviation E_n for final test are less than the unit except for initial test at CENAM for MTR 1 at mid-flow rate and high flow rate in configuration 1.
The criterion of E_n requests the absolute values of E_n were be less than unity in order to get acceptable measurements.

Table 4. *Data summary from CENAM facility (The tests 1A, 1B, 2G and 2H were run in configuration 1).*

Summary of initial test mean values at CENAM							
Configuration MTR 1	**Volumetric flow rate** qv (m³/h)	**Volume** V (m³)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m³)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor U** (%)
1	**Down stream position test A and B**						
	249,4	9,992 4	65 450,2	6 551,6	$1,26 \cdot 10^{-5}$	$3,78 \cdot 10^{-4}$	± 0,048
	150,1	10,014 7	65 663,2	6 558,3	$2,45 \cdot 10^{-5}$	$3,65 \cdot 10^{-4}$	± 0,048
	49,8	1,496 9	9 831,6	6 569,4	$8,47 \cdot 10^{-5}$	$5,04 \cdot 10^{-4}$	± 0,054
	49,6	1,491 2	9 793,4	6 569,1	$5,44 \cdot 10^{-5}$	$5,04 \cdot 10^{-4}$	± 0,054
	149,5	9,972 6	65 385,2	6 558,1	$5,60 \cdot 10^{-5}$	$3,65 \cdot 10^{-4}$	± 0,048
	248,9	9,972 0	65 316,2	6 551,6	$8,11 \cdot 10^{-6}$	$3,78 \cdot 10^{-4}$	± 0,048
	Down stream position test G and H						
	49,9	1,499 2	9 846,4	6 569,1	$6,37 \cdot 10^{-5}$	$5,04 \cdot 10^{-4}$	± 0,054
	150,0	10,005 2	65 605,2	6 558,6	$1,53 \cdot 10^{-5}$	$3,65 \cdot 10^{-4}$	± 0,048
	249,3	9,985 1	65 404,4	6 551,7	$1,24 \cdot 10^{-5}$	$3,78 \cdot 10^{-4}$	± 0,048
	249,3	9,988 7	65 424,2	6 551,4	$2,02 \cdot 10^{-5}$	$3,78 \cdot 10^{-4}$	± 0,048
	150,0	10,010 2	65 631,0	6 558,1	$1,67 \cdot 10^{-5}$	$3,65 \cdot 10^{-4}$	± 0,048
	49,9	1,498 6	9 841,6	6 568,8	$8,48 \cdot 10^{-5}$	$5,04 \cdot 10^{-4}$	± 0,054

The table above lists the mean values of K-factors and the standard deviations calculated from 5 values, the reproducibility for each flow rate from 8 mean values and the K-factor expanded uncertainty.

Table 5. *Data summary from PTB facility (The tests 1A, 1B, 2G and 2H were run in configuration 1).*

Summary of mean values at PTB							
Configuration MTR 1	**Volumetric flow rate** qv (m³/h)	**Volume** V (m³)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m³)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor U** (%)
1	**Down stream position test A and B**						
	50,3	2,769 2	18 178,0	6 564,3	$3{,}11\cdot10^{-5}$	$1{,}23\cdot10^{-4}$	± 0,032
	151,6	2,789 9	18 291,4	6 556,3	$3{,}83\cdot10^{-5}$	$3{,}81\cdot10^{-5}$	± 0,030
	251,7	2,785 0	18 237,0	6 548,2	$2{,}44\cdot10^{-5}$	$1{,}92\cdot10^{-5}$	± 0,030
	251,7	2,783 7	18 227,6	6 548,0	$4{,}20\cdot10^{-5}$	$1{,}92\cdot10^{-5}$	± 0,030
	151,2	2,781 9	18 237,4	6 555,8	$1{,}60\cdot10^{-4}$	$3{,}81\cdot10^{-5}$	± 0,030
	50,3	2,768 8	18 171,2	6 562,8	$1{,}28\cdot10^{-4}$	$1{,}23\cdot10^{-4}$	± 0,032
	Down stream position test G and H						
	50,4	2,776 1	18 242,4	6 571,3	$7{,}78\cdot10^{-5}$	$1{,}16\cdot10^{-4}$	± 0,032
	150,7	2,771 4	18 192,4	6 564,3	$3{,}65\cdot10^{-5}$	$5{,}12\cdot10^{-5}$	± 0,030
	251,8	2,785 7	18 264,6	6 556,6	$1{,}40\cdot10^{-4}$	$3{,}94\cdot10^{-5}$	± 0,030
	251,5	2,782 8	18 247,4	6 557,2	$3{,}69\cdot10^{-5}$	$3{,}94\cdot10^{-5}$	± 0,030
	151,0	2,775 6	18 219,8	6 564,2	$2{,}87\cdot10^{-4}$	$5{,}12\cdot10^{-5}$	± 0,030
	48,8	2,685 8	17 645,8	6 570,1	$6{,}93\cdot10^{-5}$	$1{,}16\cdot10^{-4}$	± 0,032

The table lists the mean values of K-factors and standard deviations calculated from 5 values, the reproducibility for each flow rate from 4 mean values and the K-factor expanded uncertainty.

Table 6. *Data summary from CENAM facility (The tests 1A, 1B, 2G and 2H were run in configuration 1).*

Summary of final test mean values at CENAM							
Configuration MTR 1	**Volumetric flow rate** qv (m³/h)	**Volume** V (m³)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m³)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor U** (%)
1	**Down stream position test A and B**						
	249,7	9,973 5	65 395,8	6 557,8	$2{,}16\cdot10^{-5}$	$3{,}78\cdot10^{-4}$	± 0,048
	149,6	9,982 2	65 518,6	6 564,3	$1{,}26\cdot10^{-5}$	$3{,}65\cdot10^{-4}$	± 0,048
	49,7	1,494 4	9 826,8	6 576,5	$1{,}44\cdot10^{-5}$	$5{,}04\cdot10^{-4}$	± 0,054
	49,8	1,497 3	9 844,8	6 576,0	$2{,}45\cdot10^{-5}$	$5{,}04\cdot10^{-4}$	± 0,054
	150,3	10,030 8	65 818,4	6 562,4	$8{,}72\cdot10^{-5}$	$3{,}65\cdot10^{-4}$	± 0,048
	249,3	9,967 2	65 342,0	6 556,5	$8{,}47\cdot10^{-5}$	$3{,}78\cdot10^{-4}$	± 0,048
	Down stream position test G and H						
	49,9	1,498 9	9 852,6	6 574,2	$2{,}16\cdot10^{-5}$	$5{,}04\cdot10^{-4}$	± 0,054
	149,5	9,976 6	65 456,6	6 561,8	$1{,}26\cdot10^{-5}$	$3{,}65\cdot10^{-4}$	± 0,048
	249,6	9,979 6	65 388,6	6 553,1	$1{,}44\cdot10^{-5}$	$3{,}78\cdot10^{-4}$	± 0,048
	249,5	9,976 8	65 365,4	6 552,6	$2{,}45\cdot10^{-5}$	$3{,}78\cdot10^{-4}$	± 0,048
	149,8	9,995 9	65 571,0	6 560,7	$8{,}72\cdot10^{-5}$	$3{,}65\cdot10^{-4}$	± 0,048
	49,8	1,494 7	9 818,8	6 570,2	$8{,}47\cdot10^{-5}$	$5{,}04\cdot10^{-4}$	± 0,054

The table lists the mean values of K-factors and standard deviations calculated from 5 values, the reproducibility for each flow rate from 4 mean values and the K-factor expanded uncertainty.

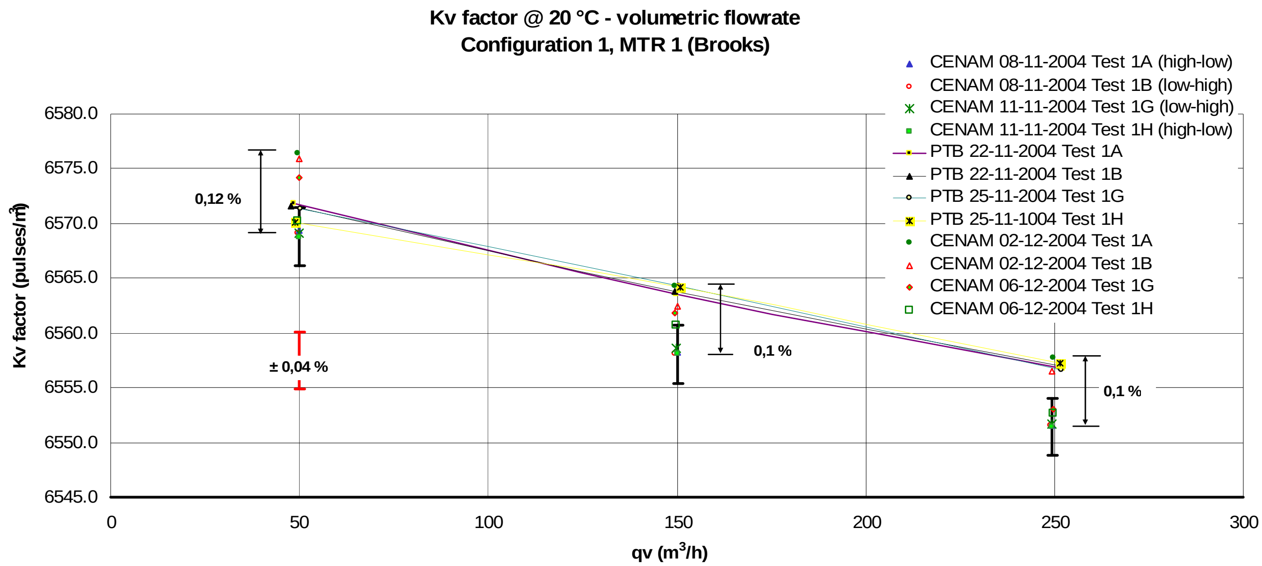

Figure 3. *The mean K factor results for down stream position of MTR 1.*
(The space between arrows represents spread of data).

Table 7. *Data summary from CENAM facility (The tests 1C, 1D, 2E and 2F were run in configuration 2).*

Summary of initial test mean values at CENAM							
Configuration MTR 1	**Volumetric flow rate** qv (m^3/h)	**Volume** V (m^3)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m^3)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor** **U** (%)
2	**Up position test C and D**						
	49,9	1,499 4	9 842,3	6 565,5	$1{,}46\cdot10^{-4}$	$6{,}96\cdot10^{-5}$	± 0,040
	149,4	9,967 7	65 345,2	6 557,0	$1{,}38\cdot10^{-5}$	$5{,}37\cdot10^{-5}$	± 0,040
	249,3	9,987 3	65 410,0	6 550,6	$2{,}07\cdot10^{-5}$	$1{,}09\cdot10^{-4}$	± 0,041
	249,2	9,984 3	65 389,2	6 550,6	$2{,}14\cdot10^{-5}$	$1{,}09\cdot10^{-4}$	± 0,041
	149,8	9,992 9	65 508,2	6 556,9	$1{,}63\cdot10^{-5}$	$5{,}37\cdot10^{-5}$	± 0,040
	49,8	1,494 5	9 809,6	6 565,3	$8{,}07\cdot10^{-5}$	$6{,}96\cdot10^{-5}$	± 0,040
	Up stream position test E and F						
	249,4	9,988 8	65 415,4	6 550,3	$3{,}68\cdot10^{-5}$	$1{,}09\cdot10^{-4}$	± 0,041
	149,6	9,979 8	65 417,4	6 556,4	$3{,}15\cdot10^{-5}$	$5{,}37\cdot10^{-5}$	± 0,040
	49,8	1,496 9	9 826,4	6 565,9	$6{,}63\cdot10^{-5}$	$6{,}96\cdot10^{-5}$	± 0,040
	49,8	1,495 9	9 817,8	6 564,6	$6{,}47\cdot10^{-5}$	$6{,}96\cdot10^{-5}$	± 0,040
	149,8	9,994 7	65 512,0	6 556,1	$1{,}63\cdot10^{-5}$	$5{,}37\cdot10^{-5}$	± 0,040
	249,4	9,988 5	65 400,0	6 549,1	$1{,}77\cdot10^{-5}$	$1{,}09\cdot10^{-4}$	± 0,041

The table lists the mean values of K-factors and standard deviations calculated from 5 values, the reproducibility for each flow rate from 8 mean values and the K-factor expanded uncertainty.

Table 8. *Data summary from PTB facility (The tests 1C, 1D, 2E and 2F were run in configuration 2).*

Summary of mean values at PTB							
Configuration MTR 1	**Volumetric flow rate** qv (m^3/h)	**Volume** V (m^3)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m^3)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor U** (%)
2	**Up stream position test C and D**						
	50,3	2,769 2	18 178,0	6564,3	$3,11{\cdot}10^{-5}$	$1,23{\cdot}10^{-4}$	± 0,032
	151,6	2,789 9	18 291,4	6556,3	$3,83{\cdot}10^{-5}$	$3,81{\cdot}10^{-5}$	± 0,030
	251,7	2,785 0	18 237,0	6548,2	$2,44{\cdot}10^{-5}$	$1,92{\cdot}10^{-5}$	± 0,030
	251,7	2,783 7	18 227,6	6548,0	$4,20{\cdot}10^{-5}$	$1,92{\cdot}10^{-5}$	± 0,030
	151,2	2,781 9	18 237,4	6555,8	$1,60{\cdot}10^{-4}$	$3,81{\cdot}10^{-5}$	± 0,030
	50,3	2,768 8	18 171,2	6562,8	$1,28{\cdot}10^{-4}$	$1,23{\cdot}10^{-4}$	± 0,032
	Up stream position test E and F						
	252,1	2,790 6	18 272,4	6 547,9	$1,94{\cdot}10^{-5}$	$1,92{\cdot}10^{-5}$	± 0,030
	151,7	2,790 5	18 295,0	6 556,3	$2,80{\cdot}10^{-5}$	$3,81{\cdot}10^{-5}$	± 0,030
	50,1	2,759 4	18 108,8	6 562,7	$3,47{\cdot}10^{-5}$	$1,23{\cdot}10^{-4}$	± 0,032
	50,1	2,756 6	18 090,8	6 562,6	$4,35{\cdot}10^{-5}$	$1,23{\cdot}10^{-4}$	± 0,032
	152,4	2,805 1	18 391,0	6 556,3	$3,08{\cdot}10^{-5}$	$3,81{\cdot}10^{-5}$	± 0,030
	251,9	2,787 7	18 253,8	6 548,0	$3,10{\cdot}10^{-5}$	$1,92{\cdot}10^{-5}$	± 0,030

The table lists the mean values of K-factors and standard deviations calculated from 5 values, the reproducibility for each flow rate from 4 mean values and the K-factor expanded uncertainty.

Table 9. *Data summary from CENAM facility (The tests 1C, 1D, 2E and 2F were run in configuration 2).*

Summary of final test mean values at CENAM							
Configuration MTR 1	**Volumetric flow rate** qv (m^3/h)	**Volume** V (m^3)	**Pulses**	**Mean K-factor** @ 20 °C (pulses/m^3)	**Relative standard deviation** s	**Relative reproducibility**	**Uncertainty of K factor U** (%)
2	**Up stream position test C and D**						
	49,7	1,494 2	9 808,6	6 565,5	$8,62{\cdot}10^{-5}$	$6,96{\cdot}10^{-5}$	± 0,041
	149,6	9,980 8	65 436,8	6 557,2	$1,46{\cdot}10^{-4}$	$5,37{\cdot}10^{-5}$	± 0,040
	249,5	9,966 6	65 266,8	6 549,5	$5,03{\cdot}10^{-5}$	$1,09{\cdot}10^{-4}$	± 0,041
	249,6	9,966 9	65 265,6	6 549,2	$1,38{\cdot}10^{-5}$	$1,09{\cdot}10^{-4}$	± 0,041
	150,3	10,025 5	65 726,0	6 556,8	$1,16{\cdot}10^{-5}$	$5,37{\cdot}10^{-5}$	± 0,040
	50,0	1,500 8	9 850,8	6 564,8	$2,07{\cdot}10^{-5}$	$6,96{\cdot}10^{-5}$	± 0,041
	Up stream position test E and F						
	249,6	9,969 3	65 279,8	6 549,0	$8,62{\cdot}10^{-5}$	$1,09{\cdot}10^{-4}$	± 0,041
	149,6	9,979 4	65 422,4	6 556,7	$1,46{\cdot}10^{-4}$	$5,37{\cdot}10^{-5}$	± 0,040
	49,9	1,498 1	9 834,6	6 565,6	$5,03{\cdot}10^{-5}$	$6,96{\cdot}10^{-5}$	± 0,041
	50,0	1,501 4	9 856,4	6 565,8	$1,38{\cdot}10^{-5}$	$6,96{\cdot}10^{-5}$	± 0,041
	149,8	9,995 7	65 526,0	6 556,4	$1,16{\cdot}10^{-5}$	$5,37{\cdot}10^{-5}$	± 0,040
	249,6	9,987 0	65 396,0	6 549,1	$2,07{\cdot}10^{-5}$	$1,09{\cdot}10^{-4}$	± 0,041

The table lists the mean values of K-factor and standard deviation calculated from 5 values, the reproducibility for each flow rate from 8 mean values and the K-factor expanded uncertainty.

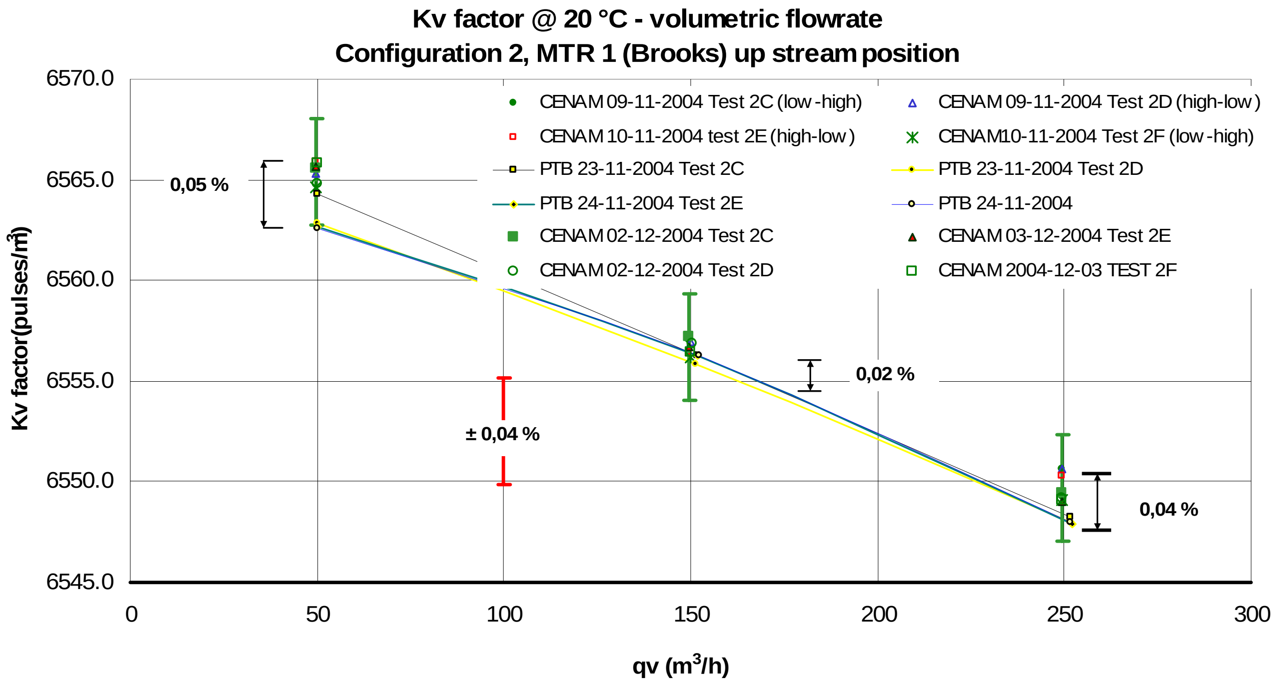

Figure 4. *The K-factor results for up stream position of MTR 1.*
(The space between arrows represents spread of data.)

Table 10. *Normalized deviation E_n in relation to the uncertainty and relative errors for MTR 1in configuration 1 and configuration 2.*

Summary Results The reference values were provided by PTB						
	MTR 1 Down stream			**MTR 1 Up stream**		
High flow 250 (m^3/h)	**CENAM**	**PTB**	**CENAM**	**CENAM**	**PTB**	**CENAM**
Mean K- factor @ 20 °C (pulses/m^3)	**6 551,6**	**6 556,9**	**6 555,0**	**6 550,2**	**6 548,0**	**6 549,2**
Deviation (%) [PTB / CENAM]	**0,08**		**0,03**	**- 0,03**		**- 0,02**
E_n number	**1,43**		**0,07**	**- 0,65**		**- 0,35**
	MTR 1 Down stream			**MTR 1 Up stream**		
Half flow 150 (m^3/h)	**CENAM**	**PTB**	**CENAM**	**CENAM**	**PTB**	**CENAM**
Mean K factor @ 20 °C (pulses/m^3)	**6 558,3**	**6 564,0**	**6 562,3**	**6 556,6**	**6 556,2**	**6 556,8**
Deviation (%) [PTB / CENAM]	**0,09**		**0,03**	**- 0,01**		**- 0,01**
E_n number	**1,54**		**0,44**	**- 0,14**		**- 0,18**
	MTR 1 Down stream			**MTR 1 Up stream**		
Low flow 50 (m^3/h)	**CENAM**	**PTB**	**CENAM**	**CENAM**	**PTB**	**CENAM**
Mean K factor @ 20 °C (pulses/m^3)	**6 569,1**	**6571,2**	**6 574,2**	**6 565,3**	**6 563,1**	**6 565,4**
Deviation (%) [PTB / CENAM]	**0,03**		**- 0,05**	**- 0,03**		**- 0,04**
E_n number	**0,52**		**- 0,74**	**- 0,67**		**- 0,72**

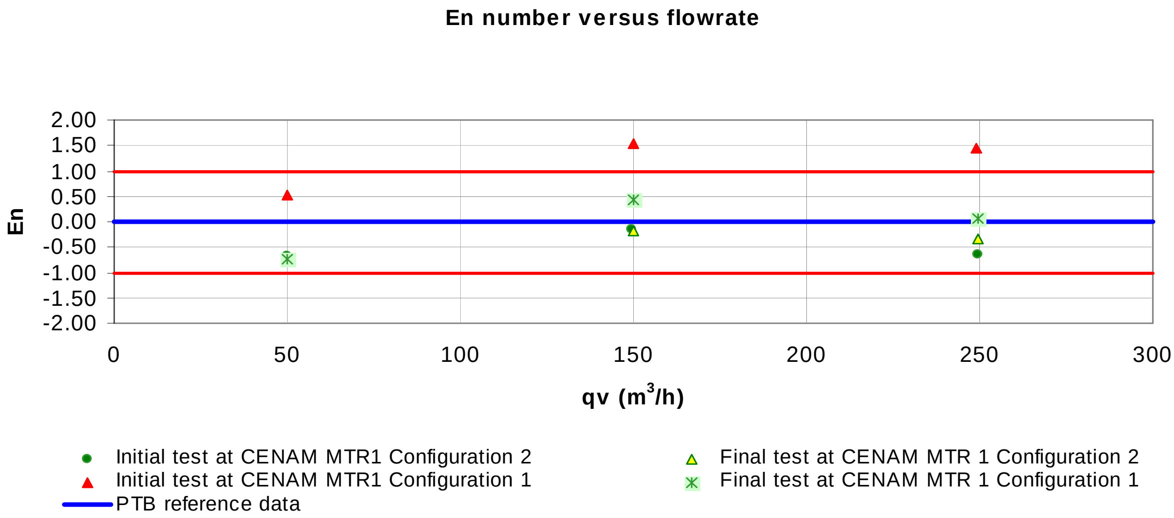

Figure 5. *The deviation E_n.*

8 Conclusion

1. **MTR 2 (XO turbine meter)** has become altered in some significant manner, in this case the rotor did not spin freely, and the bearings had become damaged.
2. The result shown that the comparison test using MTR 1 in configuration 2 – up stream position - has been successfully carried out with a maximum spread of 0,05 % and En numbers in all cases less that unity.
3. The results shown significant differences in the results MTR 1 in configuration 1 – down stream position - between PTB and CENAM. The possible cause for those significant differences can be the influence of MTR 2 on fluid flow velocity profile. The total spread in these results for MTR 1 in configuration 1 is about 0,12 %.
4. However, in general, the comparison test shows that the measurements between PTB and CENAM for MTR 1 are acceptable. **As a result, it is concluded that the MTR 1 values for that configuration obtained at CENAM is equivalent to PTB values.**
5. The comparison was produce valuable information to improve calibration work for the participating laboratories.
6. Finally, future efforts in the flow measurement assurance program between CENAM and PTB include a comparison test using 200 mm turbine meters. This second comparison using larger meters will be done in 2007.

Acknowledgements

The authors gratefully acknowledge the efforts and hard work of his colleagues: Axel Eggestein from PTB, José Lara Manríquez and Emmanuel Ríos Carrizales from CENAM for collaborating during the comparison test.

References

[1] Mattingly G. E., *Fluid Mechanics Measurements* Chapter Six, Edited by Richard J. Goldstein, 1983

[2] Pöschel W., Engel R., *The Concept of a New Primary Standard for Liquid Flow Measurement at PTB Braunschweig*, 9th FLOMEKO, pp. 7-12, Lund, Sweden, 1998

[3] EAL European Cooperation for Accreditation of Laboratories, *EAL Interlaboratory Comparisons EAL-P7*, 1st edition, 1996