

# A NEW ULTRASTABLE TRANSFER STANDARD FOR TCC'S NEW HIGH PRESSURE GAS METER CALIBRATION FACILITY

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*Abstract: Tests are reported on a 10-unit Rotary Piston Prover system that is installed at the TCC high-pressure gas meter testing facility. The paper also describes new tests that were carried out with the Rotary Piston Prover concerning its temperature dependence. Tests against a Bell Prover are also reported.*

*Keywords: Reference standards, gas meter calibration, meter proving, piston prover, high pressure gas meter testing.*

## 1 INTRODUCTION

The principle of operation and measurements concerning the performance of the novel Rotary Piston Prover were described in more detail in [1] and [2]. The instrument will further be referred to as IRPP (Instromet Rotary Piston Prover).

The instrument is derived from the traditional rotary piston meter with two 8-shaped rotors. The traditional rotary piston meter generates pulsations which make it unsuitable for use as a transfer standard. In the IRPP pulsations have been eliminated by using two meter modules coupled mechanically so that the pulsations of the two modules are in opposite phases and cancel each other in the first approximation. The higher order pulsations do not show at low pressures but are still present at high pressure resulting in an increased uncertainty. For use as high accuracy reference standard these remaining pulsations have to be eliminated. This was done by inserting the measuring unit in a rubber cylinder that effectively forms a membrane separating the inlet from the outlet.

The resulting instrument was tested at pressures from atmospheric to 65 bar and showed excellent metrological properties. Deviation was very little dependent on flow rate and pressure and there were no pulsations remaining. Its positive displacement character makes it virtually independent of velocity profiles.

Temperature dependence has since been investigated and this paper gives test results on this topic. It also reports the results of tests carried out at the NMI laboratory with atmospheric air. These experiments confirmed the fact that meters can be run in parallel without problems and also that the deviation is a property of the cartridge, independent of the vessel in which it has been inserted.

Finally, a description is given of a 10-unit IRPP system that is installed at the new TCC calibration facility in Isle des Chênes near Winnipeg. Experimental results with the full size unit in Gasunie's laboratory are also reported. The system will ultimately serve as the TCC facility's primary reference.

## 2 GENERAL CONSIDERATIONS

Retesting of high accuracy gas meters, whether they are used in large metering stations or in high pressure calibration stations is a very complicated matter. In general they have to be taken out of service and shipped over considerable distances for recalibration against more primary standards.

Primary standards tend to be low flow rate and a more or less convoluted procedure has to be followed to arrive at a reference standard for high flow rates. In some cases the most primary standard is low pressure as well, thus complicating the process even more.

The IRPP is highly stable by virtue of its low leakage, positive displacement character. Also, the measurement cartridge can be retracted, hand carried and easily sent to any primary calibration laboratory anywhere in the world. Its large range, the fact that several units can be put in parallel to increase the maximum flow rate and its low pressure dependence make it ideally suited to step up the volume and pressure.

### 3 TEMPERATURE DEPENDENCE

The cartridges are tested against primary standards in a specialised laboratory under controlled conditions. They may be used under actual conditions that are different. Specifically in the TCC testing facility the gas temperature is higher as it is located immediately downstream of a compressor station. It was therefore decided to investigate the temperature coefficient of the instrument under, as near as possible, operating conditions.

Theoretically one would expect the deviation of the cartridge to decrease with increasing temperature. The volume of the chambers that transport the gas from inlet to outlet increases as a result of the thermal expansion of the material surrounding the chambers. To transport the same volume of gas the meter runs slower. The linear thermal expansion coefficient of aluminium is approximately  $25 \cdot 10^{-6}/\text{C}$ . The volumetric expansion would therefore be about  $3 \cdot 25 \cdot 10^{-6}/\text{C} = 75 \cdot 10^{-6}/\text{C}$ .

Tests were carried out in the Gasunie laboratory in Groningen to verify the applicability of the theory.

The test rig is shown in figure 1. The gas, which enters at a pressure of about 40 bar and has previously been heated to ambient temperature, first passes location A. Subsequently it flows through a second heat exchanger H, which is equipped with a by-pass to rapidly adjust the temperature. It then flows to location B. After reducing the pressure to 9 bar (abs.) the gas is measured by the reference meters. At location A and B a single IRPP unit was installed. Measurements were carried out with and without a temperature difference. The average temperature difference that was achieved was  $12^\circ \text{C}$ . According to theory this should result in a change of 0.09 %.

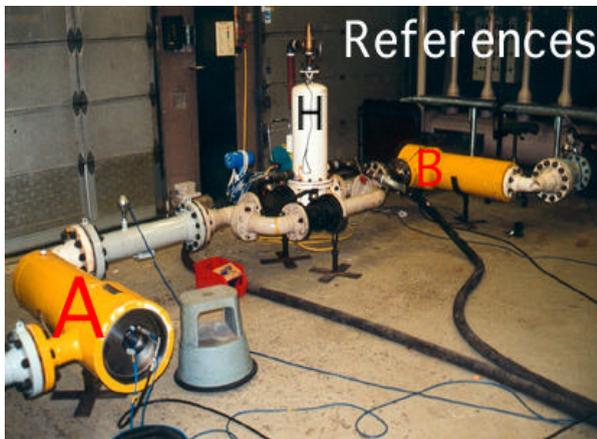


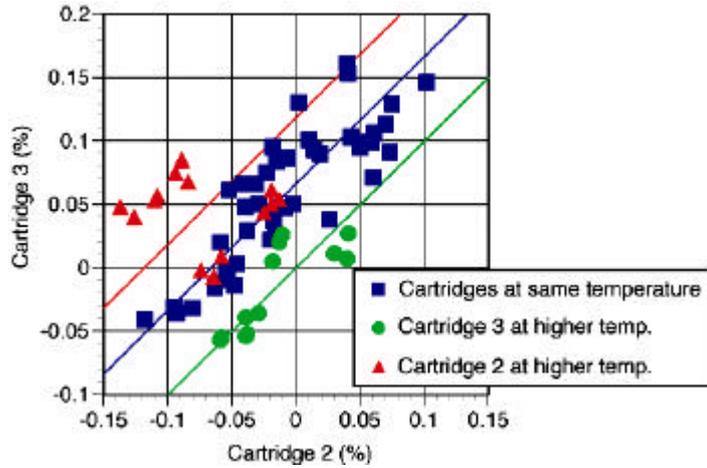
Figure 1. Test installation to test temperature dependence.

A second set of measurements was made after exchanging the cartridges. The measurement results are given in figure 2. This is a Youden plot where the measured deviations for cartridge 2 and 3 are plotted on the horizontal and the vertical axis respectively.

Linear regression curves have been calculated for the situation with equal temperatures for both meters and for the situation where the cartridge at location B is at a higher temperature. The equation used was:

$$D_3 = D_2 + p \quad (1)$$

with  $D_2$  and  $D_3$  the deviations of cartridge 2 and 3 respectively and  $p$  the fitted constant. As can be seen from figure 2 the regression curve shifts with temperature in the predicted direction. The measured temperature effect is 0.06 % as compared with the predicted 0.09 %.



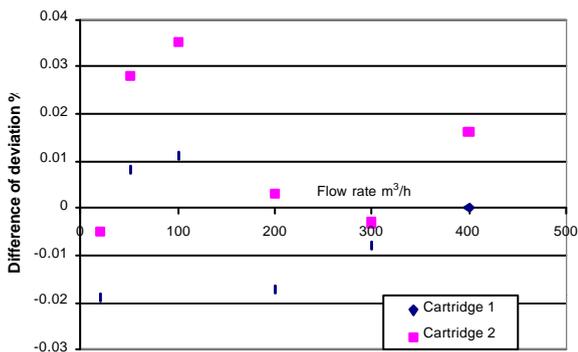
**Figure 2.** Youden plot of deviations of two cartridges at equal and different temperatures.

The measurements at equal temperature have been made with the cartridges in both positions. The data prove that, if there is a dependence on location, it is very small.

#### 4 TESTS AGAINST A BELL PROVER

Two units were tested at the laboratory of NMI in Dordrecht, the Netherlands. The tests had two main purposes i.e. to test whether indeed the deviation is independent of the body in which a cartridge is inserted and also to test whether the units could be run in parallel.

To test the possible influence of the body in which a cartridge is inserted a cartridge was calibrated with NMI's 3.5 m<sup>3</sup> bell prover using subsequently two different bodies of similar shape. The difference between the measured deviation in the two bodies is plotted as a function of flow rate in figure 3. This procedure was repeated with a second cartridge. The figure shows that there is virtually no influence of the body on the deviation of the cartridge.



**Figure 3.** Difference between deviations of one cartridge when calibrated in two different bodies.

It was then tested whether the deviation of two meters running in parallel could be predicted from the earlier measured deviations of each individual cartridge. For some flow rates it was necessary to interpolate between calibration points. For this purpose a polynomial that fits the calibration data is needed.

An equation of the form:

$$E = A + B * Q + C/Q + D * Q^2 \quad (2)$$

was used where E is the deviation, Q the flow rate and A to D are constants.

NMI then compared the measured deviation with the predicted value using these fitted curves. For flow rates higher than 16 m<sup>3</sup>/h the differences were less than 0.05 %.

The result is given in table 1.

**Table 1.** Difference between actual and predicted deviations when running two IRPP's in parallel.

Q m <sup>3</sup> /h	16	100	200
Deviation %	0.048	0.008	0.04

## 5 THE 10-CARTRIDGE SYSTEM

To be able to check the reference meters at the TCC facility a 10-cartridge IRPP System was built. The capacity of the individual cartridges is 400 m<sup>3</sup>/h and the total system capacity is therefore 4000 m<sup>3</sup>/h. The 16" meters at TCC can therefore be checked up to 40 % of the range which is the most critical for performance. If it is desired to check a 16" reference meter over its full range a single step bootstrapping exercise suffices.

The IRPP System, though it may consist of a number of IRPP units connected in parallel, functions as one single meter with one inlet, one outlet, a temperature output and a physical pressure reference point.

The IRPP units each measure the volumetric flow at the pressure and temperature in that particular unit. The IRPP System is provided with dedicated instruments and a data processing system to allow the system to function as if it were one single meter with a pressure point on the outlet header and a temperature output.

The quantity of gas flowing through the prover in a time interval is equal to N kmol. If we designate the quantity flowing through each individual unit i by n<sub>i</sub> then we can write:

$$N = \sum n_i, \quad (3)$$

where i runs from 1 to k, if k is the number of individual IRPP's that make up the system.

The quantity per unit can be expressed as:

$$n_i = P_i * V_i / (Z_i * R * T_i), \quad (4)$$

where P, V, Z and T are the pressure, volume, compressibility and temperature of the gas and the index i indicates the particular IRPP unit. R is the universal gas constant.

If the IRPP System is used to calibrate a meter, the latter will be mounted in series and the quantity of gas through both meters will be equal to N. If the pressure at the reference point of the system is P<sub>r</sub> and the reference temperature T<sub>r</sub> then:

$$\sum n_i = P_r * V_r / (Z_r * R * T_r) = \sum \{P_i * V_i / (Z_i * R * T_i)\}, \quad (5)$$

which leads to:

$$V_r = \{Z_r * T_r / P_r\} * \sum \{P_i * V_i / (Z_i * T_i)\}, \quad (6)$$

The computer determines the values of  $P_i$  from the value of the static pressure  $P_r$  and the respective differential pressure  $p_i$  ( $P_i = P_r + p_i$ ).

The value of  $Z_i$  and of its derivatives with respect to temperature and pressure are entered into the computer as parameters calculated from the gas composition and for the average values of  $P_i$  and  $T_i$ . These parameters can be refreshed regularly even before every test. The computer uses these parameters to calculate the terms in the summation.

## 6 CALCULATION

Each term in the equation for  $V_r$  is calculated as follows:

$$V_{ir} = V_i * Z_r * T_r * P_i / (Z_i * T_i * P_r) =$$

$$= V_i * (T_r / T_i) * (1 + (p_i / P_r)) * \{1 - (dZ / dT)_P * (\Delta T / Z_r) - (dZ / dP)_T * (p_i / Z_r)\}, \quad (8)$$

with  $\Delta T = T_i - T_r$

If we assume a maximum temperature difference of 1° C between the reference temperature and the temperature of an individual unit, the maximum value of  $(dZ / dT)_P * (\Delta T / Z_r)$  is less than 1 % for natural gasses in a temperature range of 0 to 50° C. Similarly, the maximum pressure difference between the reference point and the pressure in an individual unit is less than 1 bar and the maximum value of  $-(dZ / dP)_T * (p_i / Z_r)$  is less than 0.8 %. In practice the differences are much smaller. Errors in these values are second order and can normally be neglected. These values are therefore not calculated on line but introduced as constants for a particular application of the derivatives of  $Z$ .

The measured volume for each individual unit is corrected for its deviation:

$$V_{ir} \text{ (corrected)} = V_{ir} * (1 - e_i) \quad (9)$$

before all volumes are summated.

All measurement signals are collected in a dedicated PLC that also performs the calculations. The computer allows the constants A, B, C and D (2) to be introduced once they are known. The output is a modbus signal giving the line flow rate. All other parameters can be accessed if desired. For this purpose the instrument is equipped with a second serial bus.

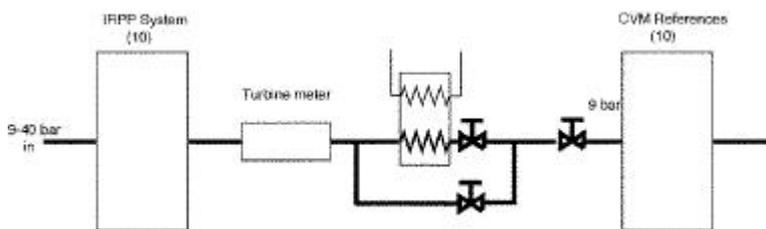
## 7 TESTS WITH THE 10-UNIT SYSTEM

Tests were performed in the Gasunie research facility in Groningen with the 10-IRPP system built for TCC.

Test pressures were 9 bar and 40 bar and the flow rates were 100 and 400 m<sup>3</sup>/h.

The objectives were to establish the dependence of the meter deviation on pressure and flow rate and to verify the proper operation with several IRPP's working together in a system.

The tests were carried out in the configuration that is schematically given in figure 3. Gas temperatures at the inlet of the system were regulated to equal the ambient temperature.



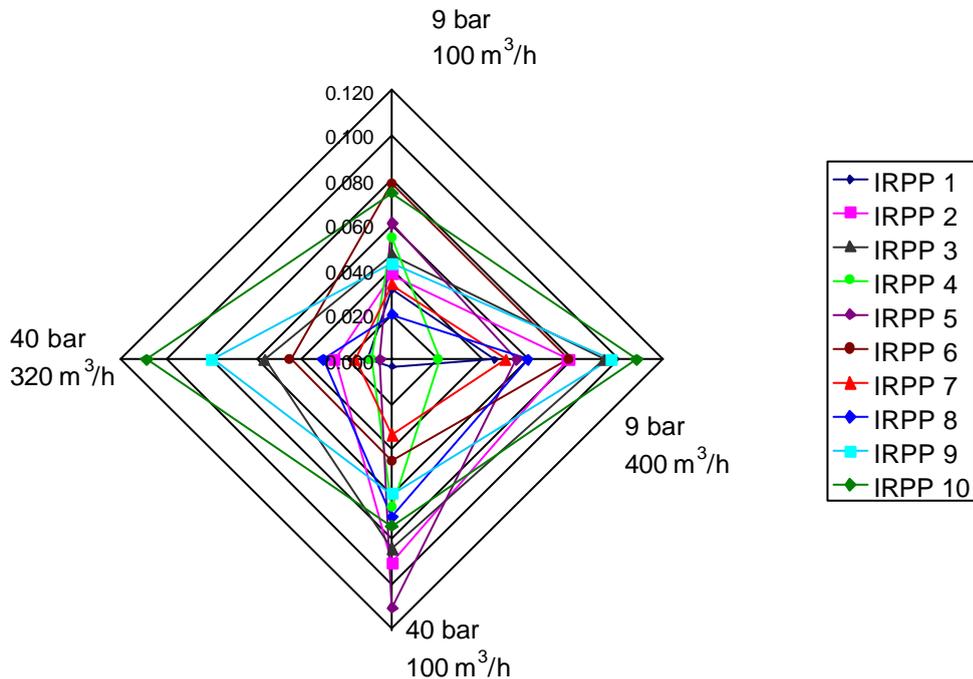
**Figure 3.** Installation to test 10-unit IRPP System.

Initially all IRPP's were tested individually at 9 bar and 40 bar at flow rates of 100 and 400 m<sup>3</sup>/h. The results are summarised in table 2. One single CVM meter was used as a reference for all these tests.

**Table 2.** Measured deviations and absolute differences from their averages.

		Deviation of IRPP number (%)									
P bar	Q (m <sup>3</sup> /h)	1	2	3	4	5	6	7	8	9	10
9	100	-0.09	0.17	0.24	0.11	0.12	-0.08	-0.13	0.06	0.18	0.22
9	400	-0.16	0.13	0.19	0.14	0.12	-0.23	-0.21	-0.02	0.12	0.19
40	100	-0.12	0.30	0.37	0.23	0.29	-0.11	-0.13	0.11	0.28	0.37
40	320	-0.11	0.23	0.34	0.17	0.18	-0.20	-0.18	0.01	0.30	0.40
Average		-0.118	0.205	0.284	0.161	0.178	-0.155	-0.160	0.037	0.220	0.295
		Absolute differences from the average deviations (%)									
P bar	Q (m <sup>3</sup> /h)	1	2	3	4	5	6	7	8	9	10
9	100	0.031	0.038	0.047	0.054	0.061	0.078	0.033	0.020	0.043	0.075
9	400	0.045	0.078	0.094	0.021	0.055	0.078	0.050	0.060	0.097	0.108
40	100	0.003	0.090	0.084	0.066	0.110	0.045	0.033	0.070	0.060	0.074
40	320	0.011	0.025	0.056	0.009	0.005	0.045	0.017	0.031	0.080	0.109

To provide a graphical representation, the four deviations measured above were averaged for each cartridge and the difference from the average of each measurement was calculated. The absolute value of each individual measurement point was then plotted in the spider graph of figure 4.



**Figure 4.** Absolute differences of deviations from their mean value for all IRPP's.

The same data were used to check on any systematic pressure and flow rate dependence.

For this purpose the increases of the deviation with pressure and flow rate were calculated. The results are given in table 3.

**Table 3.** Change of deviation with flow rate and pressure.

		IRPP number											
P bar	Q m <sup>3</sup> /h	1	2	3	4	5	6	7	8	9	10		
9	100	-0.09	0.17	0.24	0.11	0.12	-0.08	-0.13	0.06	0.18	0.22	Increases	
9	400	-0.16	0.13	0.19	0.14	0.12	-0.23	-0.21	-0.02	0.12	0.19		
Increase		-0.08	-0.04	-0.05	0.03	0.01	-0.16	-0.08	-0.08	-0.05	-0.03	Average	-0.05
Increase with flow rate @ 9 bar												Std. Dev.	0.05
40	100	-0.12	0.30	0.37	0.23	0.29	-0.11	-0.13	0.11	0.28	0.37		
40	320	-0.11	0.23	0.34	0.17	0.18	-0.20	-0.18	0.01	0.30	0.40		
Increase		0.01	-0.07	-0.03	-0.06	-0.10	-0.09	-0.05	-0.10	0.02	0.04		-0.04
Increase with flow rate @ 40bar													0.05
9	100	-0.09	0.17	0.24	0.11	0.12	-0.08	-0.13	0.06	0.18	0.22		
40	100	-0.12	0.30	0.37	0.23	0.29	-0.11	-0.13	0.11	0.28	0.37		
Increase		-0.03	0.13	0.13	0.12	0.17	-0.03	0.00	0.05	0.10	0.15		0.08
Increase with pressure @ 100 m <sup>3</sup> /h													0.08
9	400	-0.16	0.13	0.19	0.14	0.12	-0.23	-0.21	-0.02	0.12	0.19		
40	320	-0.11	0.23	0.34	0.17	0.18	-0.20	-0.18	0.01	0.30	0.40		
Increase		0.06	0.10	0.15	0.03	0.06	0.03	0.03	0.03	0.18	0.22		0.09
Increase with pressure @ 400 m <sup>3</sup> /h													0.07

It would appear that on the average the deviation decreases by approximately 0.05 % for a flow rate increase from 100 to 400 m<sup>3</sup>/h. The deviation also seems to increase by about 0.1 % for a pressure increase from 9 to 40 bar.

To make a more accurate test on the dependence on flow rate that is independent of the deviations of the individual CVM references, cartridge number 1 was first tested four times at 100 m<sup>3</sup>/h using 4 CVM reference meters consecutively. It was then tested at 400 m<sup>3</sup>/h using the same four CVM's in parallel each again at 100 m<sup>3</sup>/h.

The results are given in table 4. The pressure was 9 bar.

**Table 4.** Check of flow rate dependence.

Reference CVM nr.	Flow rate m <sup>3</sup> /h	Deviation IRPP 1				
		Testnr. 1	2	3	4	Average
1	100	0.01	0	0.02		0.010
2	100	-0.03	-0.04	0.04	-0.04	-0.018
3	100	-0.03	-0.08	-0.03		-0.047
4	100	0.06	0.04	0	0.04	0.035
Average over CVM 1,2,3 and 4						-0.005
1+2+3+4	400	-0.14	-0.17	-0.13		-0.147

Increase in deviation for increase in flow from 100 to 400 m <sup>3</sup> /h	-0.142
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The change is -0.14 %. Earlier, using only one single reference CVM at two flow rates, the change for this meter was found to be -0.08 %.

Tests were also performed using all 10 IRPP's and also using IRPP's 1 to 5 and 6 to 10. The measurements were carried out at 9 and at 40 bar and at flow rates from 1000 to 4000 m<sup>3</sup>/h. The results are given in table 5.

**Table 5.** Check of 5 and 10 IRPP's working in parallel.

IRPP's used	Pressure	Flow rate	CVM	Deviation							
				Testnr.				Average	Calculated	Difference	Flow/IRPP
				1	2	3	4				
1,2,3,4,5,6,7,8,9,10	9	1000	1 to 4	0.1	0.1	0.1		0.100	0.00	0.100	100
1,2,3,4,5	9	1000	1 to 4	0.01	0.21	0.02	0.18	0.105	0.10	0.005	200
6,7,8,9,10	9	1000	1 to 4	0.04	-0.07	0.03		0.000	0.02	-0.020	200

The measured deviations were corrected for the average deviation of the IRPP's as determined in the earlier individual tests at the particular flow rate and pressure.

For example: To determine the average correction using IRPP 6 to 10 at a flow rate of 1000 m<sup>3</sup>/h and a pressure of 9 bar first the average deviation for IRPP 6 to 10 was determined at a flow rate of 100 and 400 m<sup>3</sup>/h at 9 bar from table 1. These values are 0.05 and -0.03 % respectively. By linear interpolation we find the average deviation for this set of meters at 200 m<sup>3</sup>/h and 9 bar to be 0.023 %.

As a final test the deviation of six different combinations of 4 IRPP's was determined with the same set of 4 reference CVM meters. The pressure was 9 bar and the flow rate was 1500 m<sup>3</sup>/h i.e. 375 m<sup>3</sup>/h for each meter. The results are given in table 6. One column gives the result when corrected for the average deviation measured earlier for the respective individual IRPP's (at 400 m<sup>3</sup>/h and 9 bar). It shows that there is on the average a discrepancy of 0.08 % when using the corrected values as compared to 0.03 % when using the uncorrected raw values. This ties in with the fact that the single CVM that was used for the calibration of the individual cartridges indicates a deviation of about 0.05 % lower than the combination of the 4 CVM's. What is also striking is that the standard deviation in the (IRPP) deviations decreases from 0.086 % to 0.019 % when using the corrected values. This proves that it is still advantageous to individually calibrate IRPP cartridges for lowest uncertainty.

**Table 6.** Six configurations of four IRPP's in parallel checked against the same reference.

IRPP's used	Deviation measured	Correction	Corrected deviation	Avg. corrected deviation	Avg. raw deviation	turbine	
7,8,9,10	-0.09	0.02	-0.110			-0.12	
	-0.05	0.02	-0.070			-0.12	
	-0.06	0.02	-0.080			-0.12	
				-0.087	-0.067	-0.12	
1,2,3,4	0.06	0.08	-0.015			-0.11	
	-0.03	0.08	-0.105			-0.11	
	0.09	0.08	0.015			-0.11	
	0.00	0.08	-0.075			-0.11	
			-0.045	-0.045	0.030	-0.11	
1,2,9,10	-0.04	0.08	-0.117			-0.07	
	0.03	0.08	-0.047			-0.07	
	-0.01	0.08	-0.087			-0.07	
						-0.084	-0.007
1,2,7,8	-0.16	-0.08	-0.082			-0.05	
	-0.14	-0.08	-0.062			-0.05	
	-0.17	-0.08	-0.092			-0.05	
						-0.078	-0.157
3,4,7,8	-0.08	0.02	-0.104			-0.07	
	-0.03	0.02	-0.054			-0.07	
	-0.15	0.02	-0.174			-0.07	
	-0.05	0.02	-0.074			-0.07	
				-0.102	-0.078	-0.07	
3,4,9,10	0.07	0.16	-0.090			-0.16	
	0.08	0.16	-0.080			-0.16	
	0.11	0.16	-0.050			-0.16	
						-0.073	0.087
				Average		-0.078	-0.032
				Stdev		0.019	0.086

In the table the deviations of the turbine meter are also given. This turbine meter is a special high stability design which shows in the results. The figures also show that the turbine meter deviation, in spite of it being equipped with an X4X straightener, changes about 0.2 %. This is well within the ISO 9951 requirements but would not be acceptable for a reference standard. The change has to be attributed to the different flow patterns generated by the different IRPP configurations. The distance between the IRPP and the turbine meter was about 3D.

## 8 CONCLUSIONS

1. For individual IRPP's the deviation of the average meter factor under any of the four conditions mentioned under 7 was not more than 0.12 %.

2. There appeared to be a small systematic pressure dependence, i.e. the deviation increases slightly with pressure. There also appeared to be a slight dependence on flow rate with the average deviation decreasing by about 0.05 % when increasing the flow rate from 100 to 400 m<sup>3</sup>/h.

3. Six different combinations of 4 IRPP's compared with one single set of 4 CVM reference standards all gave the same result with a standard deviation of 0.018 % provided the deviations of the individual IRPP as found in the individual tests are corrected for.

4. There was no mutual interaction between IRPP's and flow rates could be added without further ado.

5. Though the deviations of individual IRPP's are small and dependence on pressure and flow rate is also small it still is advantageous to individually calibrate at operating pressure and flow rate.

6. The measured performance indicates that the IRPP has the potential to reduce the uncertainty of volumetric gas flow meter calibration to less than 0.1 %.

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