October 2021

Gas Coriolis performance on renewables gases, based on several testing and analysis

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This paper gives an overview of the current and future activities of Micro Motion, a business unit of Emerson and manufacturer of Coriolis meters, to get ready for the measurement of renewable gases under flowing conditions.

Contents:

1 Overview of applications for renewable gases with Coriolis technology

The figure below (figure 1) summarizes the applications with renewable gases for which Coriolis technology is a perfect candidate.

The applications include “pure hydrogen H2”, hydrogen injection up till 30% into natural gas, CO2 injection into natural gas and “pure CO2”

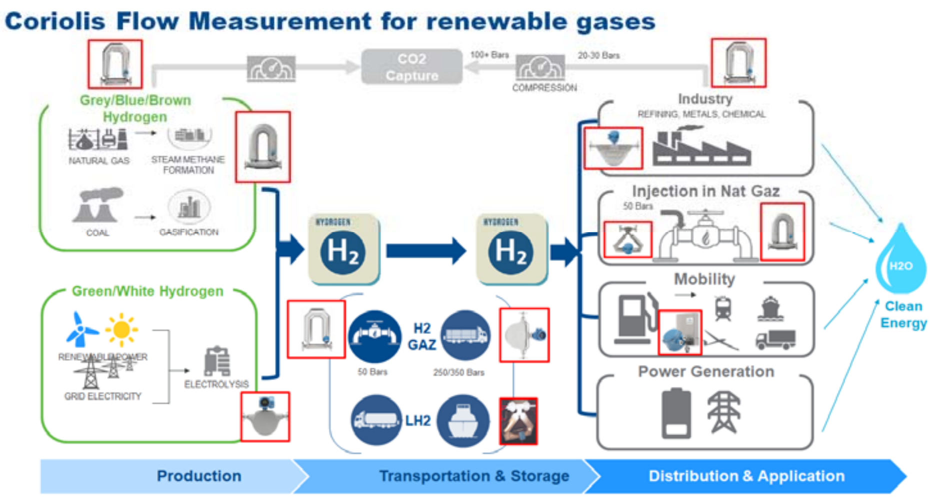

Figure 1

2 Challenges to prove the performance at renewable gases

Renewable gases (hydrogen H2; CO2; H2% in natural gas) create new challenges for Coriolis meters in relation to the performance.

Hydrogen is a very light product (base density 0.08 kg/m^3), much lower than natural gas. This implies that velocity has to be increased for the same Coriolis force in the measuring tubes.
The challenge is to show the performance with hydrogen with pressures higher than 15 bar at low flows and, high velocities to get the required rangeability for the users.
Limiting factor on the low flow side is the zero stability of the meter and sensitivity to Coriolis force. Internal relative testing has shown that sensitivity for Coriolis forces is still correct, down to 800:1 in relation to nominal flowrate of involved sensor.

Limiting factor on the high flow side is the maximum achievable velocity in relation to Mach number (velocity of sound of involved fluid).
Gas tests with natural gas were performed in the past up till 0.30 Mach, representing max 120 m/s.
Tests for low densities can be performed with air as alternative under approximately atmospheric pressure.
Tests with high velocities is a challenge with alternative fluids.

Currently, no hydrogen calibration facilities for industrial flowrates are available.
Emerson encourages the industry to develop such hydrogen calibration facilities.
Current custody transfer approvals are applicable for densities higher than 4 kg/m^3 (50 bar hydrogen), therefore tests are needed to prove performance at low density and get the notified bodies involved before certificates can be updated.
Emerson is seeking for custody transfer approvals for the renewable gas conditions acc. OIML R137 (internal organization for legal metrology) for gas meters, R139 (H2 dispensers) and European Measuring Instruments Directive (MID).

3 Update of latest tests

3.1 Low density air tests at Cesame, France

Two sensors, CMF050 (0.5”) and CMF200 (2”) were calibrated on air with densities of approx. 1.5 kg/m3 and higher to show compliance with OIML R137 (gas meters) and R139 (hydrogen dispensers), which is 1%. See figures 2 (0.5” meter) and 3 (2” meter).
The showed performance is based on settings for the sensors, as determined during the water calibration in Ede, NL. Uncertainty Cesame is 0.30%.
Maximum velocity is 104 m/s in the measuring tubes.

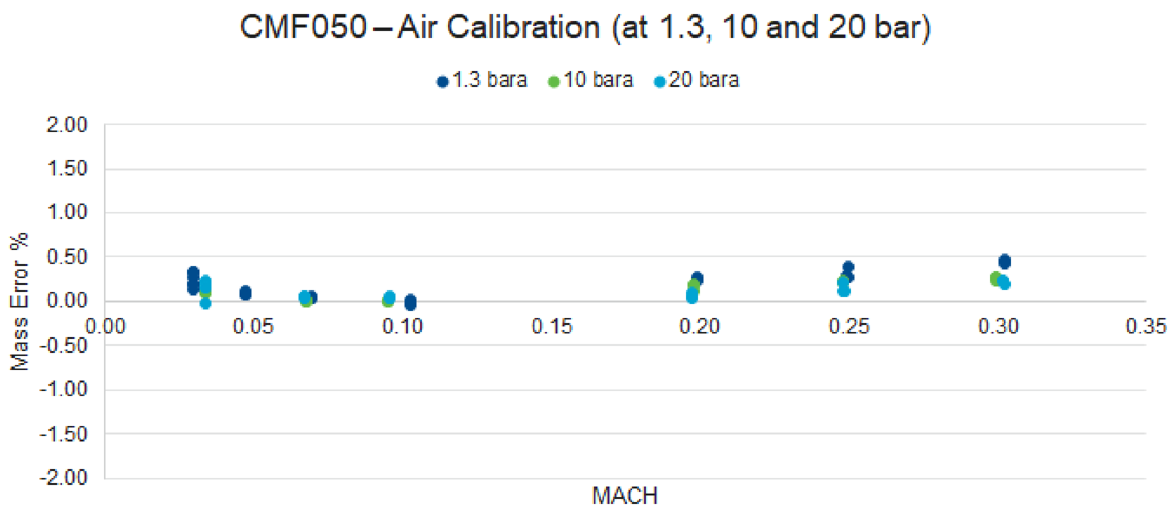

Figure 2

A mass flowrate of 700 kg/h with CMF200 in figure 3 represents 0.3 Mach (104 m/s).

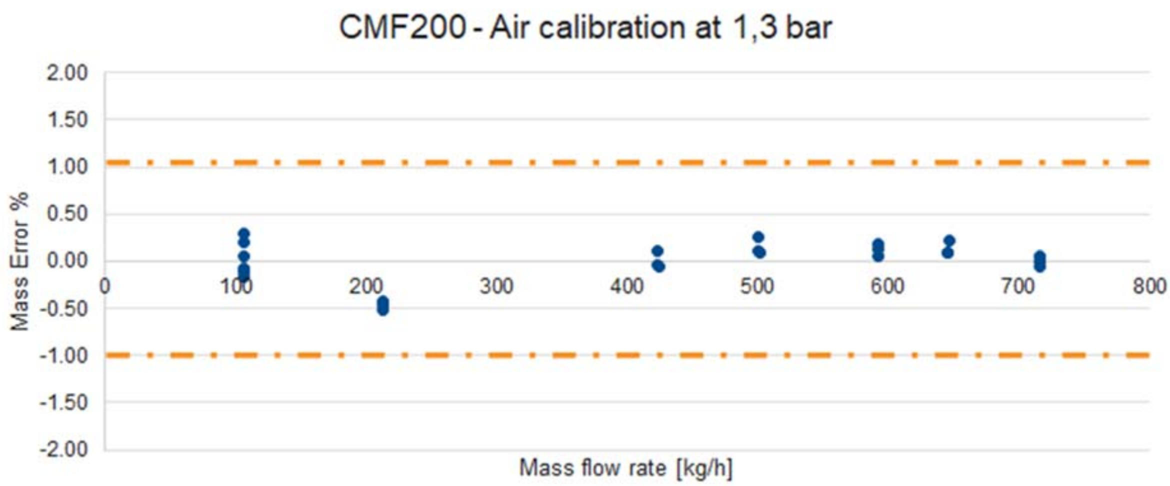

Figure 3

Meters behave as expected.
The +1% and -1% lines represent the maximum permissible errors acc. OIML R137 and R139.

3.2 DNV JIP tests at DNV, Groningen, NL

The purpose of the DNV JIP tests is to determine the fluid effect when meters are calibrated on natural gas and used on other fluids such as nitrogen, methane, CO2 injection into natural gas H2 injection into natural gas.

A very unique calibration facility was established for this JIP purpose with three different flow technologies and three different traceability chains. Used technologies: 5 nozzles, two turbine meters (TM) and two Micro Motion Coriolis meters (CMM). One TMDN100 and CMF200 in series in the 4” line; one TMDN150 and CMF300 in series in the 6” line.

See figures 4, 5 and 6.

The author of this paper, Aart Pruijsen from Emerson, was acting as technical advisor to DNV and the JIP steering committee to explain the Coriolis behavior.

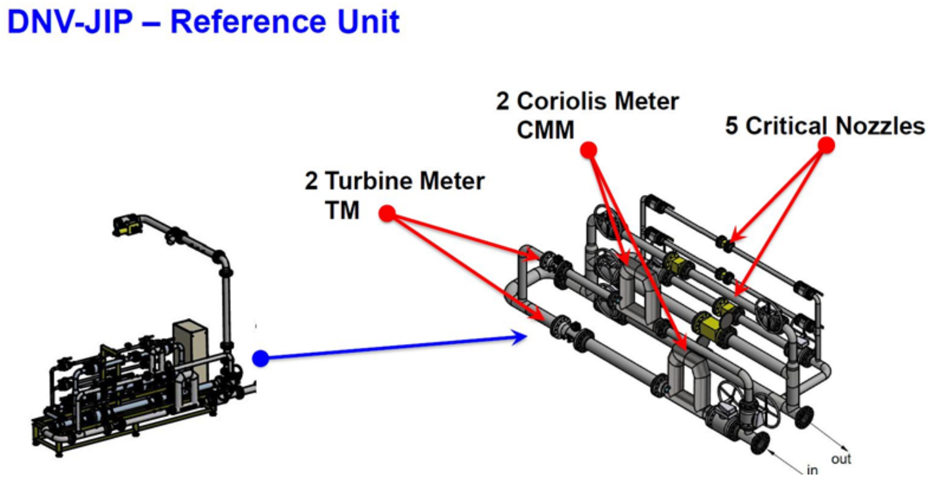

Figure 4

Figure 5: Skid with nozzles

Figure 6: skid with CMM’s and TM’s

PTB has on request of DNV reviewed the uncertainty of this set-up; uncertainty of combined uncertainty for the common reference value is 0.12%, based on 0.15% for nozzles, 0.20% for TM and 0.25% for CMM.
The initial review of PTB included variations in common reference value due to varying process conditions of 0.17% plus 0.10% for mol value, making 0.20% on top of 0.12%; overall uncertainty for three references is 0.23% (0.25% for TM/CMM in case nozzles are not in use)

The output from these reference skids is a common reference mass flowrate output, given by following equation:

$$\text{Weighed average JIP flowrate}\, Q_{crv-m} = 0.520 * Q_{nozzle} + 0.293 * Q_{Turbine} + 0.187 * Q_{m-CMM}$$

equation 1

Weighing factors are calculated from the involved uncertainties:
nozzle: 0.15%; TM: 0.20% and CMM: 0.25%; weighing factors: W_{nozzle}= 0.52 ; W_{TM}= 0.293 and W_{CMM} = 0.187.

The common reference mass flow rate output is coming from 4 sources:
nozzle, TM, CMM and density.
Mass flowrate nozzle is given by: $Q_{mass-nozzle} = \sqrt{1000 * k * P} * Ac_d * \sqrt{\rho}$ equation 2
(P is also affecting density; correlation ignored for convenience)

Mass flowrate TM is given by : $Q_{mass-TM} = Q_{Volume-TM} * \rho$ equation 3
Densities correlated for mol and Z.

Common reference mass flowrate output, given by the error/uncertainty sources:

$$\text{Weighed average JIP mass flowrate}\, Q_{crv-m} = Q_{m-real} * (1 + 0.520 * e_{nozzle} + 0.293 * e_{TM} + 0.187 * e_{CMM} + 0.553 * e_{\rho})$$

equation 4

Common reference volume flowrate output, given by the 4 error/uncertainty sources:

$$\text{Weighed average JIP volume flowrate}\, Q_{crv-V} = Q_{V-real} * (1 + 0.520 * e_{nozzle} + 0.293 * e_{TM} + 0.187 * e_{CMM} - 0.447 * e_{\rho})$$

equation 5

Based on this configuration, it is possible to calibrate the CMM's vs the weighed nozzle and turbine meter (W_{nozzle} = 0.640; W_{TM}= 0.360). Uncertainty for this case: 0.231%

$$\text{CMM vs weighed TM / nozzle} = e_{CMM} - 0.640 * e_{nozzle} - 0.360 * e_{TM} - 0.680 * e_{\rho}$$

equation 6

Note:
CMM is not calibrated against common reference mass flowrate, while common reference mass flowrate includes also CMM.
Equation for this not-used case:

$$\text{CMM vs weighed JIP} = 0.813 * e_{CMM} - 0.520 * e_{nozzle} - 0.293 * e_{TM} - 0.553 * e_{\rho}$$

equation 7

The calibration results as presented below are based on the unique sensor constants as determined during the water calibration of Emerson in Ede, NL. Calibration results are given for CMF200 at low flows or summation of CMF200 and CMF300 at high flows. The calibration results will be assessed against a criteria coming from uncertainty set-up (0.231%) and specification of meter (0.25%). Root of sum square gives 0.34%. Calibration results are only presented if both references are active (at some flowrates, nozzles are not used) to avoid variations coming from different set-ups.

Calibration results are given in following figures:
Figure 7: nitrogen (N2) at 16 and 32 bar
Figure 8: methane (CH4) at 16 and 32 bar
Figure 9: 10 and 20 % CO2 injection into natural gas at 16 and 32 bar
Figure 10: 5; 10; 15; 20% and 30% (only 16 bar) hydrogen injection into natural gas at 16 and 32 bar

Maximum velocity for CMF200 is 63 m/s and for CMF300 71 m/s.

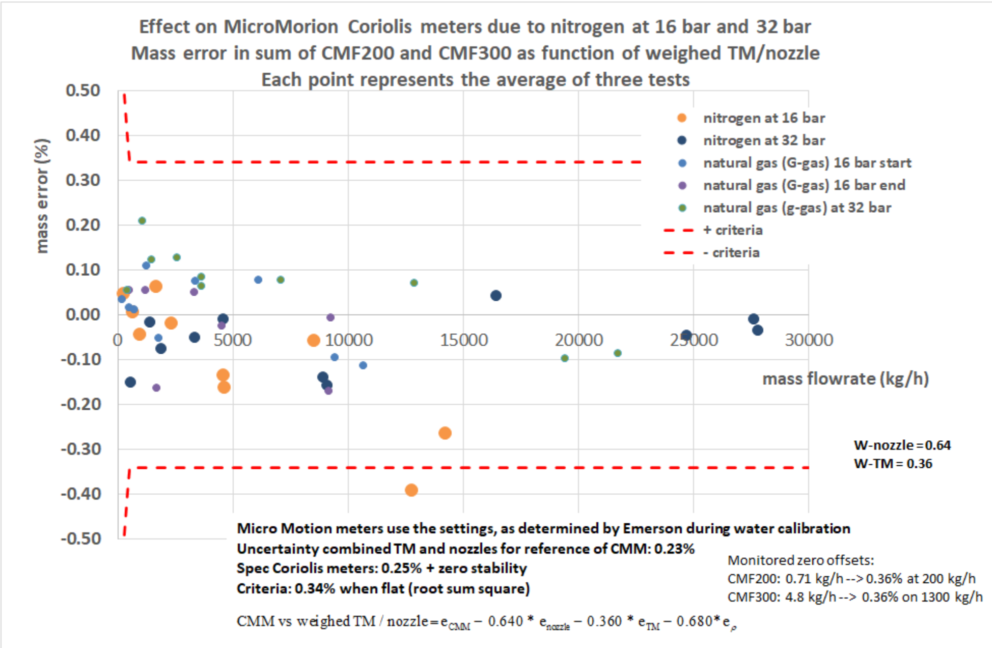

Figure 7

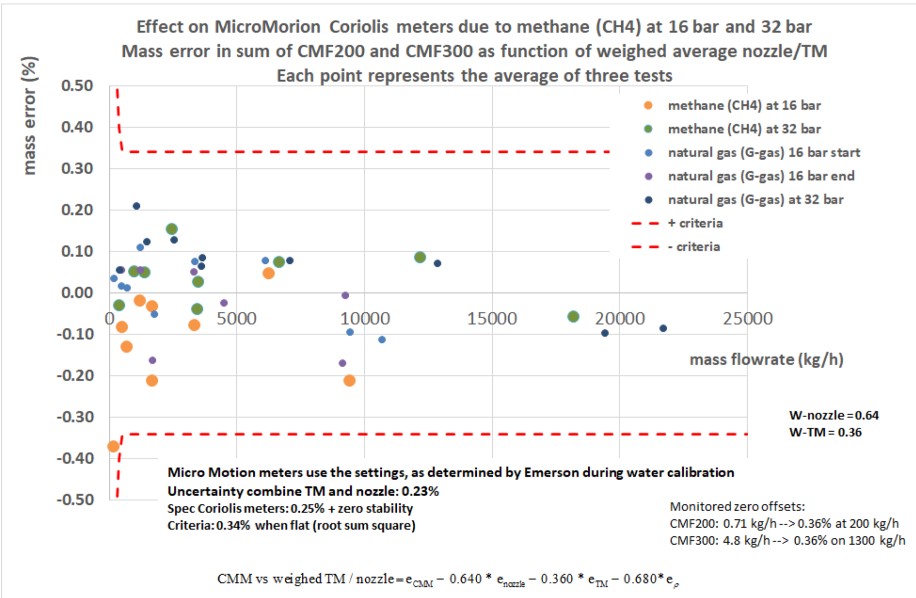

Figure 8

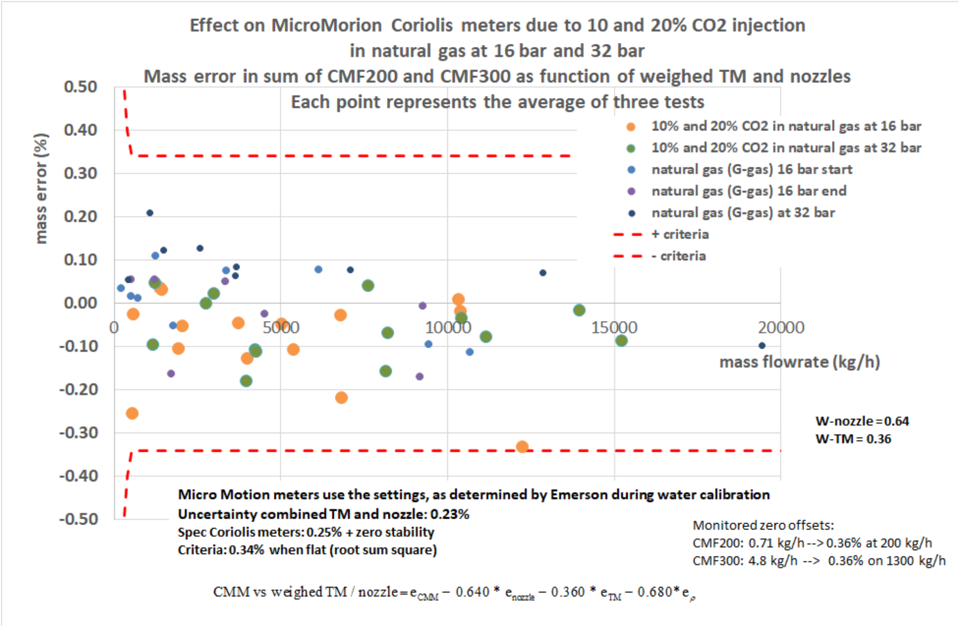

Figure 9

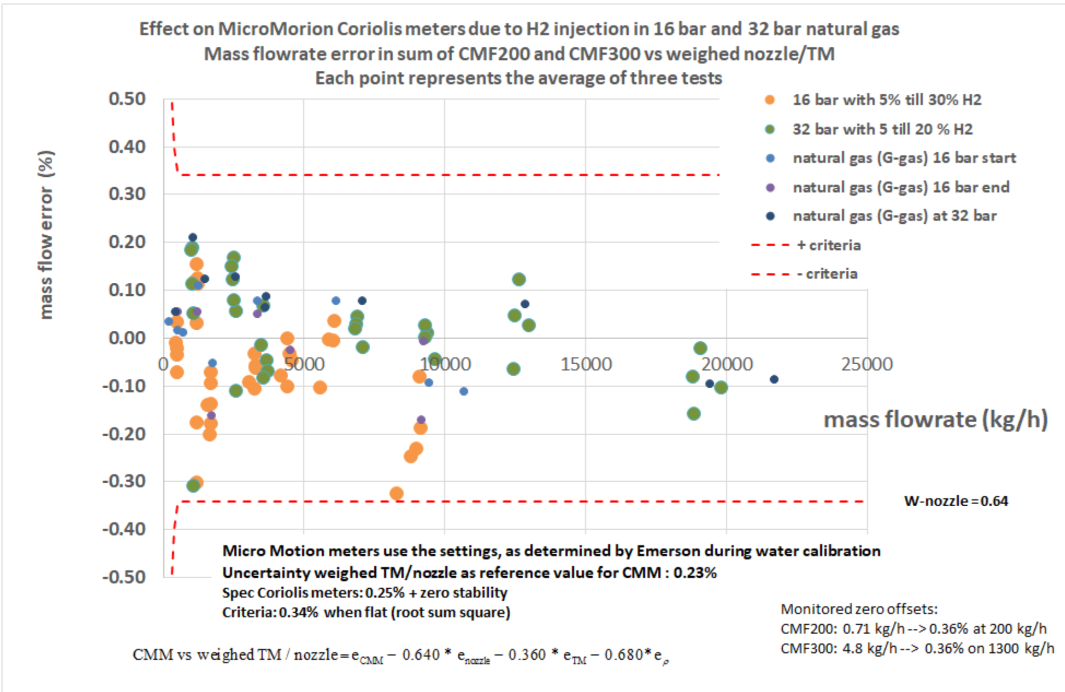

Figure 10

Summary of DNV JIP calibration results of the CMM:
- all tests within 0.40% (water settings; uncertainty set-up 0.23%; spec CMM 0.25%)
- tests at 32 bar show less variations than tests at 16 bar
- some outliers at 16 bar and at flowrates higher than 10000 kg/h with N2 (figure 7) and CO2 injection (figure 9) with big, unexpected jumps of 0.3% for successive tests; Note: Variations over the flowrates in the nitrogen N2 tests (figure 7) are bigger than variations CMF200 on air at Cesame (figure 3); N2 tests has maximum velocity of 63 m/s ; air tests at Cesame 104 m/s.
- H2 injection tests at 16 bar is trending negative at highest flowrate when %H2 is increasing; no significant effect at 32 bar (figure 10). Emerson can not explain why there is a difference between 16 and 32 bar.

The unexpected jumps of 0.3% at highest flowrate and 16 bar (figures 7 and 9) and the trending negative %H2 injection results at highest flowrate and 16 bar (figure 10) are subject to further investigation between DNV and Emerson.

Quote from Henk Riezebos – DNV:
DNV was initially not expecting that Coriolis would play a great role in the total reference system.

DNV was in retrospect very happy with the Coriolis performance as its zero stability and overall performance was such, that the CMM being a direct mass flow meter and an independent, sensitive density meter could really help in the quality control along with the SOS signals to be a check on consistency of density (gas composition, pressure and temperature).

Based on obtained experiences, following recommendations are made by the author to improve the integrity of the measurements:

A Assure that density is stable during each test by respecting stabilization time for temperature/density; density criteria 0.2%?
the use of the sensitive density function of the Coriolis meters as trend indicator may be helpful

B Assure that density difference between the three repeatable tests per flowrate does not vary more than 0.2%?

C Validate the measurements by using the redundancy in the reference system (CMM vs TM; CMM vs nozzle and TM vs nozzle) to detect bias or trends; criteria to be established, based on claimed uncertainties

3.3 Tests for hydrogen dispenser

The new HPC015 sensor from Micro Motion for hydrogen dispensers was tested and custody transfer certified.
This application includes small flowrates (0.1 till 2 kg/min), high pressures up till 850 bar

and low temperature -40 °C.
All calibrations of the HPC015 sensor was based on settings, determined during the water calibration at the calibration facility in Ede, NL.

Certification tests were performed in two steps:

3.3.1 Tests with nitrogen at 20 and -40 °C at Metas in Switzerland
Zero adjustment at 20 C and applied for both temperatures;
References are nozzles; uncertainty 0.3 till 0.5 %;
OIML R139 requirement: 1.5 %.

Calibration results are given in figure 11

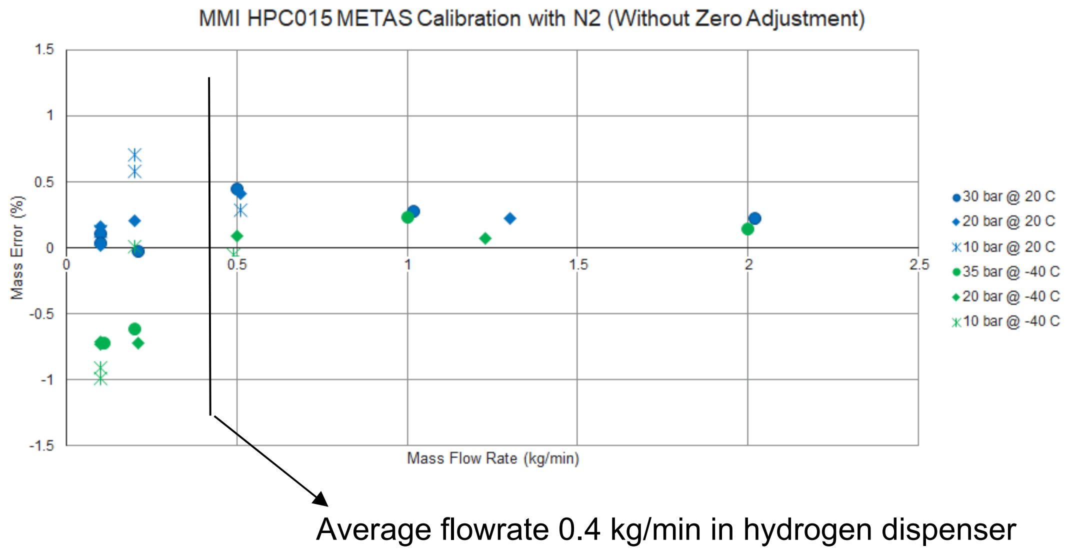

Figure 11

3.3.2 Field tests with hydrogen sensor installed in hydrogen dispenser
Two hydrogen dispensers with two different HPC015 sensors: one for 350 bar and one for 700 bar.
Reference is a weighing scale from VSL, Dutch Metrology Institute with an uncertainty of 0.30%; witnessed by NMi, Dutch notified body for certification acc. MID and OIML.

Dispenser Sensor Weighing Scale

** The TotalEnergies hydrogen refuelling station (HRS) in Arnhem is operated under the PitPoint brand*

Meter in hydrogen dispenser is subjected to non-stable process conditions (see figures 12 and 13); average 0.4 kg/min; peak 1.7 kg/min; -21 till -40 C ; 0 up till 700 bar; 0 up till 56 kg/m3.

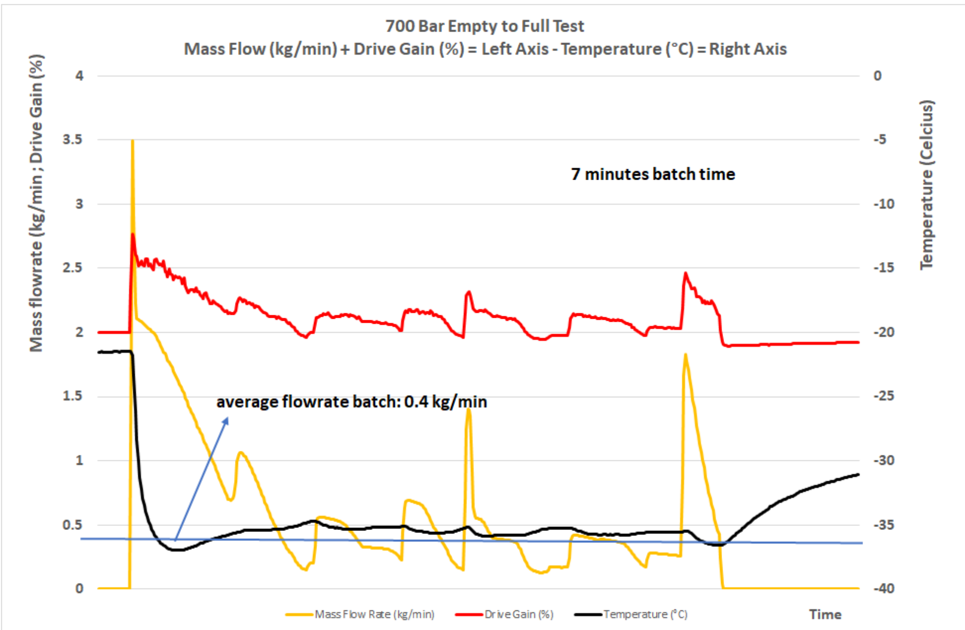

Figure 12

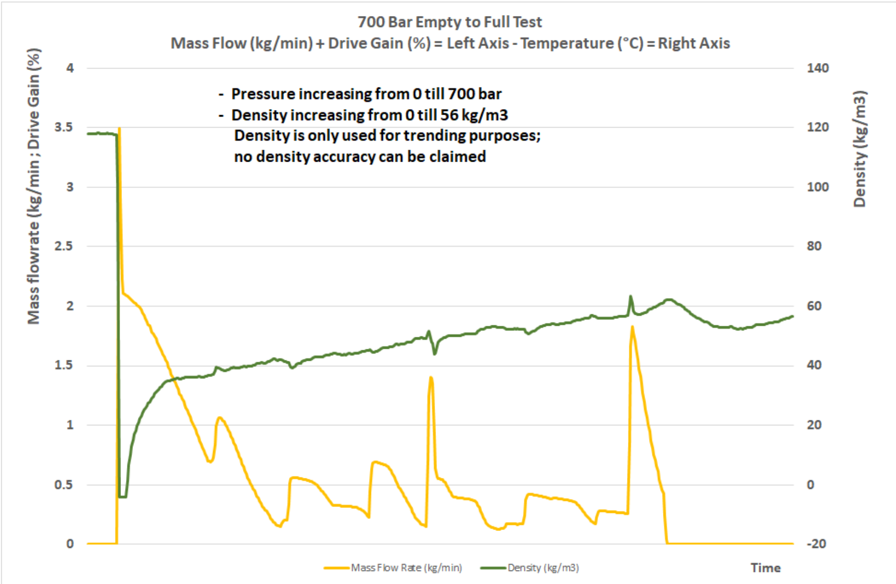

Figure 13

Results are given in figure 14.

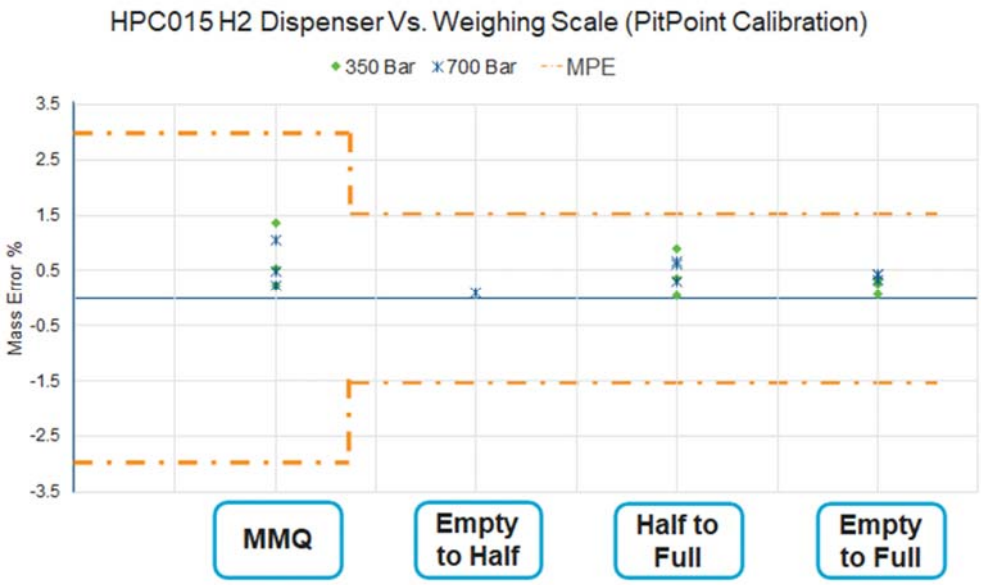

Figure 14

Difference between between nitrogen tests (flying start and stop) and hydrogen tests (no flow at start and stop with varying metering conditions) is very acceptable, given the varying process conditions.

Far within the maximum permissible error (mpe) of 1.5 % for a hydrogen measuring system (dispenser); compliant to OIML R139.
Resulted in an OIML R139 certificate from NMI (figure 15)

OIML Certificate

OIML Member State
The Netherlands

Number R139/2018-A-NL1-21.03 revision 1
Project number 2655441
Page 1 of 3

Issuing authority Person responsible:	NMi Certin B.V. M.Ph.D. Schmidt
Applicant and Manufacturer	Emerson Process Management Flow B.V. Neonstraat 1 6718 WX Ede The Netherlands
Identification of the certified type	A **measurement sensor** (Coriolis sensor) Type: HPC015
Characteristics	See page 2 and further

This OIML Certificate is issued under scheme A.

This Certificate attests the conformity of the above identified type (represented by the sample(s) identified in the OIML Type Evaluation Report) with the requirements of the following Recommendation of the International Organization of Legal Metrology (OIML):

R 139-1 (2018) "Compressed gaseous fuel measuring systems for vehicles"

Accuracy class 2 or 4

Figure 15

A perfect cooperation between:

4. Micro Motion roadmap for renewable gases

See figure 16 for the self-explanatory roadmap

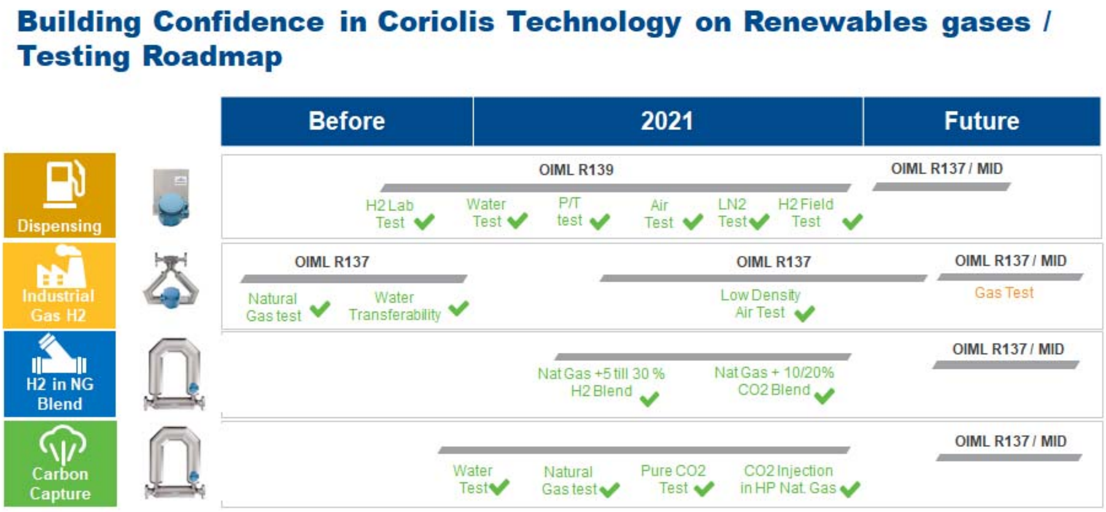

Figure 16

5. Conclusions

- All tests for renewable gases are within 0.40% for different traceability chains (Cesame; DNV JIP and VSL), based on water settings
- Coriolis is of added value to quality assurance for gas testing at all different gases at the DNV-JIP reference system
- Very acceptable match with the new hydrogen sensor for hydrogen dispensers in relation to water calibration and nitrogen calibration at +20/-40 °C
- Obtained OIML R139 certification for the new hydrogen sensor

Coriolis is the perfect technology for renewable gases

Acknowledgement goes to DNV for their cooperation concerning the DNV JIP tests.

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