TEST OF HYDROGEN IMPACT OF CLAMP-ON FLOWMETER
TEST CLAMP-ON SIEMENS IN NATURAL GAS WITH HYDROGEN UP TO 30%

Testing results for Siemens

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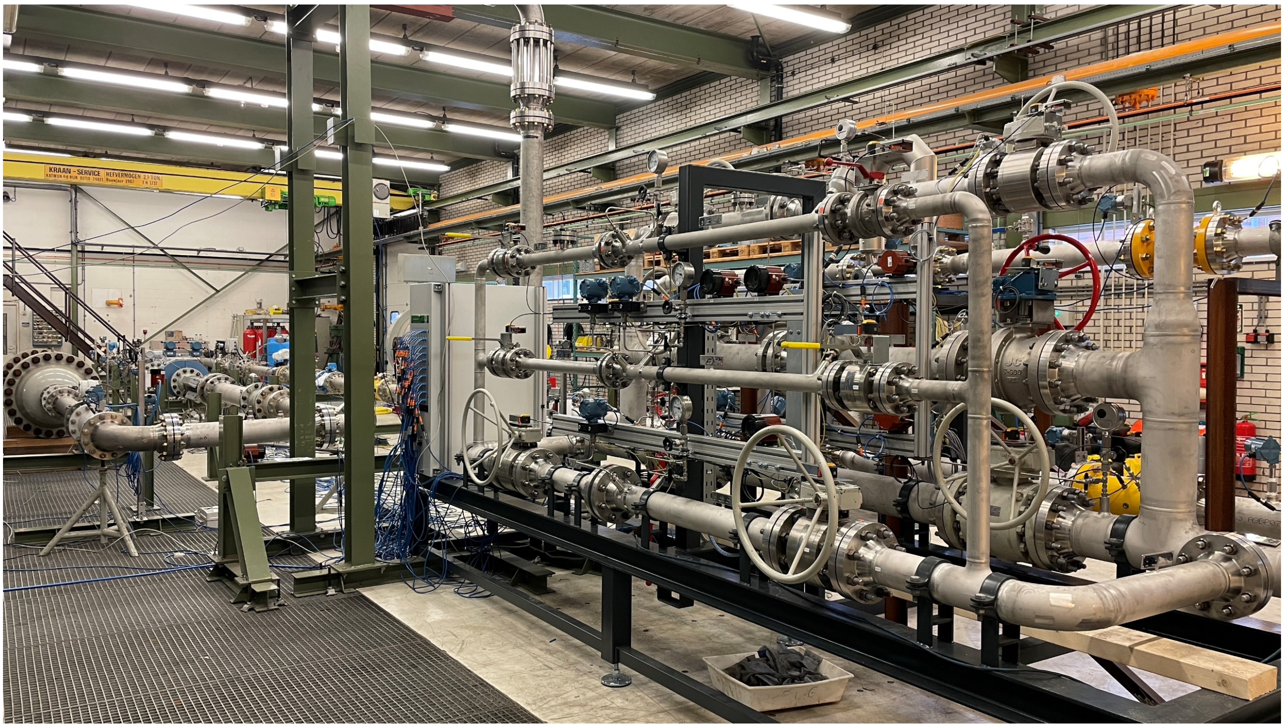

Project name:	Test of hydrogen impact of clamp-on flowmeter Test clamp-on Siemens in natural gas with Hydrogen up to 30%	DNV Netherlands B.V. Energy systems Flow and Fuel Advisory Energieweg 17 NL-9743 AN Groningen Tel: +31 6 1525 9861 Registered 09006404
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Objective:

Verification Report to determine the metrological impact of Flow meter type: Siemens-{Type} in natural gases and natural gas mixtures up to 30% Hydrogen

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Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
1	2021-07-29	First issue	Henk Riezebos	Mohammed al Saleem	
2	2021-08-09	Final report	Henk Riezebos	Mohammed al Saleem	

Table of contents

1 EXECUTIVE SUMMARY

Siemens has requested DNV to perform a test using hydrogen mixtures up to 30% in the multi-phase loop of DNV GL (MPFLG). Test setup and conditions similar to the JIP tests on new gases which DNV had done with 19 participants (manufacturers and users). The objective of the test is the validation of the performance for the meter that will be tested.

The Siemens gas flow meter is tested using 5 different gas mixtures (pure nitrogen (N2), G-gas, G-gas+10%H2, G-gas+20%H2, G-gas+30%H2, at two different pressure conditions 8 bar and 16 bar and minimum 8 flow points.

1.1 Siemens SITRANS FS230

Meter to be tested:

Manufacturer name:	Siemens AG
Type of meter (manufacturer code name):	SITRANS FS230
Measurement principle (TM or USM):	clamp-on USM

1.2 Test conditions and results

The tests have been performed on pure nitrogen and on natural gas and mixtures of H2 up to 30%.
Calibrations description

- In total 20 calibration runs were performed (different pressure, different gas composition) at the All-gas loop of the MPFLG facility in Groningen, Netherlands.
- Each test point had 3 repeats (3 times 100 seconds) and the repeatability is based on the 3 repeat points.

Note: the meter has been mounted on a DNV pipe spool and the whole has not been calibrated before the tests started. The results on natural gas (G-gas) shows typical error of ~1.3% and those calibration results are treated as calibration reference for determining the performance at other gases.

1.3 Results repeatability and average meter errors

	Gas type	Average error	Average repeatability (%)	FWME Flow weighted mean average error	FWM flow weighted mean repeatability
1	N2 p=32bara	*1.41%*	*0.051*	*1.62%*	*0.055*
2	N2 p=16bara	*1.13%*	*0.080*	*1.37%*	*0.114*
3	Ggas p=32bara	*1.20%*	*0.062*	*1.22%*	*0.071*
4	Ggas p=16bara	*1.39%*	*0.044*	*1.40%*	*0.047*
5	10H2 p=32bara	*0.76%*	*0.105*	*0.84%*	*0.098*
6	10H2 p=16bara	*1.08%*	*0.062*	*1.21%*	*0.066*
7	20H2 p=32bara	*1.02%*	*0.059*	*1.06%*	*0.062*
8	20H2 p=16bara	*1.38%*	*0.061*	*1.40%*	*0.067*
9	30H2 p=32bara	*1.01%*	*0.057*	*1.01%*	*0.061*
10	30H2 p=16bara	*1.27%*	*0.114*	*1.20%*	*0.079*

Table 1 Summarised calibration results

Every calibration is characterised by an averaged error and repeatability number (over all flow points in the calibration). Also, a FWME (Flow Weighted Mean Average) error and a repeatability number is obtained by linear weighing the errors and weighing the repeatability number by the volume flow over all flow points. This last value has been defined as *FWME repeatability.*

The detailed calibration results over of all points and repeats are shown in graphs in Appendix 1. A separate Excel sheet has been provided to Siemens with all calibration details.

1.4 Reproducibility and transferability

The day-to-day reproducibility has not been established in this test as in the test program no repeated calibrations have been performed at other days. A typical transferability value of 0.35% has been used for further evaluation of drift behaviour.

1.5 Meter drift at other gases

Gas-to-gas differences can be compared on the basis of the Flow Weighted Mean average Error numbers. For the pure gas N2 and hydrogen these shifts are

Table 2 Summarised drift behaviour in new gases

* PWA is the percentage-weighted-average shift (for more details, please see chapter 5)

** E-number below 1 indicate, that the X-gas behavior is not significant compared to the reproducibility of the meter.

The gas dependent FWME shift-behavior is shown in the following graphs:

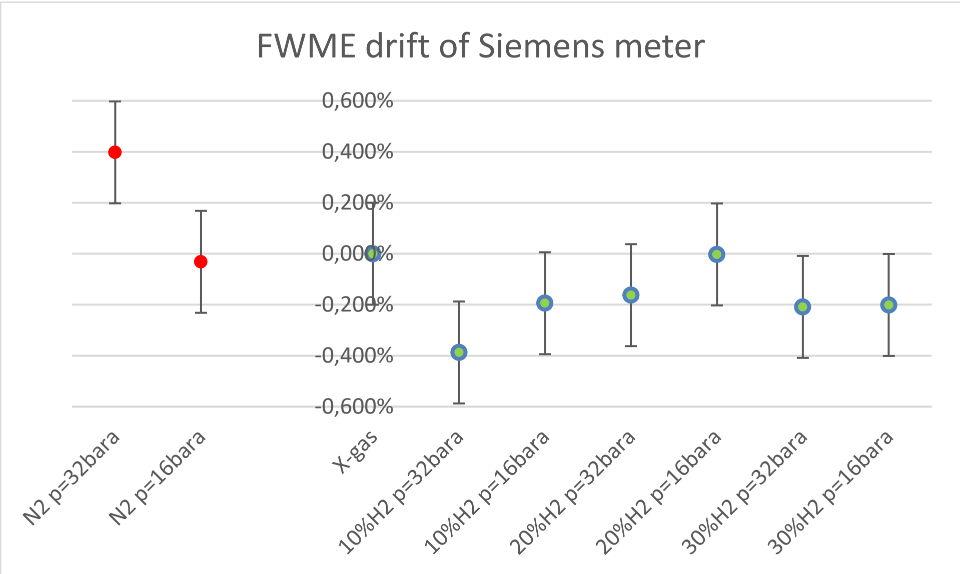

Figure 1 *Meter drift with pure gas N2 (higher density) on left side and H2 mixes (lower density) on right side*

1.6 Conclusions

1.6.1 Robustness

The meter kept working and producing flow numbers at all the test conditions.

1.6.2 Repeatability

Average repeatability over all flow point between Qmin and Qmax was 0.07% varying between 0.04% for the calibration at G-gas(16 bar) and 0.11% for the calibration at G-gas with 30% H2 (16 bar).

Flow weighted average repeatability over all flow point between Qmin and Qmax was 0.07% varying between 0.05% for the calibration at G-gas(16 bar) and 0.11% for the calibration at gas N2 (16 bar) %.

1.6.3 Drift

Natural gas is used as a reference to judge the drift behaviour of the meter.

Using the G-gas as a reference the meter shows a significant positive drift towards higher density gases like Nitrogen and a significant negative drift at lower density when hydrogen is mixed to the natural gas. The drift is considered small (< 0.4%) as compared to the overall assumed measurement uncertainty of 1% to 3% considered for clamp-on flow applications.

1.6.4 Overall conclusion

The meter performs very adequate as a process flow instrument suited for multiple gases.

1.7 Supporting information on the meter provided by Siemens

The input of this section has been provided by Siemens

AG Siemens uses the SITRANS FS230, a state-of-the-art clamp-on ultrasonic measuring device in a new design. The FS230 consists of the flow sensors FSS200 and a transmitter SITRANS FST030, combined with an external DSL (Digital Sensor Link), which offers the system a very robust digital communication environment that provides the best possible protection against electrical interference.
For this test, high-precision FSS200 sensors were used that are precisely matched to one another and send a Lamb wave or broad-beam ultrasonic signal into the steel tube wall of the measuring tube. The measurement was carried out in a two-path installation using two pairs of sensors mounted in reflection mode. This configuration offers very precise accuracy even with complex flow parameters.
The External Digital Sensor Link (DSL) is a remote electronic module that forms the analog measurement value acquisition and digitizes the relevant data directly. These data are made available to the sender via a data cable (SSL cable). The DSL is placed as close as possible to the sensors. This proximity ensures short analog cable lengths and minimizes EMC interference. The DSL processes pressure and temperature via external inputs and corrects the volume measurement with Reynolds number compensation. The DSL can be operated with up to four pairs of sensors and always processes the data quickly with a data update rate of 100Hz. DSL and sensors are for Ex zone 0/1 or Class 1 Div 1/2 authorized.
The SITRANS FST030 transmitter can be installed up to a distance of 150 m (500 ft) from the sensors using the digital signal of the DSL. The process data are shown on the transmitter display and at the same time output in the desired form via the configurable output modules. The transmitter FST030 also provides and monitors the programming, parameterization and diagnosis as well as the recording of the data on a 4GB micro-SD card.
The clamp-on technology works without direct media contact and therefore has several major advantages: No contamination or wear and tear on the sensors and no cutting into the existing pipe system. Retrofitting under operating conditions is also just a simple connection of the sensors. With ultrasonic clamp-on flow measurement for gas, it should be noted that the gas pressure in the pipeline must be approx. 8 bar (100 psi). This line pressure is individually dependent on the pipe material, diameter, wall thickness and gas composition. Small, thick-walled pipes require more pressure.
In addition, with a clamp-on measurement, the measuring tube is part of the measuring system and therefore practically cannot be calibrated on a test bench. This means that there is often only a field calibration against zero flow and verification of the speed of sound. As can be seen from the test result, impressive flow performance and accuracies are achieved in a simple manner with these test paradigms.
Multipath measurements with 2, 3 or 4 paths significantly improve the measurement accuracy under difficult flow profile conditions. For this reason, gas flow measurements should always be used with at least two paths or more. For pipe sizes larger than DN 600 (24 in.), The use of additional paths is strongly recommended when accuracy and repeatability are critical.

Figure 2: Picture 01 from Siemens: FSS200 Sensors dual path installed in reflect mode at DNV

Figure 3: Picture 02 from Siemens: SITRANS FS230 – external DSL

Figure 4: Picture 03 from Siemens: SITRANS FS230-Transmitter (Wallmount enclosure)

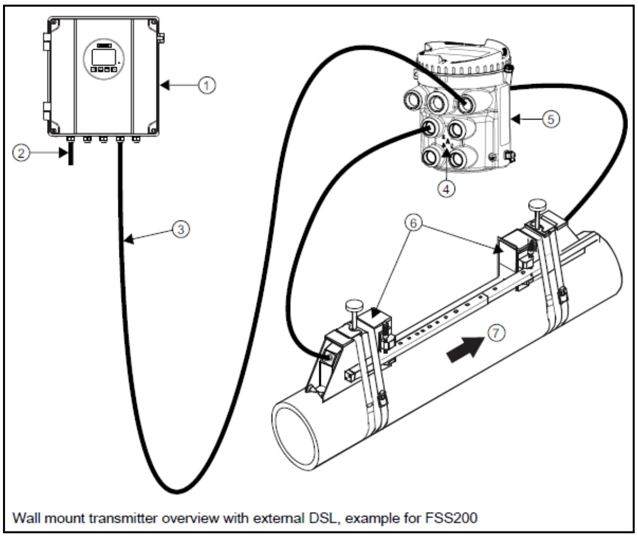

Figure 5: Schematic overview of the FS230 clamp-on system

1.8 Objective of tests for Siemens AG

The objective of the test is to investigate the response and performance of the novel clamp-on technology to the introduction of non-conventional gases based on the differences in physical properties.

For the test, the high-pressure closed loop facility at the DNV office in Groningen has been used. This facility allows the introduction of different gases at a maximum pressure of 33 bar and has a maximum gas flow rate of 1000 m3/h.

The traceability and gas-to-gas reproducibility of the reference standards has been covered in a collaboration of DNV with Bodo Mickan and Jos van der Grinten from PTB (Physikalisch Technische Bundesanstalt), see also ref. [3].

2 GENERAL INFORMATION OF METER UNDER TEST

2.1 Test object

	unit	USM-x
Manufacturer name	-	Siemens AG
Type of meter (manufacturer code name)	-	SITRANS FS230
Material spec		C-steel (pipe of DNV)
Measurement principle (TM or USM)	-	Clamp-on USM
Qmin	m3/hr	20
Qmax	m3/hr	2400
Size / Nominal diameter flange (DN)	mm	DN150 (pipe of DNV)
Inner diameter of meter	mm	DN150 sch 40
Built-in length of meter	mm	
Pressure class		DNV pipe spool
Flange type		DNV pipe spool
Pulse/ HF output	pulses/m3	14000
new design meter / existing new/ used		new

Extra information for USM

Number sensors	High Precision C2H sensors (Lamb wave sensors)
Number paths	2
Type of path configuration	Reflect mode
US sensor frequency	~470 kHz
Sensor material (on gas side)	DNV pipe spool
Configuration parameters (e.g. Type of gas)	Natural gas

Table 3 USM specifications

2.2 Information on configuration

The meter was delivered and provided with the following configuration:

- Diagnostics available on SOS, signal gain and SNR
- Diagnostics values were logged by Siemens

The meter was provided with the following settings and corrections:

- Reynolds compensation mode based on p,T transmitter input (transmitters of DNV)

2.3 Contact details Siemens

Full company name: Siemens AG

Address Östliche Rheinbrückenstr. 50, 76187 KARLSRUHE, Germany

Contact person: Wolfgang Ottinger DI PA MI PRM FT

Email contact person: wolfgang.ottinger@siemens.com

3 TEST PROTOCOL

3.1 Table of test conditions

The tests were performed between 21st of June 2021 and 25th of June 2021 at the MPFLG facility in Groningen. The total test program is shown in the table below:

Test day	Gas - calibrations
21st of June	Nitrogen at 16 bar and 32 bar
22nd of June	G-gas at 16 bar and 32 bar
23rd of June	G-gas with 10% H2 (16 and 32 bar)
24th of June	G-gas with 20% H2 and 30% H2 (16 bar)
25th of June	G-gas with 20% H2 and 30% H2 (32 bar)

Calibration description

- In total 20 calibration runs were performed (different pressure, different gas composition) at the All-gas loop of the MPFLG facility in Groningen, Netherlands.
- Each test point had 3 repeats (3 times 100 seconds) and the repeatability is based on the 3 repeat points.

3.2 Test setup

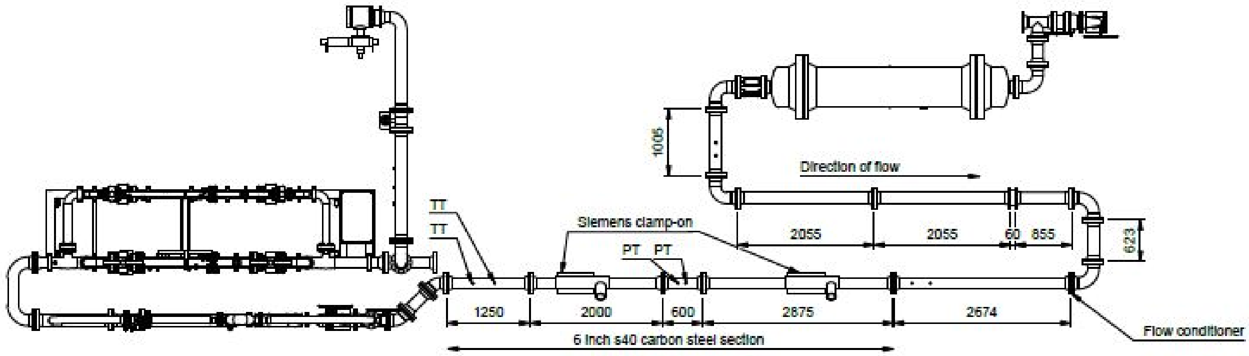

Figure 2: Test setup

The isometric layout of the test section of the JIP tests is shown in the above graph. The meter of Siemens was situated on the most right location marked with Siemens clamp-on in Figure 2.

The meter flow signals were recorded in the DNV data acquisition as pulse signals and each meter was connected with its own pressure transmitter. Every section of the setup was connected to one temperature transmitter, which was expected to be representative for all meters in the section.

Pressure and temperature information was checked on consistency and used to convert the volumetric flow signal of the meter to a mass flow to be compared with the all-gas references, consisting of nozzles and TM/Coriolis combination.

For ultrasonic meters-under-test system diagnostic information was logged on a separate system controlled by the manufacturer of the meter. The information on configuration and settings was provided to DNV before and after the test.

3.3 Test Facility

DNV has a long track record in multi-phase meter testing. Our knowledge is founded in the operation of several laboratories like our high-pressure gas meter calibration facility and wet gas test facility. In 2012 DNV built a new test facility the Multi-Phase Flow facility, which is operational since 2013. The Multi-Phase Flow facility serves as an independent check for operators, manufactures and other solution providers. The Multi-Phase Flow facility is a closed loop designed to operate with different fluid combinations. By applying live oil, in which pressure drop causes degassing and resulting rheological phenomena, the fluid behaviour closely mimics the situations in a multi-phase oil and gas field. Our mathematical model for flow recalculation gives the exact phase flows at the pressure and temperature in the test location, including their uncertainties (FRUM model). Therefore, the facility can serve as an accurate reference for e.g. multi-phase meter calibration/testing. A schematic representation of the Multi-Phase Flow facility is given below.

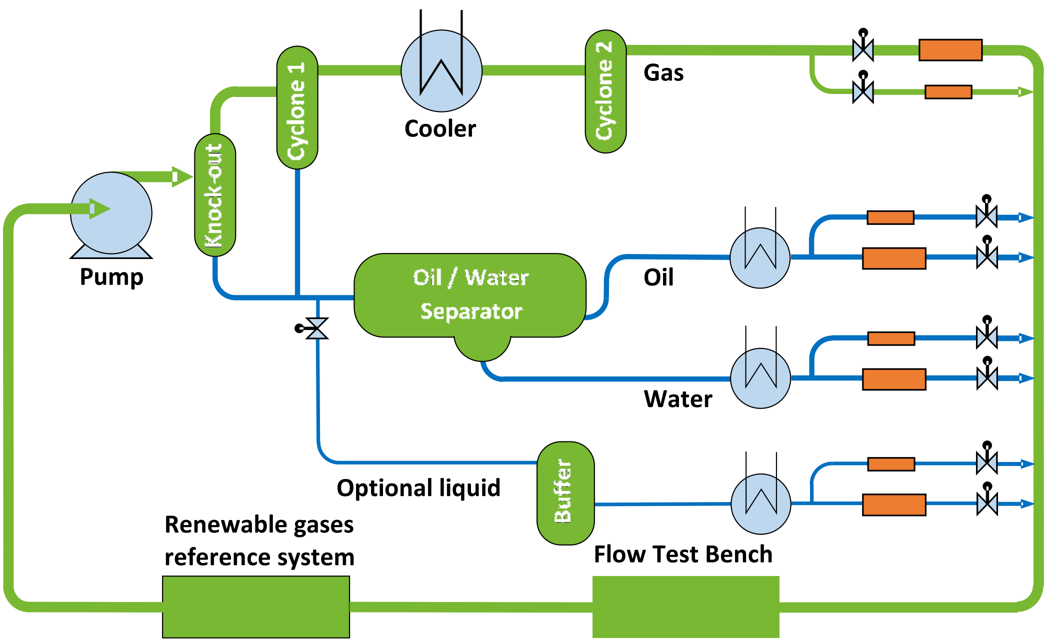

Figure 3 Simplified process flow diagram Multi-Phase Flow Laboratory Groningen

3.4 Test References

The reference system consists of:

- A primary reference system consisting of sonic nozzles
- A secondary reference system consisting of Turbine meters in combination with Coriolis meters
- A gas quality registration system consisting of a field gas chromatograph

DNV has designed the reference system in collaboration with the German Metrological authority PTB.

3.4.1 Primary reference system consisting of 5 sonic nozzles

The primary reference system consists of sonic nozzles, which are mounted in one skid.

Figure 4 Nozzle Skid

- The test setup includes five measurement sections (nozzle lines), with design flow rates 16 m3/h, 40 m3/hr, 100 m3/hr, 250 m3/hr, 500 m3/hr (on Groningen type natural gas)
- Each nozzle line has a separate pressure and temperature sensor

3.4.2 Secondary flow reference system

The primary reference system is only able to serve for specific flows related to the speed-of-sound in the gas. Therefore, a secondary flow system has been designed and built to cover all reference flows within the specified conditions of the Multi Phase Flow facility of DNV (minimum gas flow 16 m3/h and maximum gas flow 1000 m3/hr).

The secondary system consists of two lines with a turbine meter and Coriolis meter each.

- High flow line DN150 covering flows between 100 and 1000 m3/hr
- Low flow line DN100 covering flows between 10 and 250 m3/hr

3.4.3 Determination of gas composition

For all calibrations an ABB Quad microGC was installed in the loop to analyse the gas. A natural gas sample is taken continuously from an operating flow measurement run via a very small sample line (ID 2 mm). The analysis cycle time is approximately 4 minutes. Multi-level calibrations have been performed and a daily calibration was done after each test day.

Figure 5 *Secondary reference skid (combination of TM and Coriolis meters)*

3.4.4 Traceability and uncertainty of flow references

Traceability of the Coriolis is done via a water calibration system (at Micro motion facility in Ede Netherlands). Traceability of the Turbine meters is done via EuReGa (DNV flow facility in Groningen is traceable to FORCE). Full traceability is dealing with 3 independent chains as pictured below

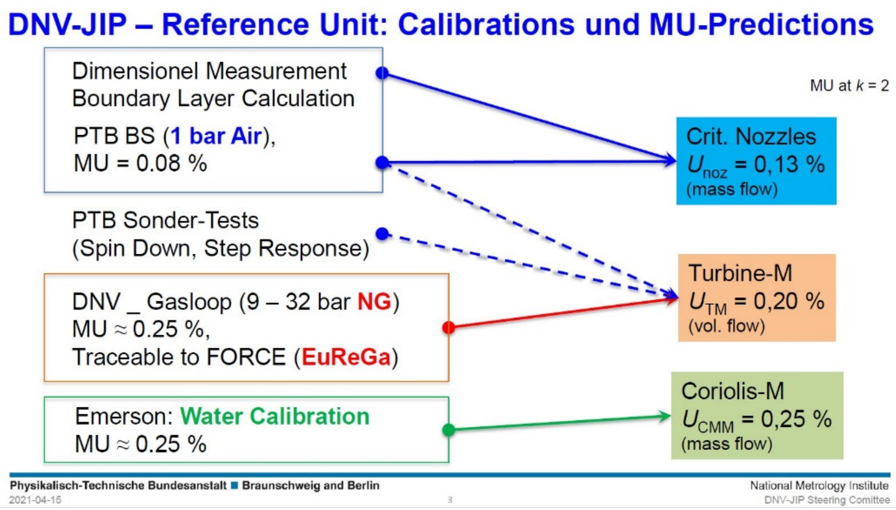

Figure 6 Traceability of DNV JIP primary and secondary flow reference instruments as established by PTB

The results of the traceability analysis of PTB (ref. [3]) is that the whole system of references consisting of nozzles, turbine meters and Coriolis meters and the gas quality measurement has an overall k=2 CMC uncertainty < 0.22% on mass and volume flow of any gas, taking into account a traceability uncertainty of 0.11%, a reproducibility of 0.17% and a molar mass uncertainty of 0.10%.

4 TESTING RESULTS

4.1 Repeatability

For determining the repeatability of any point on the calibration curve labeled *i* the repeatability is determined on the basis of the n=1,2,3 repeated measurements of 100 seconds for each point. This is a number determined by the standard deviation of the mean results i.e. the standard deviation of the three repeated deviation ε_n . As we are used to present uncertainty with a coverage factor of 2 (95% confidence level) we obtain as result for repeatability U_i: U_i = 2*stdev(ε_n) divided by the square root of 3, the number of repeats being n=3.

4.2 Estimation of Reproducibility and Transferability

No tests were repeated on one of the other test days, so the day-to-day reproducibility of this meter can not be established based on a reproducible measurement.

Instead, a best estimated value by DNV of reproducibility of U_{rep} =0.30% and transferability U_{trf}=0.35% has been used in the below calculations as a reference value to determine whether the observed drifts are considered significant.

4.2.1 Transferability

Transferability is defined as the reproducibility from one gas to another gas. Minimum is the reproducibility day-to-day of the instrument U_{rep} as defined above. On top of the molar mass uncertainty of the other gas (X-gas) is to be used $U_{Molar\ mass,\ x}$. This number has been determined by PTB based on the reference system to be $U_{Molar\ mass,\ X}$ = 0.1%. Total transferability or uncertainty of the test at other gas to be:

$$U_{trf}^2 = U_{rep}^2 + U_{molar\ mass}^2$$

4.2.2 Drift behaviour at other gases

Gas-to-gas differences can be compared on the basis of the Flow Weighted Mean average Error numbers. We refer to ISO17089-1 (ref.[5]) for the definition of FWME. It is important to understand how the meter drifts away when hydrogen, CO2 or other gases are used in comparison with the reference situation at natural gas (in this case G-gas).

- Reference situations for all 32 bar calibrations on different gases: Q_{ref32}= FWME @32 bar G-gas1
- Reference situation for all 16 bar calibrations: Q_{ref16} = (FWME@16 bar G-gas1)
- The X-gas shift is based on flow weighted mean average shifts (FWME):
  - Dev_{x16} = $FWME_{@16\ bar\ X\text{-}gas}$ – Q_{ref16}
  - Dev_{x32} = $FWME_{@32\ bar\ X\text{-}gas}$ – Q_{ref32}

<u>Are the drifts or deviations found significant?</u>

To determine whether the shifts are significant we follow here a procedure as described in the ISO17043 for proficiency testing. In this standard, the so-called E_x number is introduced which scales the difference in two FWME measurements with the expected uncertainty of the FWME. Note for the FWME uncertainty for gas X we take here the $U = \frac{U_{trf}}{\sqrt{n}}$ with n=number of points in calibration with X-gas.

Significance of the shift is determined by the E_x-number in which we determine the significance by looking at the ratio of the FWME deviation compared to the gas-to-gas transferability number U_{trf}:

$$E_x = Dev_x * \frac{\sqrt{n}}{U_{trf}}$$

Based on the value of the E_x number, the following conclusions can be drawn (ref. [1])

- $|E_x| \leq 1$: the difference is statistically insignificant
- $1 < |E_x| < 1.5$: the difference is statistically questionable
- $|E_x| \geq 1.5$: the difference is statistically significant

Furthermore, the judgement of significance is also based on the whole picture of gases, not only for one particular gas X. To help in this we define here for all the hydrogen mix calibrations tests a PWA (Percentage Weighted Average) shift as follows

$$\text{H2-shift}_{PWA} = \Sigma_i \, \text{perc(H2)}_i \, {}^*\text{FWME}_i \, / \, \Sigma_i \, \text{perc(H2)}_i$$

The same can be done for the overall average $E_{x,av}$ number to determine whether the shifts are to be considered significant. For the overall significance we then multiply $E_{x,av}$ with sqrt(n) with n the number of different gases tested.

4.3 Meter drift at other gases

Gas-to-gas differences can be compared on the basis of the Flow Weighted Man Average error numbers. For the pure gases these shifts are

X-gas	X-gas shift (Dev)(%)	Significance E_x
N2 p=32bara	0.398%	2.4
N2 p=16bara	-0.032%	-0.2

Table 4 *Average FWME shift for the calibrations with nitrogen*

For hydrogen mixes the shifts compared to Groningen gas are:

X-gas	X-gas shift (Dev)(%)	Significance E_x
10%H2 p=32bara	-0.387%	-2.1
10%H2 p=16bara	-0.194%	-1.2
20%H2 p=32bara	-0.163%	-0.9
20%H2 p=16bara	-0.003%	0.0
30%H2 p=32bara	-0.209%	-1.3
30%H2 p=16bara	-0.201%	-1.2

Table 5 *Average FWME shift for the calibrations with Mix of natural gas(G-gas) and H2*

Using the G-gas as a reference the meter shows a significant positive drift towards higher density gases like Nitrogen and a significant negative drift at lower density when hydrogen is mixed to the natural gas. The average drift is considered small (< 0.4%) as compared to the overall assumed measurement uncertainty of 1% to 3% considered for clamp-on flow applications.

5 REFERENCES

[1] ISO17043, Conformity assessment, General requirements for proficiency testing (2010).

[2] ISO5168, Measurement of fluid flow – Procedures for the evaluation of uncertainties (2005).

[3] Mickan B., Uncertainty assessment of Traceability in DNV-JIP based on cross-check measurements, PTB dept 1.4 gas (2021).

[4] OIML, R 137-1 Gas meters, part 1: Requirements, (2006).

[5] ISO17089-1 2010 : Measurement of fluid flow in closed conduits — Ultrasonic meters for gas — Part 1:Meters for custody transfer and allocation measurement

APPENDIX A

Graphs of detailed results

Results are shown below in graphical form either as function of volume flow and/or as function of Reynolds number. In the Reynolds number graph a reference line has been drawn based on the results of Groningen gas. This gas has been used as a reference to determine and characterise the behaviour in different other gases.

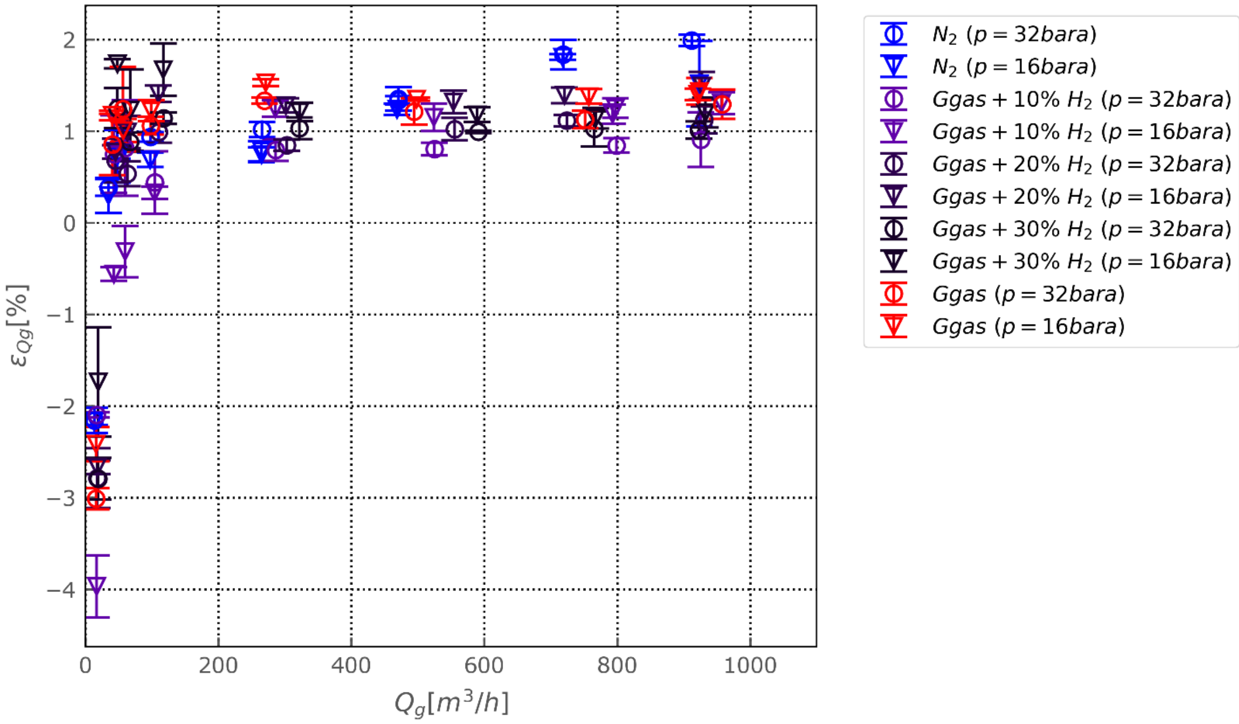

Figure 7 Results as a function of volume flow

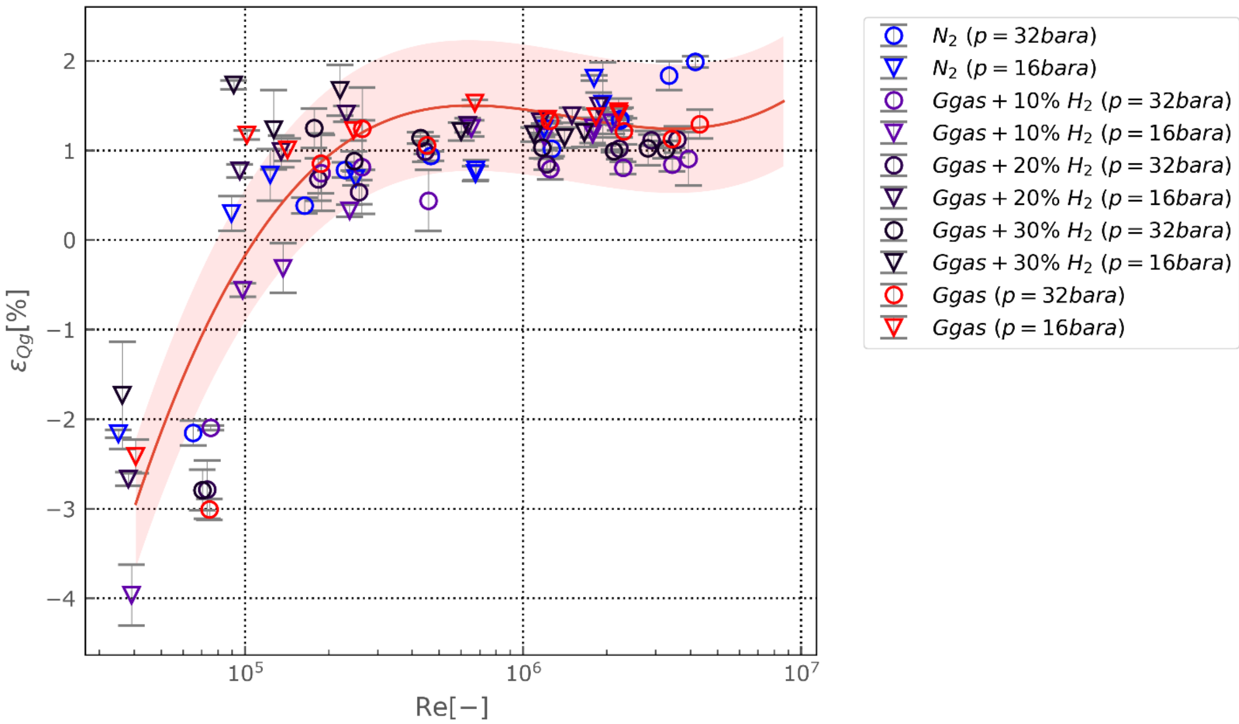

Figure 8 Results as a function of Reynolds

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