Paper 12 JIP renewable gases; results on performance of turbine and ultrasonic flow meters up to 30% Hydrogen and 20% CO_2

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Paper presented at the North Sea Flow Measurement workshop 2021

PARTICIPANTS JIP flow metering in non-conventional gases

10 Users/ TSO:

1. Enagas
2. Fluxys
3. Gascade
4. Gasunie
5. Gas Networks Ireland
6. Gazsystem
7. Grtgaz
8. Ontras
9. Open Grid Europe
10. SNAM

9 Manufacturers:

1. Emerson
2. Endress+Hauser
3. Flexim
4. Honeywell
5. Krohne
6. Pietro Fiorentini
7. RMG
8. SICK
9. Tancy

DNV – Project execution

Mohammed al Saleem (project Manager)

Henk Riezebos (Technical Lead)

Dennis van Putten (Technical specialist)

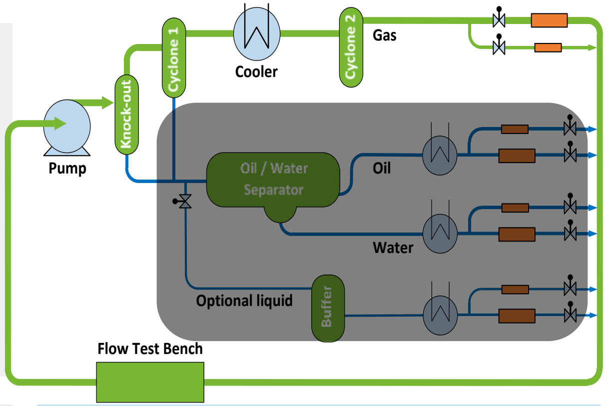
Ronald ten Cate (Business lead)

Aimed results for JIP renewable gases

1

Increase knowledge on metering in renewable environment:

- Improve knowledge on ***transferability of Natural Gas chain*** (calibration and uncertainty) into renewable gases
- Improve knowledge on effect of gas composition and physical properties on flow technologies used as flow references (Reynolds number, Mach number, etc)



2

Understanding of transferability to new gases :

- Increase understanding on the ***sensitivities*** of adding mixtures of H2 and CO2 to natural gas flow metering technologies. How far can natural gas flow meters be pushed into mixtures of renewable gases
- Increase understanding of ***Scaling rules*** to support the translation of calibration results from natural gas to another (renewable) gas

ISO/API/DNV GL
& Industry
rules and standards

3

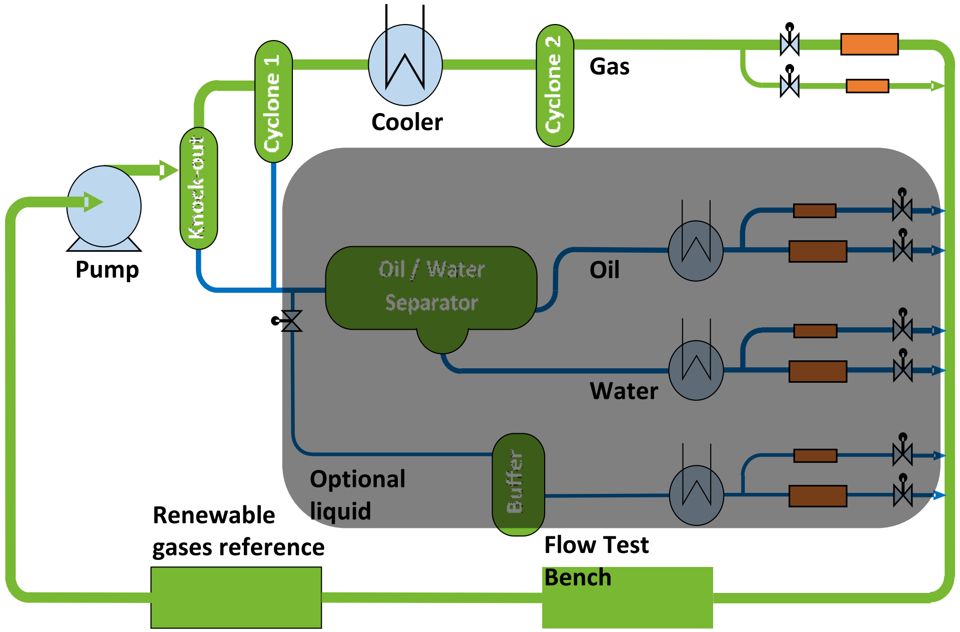
Verification:

- Independent, transparent and traceable ***performance evaluation*** of individual flow meters in renewable gas conditions
- Interpretation of ***ability of flow technologies*** (USM and TM) to cope with mixtures of renewable gases

ASSESSED BY
DNV·GL
Renewable
Gas Flow Meter

All-gas loop at DNV Groningen

Flow performance test



- Multiphase flow facility of DNV in Groningen:
  - Used in "dry" operation
  - Closed loop configuration
  - Screw pump, so high pressure drop possible

- Reference system based on sonic nozzles and turbine/Coriolis skid:
  - Designed in collaboration with PTB

Multiphase flow facility of DNV – gas capabilities

Gas mixtures for JIP

- Natural gas (G-gas)
- Mixed natural gas and CO2 (**scope up to 20%** , but test up to 30%)
- Mixed natural gas and H2 (**scope up to 20%,** but test up to 30%)
- Single gases (100% CH4, 100% N2)
- **Other gas options** (100% CO2, 100% Ar, in future 100% H2)

Flow

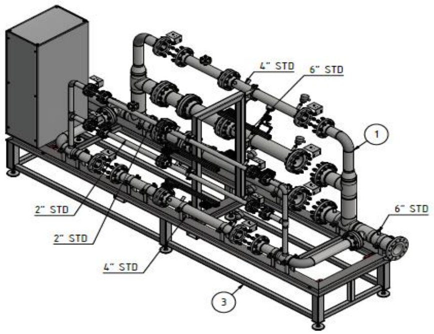
Gas 10 – 1000 m^3(a)/h

Conditions

- Temperature: 5-35°C
- Pressure: 5-33 barg
- DP test section: 0-25 bar

Gas reference

- (Critical) Venturi nozzles
- Coriolis meters
- Turbine flow meters
- Combinations of above



Sonic nozzle reference skid

Test setup

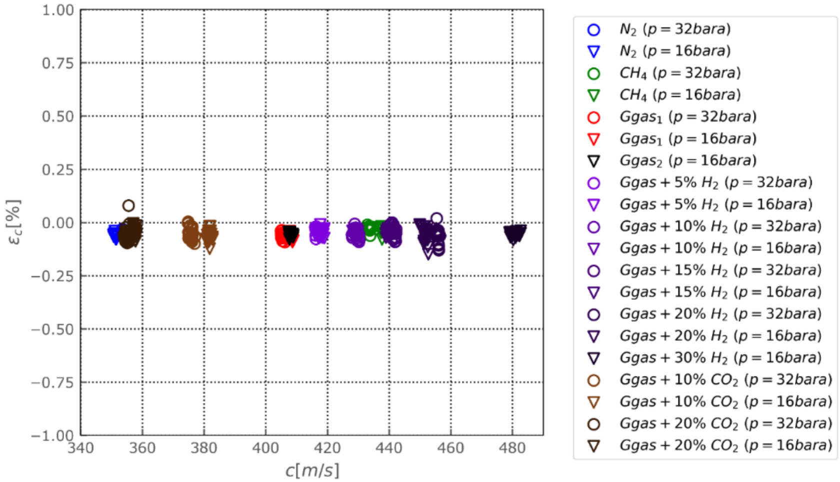
EXISTING GAS METERS suited and calibrated on Natural gas

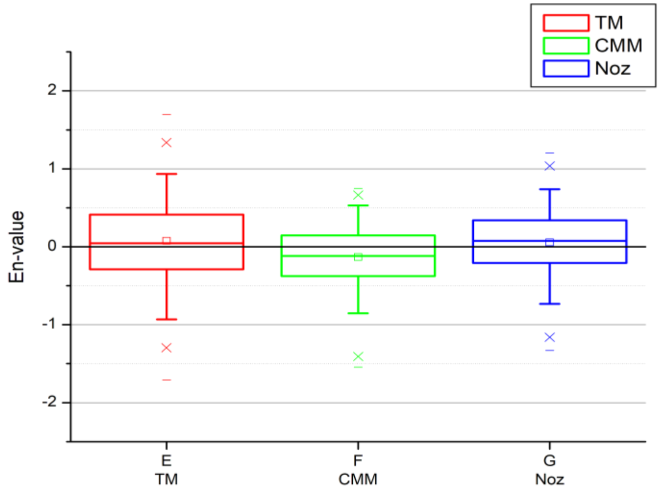
Connection diameter test subject 2 – 12 inch

- For this JIP 6” and 8“ meters
- Large pressure drop due to screw pump allows all meters in series (incl. the gas reference meter setups)

A new optimized gas quality determination =using dual-GC in combination with SOS based gas composition correction

- Initial Molar Mass uncertainty estimate was 0.10%
- PTB advised a correction based on difference CMM and TM. This was only implemented in the nozzle reference value
- Further optimisation of gas composition was done based on SOS values of ultrasonic flow meters and the perception, that the SOS values were not correlated with any US instrument drift
- Small changes in gas composition were implemented to correct for all physical quantities of all meters (references + MUT)
- Results:
  - All reference technologies (nozzle, TM and USM) are acting consistently within the claimed uncertainties (k=2; 95% probability), see PTB-DNV paper #11 presented by Jos van der Grinten
  - All MUT flow-average drifts due to gas composition can be observed within a significance level of 0.05%





Tests performed simultaneously for 13 meters (ten 6”and three 8”) in jan/feb 2021:

- 4 Turbine meters
- 5 Fiscal ultrasonic meters
- 4 Process ultrasonic gas meters

10 different gases:

- Pure gases (N2 (M=28); CH4 (M=16))
- Groningen gas (G-gas1 (M=18.65))
- Hydrogen mix gases: G-gas with 5%,10%,15%, 20%, 30% H2 (M = 17.92 ….13.65)
- Reproducibility test G-gas (G-gas2)
- CO2 mix gases: G-gas with 10%, and 20% CO2 (M= 20.97;23.53)

Other conditions for each gas test:

- same Temperature T~20 Celsius
- Two pressures: p=16 bar; 32 bar
- ~10 different flow rates 16-1000 m3/hr

REFERENCE SYSTEM uncertainty and reproducibility

An uncertainty based weighing was applied to the reference to obtain an overall uncertainty on mass flow of <0.12%

Typical numbers for the reference system (based on the weighed contribution of nozzles, TMs and Coriolis) are

- Repeatability (minute-to-minute reproducibility) references < 0.015%
- Reproducibility (day-to-day– same setup, gas, p,T, flow) reference system < 0.10 %
- Transferability (day-to-day - other gas same setup, p,T, flow) reference system < 0.14% / (with optimised gas composition 0.11%)

These numbers are single flow point numbers based on all MUT results of the JIP as the results of the reference system and calibration process are better than those of the best repeatable, reproducible and transferable instrument

Results

(For the JIP 9 USM meters and 4 TM meters in series)

MUT results– Repeatability

Repeatability numbers are calculated as twice the standard deviation of the mean value of 3 consecutive 100 seconds repeat points.

Turbine meters

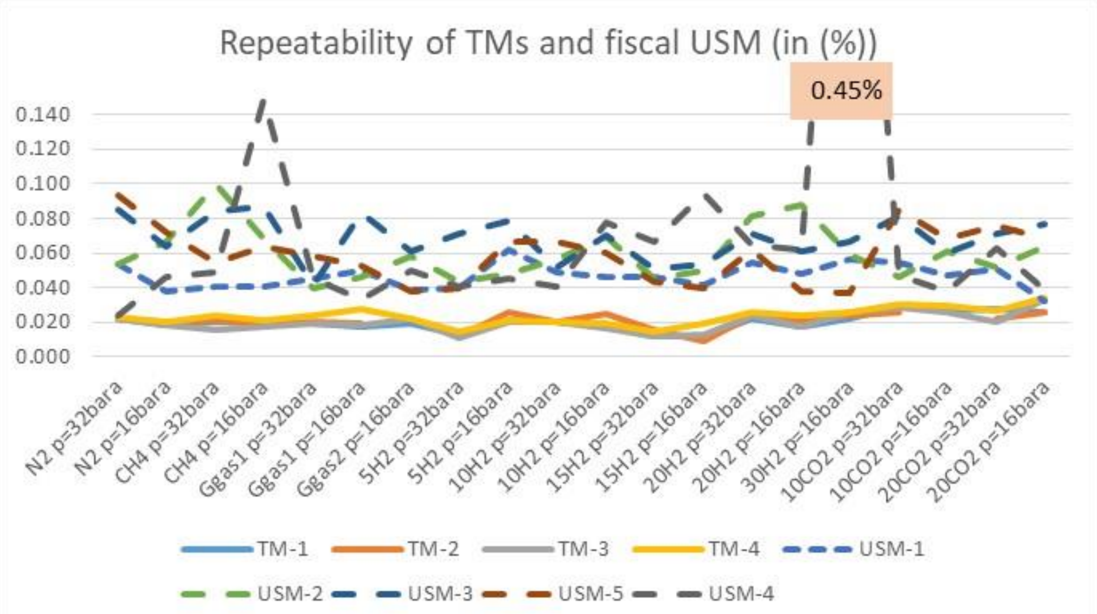
- Repeatability ~ 0.02%
- No specific X-gas dependency

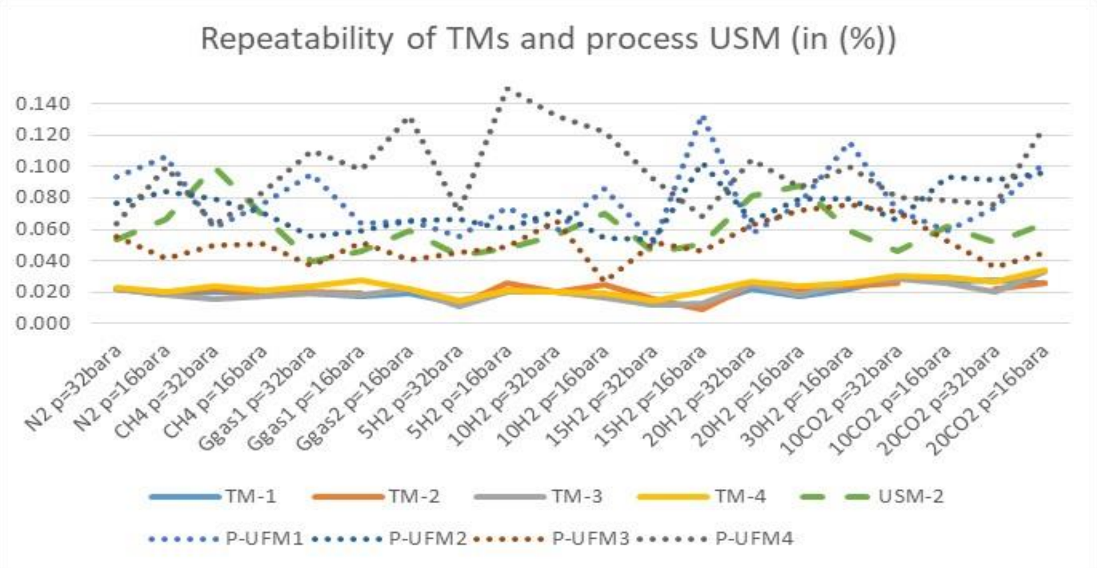
Fiscal US meters

- Repeatability ~ 0.04%- 0.08%
- X-gas dependency

Process US gas meters

- Repeatability ~ 0.05%- 0.11%
- X-gas dependency





MUT results– Reproducibility

Reproducibility numbers are day-to-day single point reproducibility values calculated for each MUT meter based on tests at G-gas (1-feb-21) and similar repeated test with the same gas on 8-feb-21.

Turbine meters

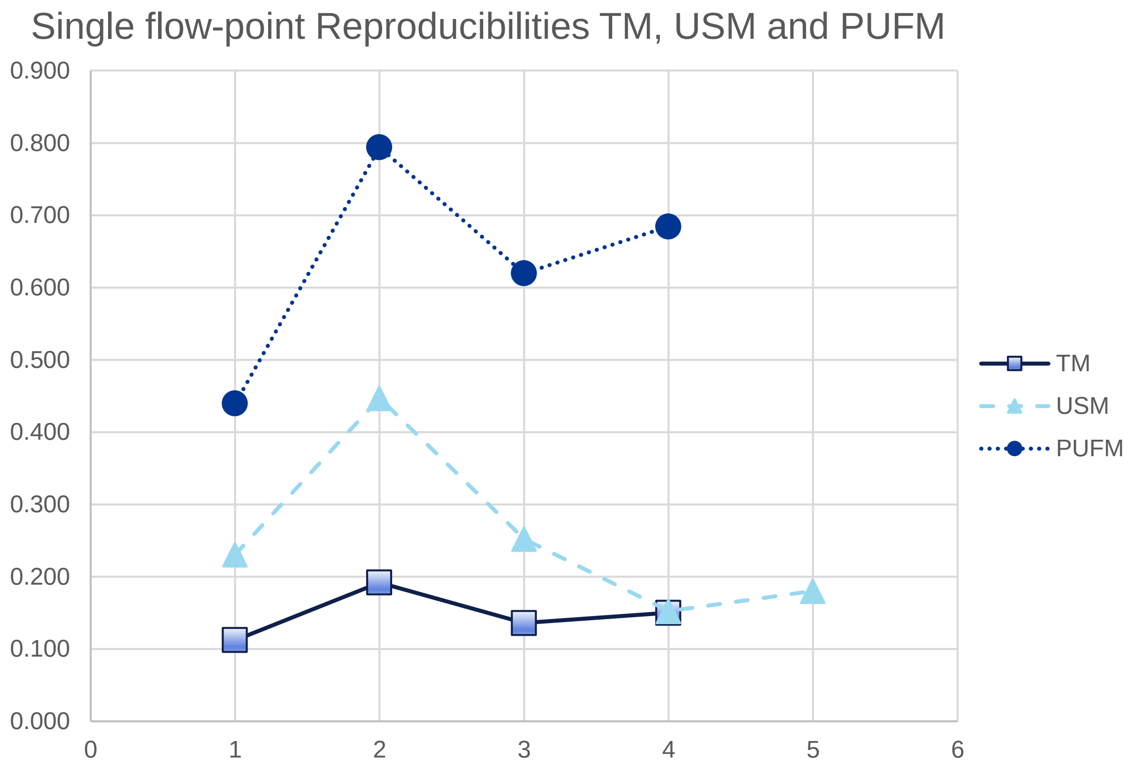
- Reproducibility ~ 0.10% - 0.19%

Fiscal US meters

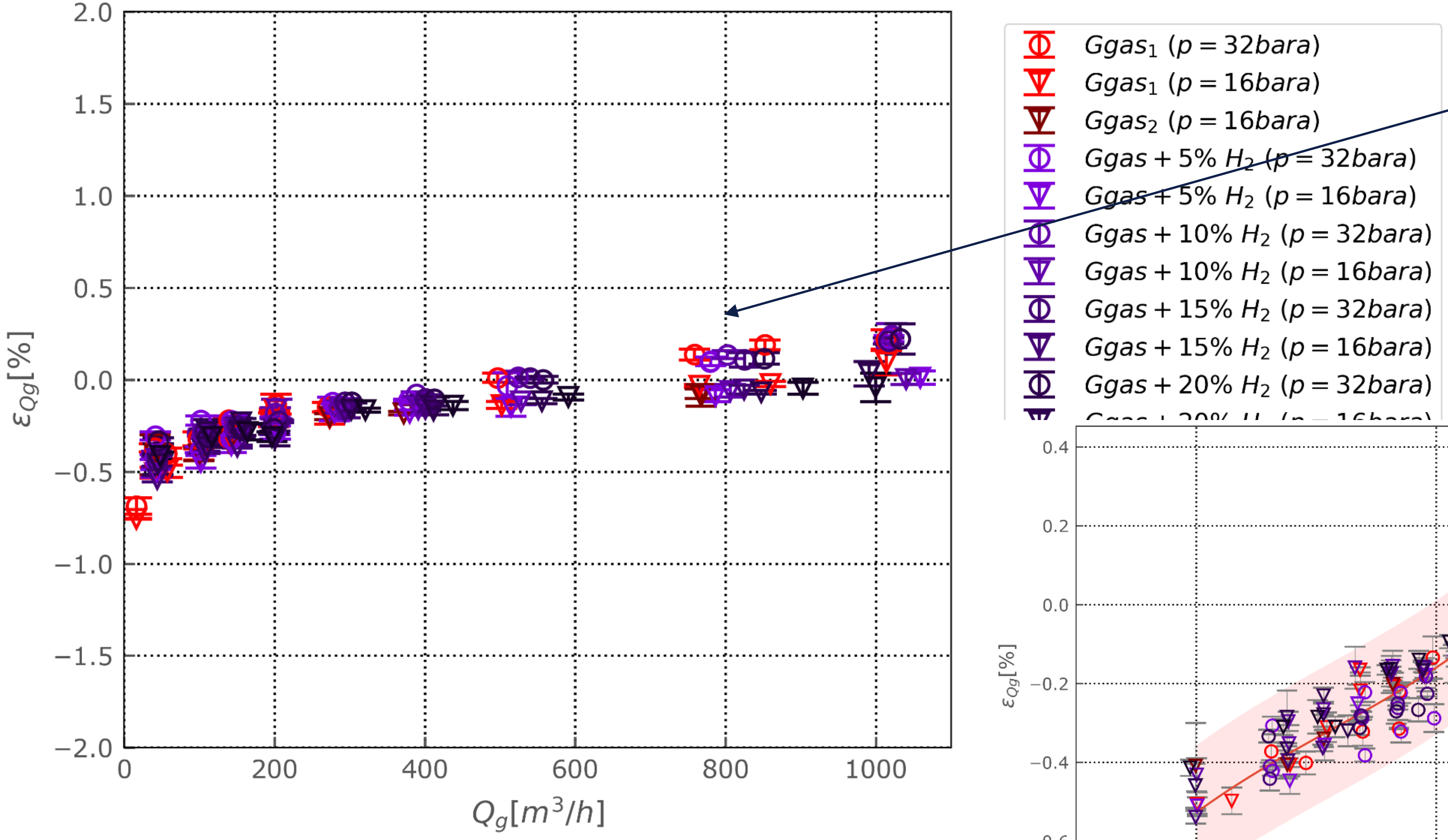
- Reproducibility ~ 0.15%- 0.45%

Process US gas meters

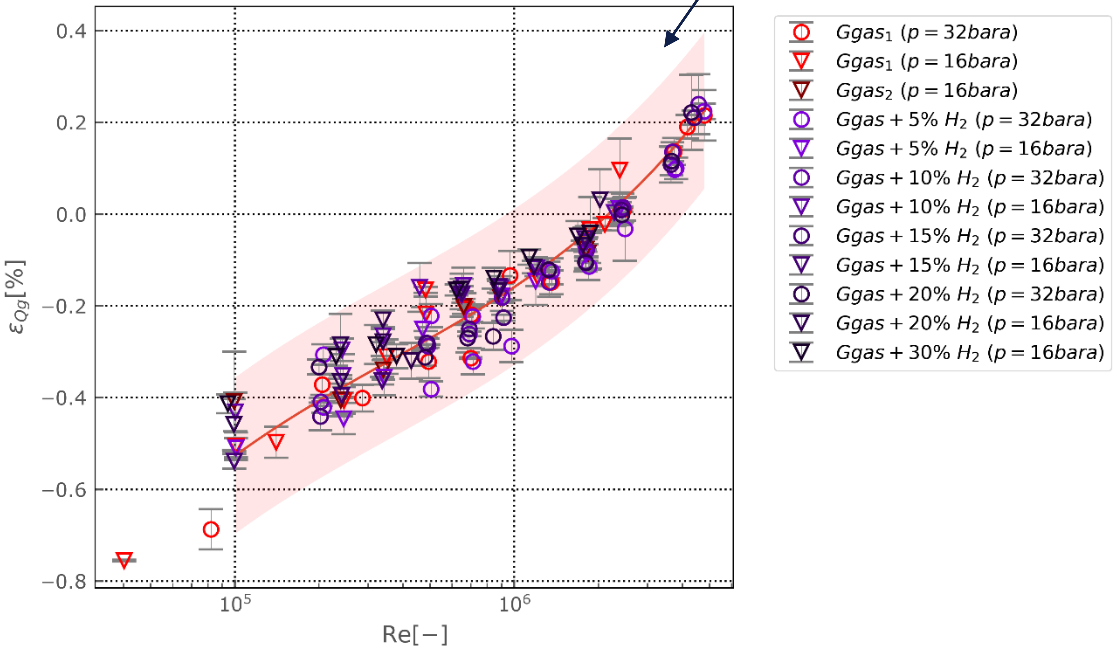
- Reproducibility ~ 0.45%- 0.8%



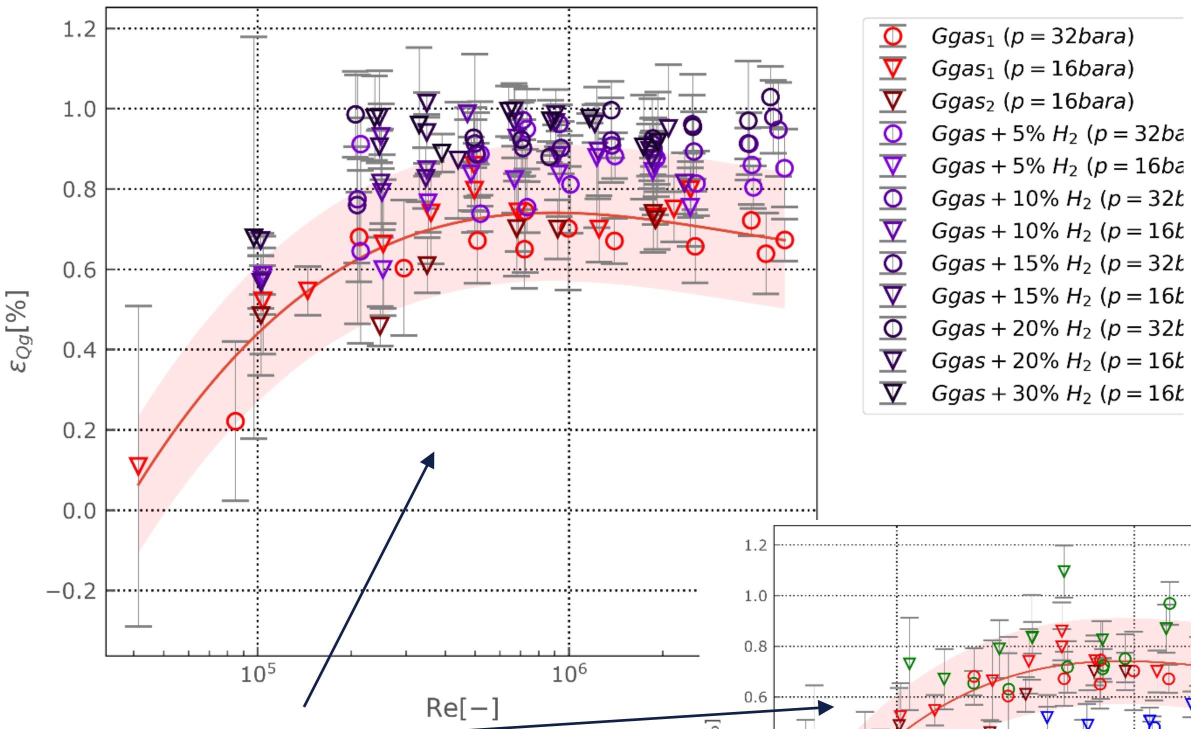
Typical MUT TM RESULTS (Reynolds)

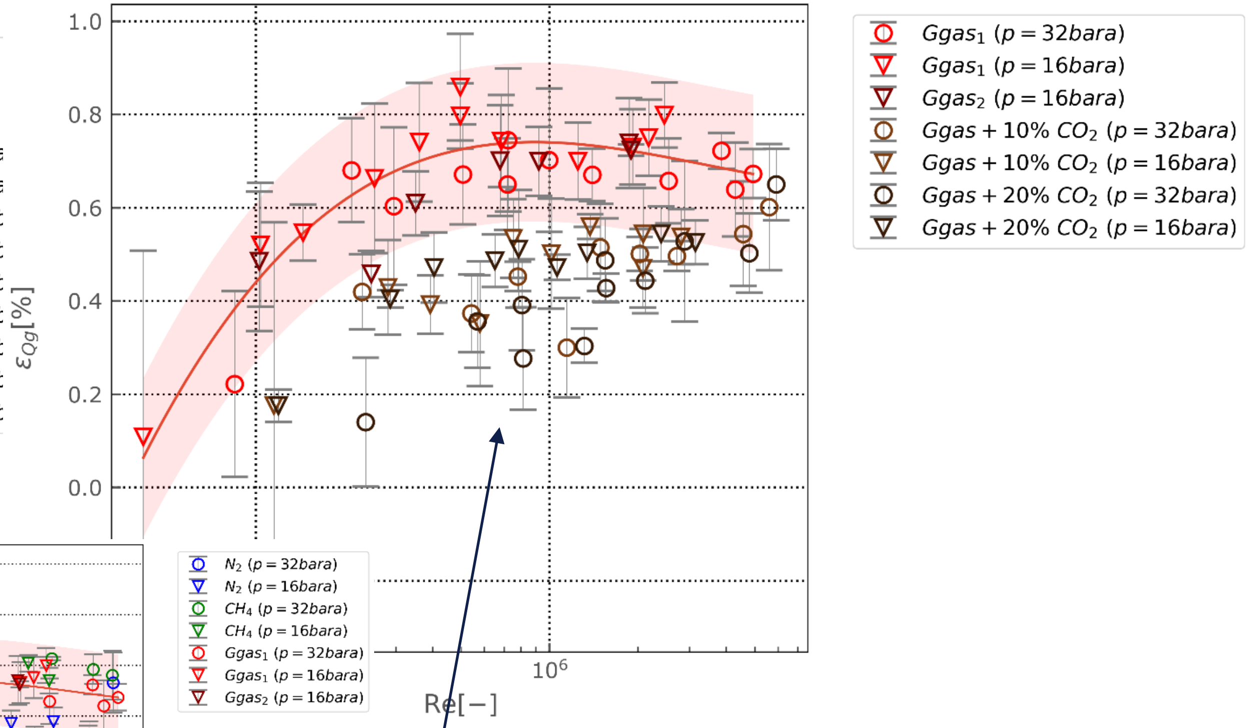


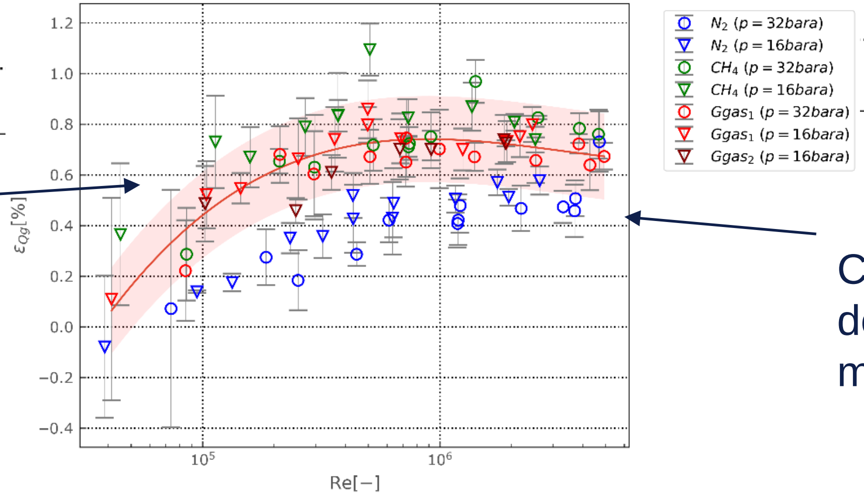
- In normal presentation there are different curves at 16 bar and 32 bar (0.2 % difference)
- In Reynolds presentation this is one curve (all fitting within the point-by-point reproducibility



Consistent molar mass dependent drift of US meter







Consistent drift behaviour upward at lower molar mass M (Hydrogen) and CH4

Consistent drift behaviour downward at higher molar mass M (CO2-mix) and N2

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MUT results– Flow Weighted Mean Average Error

The JIP is interested to understand and characterise the drift depending on gas composition.

- In the gas industry one characterises drift by a FWME number is used (definition cf. ISO17089)
- We process the data by determining for all 13 MUT at all 20 different tests a FWME value
- Note: Random effects are reduced due to averaging
- To eliminate pressure/ Reynolds effects we have compared all 32 bar results with G-gas 32 bar as a reference, and all 16 bar results with G-gas 16 bar as a reference and look at the differences:
- X-shift = $DEV_X = FWME_X - FWME_{G\text{-}gas}$
- By taking this method based on differences we have also eliminated systematic effects related to line-up and measurements of p, T, and flow and mainly see the gas composition effects on the meter

ISO 17089-1:2010(E)

6.3.4 Calculation of flow-weighted mean error (FWME)

The FWME, $\overline{E}(q_V)$, is calculated as follows:

$$\overline{E}(q_V) = \frac{\sum\left[\left(q_{V,i}/q_{V,\,\text{max, op}}\right)E_i\right]}{\sum\left(q_{V,i}/q_{V,\,\text{max, op}}\right)} \quad (25)$$

where

$q_{V,i}$ is the tested flow rate;

$q_{V,\,\text{max, op}}$ is the maximum rated operational capacity of the meter;

E_i is the error, as a percentage, indicated at the tested flow rate, $q_{V,i}$;

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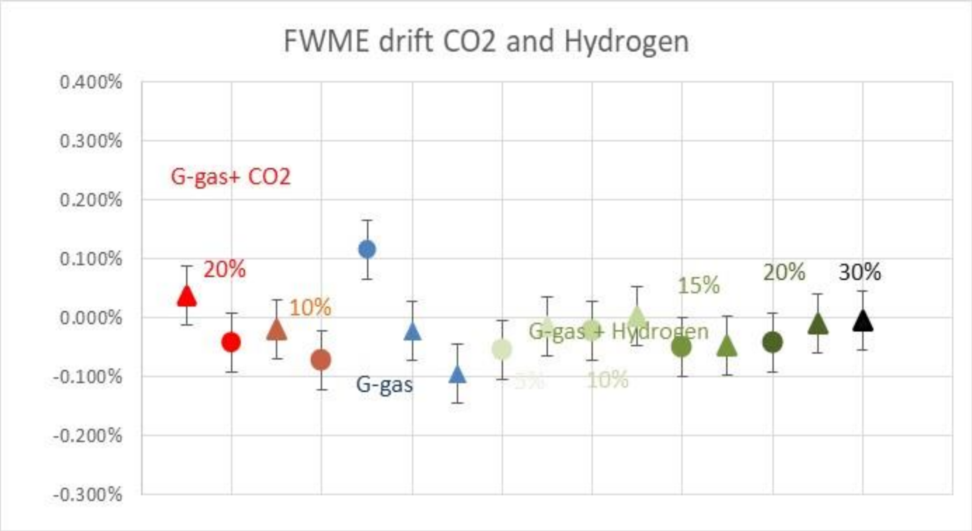
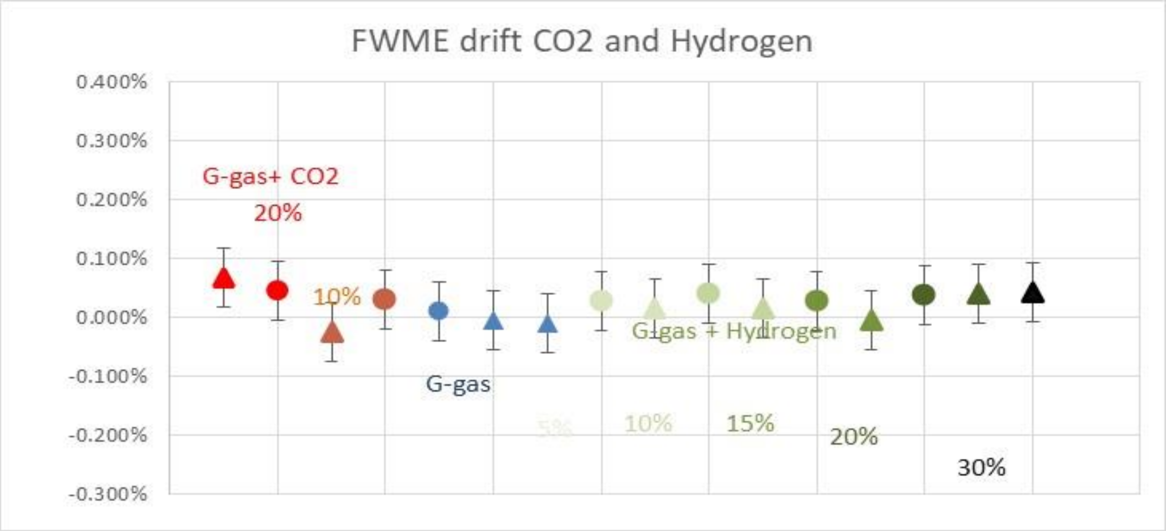
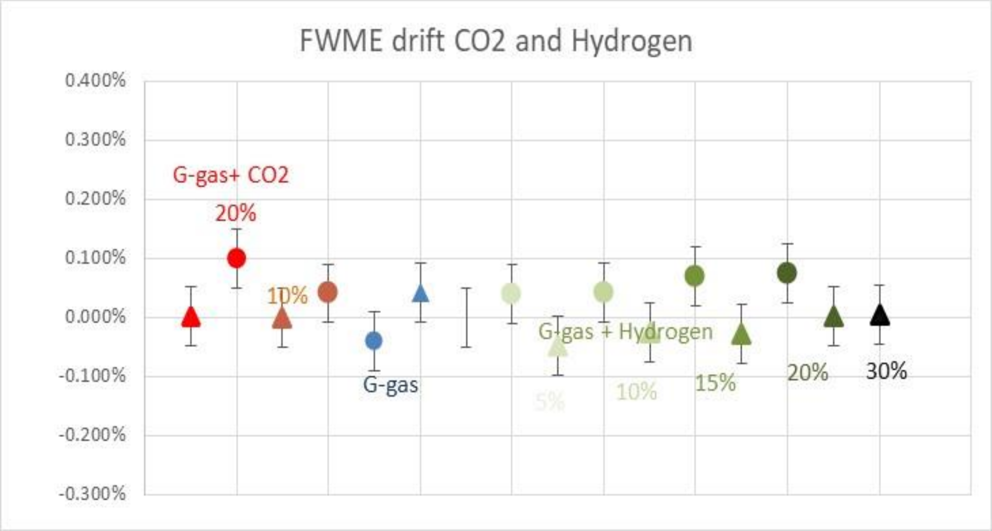
MUT results– FWME drift results Turbine meters

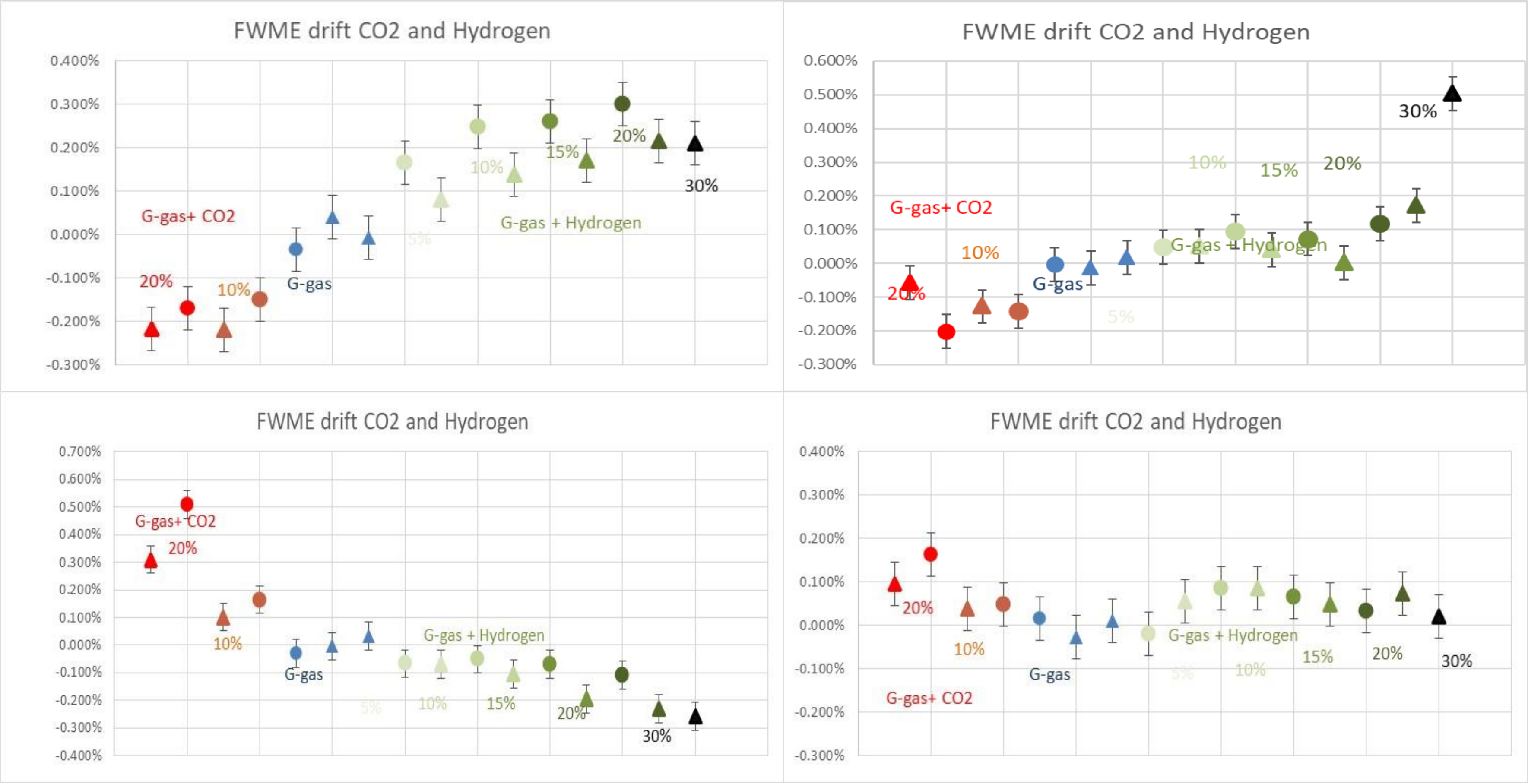






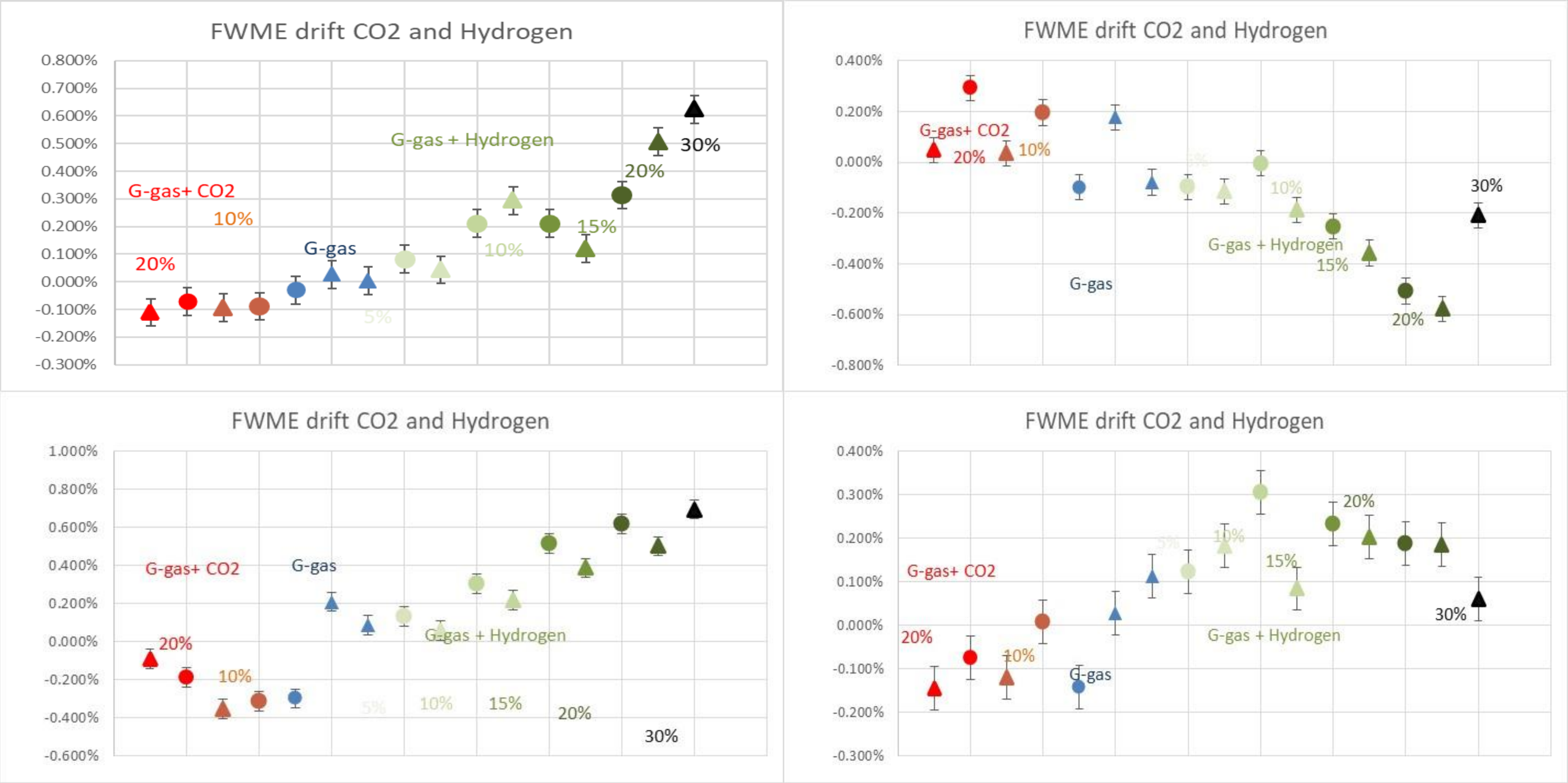
- Results of 3 (new) TMs
- Note: error bars are 0.05% (facility FWME day-to-day reproducibility)
- no systematic gas composition effects are observed
- Deviations found are consistent within the meter's FWME transferability (TM-value typically 0.07% - 0.08%)
- Significance check for new TMs only 1 out-of-50 tests has a significant deviation

MUT results– FWME drift results fiscal US meters



- Note: error bars are 0.05% (facility FWME day-to-day reproducibility)
- systematic gas composition effects are observed on 3 of the 5 fiscal USM
- Deviations found for those 3 are consistent within a meter's molar mass trend (two with 17-out-of-17, one with 15-out-of 17)
- From the meter shown with no significant drift only 1 out of 17 tests is considered significant based on the meter's reproducibility (typical FWME reproducibility 0.08%-0.15%)

MUT results– FWME drift results process US meters



- Note: error bars are 0.05% (facility FWME day-to-day reproducibility)
- systematic gas composition effects are observed on all 4 process USM
- Deviations found for those 4 are consistent within a meter's molar mass trend (3 with positive slope and one with negative slope
- Typical FWME day-to-day reproducibility to other gases: 0.15% - 0.25%

Results – General technology results

In general terms we can say the following about the results:

- TM meters have a better repeatability and reproducibility in comparison with USM
- Also, the drift behaviour of TMs is small and insignificant within the meters and facility reproducibility/ transferability
- USMs show drift behaviour, that differs from meter-to-meter depending on path configuration, settings and correction algorithms.
- For fiscal USM the observed drifts are in linear terms between -0.06% and +0.05% per molar mass change dM (only for hydrogen mixtures the drift varies between -0.09% and 0.05%)
- For non-fiscal USM the observed drifts are between -0.14% and +0.06% per molar mass change dM (only for hydrogen mixtures the drift varies between -0.14% and 0.10%)
- SOS is a good indicator of consistency gas composition, pressure and temperature, but is not indicating meter drift related to different gases

Conclusions Lessons learned on useability of flow meters in renewable gas

- For fiscal meters in natural gas it will be necessary to understand and correct the drift behaviour of US flow meters
- In the gas industry one has been used to calibration of flow meters close to operational conditions and correct only using **flow dependent** coefficients. To use the meter in significantly different gases (molar mass differences > 1) **Reynolds values** are to be used as means to implement corrections from one gas at calibration to another gas in the field environment.
- The drifts of USM are depending on settings, corrections and configurations and so those conditions need to be logged as well along with a calibration
- It is not yet fully understood what effects play a role in gas composition dependent drift behaviour. Next challenge to manufacturers of US meters to prove and understand those differences.
- Note: For this JIP It was agreed upfront, that manufacturers deliver a meter suited for natural gas, and not a meter suited for all mixed gases. So upfront it was not meant to be a competition between manufacturers, but the JIP was set up to learn which factors can affect the drift behaviour.
- We greatly acknowledge the support of all JIP partners

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Let’s join forces to overcome tomorrow’s industry challenges today

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