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Technical Paper

Flow Meter Performance for The New Hydrogen and Carbon Capture Economy

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1 INTRODUCTION

World policy makers and energy sector leaders are ramping up efforts to establish the infrastructure that will support the energy transition and lead the way to Net Zero Energy which is promised to offset the carbon footprint and mitigate rising climate temperature. To achieve Net Zero Energy, policies and large scale investments need to produce and put into operation the technology that facilitates a balance between the energy produced and the Green House Gas (GHG) emissions released into the atmosphere.

As the Energy Transition value chain, Fig. 1, grows enabling Net Zero Energy, both the Hydrogen (H_2) in all its forms and the captured Carbon Dioxide (CO_2) will be subject to transportation tariffs, storage fees, fiscal hand-overs, and carbon tax rebate. This will necessitate a unified approach of quantity/quality measurement and thus the necessity for the means/infrastructure for traceability of measuring instruments to a reference standard. Until such time dedicated traceability platforms are built, tested, and recognized for Net Zero Energy enablers, it is technically feasible to employ the existing calibration facilities for measurement accuracy transferability from other fluids similar to what have been adopted for the Oil and Gas industry.

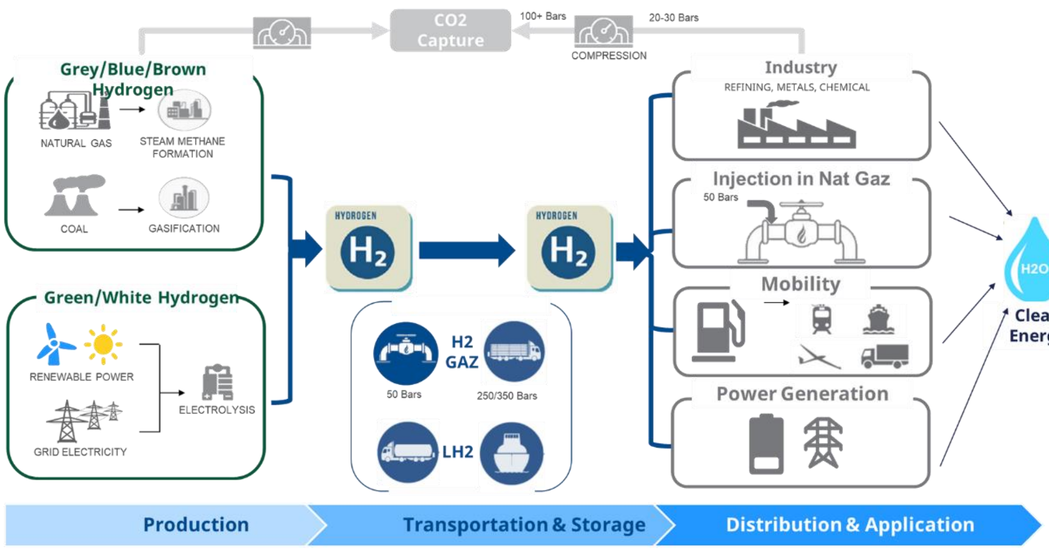

Fig. 1 - Energy Transition Value Chain

Technical Paper

This paper presents a qualitative evidentiary overview with preliminary results on H_2 and CO_2 for Coriolis flow meter transferable performance (mass or volume) from water calibration standards and other gases offering a projection on its viability as a strong candidate for the Energy Transition applications.

2 MEASUREMENT ACCURACY TRANSFERABILITY

The principle of measurement accuracy transferability is that performance and error curves of a measuring instrument can be generated using an alternative fluid (gas or liquid) that simulates the characteristics and conditions at which the measuring instrument will be operated at with a different fluid. Utilization of substitute gases and liquids for calibrating measuring instruments have been employed in the Oil and Gas industry to establish traceability to a reference standard.

This approach addresses the technical, logistical, and safety constraints that often limits the ability to calibrate with fluids for which the measuring instrument is actually intended to measure. For example, mineral and synthetic oils are commonly used as an alternative to viscous Crude Oils, Fuel Oils, and Diesel. Liquid Nitrogen has been used for calibrating measuring instruments to simulate cryogenic applications.

Water calibration was also proven to be a reliable approach to replace calibration on gas or other liquids for Coriolis flow meters. For example, statistically significant tests demonstrate that water transferability is viable and can generate results within ±0.3% for a class 1.0 meter used for gas applications. An example of performance traceability from water to gas is presented in Fig.2 where a Coriolis flow meter was calibrated on Natural Gas after calibration on water.

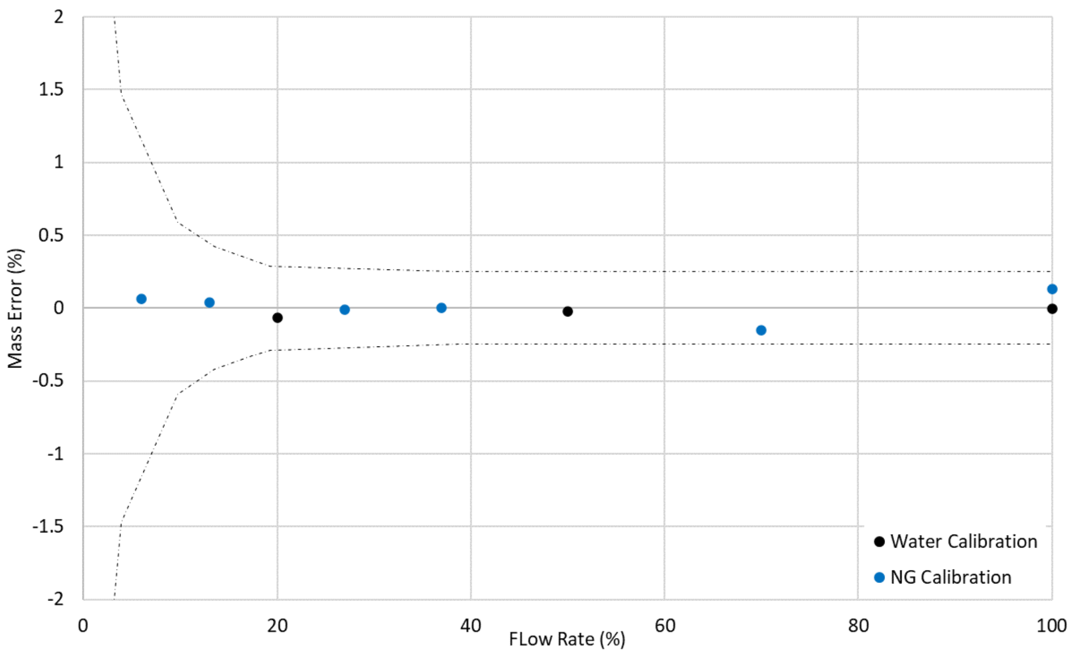

Fig.2 - Example: CMFHC2 test on NG after calibration on water with Meter Specification of 0.25%

Given the evidential viability of employing alternative fluids for calibrating Coriolis flow meters in the oil and gas industry, it can be argued that similar consideration is technically feasible for Coriolis flow meters used in measuring H_2 and CO_2. This consideration can at least be viable in the short-term until it is technically and commercially viable to store and operate H_2 and CO_2 as a test medium for the purpose of calibrations at third-party calibration houses.

2.1 Water as an Alternative Calibrating Medium for the Energy Transition Economy

Water as a calibration medium offers a multitude of advantages. It is easy to store, safe to handle, and facilitates calibration reproducibility. Furthermore, calibrating on water allows tighter controls on uncertainties associated with changes in temperature, pressure, and density conditions during the calibration.

2.1.1 Water Calibration of H_2 Gaseous Measuring Instruments

In comparison to H_2 in gaseous or liquid form, water does not have obvious characteristics such as the known low density of H_2. However, due to the physical capabilities of a Coriolis flow meter to measure mass/volume, it is possible to prove a relationship between H_2 and water with additional consideration for uncertainties associated with the H_2 density.

Emerson's new High Pressure Coriolis (HPC) flow meters, Fig.3, performance on H_2 were validated against a VSL weigh scale system [1] using H_2 during dispensing application at 350 bar and 700 bar.

As seen in Fig.4, the accuracy performance is well within the defined accuracy class of 1.5 set by OIML R139. On average, the percent error is twice better than the Maximum Permissible Error (MPE) across the different modes of operation [1].

Fig. 3 - Emerson HPC (H_2 dispensing) [1]

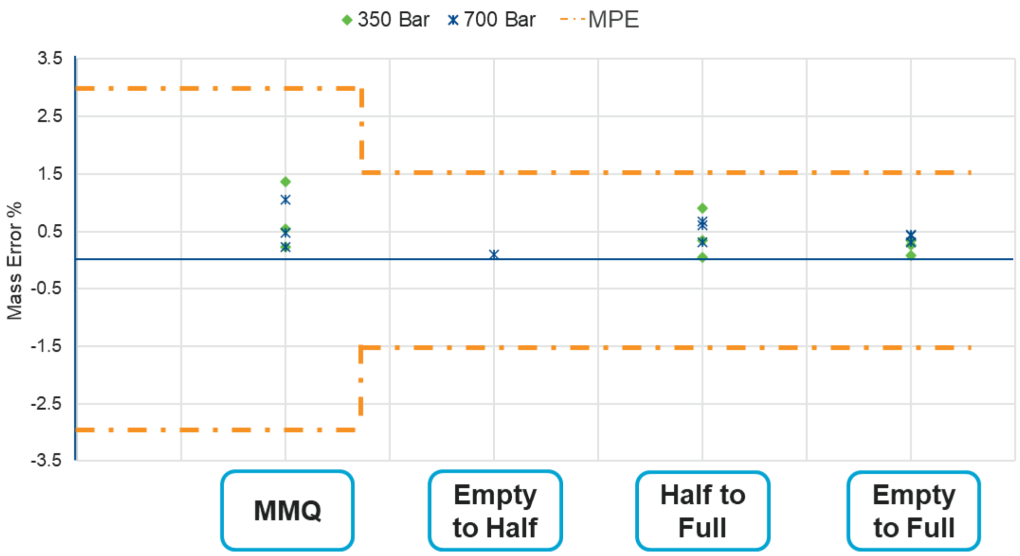

Fig. 4 - HPC performance assessment on Pure H_2 [1]

The now commissioned meters were not subjected to calibration on Pure H_2 prior to installation and testing with H_2. Instead, the performance on H_2 shown in Fig. 4 was achieved with the original Factory Calibration Factors as determined by water calibration in accordance with ISO 17025 guidelines, Fig. 5.

It is important to note, that the above mentioned verification of the HPC meters were executed together with the complete dispensing system. Therefore, the results presented in Fig.4 includes the uncertainties of the complete dispensing solution.

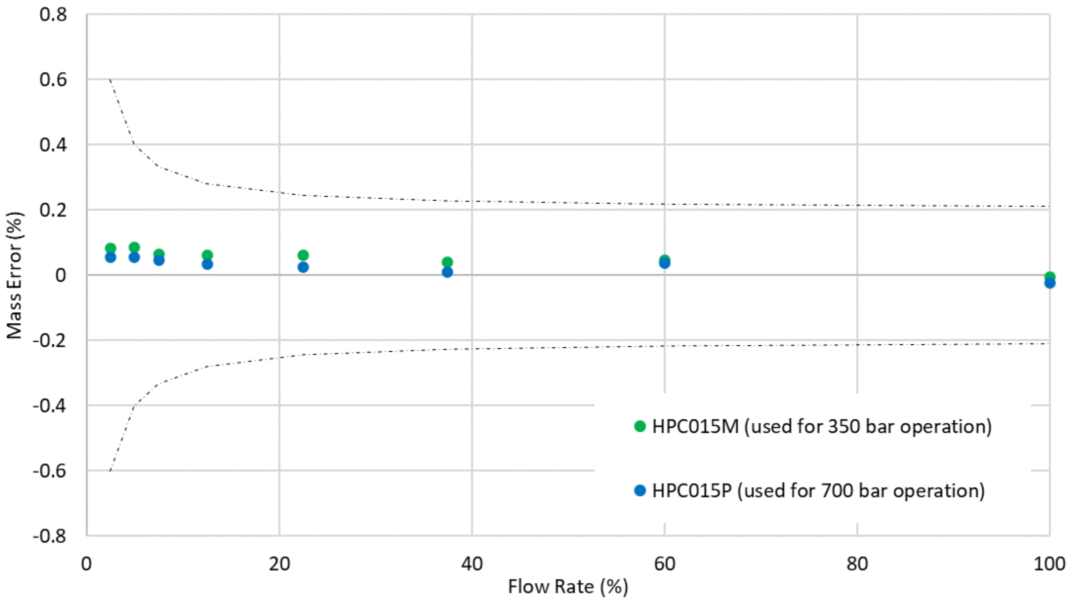

Fig. 5 - HPC water calibration (ISO 17025)

2.1.2 Water Calibration of CO_2 Gaseous Measuring Instruments

Despite the obvious differences in fluid characteristics between H_2 and CO_2, evidence for water transferability to CO_2 is technically feasible. Emerson's Elite Flow Meter (CMFHC2) was calibrated on CO_2 with various impurities ranging from 90% to 100% CO2. Fig.6 presents the relationship between the average error at different flow rates and the water calibration results. It is evident that the meter performed within an average error limit of ±0.5% which is compliant with accuracy class 0.5 for gas meters as specified in OIML R137.

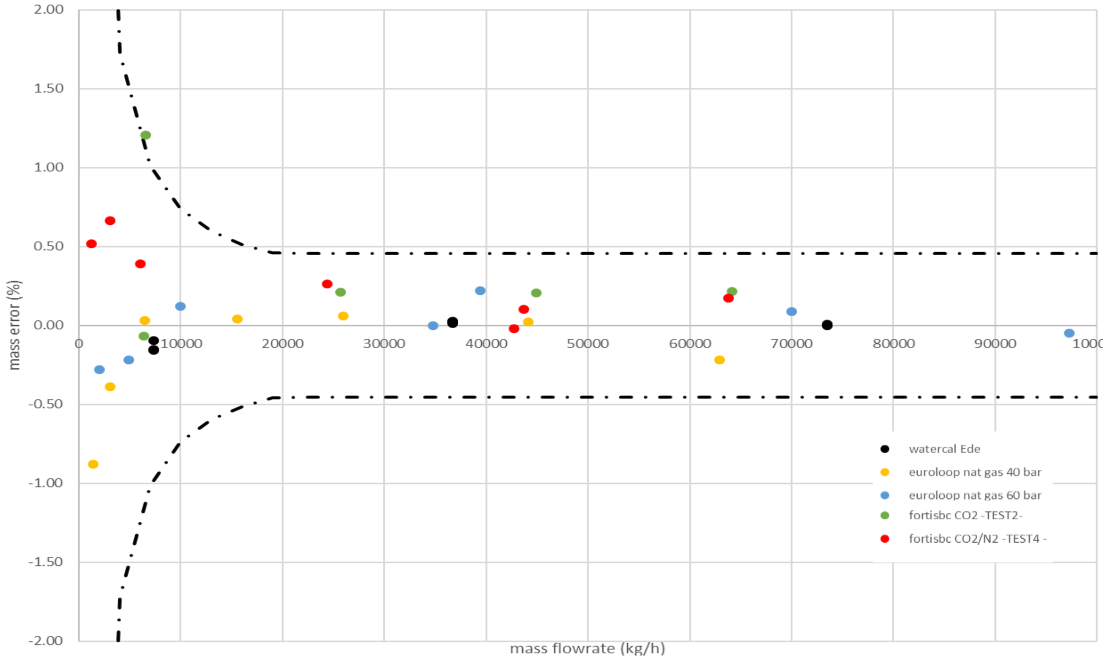

Fig. 6 - Calibration on CO2, Natural Gas and Water (ISO 17025)

2.2 Substitute Gases as Alternative Calibrating Mediums

Just as with water, there are alternative options for gases that can be used as a calibration medium to which traceability and transfer of accuracy between gases can be demonstrated. The salient difference is the need for additional consideration of uncertainties associated with fluid compressibility between the different gases as proposed by Kemp and Kutin in their estimation of mass error in a Coriolis flow meter [2].

Some examples of alternative gases to be considered as calibration mediums for H_2 and CO_2 are Air, Nitrogen, Natural Gas, and Helium. They are available in abundance and safe to handle with the exception of Natural Gas which is often available safely through access to gas supply lines. These gases can be manipulated to simulate conditions comparable to H_2 or CO_2 however that will come with certain limitation on flow rate capabilities and stability.

2.2.1 Substitute Gases for Calibrating H_2 Measuring Instruments

Considering the low density characteristic of H_2, Air, Nitrogen, or Helium can offer the closest proximity that could be considered as a viable alternative to establish accuracy transferability. To test that theory, Emerson's HPC flow meter, Fig. 3, was tested on Nitrogen at various pressures. As evident in Fig.7, the performance error remained within the ±1.0% MPE margin for a class 1.0 gas meter. This is in line with the H_2 performance highlighted in Fig. 4. The mass error significantly improved to within ±0.5% as the pressure increased from 10 bar to 30 bar. This observation also supports the argument that gas compressibility is an area of focus that will be evaluated and discussed in a later paper.

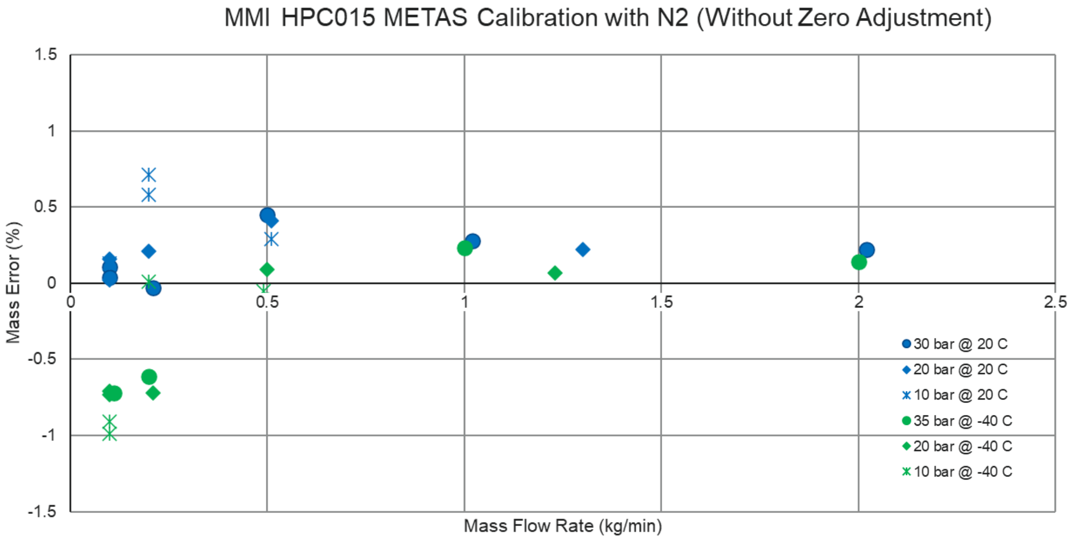

Fig. 7 - HPC calibration on Nitrogen at different pressures and temperature conditions [1]

Testing against traceable laboratory reference measurements with commonly available calibration mediums like natural gas and carbon dioxide, Fig.6, has already shown that results align between tests on different gases for the same meter.

A clear challenge of using gases as a calibration medium, however, especially for measuring instruments with a pressure drop is the rangeability and the maximum flow rate that can be achieved at different conditions. This is attributed to the maximum allowable velocity of the fluid through the meter. As evident from Fig.7, at lower pressures, the maximum mass flow rate possible through the meter is significantly reduced. Therefore, the conventional mass error curve vs. mass flow rate may not be the optimal path forward to establish traceability with substitute gases.

One possible option to overcome this challenge is evaluating a new relationship of mass error to the velocity of fluid through the measuring instrument. i.e. instead of generating a mass error vs. mass flow rate, the measuring instrument behaviour can be described in terms of mass error vs. the velocity of the fluid as a fraction of the Speed of Sound (also referred to as the MACH number).

2.2.2 Mass Error Curve vs. MACH Number for Gases

To understand the potential for this relationship, it is important to start with the fact that sound travels at different speeds through different gases. This property can be quantified using a dimensionless number referred to as the MACH number. The Mach number for a gas is defined as the velocity of that gas as a fraction of the Speed of Sound and is described in (1)

$$M = \frac{u}{c} \tag{1}$$

Due to the low density of H_2, the Speed of Sound of most substitute gases is lower than that of H_2. This makes the maximum mass/volume flow rate significantly higher for H_2 gas than it is for most other gases. For example, a 0.3 Mach flow rate of natural gas with a speed of sound of 466 m/s would be 140 m/s. In contrast, a

0.3 Mach flow rate of H_2 gas with a speed of sound equal to 1320 *m/s* would be 396 *m/s* (2.8 times higher than natural gas). The maximum flow rate (Qmax) of a Coriolis meter is typically set at 0.3 Mach for all gas compositions which will be a different maximum velocity in units of *m/s* for each different gas (depending on the speed of sound in that gas).

To test this concept, an Emerson Coriolis flow meter was tested with Air at various pressures. No specific attention was necessary for this initial test to demonstrate accurate mass error since the primary objective was to determine if there is a feasible relationship between the mass error and the Mach number. When plotting the mass error in relation to the mass flow rate, no discernible pattern is observed except the obvious maximum flow rate limitation at low pressure runs, Fig.8.

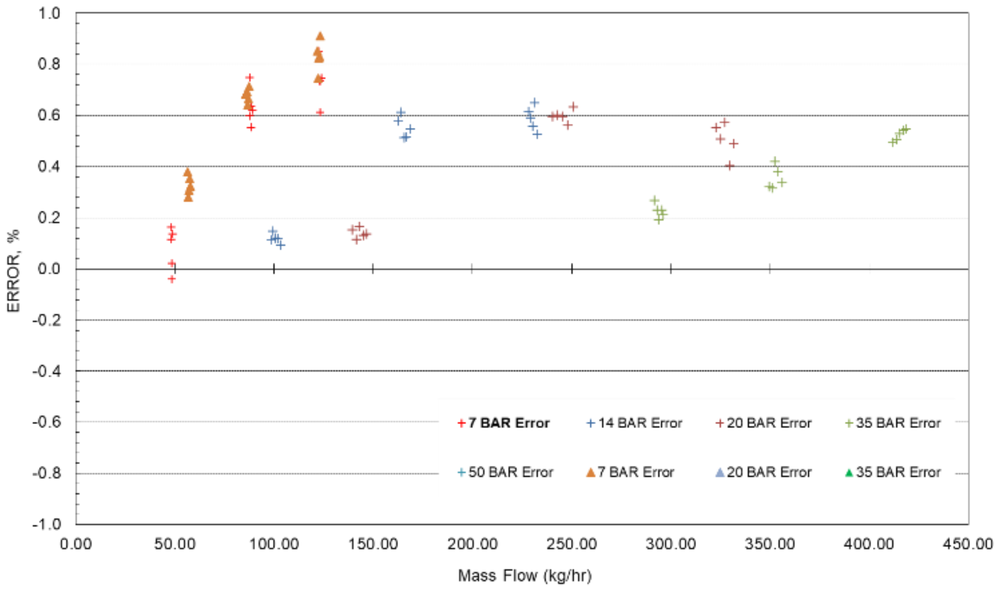

Fig. 8 - Results at various pressures plotted by mass flow rate

However, when this meter performance is plotted in terms of mass error vs. MACH number, Fig.9, a clear pattern emerges. It becomes evident that modelling the meter performance on one gas may be transferrable to another solely on the MACH number.

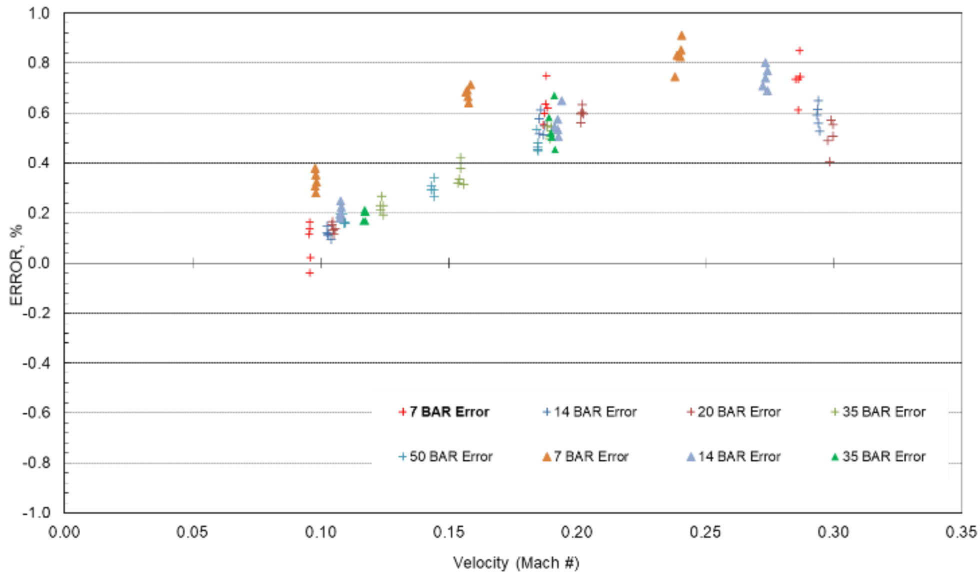

Fig. 9 - Results at various pressures plotted by Mach number

Additional tests were conducted on an Emerson Elite 2 inch Coriolis flow meter (CMF200) on air with different pressures. A similar pattern, Fig.10, was observed with very high degree of alignment thus proving a single meter performance can be transferable at different gas conditions. This meter is planned for a calibration on H_2 to confirm transferability using this concept.

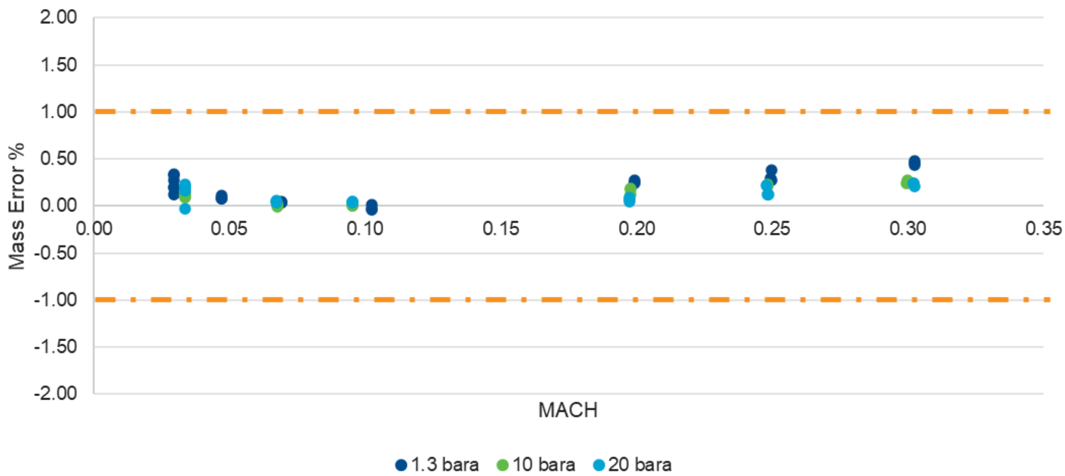

Fig. 10 - Results at various pressures by Mach flow rate (CMF200) [1]

2.3 Conclusion

The presented preliminary results supports the argument made in this paper that calibration curves can be generated based on a transferable relationship from other fluids. In the case of substitute gases, the mass error curve can be applied as a function of Mach number and be transferred with confidence based on units of Mach number instead of volume or mass flow rate for H_2 and H_2/NG mixtures. Otherwise, considering the limitation discussed earlier, it may not be feasible to employ most of the calibration resources globally especially in the short-term to calibrate measuring instruments over their full useful range for pure H_2 measurement.

The results above are empirical and offer qualitative argument for considering water and alternative gases as substitute calibration mediums for H_2 and CO_2. They are a reflection of the authors point of view based on available proven results. A deeper analysis is needed however to build statistically significant confidence in water and substitute gases as alternative calibrating mediums for H_2 and CO_2.

3 NOTATION

u	Fluid velocity (m/s)
c	Speed of Sound (m/s)
M	MACH number
m/s	meter per second
H_2	Hydrogen
CO_2	Carbon Dioxide
NG	Natural Gas
SoS	Speed of Sound
MPE	Maximum Permissible Error
GHG	Green House Gases
OIML	International Organization of Legal Metrology
ISO	International Organization for Standardization
VSL	National Metrology Institute of the Netherlands
HPC	High Pressure Coriolis
CMF	Emerson Elite Coriolis Series

4 REFERENCES

[1] Aart Pruijsen, “Gas Coriolis performance on renewables gases, based on several testing and analysis”, North Sea Flow Measurement Workshop, 2021.

[2] J. Hempa and J. Kutin, “Theory of errors in Coriolis flowmeter readings due to compressibility of the fluid being metered”, Flow Measurement and Instrumentation 17, 2006