HyAC

HyAC - high measurement accuracy of hydrogen refueling

**Funding:** European (7th RTD Framework Programme)

**Duration:** Oct 2013 - Sep 2014

**Status:** Complete with results

**Total project cost:** €737,920

**EU contribution:** €497,129

**CORDIS RCN:** 111013

**Objectives:**

The overall purpose and ambition of HyAC is to address the two main obstacles for accurate and legal metering for commercial hydrogen fuel dispensing:

- Validate and demonstrate that state-of-the-art hydrogen mass flow metering can meet expected legal requirements by conducting accuracy testing
- Analyse existing legislation & standards on gas fuel metering accuracy and provide detailed recommendations on how hydrogen can be included and handled

The outcome of the HyAC project will primarily be a report named: “Recommendations for legal requirements & procedures & for verification & approval of hydrogen metering accuracy”. Scope and purpose of the report will be to provide a thorough basis for later inclusion of hydrogen in the MID directive and OIML recommendation as well acting as a guideline for the handling of hydrogen by national authorities.

In short term EU member countries may use HyAC results for individual handling legal accuracy processes for hydrogen. This may help enable an early roll-out of a hydrogen refueling infrastructure in key EU member countries where market introduction of fuel cell electric vehicles are considered, e.g. Germany, UK, Netherlands and Scandinavia.

Also the HyAC project results can contribute to a potential inclusion of hydrogen in the European MID directive and OIML standard in medium to long term. This would provide a uniform approval process for hydrogen accuracy across Europe and help support a European wide roll-out of hydrogen refuelling infrastructure.

To both collect input for the HyAC activities and secure a strong dissemination platform, networking and dialogue will be secured to authorities in selected EU member countries, working groups of MID and OIML, major European hydrogen initiatives (CEP, SHHP and UK/DE H2Mobilities) as well as major ongoing FCH-JU funded transport demonstration projects.

**Parent Programmes:**

**FP7-JTI - Specific Programme "Cooperation": Joint Technology Initiatives**

**Institute type:** Public institution

**Institute name:** European Commission

**Funding type:** Public (EU)

**Lead Organisation:**

**Nel Hydrogen As**

**Address:**

INDUSTRIEPARKEN 34 B LIND
7400 HERNING
Denmark
Organisation Website:
http://www.h2logic.com
EU Contribution: €215,240

Partner Organisations:

Heinrichs Messtechnik GmbH

Address:
ROBERT PERTHEL STRASSE 9
50739 KOLN
Germany

Organisation Website:
http://www.heinrichs.eu
EU Contribution: €153,835

Rise Research Institutes Of Sweden Ab

Address:
Scheelvägen 27
22370 Lund
Sweden
EU Contribution: €34,496

Doms Metrology Aps

Address:
Formervangen 28
Glostrup
Denmark

Organisation Website:
http://www.domsmetrology.dk
EU Contribution: €57,182

Department For Business, Innovation & Skills

Address:
Victoria Street 1
London
SW1H 0ET
United Kingdom
EU Contribution: €36,376

Technologies:
Fuel cells and hydrogen fuel
Hydrogen refuelling station using ionic compressor

Development phase: Research/Invention

Key Results:

Final Report Summary - HYAC (HyAC – high measurement accuracy of hydrogen refueling)

The project has developed and tested recommendations for accuracy requirements, criteria and procedures for accuracy legal metering of hydrogen, which can be applied and used on national basis for accuracy approval. The conducted accuracy tests with the developed test...
Executive Summary:

The project has developed and tested recommendations for accuracy requirements, criteria and procedures for accuracy legal metering of hydrogen, which can be applied and used on national basis for accuracy approval.

The conducted accuracy tests with the developed test equipment, showed various areas of improvement.

Reducing the total weight of the test equipment could provide more options with regard to supply of the precise weighing device. The higher weight of the equipment the high resolution required of the weighing device, which limits the supply base. Reducing the weight whilst keeping the weighing resolution will also enable a more precise measurement. The present test system design was not developed with weight optimization in mind, so there is great potential for reductions.

The reported peak deviation of -5.32% may be due to either the mass flow meter itself, or various areas of the test equipment which could be optimized:

- During fueling moisture from the surroundings may vaporize on the vessels, indirectly increasing the weight measured. The potential impact of this needs to be verified, and then possible solutions to be considered
- Pressure drop in the test system has not been measured in detail. If they prove to be too high, this could also impact the accuracy measurement on the mass flow meter side.

For future tests of multiple suppliers the test system design needs to be updated to enable a faster change of the mass flow meter in the test set-up. The present design requires an extensive exchange process where parts of the system is disassembled. A faster process and design for change of the mass flow meter can reduce the cost (time) spent on testings.

At present the OIML/MID does not cover metering accuracy for hydrogen. Even though hydrogen is mentioned in recent versions of the OIML/MID (after the HyAC project), the actual specifications has not be formulated with hydrogen in mind, instead CNG. Thus the practicality of the requirements for hydrogen is questionable. E.g. the OIML/MID foresees an accuracy level of only 2%, whereas the specific hydrogen accuracy regulation in California has a “relaxed” targets depending on the time of operation start.

The Californian approach provides room for the technology to mature over the years, and accordingly the accuracy requirements will be stricter every year. In addition the Californian targets are split on measured at the beginning of operation (Acceptance Tolerance) and during operation (Maintenance Tolerance), whereas the latter allows for higher deviations.

In the HyAC project the highest deviation measured was -5.32% out of a total of 16 fuelings, which is slightly outside target requirements in California of 5% in 2018. The remainder 15 fuelings where all inside the target of 4% for 2020. Compared to the accuracy levels experienced prior to the HyAC project (e.g. in Germany where 35% of all fuelings had deviations above 9% as reported in D3.2), the accuracy has become more stable with the optimized mass flow meter design developed in the project. However the peak deviation still needs further addressing through continued R&D on the mass flow meter.

It was planned during the project to conduct testing of mass flow meters from multiple suppliers, instead of only one. This could have enable more detailed recommendations for legal handling of hydrogen metering.

It is therefore relevant to consider future projects that can continue the efforts of HyAC. This could involve tests of mass flow meters from multiple manufacturers with the aim to further validate and advance the test method from HyAC and provide a complete recommendation for legal handling of hydrogen accuracy.

Project Context and Objectives:

The overall scope of the HyAC project has been address the topic of legal metering for commercial hydrogen fuel dispensing.

The project has analyzed existing regulation for fuel metering and past experiences on hydrogen. This has been done for a range of selected countries, where construction of Hydrogen Refueling Stations (HRS) and roll-out of Fuel Cell Electric Vehicles (FCEV) is either ongoing or planned.

Boundary conditions for hydrogen mass flow meters when used for 70MPa have been developed based on technical analyses. The aim has been to provide mass flow meter suppliers with a better understanding of the operation environment in which the component is to be used at 70MPa Hydro-gen Refueling Stations (HRS).
Within the hydrogen development efforts has also been conducted on optimizing existing hydrogen mass flow meter technology. In addition test equipment for mass flow meter accuracy has also been developed enabling verification at factory or in field at the HRS of the mass flow meter used.

Project Results:

The HyAC project has conducted activities and S&T results within the following areas in relation to hydrogen accuracy metering:

1. Analysis of regulation for metering of fuel dispensing & experiences with hydrogen
2. Boundary conditions for hydrogen mass flow meters
3. Mass flow meter optimization & accuracy test equipment
4. Hydrogen accuracy fueling tests

The sections below outline further details of the S&T results within each area. A public report (D4.3) is also made, which provides a more elaborate reporting of results including pictures, figures and graphs.

1. Analysis of regulation for metering of fuel dispensing & experiences with hydrogen

1.1 OIML standard & MID directive – possible inclusion of hydrogen

HyAC has identified various existing OIML standards and MID directives for metering that could as a basis for considerations on hydrogen accuracy metering. Hydrogen would most likely have to be added in the future as an ANNEX to one or several of these directives and/or standards.

Concerning adding hydrogen as an annex to MID and/or standard, this could be based on the OIML recommendations for the “model” national legislation.

During the period that the project work in the HyAC project has been on-going, the OIML R139 has been split in to sub-documents and updated to include also Hydrogen. This is excellent as such, as there will be normative documents available to refer to in national legislations. The HyAC project has however not been in a position to influence the technical contents, which has not been adapted for hydrogen, i.e. the same MPE (maximum permissible error) applies for Hydrogen as for other gases. No consideration is thus taken for the stable energy content of hydrogen. Neither is any adapted procedure specified, e.g. adapted pressure level when starting measurement.

OIML R139 – Compressed gaseous fuel measuring systems for vehicles

This Recommendation applies to measuring systems intended for the refueling of motor vehicles, small boats, and aircraft with compressed natural gas, hydrogen, biogas, gas blends or other compressed gaseous fuels. They may also be applicable to other vehicles, for instance trains.

The MPE of mass indication is +/- 2 % at verification. At approval the MPE is +/- 1.5% for the system (+/- 1% for the meter). This is independent of gas, i.e. the same for hydrogen as for e.g. CNG. Re-verification period if applied, is set to 5 years.

Other OIML documents that can be of interest concerning the structure and content are e.g.:

OIML R140 - Measuring systems for gaseous fuel

This Recommendation applies to measuring systems for gaseous fuel: with a designed maximum flow rate Qmax equal to or greater than 100 m3/h at base conditions and for operating pressures equal to or greater than 200 kPa (2 bar) absolute. This recommendation includes:

- Metrological requirements
- Accuracy classes
- Maximum permissible errors (MPE)
- Technical requirements
- Rated operating conditions
- Ancillary devices
- Indications
- Markings
o Sealing

o Type evaluation tests

Test procedures

o Initial verification

o Subsequent verification

OIML R137 - Gas meters

This Recommendation applies to gas meters based on any measurement technology or principle that is used to measure the quantity of gas that has passed through the meter at operating conditions. The quantity of gas can be expressed in units of volume or mass. This Recommendation applies to gas meters intended to measure quantities of gaseous fuels or other gases. It does not cover meters used for gases in the liquefied state, multi-phase, steam and compressed natural gas (CNG) used in CNG dispensers. This recommendation includes:

o Metrological requirements

Rated operating conditions

Accuracy classes and maximum permissible errors (MPE)

o Technical requirements

Construction

Ancillary devices

Power sources

o Inscriptions

Markings and inscriptions

o Sealing

Verification marks and protection devices

o Type evaluation tests

Test procedures

Initial verification and subsequent verification

1.2 Experiences with hydrogen metering in selected countries

United Kingdom


Subject to certain limitations (in the Regulations), these Regulations apply to a measuring system which is— (a) for use for trade in the making of a continuous and dynamic measurement of liquid fuel in a quantity equal to or less than 100 litres or 100 kilograms; and first placed on the market or put into use on or after 30th October 2006.

These regulations define the maximum permissible errors dependent upon the designated accuracy class.

Where any weighing or measuring equipment is found in the possession of any person carrying on trade or on any premises which are used for trade, that person or, as the case may be, the occupier of those premises shall be deemed for the purposes of this Act, unless the contrary is proved, to have that equipment in his possession for use for trade
There is currently no national legislation for the accuracy of metering hydrogen as a gas for fueling motor vehicles, in the UK, therefore it would be necessary to contact any (commercial) users to establish the methods - if any - related to metering accuracy including the processes and reference equipment used involved and the traceability of the measurements.

The HONDA Motor Company vehicle assembly plant, situated in Swindon (UK), have a fuel station which is used for re-fueling the forklift trucks operating within the plant. The station is not generally available to the general public.

London transport now has a fleet of eight hydrogen fuel buses running on route RV1 between Covent Garden and Tower Gateway.

Scandinavia

The Scandinavian countries Norway, Sweden and Denmark have various regulation basis for fuel metering as outlined below:

- **Sweden**

  SWEDAC is the Swedish authority for regulation of fuel metering accuracy. Meter accuracy for fuel meters distributing fuel in the state of gas, is not covered by any regulations in Sweden today. Fuels that are in the state of gas when they are filled in a fuel station are not covered by the MID directive. The OIML’s recommendations R 139 are probably used by the manufacturers of the metering equipment on a voluntary basis.

- **Norway**

  Justervesenet (JV) is the Norwegian authority for regulation of fuel metering accuracy. Meter accuracy for fuel meters distributing fuel in the state of gas is not covered by any regulations in Norway today. Decisions taken by the Ministry of Trade and Industry during 2011 were not to include legislation for gas metering accuracy.

- **Denmark**

  The Danish Safety Technology Authority is handling regulation of fuel metering accuracy. The MID-directive Annex MI-002 “Gas meters and volume conversion devices” applies in Denmark and this also includes gas meters for the automotive sector in Denmark. OIML R 139 “Compressed gaseous fuel measuring systems for vehicles” is also to be applied.

  The main experience on hydrogen metering accuracy in Scandinavia is mainly based on Hydrogen Refuelling Stations (HRS) installed and operated in Denmark.

  The MID directive OIML are not used as basis for hydrogen metering in Denmark (as hydrogen is not included).

  Since 2008 more than 10 fueling stations of various pressures have been demonstrated in Denmark. This has created basis for developing a pragmatic approach to handling hydrogen metering, despite no regulation or standard is in place.

  The Danish Safety Technology Authority is handling metering accuracy in Denmark. Based on a dialogue a methodology has been developed that includes a third party validation of the hydrogen metering accuracy prior to installation of a HRS.

  The validation is based on weighing the amount of hydrogen fuelled into a test tank, using precision scales. The tests are done prior to start of HRS operation and is monitored by a third party that calculates the accuracy (% deviation) and issues a test report. In general a consistent accuracy of a few % deviation have been observed on the HRSs installed.

  The approach does not necessarily ensure a coherent approach to accuracy measurement but it ensure that attention is put on accuracy before installing an HRS.

  When hydrogen at a later stage is included in European directives and/or standards, it is likely that this will be implemented in Denmark.

Germany

In Germany activities on hydrogen accuracy is in particular conducted under the public-private the Clean Energy Partnership (CEP). CEP is a joint initiative of government and industry lead-managed by the German Ministry of Transport and Industry with twenty industry partners.

Within the CEP a dedicated working group is active on various hydrogen metering topics:
• Assess fueling data and matching thereof between cars and fueling station
• Assess status on development and availability of metering devices
• Test the accuracy of current metering methods and assess technical feasibility
• Explore variants of Measuring Mass (transfer)

The aim is to establish a metering method in coordination with German authorities (Eichamt) and agencies (e.g. PTB - the National Metrology Institute of Germany).

In 2013 the CEP initiative published results from accuracy tests conducted at various HRSs in Germany. On average 35% of all refuelings had a deviation above 9% and generally the higher the refueled quantities the lower the deviation. Presently the “Weights and Measures Act” applicable for CNG only allows ±2% deviation.

CEP are at present executing a 3-step-development-program to further address the accuracy topic.

This includes a feasibility study on measurement methods, development of prototype measurement equipment for laboratory and later for in-field testing.

CEP has also formulated some initiation boundary conditions for hydrogen accuracy (2013):
• Medium: CGH2
• Pressure: up to 87.5 MPa
• Temperature window: +50°C -40°C, high gradient (cool down from ambient temperature to -30°C in
• Max. mass flow: 50 g/s, operating range between 33 - 34 g/s
• Min. mass flow: < 5 g/s
• Pipe diameter: 3/8"  
• Average refueling amount: 2-4 kg, a minimum amount has not yet been defined

Japan

At present there is no governmental regulations on hydrogen metering so instead suppliers are only to measure as accurate as possible.

In Japan NEDO is therefore facilitating a project with the aim to establish technical standards for Gravimetric and Master Meter Methods on hydrogen accuracy and metering.

The aim of the NEDO project is to firstly establish a voluntary Self Guideline based on “Gravimetric method” before 2015. This can then be used for manufacturers own assessment of accuracy.

After collecting sufficient technical data and results from use of the voluntary guideline it is to be updated with a “Self Standard” based on “Master Meter method” scheduled onwards 2019.

The technical approach in Japan is firstly to use the Gravimetric method as this is technically feasible and achievable today. As the data and experience basis mass flow meters are increase this may enable a new and more simple approach using a calibrated master flow meter as measurement basis.

USA/California

The experience in USA on hydrogen metering is in particular linked to the HRS roll-out efforts in California.

In order to offer commercial sale of hydrogen, A HRS operate must receive a Certificate of Approval that indicates the dispenser accurately measures the amount of hydrogen it dispenses during sales to customers.

California’s Department of Food and Agriculture (CDFA) is the authoritative agency for motor fuel sales certification and also hydrogen. CDFA has adopted the standards outlined in the National Institute of Standards and Technology Handbook 44 (NIST 44).

The NIST 44 outlines weighing and measuring devices of which the section 3.39 is relevant for hydrogen dispensing and specifies a tolerance of 1.5% for acceptance (typically for commissioning) and 2% for maintenance (or continued operation).

To support adoption of the standard several organizations have collaborated on designing, building and
testing a “Hydrogen Field Standard (HFS) Metrology Testing Device”. It was built to follow the requirements of NIST 44 and has tested most of the currently-operating HRS.

Based on the results and analyses completed, CDFA is the process of adopting regulation to establish three additional accuracy classes of 3%, 5%, and 10%, based on certification with the HFS device.

HRS’s will be able to receive certification to one of these degrees of accuracy. Distinction will be made between accuracy of HRS at commission and testing conducted as part of normal operation. The intent is to relax today for the present HRS technology, and then to increase the targets as the technology progresses.

2. Boundary conditions for hydrogen mass flow meters

The project has developed a proposal for boundary conditions for mass flow meters used for 70MPa hydrogen.

The aim is to provide mass flow meter suppliers with a better understanding of the operation environment in which the component is to be used at 70MPa Hydrogen Refueling Stations (HRS).

The boundary conditions stem from the SAE J2601 refueling protocol with specifies a very precise definition of 70MPa hydrogen refueling.

Based on this the suppliers can describe the specific issues that may be for mass flow meters in coping with the conditions and operation environment. This can lead to suggestions for a definition of hydrogen metering accuracy that takes into account those issues.

2.1 HRS Refueling principle & location of mass flow meter

State-of-the-art 70MPa refueling is conducted using a cascade principle, possible in combination with a compressor. In order to full-fill the SAE J2601 standard hydrogen is pre-cooled during the refueling down to minus 40 degrees Celsius.

The SAE J2601 standard defines how a 70MPa refueling is to be conducted in order to be safe, uniform and fast. With regards to mass flow meters the standard provides a very specific definition of the various “refueling situations” that can occur (various temperature, pressures, flows etc.).

The SAE standard defines the method and values to be used in any given refueling, depending on the boundary conditions of that refueling. A table look-up (from the SAE J2601 standard) is made of the Average Pressure Ramp Rate (APRR) depending on the type of fueling (communication or non-communication), the ambient temperature, the pressure of the vehicle and the status of the station.

This APRR is a definition of how much the pressure should increase per second. This pressure increase should be followed during the entire filling, with limited error margin. The vehicle tank sizes are split into three ranges (2-4 kg, 4-7 kg and 7-10 kg). The refueling within a tank range happens with the same APRR, which means that the mass flow varies depending on the size of the vehicle tank.

2.2 Flow curve spectrum

HyAC has asses the minimum and maximum mass flow, the flow meter should be able to measure.

The assessment shows maximum and minimum mass flow for refueling with a variant elapse and is based on simulations of maximum and minimum flow when refueling according to the SAE J2601 and -40 degrees Celsius pre-cooling.

The flow during fuelling can move anywhere within the measuring range at a given time (depending on starting conditions for the fueling). For instant after 100 sec. the mass flow is between 0.06 g/s and 0.004 g/s if the flow is not stopped and equal to zero. When there is a flow this simulation shows that the flow varies between 0.06 g/s and 0.002 g/s. The filing takes different time depending on the size and state of charge of the tank.

The flow range during a refueling however follows some simplified principles:

- The smaller tank and/or higher ambient temperature the lower flow
- The larger tank and/or lower ambient temperature the higher flow
- Vehicle tank State-of-Charge at start of refueling (may) only affect flow very little
- The higher pre-cooling temperature the lower flow
- The lower pre-cooling temperature the higher flow
• The higher pressure drop (nozzle-vehicle tank) the lower flow
• The lower pressure drop (nozzle-vehicle tank) the higher flow

2.3 Media and ambient conditions

Below are listed media and ambient conditions for 70MPa refueling:
• Media: hydrogen
• Temperature: -40 to 50 °C
• Pressure: 0.5 – 96.3 MPa
• Density: 0.37 – 53 kg/m3
• Flow rate: 0-0.06 kg/s
• Absolute flow: 2 to 10 kg per filling
• Absolute flow: 0 to 2 kg per filling in case of a user interruption or emergency stop
• Pressure drop
• Ambient temperature: -40 to 50 °C
• Ambient pressure: Normal ambient pressure

2.4 Other conditions

Approval

The flow meter should be approved according to
• PED
• EMC
• ATEX zone 2 IIC (only a requirement for the sensor part if the controller can be moved more than 10 meters from the sensor) and be
• CE approved and documented.
• Documentation that all wetted material can be used for hydrogen (withstanding e.g. hydrogen embrittlement)

Connections

• 1 Analogue output 4-20mA
• At least 1 digital output, preferably 2 digital output pulses 90° phase between the pulses; 2 pulses are required for payment systems. The frequency of the pulses should be between 0.6 – 1 kHz.
• Process connection: Standard Auto clave medium pressure fittings 3/8” (or 9/16”)

Other conditions:

Temperature of the flow meter can change from ambient to -40 °C within 30 sec., but the flow meter can also be constantly at -40 °C when having consecutive refuellings.

It should be able to measure flow in the whole range and at the same time have a reasonable resolution.

It is a highly dynamic mass flow, going from no flow to full flow within a second and from full flow to zero flow within a second. This happens during the pressure pulses, or during start/stops of the filling. This requires a fast response and settle-time. The response time is not as such defined, but it has an impact on the error of the measurement.

The flow meter should still be working when having short stops, going to zero flow for limited time and starting again – this is important to take into consideration when looking at the precision of the flow meter. For instant if it is not having a signal of zero when there is no flow it will have an influence the precision of the flow meter. The flow meter measurement is not started before the filling actually starts, so any ghost flow before the filling is not relevant.
As the flow meter should be sitting in a small compartment and have as little thermal mass, size does matter. It is expected to be less than 2-3 liter.

3. Mass flow meter optimization & accuracy test equipment

3.1 Accuracy optimized hydrogen mass flow meter

As part of the project existing hydrogen mass flow meter technology has been optimized with regards to accuracy.

This has been done by conducting development of improved meter designs where a range of parameters are changed and tested to assess the impact on flow and accuracy.

Below are listed the main design parameters.

A. Reducing wall thickness

Higher sensitivity by reducing the wall thickness of the measuring pipes and using smaller inner pipe diameters. Tests are to define the maximum possible flow velocity in the meter, defining the minimum H2 pressure and reaching the target accuracy.

B. Increasing measuring frequency – reduced wall thickness

Higher sensitivity by reducing the wall thickness, using smaller inner pipe diameters and by increasing the measuring frequency. Tests are to define the maximum possible flow velocity in the meter, defining the minimum H2 pressure and reaching the target accuracy.

C. Larger inner pipe diameter

Higher sensitivity by reducing the wall thickness and using a larger inner pipe diameters. Tests are to define the minimum possible flow velocity in the meter, defining the minimum H2 pressure and reaching the target accuracy.

D. Increasing measuring frequency – larger inner pipe diameter

Modifications: Higher sensitivity by reducing the wall thickness using bigger inner pipe diameters and by increasing the measuring frequency. Purpose of tests with this meter: defining the minimum possible flow velocity in the meter, defining the minimum H2 pressure and reaching the target accuracy.

3.2 Formulation of test procedures and specifications

A range of detailed test procedures and specification has been compiled based input and inspiration from a range of sources.

The input source combines relevant hydrogen specific knowledge generated inside the project and outside, e.g. SAE J2601 and CSA 4.3. In addition the existing legal requirements and methodologies for gas metering used in OIML and MID is also taken into account.

This has resulted in the formulation of a general test specification and specific test procedures and steps. This also acts as basis for the test equipment to be developed.

Accuracy testing steps:

Below are listed the developed proposal for accuracy testing steps and procedures.

1. Setting up a large weighing scale (350 kg)

2. Setting up the dispenser with the complete measuring unit (flow meter, heat exchanger, piping, valves, hose, nozzle) next to the weighing scale.

3. Place the tank (resp. tank system) on the weighing scale.

4. Test 1: “Empty tank”

a. Empty the tank system as close to 0 MPa as possible.

b. Weigh the empty system, set the weighing scale to zero.

c. Bank pressure must be maximal in all banks (95 MPa).

d. Connect the nozzle to the system.

e. Refuel the system till maximum pressure (70 MPa).
f. Disconnect the nozzle from the system.
g. Weigh the amount of hydrogen in the tank.
h. Report the value measured by the flow meter.
5. Test 2: “Half full tank”
a. Empty the tank system as close to 35 MPa as possible.
b. Weigh the system, set the weighing scale to zero.
c. Bank pressure must be:
   i. Maximum in high bank (95 MPa)
   ii. Medium bank at 70 MPa
   iii. Low bank at 52.5 MPa
d. Connect the nozzle to the system.
e. Refuel the system till maximum pressure (70 MPa). Start refueling from low, medium and at last high bank.
f. Disconnect the nozzle from the system.
g. Weigh the refueled amount of hydrogen in the tank.
h. Report the value measured by the flow meter.
6. Test 3: “Three quarter full tank”
a. Empty the tank system as close to 52.5 MPa as possible.
b. Weigh the system, set the weighing scale to zero.
c. Bank pressure must be:
   i. Maximum in high bank (95 MPa)
   ii. Medium bank at 70 MPa
   iii. Low bank at 52.5 MPa
d. Connect the nozzle to the system.
e. Refuel the system until the maximum pressure (70 MPa).
f. Disconnect the nozzle from the system.
g. Weigh the refueled amount of hydrogen in the tank.
h. Report the value measured by the flow meter.
7. Test 4: “Minimum measured quantity”
a. Empty the tank system close to 0 MPa.
b. Weigh the empty system, set the weighing scale to zero.
c. No requirements for initial bank pressure (find out through prior testing; at least one bank has to be on full pressure)
d. Connect the nozzle to the system.
e. Refuel the system with the minimal flow rate (make sure that this flow rate still stays constant near to Pv).
f. Refuel the system as close as practical to 70 MPa. Make sure that the transferred gas is at least the minimum measured quantity.
g. Disconnect the nozzle from the system.
h. Weigh the amount of hydrogen in the tank.

i. Report the value measured by the flow meter.

8. Repeat all four tests (1,2,3,4) three times each (maybe another order makes more sense wrt hydrogen savings)

9. Minimal required amount of pressurized (refueling) hydrogen if testing with a 7kg tank system:
   a. Test 1: 0 to 7 kg → 7 kg
   b. Test 2: ~4 to 7 kg → 3 kg
   c. Test 3: ~5,7 to 7 kg → 1,3 kg
   d. Test 4: 0 to ~7 kg → 7 kg
   e. Total: 3x 18,3 kg = 54,9 kg

3.3 Mass flow meter accuracy test equipment

As part of the project a prototype metering accuracy test system has been developed and constructed.

The system includes a range of storage vessels of different volumes – representing different vehicle tank sizes. The vessels can be used in combination to simulate vehicles with multiple tanks or individually to both represent different tank sizes and different types of fuelings.

The system has its own control system to handle the different fueling tests and set-ups. Mass flow meters are installed manually for every tests in order to enable test of products from various suppliers.

4. Hydrogen accuracy fueling tests

A range of 70MPa fueling tests has been conducted within the project, with the aim to test the developed test equipment with regards to measuring and validating accuracy of the mass flow meter.

A total of 16 fueling tests and accuracy measurements were conducted, allocated on 4 sessions, of which 2 was supervised and acknowledged by a legally accredited third party.

The accuracy test method uses a very precise weighing device to measure the weight of the tank vessel before and after a fueling, thus providing an exact measurement of the fueled hydrogen mass.

This measurement is then compared to the mass flow meter reading from the fueling and based on this the accuracy is calculated.

Accuracy is the deviation in % between the measured hydrogen mass and the mass flow meter. A negative deviation means that more hydrogen was fueled than actually measured by the mass flow meter, and opposite for a positive deviation.

The tests shows that the present equipment and methodology today provides a reasonable accuracy. Measured accuracy deviation ranges from -5,352% to +0,65%. On average the measured deviation was negative, meaning a fueling customer would gain more hydrogen that actually charged for by the mass flow meter reading.

Potential Impact:

The project has developed and tested recommendations for accuracy requirements, criteria and procedures for accuracy legal metering of hydrogen, which can be applied and used on national basis for accuracy approval.

Also during the project period, the International Recommendation OIML R 139 for Compressed gaseous fuel measuring systems for vehicles, has however been up-dated to include also Hydrogen. However the actual inclusion of hydrogen is not based on any supporting analysis, and thus the actual specifications has been done with CNG (Compressed Natural Gas) in mind.

Despite the OIML was not updated with hydrogen in mind, the recommendations from HyAC for test procedures may be used by stakeholders who want to document compliance with the OIML accuracy requirements.

It was planned during the project to conduct testing of mass flow meters from multiple suppliers, instead of only one. This could have enable more detailed recommendations for legal handling of hydrogen metering.
It is therefore relevant to consider future projects that can continue the efforts of HyAC. This could involve tests of mass flow meters from multiple manufacturers with the aim to further validate and advance the test method from HyAC and provide a complete recommendation for legal handling of hydrogen accuracy.

A new project could also build on the HyAC experience and develop mobile test equipment and processes for conducting continuous accuracy tests at HRS in daily operation. This is likely to be required as is the case for conventional fuels, where accuracy is verified regularly.

The results of the HyAC project has been summarized in a public results report (D4.3) which will be made available on the HyAC website once approved by the FCH.

In addition the stakeholders identified during the project will also be informed about the outcome. An extensive network list of key international, EU and national stakeholders has been created. The list includes 112 relevant contact persons at governments, notified bodies, organizations and companies - all which have either shown interest for the HyAC project or which have been identified as relevant for addressing the hydrogen accuracy topic.

The list can be also used in future advocacy efforts on addressing hydrogen accuracy and e.g. developing joint international and/European guidelines and regulation.

List of Websites:

www.hy-ac.eu

Documents:

Final Report Summary - HYAC (HyAC – high measurement accuracy of hydrogen refueling)

STRIA Roadmaps: Infrastructure
Transport mode: Multimodal transport
Transport sectors: Passenger transport, Freight transport
Transport policies: Societal/Economic issues
Geo-spatial type: Other