# VII.B.6 Hydrogen Meter Benchmark Testing

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## Overall Objectives

- Design and build a laboratory grade gravimetric standard for measurement of hydrogen flow. The gravimetric standard will be capable of verifying compliance with National Institute of Standards and Technology Handbook 44 requirements for ±1.5% accuracy for the dispensing of motor vehicle fuel (gravimetric standard capability of one-third the required level or ±0.5%).
- Measure flow meter performance of three commercially available meters using the gravimetric standard. Testing will be conducted in high-pressure hydrogen at flow conditions simulating the range of dispenser operation.
- Disseminate results through communications and reporting to provide data on current flow meter performance, identifying the shortfalls to meeting regulations.

## Fiscal Year (FY) 2017 Objectives

- Design, build, and conduct flow meter performance testing on three hydrogen flow meters.

## Technical Barriers

This project addresses the following technical barriers from the Technology Validation and Safety, Codes and Standards sections of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

Technology Validation

(D) Lack of Hydrogen Refueling Infrastructure Performance and Availability Data

Safety, Codes and Standards

(F) Enabling National and International Markets Requires Consistent RCS

(G) Insufficient Technical Data to Revise Standards

(J) Limited Participation of Business in the Code Development Process

## Contribution to Achievement of DOE Technology Validation and Safety, Codes & Standards Milestones

This project will contributes to achievement of the following DOE milestones from the Technology Validation and Safety, Codes and Standards sections of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration Plan.

- Technology Validation Milestone 4.4: Complete evaluation of 700-bar fast fill fueling stations and compare to SAE J2601 specifications and DOE fueling targets (3Q, 2016).
- Safety, Codes and Standards Milestone 3.1: Develop, validate, and harmonize test measurement protocols (4Q, 2014).

## FY 2017 Accomplishments

- Completed fill testing on three hydrogen flow meters: two Coriolis, one turbine.
  - C1 – Coriolis, commercially available, designed specifically for hydrogen
  - C2 – Coriolis, in development, designed specifically for hydrogen
  - T1 – Turbine, commercially available, not designed specifically for hydrogen
- Used statistical analysis to determine significant difference in flow meter performance based on different conditions (e.g., meter position, flow rate, and pressure range).

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## INTRODUCTION

The hydrogen meter benchmarking project is being supported under the DOE Technology Validation program and is part of the DOE–NREL–Sandia National Laboratories–H2FIRST (Hydrogen Fueling Infrastructure Research and Station Technology) project. The H2FIRST objective is to ensure that fuel cell electric vehicle customers have a positive fueling experience similar to conventional gasoline and diesel stations as vehicles are introduced (2015–2017) and transition to advanced fueling technology beyond 2017. The H2FIRST activities are expected to positively impact the cost, reliability, safety, and consumer experience of fuel cell electric vehicle stations.

## APPROACH

The meter benchmark (Figure 1) project collected baseline performance data on three different hydrogen flow meters with the following approach:

- Design and build a laboratory-grade gravimetric hydrogen standard.
- Conduct high-pressure hydrogen testing at a range of typical flow rates.
- Report on flow meter performance.

## RESULTS

A hydrogen flow meter's purpose in a hydrogen dispenser is to accurately and precisely measure the amount of hydrogen a station sells to a customer. Accordingly, NREL considered the percent error of the meter from the start to the end of a fill as the ultimate performance metric, since this will account for all hydrogen that flows through the meter. NREL labeled this measurement as the peak pulse error.

**FIGURE 1.** A picture of the hydrogen metering test apparatus

There are many other performance metrics that need to be taken into consideration by the industry when considering a meter's applicability to the hydrogen dispenser application, for instance: instantaneous error, pressure differential, temperature differential across the meter, external vibration effects, and the delay in meter readout after the cessation of flow. As part of this project, NREL tracked all of these metrics.

NREL used the percent error equation below to calculate the peak pulse error. When the peak pulse error was positive, the meter over predicted the amount of hydrogen dispensed and the customer would be burdened with the extra cost. When the percent error was negative the meter under predicted the amount of hydrogen dispensed and the station operator would bear the cost burden.

$$Peak\ Pulse\ Error = \left(\frac{\Delta Scale - \Delta Meter}{\Delta Scale}\right) * 100$$

$$\Delta Scale = Scale\,(kg)_{end\ of\ fill} - Scale\,(kg)_{start\ of\ fill}$$

$$\Delta Meter = Meter\,(kg)_{end\ of\ fill} - Meter\,(kg)_{start\ of\ fill}$$

With each meter, NREL split the data into the identified factors and calculated the peak pulse error. The probability a single fill would be within a specified error range is the ultimate way that a meter would be tested by weights and measures agencies. This probability was calculated by using the mean, standard deviation, and confirming the normality of the data and analyzing with Minitab. The normality of the data was checked using the Anderson–Darling test and when confirmed, the mean and standard deviation were input into a distribution plot to obtain the single fill probability.

The results of the data suggested that on average, a sum total of fills would meet the 2% maintenance requirement; however, this does not necessarily mean that a single fill would fall into that category. Looking solely at the mean of a data set can be deceiving. For instance, over every test, the C2 meter had a mean error of 0.5% and the C1 meter had a mean error of -0.1% which gives the perception that the C1 meter performed better than the C2 meter. However, both are within the 2% maintenance tolerance. Upon further inspection, it was discovered that the C1 meter had a much higher standard deviation than the C2 meter (Figure 2). This means that one fill could be -4% and the next could be +4%, which is undesirable when comparing to a 2% accuracy requirement. For this reason, the data sets were sorted into probabilities based on a single fill being within the specified range.

The C2 flow meter performed consistently better than the C1 and the T1 meters in every category associated with meter error. The C1 meter performed slightly better than the T1 meter under most categories except for at high flow rates where the meters were nearly identical with regard to overall performance. The probability that a single fill would fall

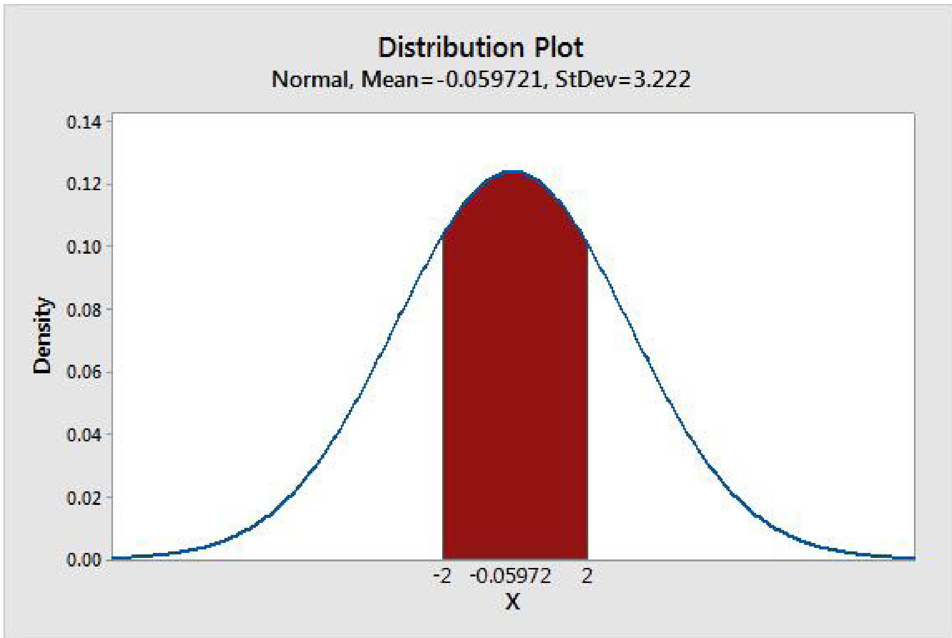


**FIGURE 2.** Distribution plot for 2% accuracy class, meter C1 – all data

within the 2% or 10% accuracy classes for all the data, and for high flow cases (≥2 kg/min), is shown in Table 1.

**TABLE 1.** Single Fill Performance Data

| Probability a Single Fill Falls Within an Accuracy Class | All Data | | High Flow Data (2+ kg/min) | |
|---|---|---|---|---|
| Accuracy Class | 2% | 10% | 2% | 10% |
| C1 | 46.5% | 99.8% | 34.1% | 97.3% |
| C2 | 82.2% | 100% | 64.6% | 100% |
| T1 | 12.6% | 58.7% | 35.0% | 98.5% |

## CONCLUSIONS AND UPCOMING ACTIVITIES

This project has reached its conclusion. NREL plans to publish a report on the findings from the project so that the information is available to the public.

Potential future work could include an advanced dispenser control scheme that would adjust predicted kilograms dispensed based on meter accuracy data, developing a next generation mobile metrology device, testing meters under pre-chilled conditions, and working with meter manufacturers to develop next-generation metering technologies that have the potential to meet market requirements for cost and accuracy.

## FY 2017 PUBLICATIONS/PRESENTATIONS

**1.** "Hydrogen Meter Benchmark Testing," 2017 DOE Hydrogen and Fuel Cells Program, Annual Merit Review, June 2016 (presentation).

**2.** "Hydrogen Meter Benchmark Testing Interim Report," NREL Report, January 2016.