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Hydrogen field test standard: Laboratory and field performance

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ABSTRACT

The National Institute of Standards and Technology (NIST) developed a prototype field test standard (FTS) that incorporates three test methods that could be used by state weights and measures inspectors to periodically verify the accuracy of retail hydrogen dispensers, much as gasoline dispensers are tested today. The three field test methods are (1) gravimetric, (2) Pressure, Volume, Temperature (*PVT*), and (3) master meter. The FTS was tested in NIST's Transient Flow Facility with helium gas and in the field at a hydrogen dispenser location. All three methods agree within 0.57% and 1.53% for all test drafts of helium gas in the laboratory setting and of hydrogen gas in the field, respectively. The time required to perform six test drafts is similar for all three methods, ranging from 6 h for the gravimetric and master meter methods to 8 h for the *PVT* method.

The laboratory tests show that (1) it is critical to wait for thermal equilibrium to achieve density measurements in the FTS that meet the desired uncertainty requirements for the *PVT* and master meter methods; in general, we found a wait time of 20 min introduces errors $<0.1\%$ and $<0.04\%$ in the *PVT* and master meter methods, respectively and (2) buoyancy corrections are important for the lowest uncertainty gravimetric measurements.

The field tests show that sensor drift can become a largest component of uncertainty that is not present in the laboratory setting. The scale was calibrated after it was set up at the field location. Checks of the calibration throughout testing showed drift of 0.031%. Calibration of the master meter and the pressure sensors prior to travel to the field location and upon return showed significant drifts in their calibrations; 0.14% and up to 1.7%, respectively. This highlights the need for better sensor selection and/or more robust sensor testing prior to putting into field service. All three test methods are capable of being successfully performed in the field and give equivalent answers if proper sensors without drift are used.

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1. Introduction

Today's fuel cell electric vehicles are typically refueled with precooled hydrogen (H_2) gas from dispensers within 3–5 min using sequential gas releases from a bank of pressurized cylinders. The sequential releases generate large, rapidly-changing, gas flows (0 kg/min to 10 kg/min) spanning a wide pressure range (0.1 MPa to nominally 70 MPa) at gas temperatures down to -40 °C. While there have been studies of high pressure hydrogen flow meters under steady flow conditions [1,2], measuring the flow under rapidly changing temperature, pressure, and flow conditions has received less attention. Prior research in our Transient Flow Facility (TFF) shows that coriolis mass flow meters can measure the totalized flow within 1% under simulated H_2 dispenser conditions [3]. Therefore, it is feasible for well-designed commercial hydrogen dispensers to meet the proposed international requirement of 1.5% accuracy for dispensing units [4].

Here, our attention turns to how state weights and measures inspectors will verify the accuracy of dispensers in the field. A similar effort is underway in the state of California in cooperation with the National Renewable Energy Laboratory [5]. What will be the analog of the 5 gallon test measures presently used to check gasoline dispensers [6]?

In this work, we tested three methods for field testing H_2 dispensers: (1) gravimetric; where the mass dispensed is determined by weighing a hydrogen pressure vessel (*i.e.*, tank) before and after filling it with H_2, (2) Pressure, Volume, Temperature (*PVT*); where the mass dispensed into the tank is determined from the tank's internal volume and gas density (ρ) change from before and after filling, and (3) master meter (MM); where the mass dispensed is determined by integrating a well calibrated flow meter's measurements of the H_2 gas being blown-down (or withdrawn) from the filled tank. This work was performed in two parts: (1) a laboratory phase [7] and (2) a field phase. An uncertainty analysis is provided for each method. The desired uncertainty is 0.5%, one third of the proposed requirement of 1.5% for dispensing units. We constructed a prototype field test standard (FTS) to compare the

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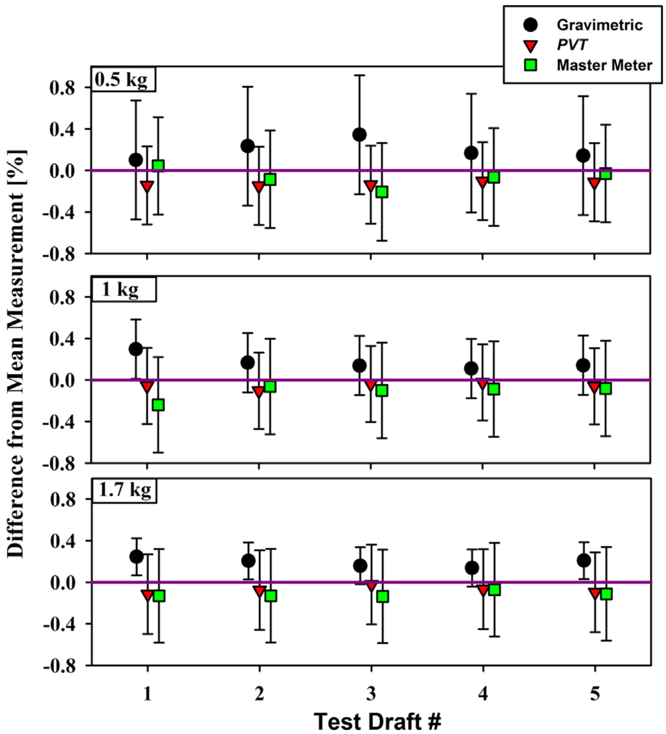

Fig. 1. Comparison of the three test methods for the test draft of 0.5 kg, 1 kg, and 1.7 kg of He gas. The error bars are the $k=2$ expanded measurement uncertainty corresponding to a confidence level of 95%. The average of all three methods is used as the reference value (difference = 0).

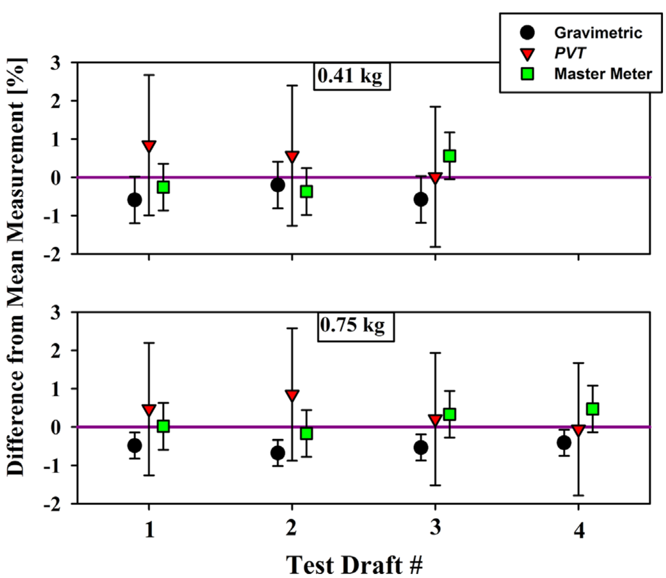

Fig. 2. Comparison of the three test methods for the test draft of 0.41 kg and 0.75 kg of H_2 gas. The error bars are the $k=2$ expanded measurement uncertainty corresponding to a confidence level of 95%. The average of all three methods is used as the reference value (difference = 0).

three methods in terms of ease of use, time efficiency, and uncertainty. All three methods agree within the expected uncertainty of 0.57% for all test drafts of helium (He) gas in the laboratory setting. Fig. 1 shows these results for five test drafts of 0.5 kg, 1 kg, and 1.7 kg He gas. All three methods agree within 1.53% for the test drafts of H_2 gas in the field setting. Fig. 2 shows these results for three test drafts of 0.41 kg and four test drafts of 0.75 kg H_2 gas. A larger uncertainty was expected for the field tests than the laboratory tests due to the use of different pressure sensors that are suitable for use in H_2 gas. These sensors' calibrations drift over time. The disagreement in the field is more than the expected uncertainty due to excessive pressure sensor drift.

The purpose of the laboratory phase was to design, construct, and test a FTS in a controlled environment, *i.e.*, NIST's Transient Flow Facility (TFF) and using He as a surrogate gas for H_2. The TFF allows us to (1) evaluate each field test method without the time constraints that will be encountered in the field, (2) use a more-accurate pressure gauge that is incompatible with hydrogen, and (3) achieve more reproducible results under controlled environmental conditions. The purpose of the field test phase was to verify the laboratory results using H_2 gas in a more challenging setting; an outdoor H_2 dispenser.

2. Experimental design

2.1. The field test standard

The FTS consists of a 35 MPa (at 15 °C), 1 kg H_2 capacity storage tank that is mounted into a frame made from 2.5 cm^2 T-slotted aluminum with casters for mobility. The storage tank is a Type III cylinder; a seamless aluminum liner fully wrapped with a continuous filament made of carbon fiber in an epoxy reinforcement laminate [8]. The empty weight of the FTS is approximately 80 kg. Fig. 3 shows the FTS in the horizontal position. For density measurements, the FTS is equipped with two, 46 cm long type K thermocouples (TCs) inserted at each end (to reduce stem conduction errors, TCs with a long insertion depth were chosen) and two analog pressure sensors; one with a 35 MPa range and one with a 1.4 MPa range. A plumbing and instrumentation diagram is shown in Fig. 4. A detailed description of the operating instructions and specifications can be found in the NIST technical publication NIST-TN 1888 [9]. Accompanying the FTS are (1) a 150 kg capacity weigh scale with 1 g resolution for gravimetric measurements, (2) a 3.7 m × 3.7 m tent with ventilated holes to protect the weigh scale from the environment, (3) a portable data acquisition (DAQ) system and laptop with acquisition software, (4) a 0.95 cm diameter, 3.05 m tall stainless steel vent stack with support stand for venting H_2 gas in the field, and (5) a hand truck with a tie down strap for moving the FTS securely while in the vertical position; the FTS must be in the vertical position during testing due to the position and orientation of pressure relief valves. The pressure relief valves were tested and found to be leak free. The DAQ box supplies power to the master meter and acquires data from the temperature and pressure sensors. All wires can be easily plugged into or unplugged from the DAQ box and coiled on

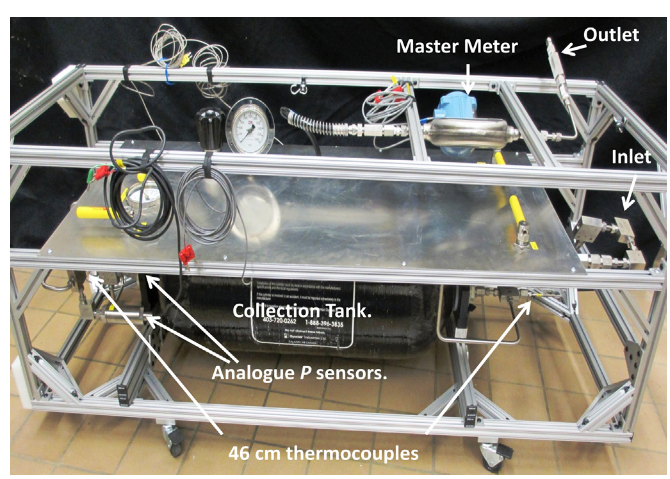

Fig. 3. Portable FTS in horizontal position.