III.14 Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks

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Contract Number: DE-EE0007273

Subcontractors:
- Air Liquide Advanced Technologies, Houston, TX
- Rheonik GmBH, Oldehausen, Germany
- National Renewable Energy Laboratory (NREL) Golden, CO

Project Start Date: June 1, 2016
Project End Date: December 14, 2018

Overall Objectives

- Improve reliability of vehicle-to-dispenser communication with the use of emerging connected-vehicle-to-infrastructure wireless communication technologies employed for Intelligent Transportation Systems, using the secure Institute of Electrical and Electronics Engineers (IEEE) 1609 vehicle communications protocol.
- Achieve consistent 2% or better metering accuracy of the dispenser system through tight design control of flow dynamics and thermal response of the meter, as well as improved thermal mass flow regulation enabled by advanced fueling event notification.
- Reduce cost and complexity of dispenser hardware, such as hydrogen pre-cooling systems, via intelligent and predictive controls incorporating individual vehicle data, and where possible, wide-area fleet data, to allow more appropriately sized equipment.

Fiscal Year (FY) 2017 Objectives

- Complete functional requirements and verification plan documents for critical components including hydrogen dispensing hardware, dedicated short-range wireless communication (DSRC) and high accuracy meter.
- Identify and procure commercially available DSRC hardware suitable for use in prototype and commercial hydrogen refueling applications.
- Develop robust multi-physics models of hydrogen dispenser system to inform component selection and hydrogen refueling control.
- Create custom software/firmware allowing DSRC to exchange all required data and commands per requirements of SAE J2799 (2014) and SAE J2601/1 (2016).
- Communicate data of multiple refueling events from a simulated dispenser to a simulated vehicle using DSRC wireless over IEEE 1609 protocols.
- Demonstrate less than or equal to 4% accuracy of flow measurement in the bench testing of a Coriolis meter, including operation at pressures up to 700 bar, fluid temperatures equal to that required in SAE J2601/1 protocols and flow rates up to at least 30 g/s hydrogen equivalent.
- Design advanced dispenser prototype system that integrates DSRC wireless communication, improved Coriolis meter hardware, and a system architecture that reduces cost while improving robustness of flow control and hydrogen cooling.

Technical Barriers

This project addresses the following technical barriers from the Hydrogen Delivery section of the Fuel Cell Technologies Office Multi-Year Research, Development, and Demonstration (MYRDD) Plan.

(I) Other Fueling Site/Terminal Operations

Technical Targets

This project will develop a SAE J2601 compliant dispenser system that aims to address reliability concerns with vehicle to dispenser communication, compliance with weights and measures standards for commercial fueling, and dispenser cost and complexity. Specifically, the project team will develop, test and demonstrate DSRC hardware for vehicle to station communication as opposed to the current infrared communication standard, as well as engineering a new high accuracy Coriolis flow meter specifically designed to maintain an accuracy of 4% or better in automotive hydrogen refueling application conditions. This meter will be integrated with the prototype dispenser in an optimized way to ensure accuracy is maintained, enabling a pathway for National Institute of Standards and Technology Handbook

44 compliance of dispenser systems. Lastly, the project will engineer and develop novel methods for hydrogen pre-cooling, flow control, and predictive control algorithms to decrease system complexity and cost. Technical targets are detailed in Table 1.

TABLE 1. Hydrogen Dispenser Targets Compared to Corresponding MYRDD Targets

Category	Project Target	MYRDD
Dispenser Capital Cost	$150,000 at low volume	$40,000 by 2020 at high volume
Communication Method	DSRC using IEEE 1609 protocols	Nozzle IR Alternative
Meter Accuracy	≤ ± 2% accuracy at temperatures between -40°C and 85°C and flow rates between 0.6 and 60 gps	≤ ± 4% Commercial Goal of ± 1.5$
Cooling System Cost	≤ $100,000 at low volume	$70,000 by 2020

IR - infrared

FY 2017 Accomplishments

- Completed functional requirements and verification plan documentation for dispenser system, mass flow meter, wireless communication and control systems.
- Research, selection and procurement of commercially available DSRC hardware for use in bench and full scale testing of wireless communication system.
- Initiated system modeling activities to understand tradeoffs of different flow control and cooling methods.
- Key factors that impact hydrogen meter accuracy were identified using empirical and computer aided engineering tools, including the following:
  - Temperature impacts on mechanical structure at variable pressure, temperature, and flow conditions were investigated using computational fluid dynamics modeling techniques.
  - Thermal shock experienced during refueling was simulated using models validated with climate chamber testing of meter hardware with chilled glycol.
  - The impact of sensor housing humidity on sensor performance was studied over multiple conditions.
- Designed, manufactured, and bench tested several prototype meters in lab and full scale settings, including the following activities:
  - Development of correction factor algorithms to compensate flow readings actively based on measured pressure and temperature of components within the device.
  - Addition of temperature sensors located throughout the meter housing to aid in measurement accuracy and sensor stability.
  - Purging of sensor housing with dry non-reactive gas to eliminate humidity/condensation.
  - Mono-block tube design to reduce turbulence and significant temperature differences between omega tube and torsion bar.
- Completed preliminary testing in a hydrogen dispensing application demonstrating that meter design is capable of obtaining <4% overall accuracy over varying flow, pressure, and temperature conditions.

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INTRODUCTION

This project aims to improve early adoption of fuel cell electric vehicles (FCEVs) by addressing technical obstacles and high cost associated with SAE J2601/1 compliant hydrogen dispenser systems. The team will focus on three main areas: robustness of vehicle to dispenser (SAE J2799) communication, ability to comply with National Institute of Standards and Technology Handbook 44, and complexity of system design associated with hydrogen cooling and flow control. The team intends to address these issues by improving hydrogen meter accuracy, replacing infrared communication with wireless technology used for vehicle to vehicle and vehicle to infrastructure communication, and implementing improved modeling and controls around thermal and flow management.

APPROACH

The team will design, develop and deploy an advanced hydrogen dispenser that incorporates DSRC wireless communication and improved hydrogen meter accuracy to a minimum of ≤4%. During the beginning phases of the project, demonstration of core technologies will occur at the bench level along with detailed system modeling. Testing will include wireless communication of refueling protocol messages using DSRC hardware and bench scale demonstration of hydrogen meter accuracy of at least 4% over varying temperatures, pressures, and flow conditions.

After bench validation, a prototype dispenser will be designed and manufactured for full scale simulated-environment testing at the NREL Hydrogen Infrastructure Testing and Research Facility. This phase's goals are to validate compliance with SAE J2601/1 (2016), demonstrate hydrogen meter accuracy of ≤4% when integrated in a dispenser, and show wireless communication of refueling messages from a simulated vehicle to the dispenser control unit. Lastly, an up to six-month test of the prototype dispenser will be conducted at an Air Liquide station to validate the advanced communication, meter accuracy, and dispenser performance under real environmental operating conditions fueling FCEVs.

RESULTS

The team did extensive research on commercially available DSRC hardware suitable for use in hydrogen refueling applications and selected a hardware and software package for the prototype system. This equipment will be used to demonstrate wireless communication of refueling messages at both bench and full-scale prototype conditions. Using requirements developed for the wireless communication system, five hardware suppliers were identified and evaluated against various criteria including experience with commercial deployment, hardware cost, support capability and compliance to standards such as IEEE 1609 and IEEE 802.11p.

Requirements documents have been developed for major subsystems including wireless communication (DSRC), dispenser, mass flow meter, and control system. Additionally, detailed component specifications for pressure relief valves, heat exchanger, and solenoid valves have been created for use in component selection. Verification plans using the Design Verification Plan & Report process have been developed to define and guide testing of all critical aspects of the prototype dispenser in bench, full-scale lab, and demonstration phases. These verification plans detail specific test requirements, when to test, responsibility for testing, and pass/fail criteria.

The Rheonik team successfully completed development and preliminary testing of a high accuracy hydrogen meter. Empirical testing and computer aided engineering tools were used to study effects of pressure, temperature, and flow on current meter designs. Computational modeling was used to study turbulence and temperature effects in various parts of the meter. The team validated these models using environmental chamber testing (Figure 1).

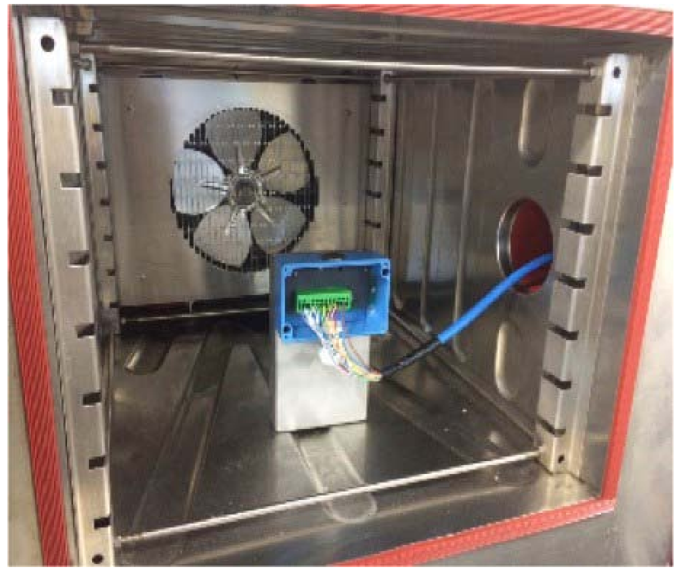

FIGURE 1. Photo of climate chamber test apparatus for meter development work

Meter test results informed placement of additional temperature sensors, new compensation algorithms, and new manufacturing processes to improve meter accuracy (Figure 2). Several prototype meters were built and tested both at bench scale and at full scale in SAE J2601/1 compliant dispenser systems. Initial tests indicate that the meter is capable of achieving accuracies less than ±4% (Figure 3) in real application conditions. Additional testing is scheduled for August 2017 to complete validation of the new meter hardware.

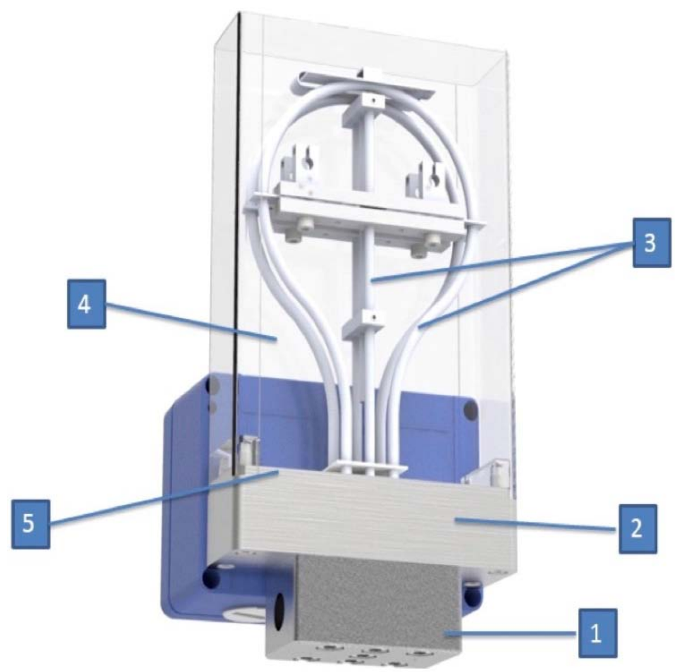

FIGURE 2. New meter design developed in the project, showing locations of various improvements: (1) Improved inlet block design; (2) and (3) Added temperature measurement locations; (4) Sealed and purged housing; (5) New seal materials

The team began system modeling activities, focusing on studying feasibility and tradeoffs of variable orifice control vs. an array of fixed orifices. The model identified the range of orifice areas needed to meet flow rates between 0.6 gps and 60 gps as specified in SAE J2601/1. Sensitivity to storage pressure, vehicle initial pressure and hydrogen temperature have also been analyzed to increase model fidelity. The results show that an array of fixed orifices can be used to control of hydrogen in automotive refueling applications;

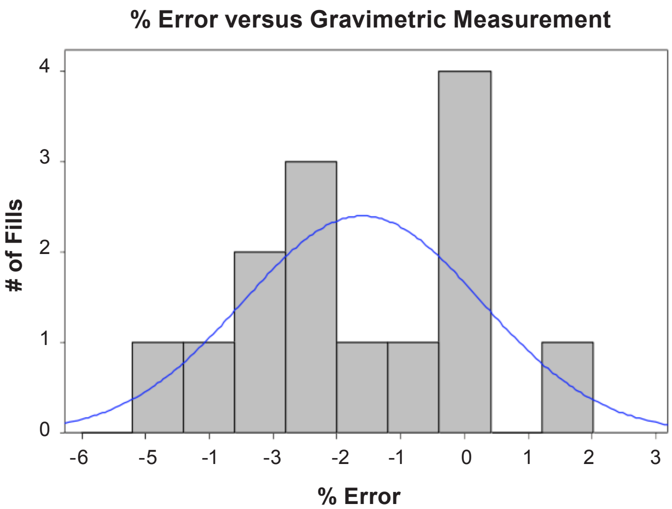

FIGURE 3. Results from initial meter testing in a hydrogen dispensing application

further cost studies and component evaluations will be involved in the final choice of flow control method and hardware.

CONCLUSIONS AND UPCOMING ACTIVITIES

In the first year of this project, significant progress has been made on bench-scale development of hydrogen meter and wireless communication technologies. Dispenser system design and modeling have been conducted to inform the design and build of the prototype dispenser system, scheduled for deployment and testing in FY 2018. Future planned activities include:

- Demonstrate successful wireless connection from a simulated dispenser to simulated vehicle and exchange of refueling event data and SAE J2601 communication filling messages over IEEE 1609 vehicle communications protocol with no messages delayed by more than 500 ms.
- Demonstrate ≤4% accuracy of flow measurement in bench testing of Coriolis meter.
- Develop first order system modeling to properly size critical dispenser components (e.g., heat exchanger, flow control valves) and to inform controls development.
- Complete detailed design, safety review and build of SAE J2601/1 prototype dispenser system that implements high accuracy meter, flow control and hydrogen cooling improvements while providing a means to demonstrate wireless communication between a vehicle and dispenser.
- Install and validate a prototype dispenser for compliance to SAE J2601/1 at the NREL's Hydrogen Infrastructure Testing and Research Facility.
  - Demonstrate ≤4% accuracy of flow measurement during simulated filling events.
  - Demonstrate ≤2.5% accuracy of flow measurement in secondary bench testing using hydrogen meter qualification equipment at NREL at pressures up to 700 bar, flow rates up to at least 30 gps and ambient hydrogen temperature.
  - Demonstrate transmission of SAE J2601/1 refueling messages from a simulated vehicle to the dispenser control unit per the requirements of SAE J2799.
- Install and validate prototype dispenser under real environmental operating conditions with FCEVs including:
  - Demonstrate ≤4% hydrogen metering accuracy with a stretch goal of ≤2% using the Hydrogen Field Standard dispenser accuracy verification.
  - Demonstrate successful wireless connection from FCEV to prototype dispenser and exchange of refueling event data using DSRC wireless communication.

FY 2017 PUBLICATIONS/PRESENTATIONS

1. Christopher O'Brien, Bryan Gordon, and Darryl Pollica, "Advancing Hydrogen Dispenser Technology by Using Innovative Intelligent Networks," presented at the 2017 DOE Annual Merit Review and Peer Evaluation Meeting, Washington, D.C., June 2017.