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Hydrogen Pressure Vessel Testing Program

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Abstract

The Hydrogen Pressure Vessel Testing Program has been designed to meet two objectives, including: 1) providing visual and quantitative information to OEM's, regulatory agencies, and the public, regarding the consequences of on-board high pressure hydrogen as a fuel source and 2) through a collaborative effort with experts in the field, use the data generated from this project to provide a predictive, validated model to use in evaluating on-board accidents scenarios involving compressed gases. An Oversight Committee of experts in the field of hydrogen storage and pressure vessel testing has been assembled to monitor all aspects of the project. Pressure vessels have been procured and testing is to begin in the July-August time frame. Test objectives will be completed by the end of the FY00 time period. The test data will be documented and distributed in written form and in film through a collaborative effort with the H2000 project.

Introduction

The long term goal of this project is to gain acceptance of on-board compressed hydrogen storage for use in hydrogen powered vehicles. To meet this goal, we are conducting a comparative study between hydrogen and other fuels which are widely accepted, such as gasoline, natural gas, and propane. The data from this study will be documented and distributed both in written form and in film through a collaborative effort with the H2000 project. Further, with this data, we will develop a predictive, validated model for use in determining the response of composite cylinders in accident scenarios. These models may in turn be used by federal agencies and insurance companies. This work builds on previous hydrogen safety studies conducted by M. R. Swain et al (ref: 1-4).

The project consists of testing, modeling, documentation, and dissemination of the results. An Oversight Committee, consisting of experts in the field of hydrogen storage and pressure vessel testing has been formed to monitor all aspects of the work. The committee membership is as follows:

Robert Mauro - National Hydrogen Association
Mahendra Rana - Praxair
George Schmauch - Air Products / Hydrogen Technical Advisory Panel
John Smith - National Institute of Standards and Testing
Robert Zalosh - Worcester Polytech
W. Hoagland - Hydrogen-2000 Project

Test Program Description

State-of-the-art, composite cylinders (Type IV) were manufactured by the IMPCO company in Carson, California specifically for these tests. These are polymeric lined, graphite/glass re-enforced epoxy cylinders which were tested to 96 MPa without visible damage. The internal volume is 24 liters with an outside diameter of 23 cm and a total outside length of 35 cm (figure 1). These cylinders are compatible with both hydrogen and natural gas. Tank features include a steel (4340 HSLA) single collar with an attached valve. An integrated pressure relief device is not included in these tanks. A small number of similarly constructed cylinders (Type IV) were purchased from another vendor (Lincoln Composites, Lincoln, Nebraska). The current test matrix does not include these tanks.

The objective of this project is to determine the response of these pressure vessels to extreme conditions, compare the results of hydrogen gas to other fuels, quantify the results, and document the results for public awareness. It is hoped that the results will aid in fostering acceptance by the general public.

This year, we have acquired the cylinders for testing and shipped them to the test site. The test facility will be Sandia National Laboratory-New Mexico, Test Site III. Engineering support is being supplied by the test site staff. The test site staff have prepared the equipment and cameras necessary to begin testing. In preparation for this project, we have reviewed the literature and certification documents on pressure vessel testing (ref: 5-10), formed an Oversight Committee, and established a test matrix that meets our objectives. Testing will begin during the months of July-August, '00. Several delays have occurred in the test schedule because of the drought conditions in New Mexico and the awareness raised by the Los Alamos fire.

Oversight Committee

A meeting was held in Albuquerque, NM on March 15, 2000 with the Oversight Committee to review the initial test matrix, generate feedback from the committee, and tour the test site. From this meeting several modifications were made to the initial test matrix. Test diagnostics were also reviewed and modified during this important meeting. A film crew from the Hydrogen-2000 project was also in attendance both as consultants and to plan their activities in documenting the test results on film.

Further, suggestions made during the DOE Hydrogen Program Review and the Hydrogen Codes and Standards Workshop were considered and integrated into the modified test matrix.

Test Description

The test matrix for FY00 is shown in the table below.

Hydrogen Pressure Vessel Test Matrix

Manuf.	Pressure (MPa)	Fuel	Penetration	Flame
IMPCO	35	N_2*	1	1
IMPCO	35	H_2	2	2
IMPCO	25	H_2	2	2
IMPCO	25	CH_4	2	2

*Preliminary testing will be conducted to determine the energy required to penetrate the tank using nitrogen as the fill gas.

The test diagnostics include: temperature, pressure, high speed video, IR video, spatial and temporal distribution of shrapnel, magnitude of shock wave, and standard video. Both standard and high speed video will be used to provide a real time record of the test event from a minimum of two angles; perpendicular and parallel to the container axis of symmetry. An additional camera will be used by the H2000 film crew. An IR camera will be employed to record the temperature profile during the test event. Spatial and temporal distributions will be determined by visual evidence following the test sequence. Post-test examination of the fracture region will yield information on the failure characteristics of the materials used in the fabrication of the cylinders.

The penetration test will be done using a 5 cm diameter steel rod with a hemispherical end configuration. The cylinder will be fixed in a horizontal position and the rod positioned at a pre-determined distance above the cylinder. Initially, the drop distance will be adjusted to determine the energy required for penetration. Preliminary testing with nitrogen gas will provide the actual energy requirements for penetration and yield additional information on the strength and fracture properties of the material. A cable-guided drop tower (figure 2) will be used to guide the weighted rod from the pre-determined height to the cylinder. The penetration tests will also include an external spark ignition source placed in a position which presents the highest probability of ignition.

Initial calculations indicate a penetration energy between 1630-1900 joules. The higher value is based on information from the manufacturer (ref: 11) which came from firing a 50 caliber, 163 grain (10.6 gm) bullet with a muzzle velocity of 850 m/sec. The kinetic energy of this bullet generates 3800 joules which was sufficient to penetrate both sides of the tank. Approximately half that value should be sufficient to penetrate a single wall thickness. The lower value is based on the rod diameter and an estimate for the shear strength of the material. If the rod diameter is 5 cm and the tank wall is 1.27 cm, the shear area for a 5 cm diameter plug is 20.25 cm^2. A typical shear strength for a graphite epoxy structure is 64 MPa which translates to a 13,280 kg (force) acting on the rod. Thus the work required to act against that force over a 1.27 cm wall is approximately 1630 joules. These two calculated values for penetration energy are sufficiently close to give us some confidence in choosing a starting value for the penetration tests. As mentioned earlier, preliminary tests to determine the experimental value for penetration will be conducted using compressed nitrogen.

Figure 1- Type IV cylinder: IMPCO

Figure 2- Drop Tower

The flame test will be conducted in an open flame pit with the cylinder in a horizontal position approximately 10 cm above the fire source. For the flame tests, the container (and thermocouples) will be shielded from the flame source using a thin metal plate to prevent direct contact with the flame. The test will proceed until rupture of a pressure relief device occurs. In this case, a pressure relief device such as a burst disc will provide a closer comparison with other fuel containers such as propane or gasoline tanks.

Impact of Project

The impact of the project will be two-fold: 1) providing visual and quantitative information to OEM's, regulatory agencies, and the public, regarding the use of on-board high pressure hydrogen as a fuel source and 2) through a collaborative effort with experts in the field, use the data generated from this project to provide a predictive, validated model to use in evaluating on-board accidents scenarios involving compressed gases. This second point has the potential for use by both the US government and insurance companies.

Future Studies

Plans for next year include testing other fuels including propane, CNG, and gasoline, and completing any additional testing indicated by test results from this year. We have several cylinders in inventory for additional testing including both IMPCO and Lincoln. Further, if warranted, we will include tests on new tank designs such as conformable tanks and the cryotank design from LLNL using the facilities, staff, and test procedures developed this year. These test results will be combined with the tests from this year.

Acknowledgements

Special thanks to the efforts of Timothy Brown with the Sandia National Laboratories-New Mexico test site. Mr. Brown is responsible for setting up the facilities and directing the tests for the hydrogen pressure vessel project. This has been a particular challenging project in New Mexico with the current drought conditions and the increased awareness caused by the fire in Los Alamos, New Mexico. Also, we would like to acknowledge the assistance of the Oversight Committee members mentioned in the text. Their efforts have been most helpful and appreciated. Bill Hoagland and Geoffrey Holland from the H2000 Project have also been major contributors during the planning stages for the tests. Their film documentation should be a valuable contribution to the acceptance of hydrogen for vehicle applications.

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