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HYDROGEN STANDARDIZATION INTERIM REPORT

For Tanks, Piping, and Pipelines

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ABSTRACT

This interim report is intended to address priority topical areas within pressure technology applications for hydrogen infrastructure development. The scope of this interim report includes addressing standardization issues related storage tanks, transportation tanks, portable tanks, and piping and pipelines. It is anticipated that the contents and recommendation of this report may be revised as further research and development becomes available.

The scope for the tank portions of this report (Parts I and II) includes review of existing standards, comparison with ASME Boiler and Pressure Vessel Code (BPVC) Section VIII, and recommendations for appropriate design requirements applicable to small and large vessels for high strength applications up to 15,000 psi. This report also includes identification of design, manufacturing, and testing issues related to use of existing pressure vessel standards for high strength applications up to 15,000 psi, identification of commonly used materials, and developing data for successful service experience of vessels in H_2 service.

Similarly, the scope of piping and pipelines portion of this report (Part III) includes reviewing existing codes and standards, recommending appropriate design margins and rules for pressure design up to 15,000 psi, reviewing the effects of H_2 on commonly used materials, developing data for successful service experience, researching leak tightness performance, investigating effects of surface condition of piping components, and investigating piping/tubing bending issues.

Part I - H_2 Tanks: Review of Existing Reference Standards

The study provides a detailed overview of various compressed gas cylinder standards in comparison to ASME Section VIII rules with particular emphasis on the differing design burst margins and the modifications required to make the rules applicable to high-strength metal or composite vessels for both stationary and transport uses at pressures up to 15,000 psi.

The margins between burst and maximum operating pressure for common transport compressed gas cylinders and vehicle fuel containers were found to be very similar to one another and also very similar to the basic design margin of ASME Section VIII Division 3 vessels. The minimum margin found was for the U.S. Department of Transportation (DOT) DOT-3AA specification, and this margin is recommended as the minimum for future design rules. The various metal cylinder design formulas were found to deviate significantly from the burst prediction formula as pressures were increased to 15,000 psi and the ASME Section VIII Division 3 collapse formula is recommended for future rules at these high pressures. Low design margins for metal vessels were found to be dependent on associated periodic requalification and specific recommendations are included for all designs except the higher margin rules of ASME Section VIII Division 1 and ASME Section VIII Division 2. The standards do not presently provide adequate coverage of fatigue and fracture issues for 15,000 psi metal vessels in a hydrogen environment and the concerns are discussed in comparison to lower pressure experience. It should be noted that standards developed by different standards developing organizations utilize different consensus processes, may have different approaches, and are typically intended for different applications; therefore design margins and pressure definitions vary accordingly.

It was found that evaluation of composite gas cylinder margins must address time at various stress levels for time-dependent mechanisms such as stress rupture to control. The allowable stress for glass composites was determined to be very similar for all standards and the glass stress requirements of the DOT Fiber Reinforced Plastic (FRP) specifications are recommended as the initial basis for future rules. It should be noted that FRP-1, FRP-2, and CFFC are limited in scope, sizes, designs, and materials and these limitations, along with the operating experience of other standards, such as natural gas vehicle-2 (NGV-2), should also be considered for future rules. Generally, composite cylinders

were not found to be designed using consensus-based rules. A preliminary proposal was outlined whereby simplified design may be developed and verified for general application. The allowable stress and resulting burst margins for carbon composites were found to vary significantly among the standards, presenting no single value. The discussion includes the significant differences between the service conditions of stationary and transport vessels and this should facilitate study of the necessary allowable design stress for future carbon composite design rules. The various composite cylinder standards vary significantly with regard to required resistance to external damage from chemicals and impact, and significant gaps are identified. Specific recommendations are included for the development of nondestructive examination (NDE) techniques for composite requalification, and recommendations for a performance based approach for validation of new techniques for use on different designs are provided.

Part II - H_2 Tanks: Study of Existing Data, Standards, and Materials

This study evaluates the potential use of four metallic vessel standards [ASME VIII-1 Appendix 22, 49 Code of Federal Regulations (CFR) 178, American National Standards Institute (ANSI)/CSA NGV2-1], and International Organization for Standardization (ISO)/Draft International Standard (DIS) 15869-2, and six composite vessel standards (DOT FRP-1 and FRP-2, ANSI/CSA NGV2, ASME VIII-3 Code Case 2390, ISO 11119, and ISO/DIS 15869) for 15,000 psi hydrogen service.

The study identifies problems with using existing standards (1) for pressures well above current common practice and (2) for hydrogen with its material compatibility issues, flammability, and small molecular size. Design, manufacturing, and testing gaps are identified in existing standards, and recommendations are made for future standards dedicated to this challenging service.

Commonly used materials are rated for their resistance to hydrogen embrittlement and crack growth. Where test data are lacking, recommendations are made for future data collection. In-service inspections (ISIs) based on fracture mechanics, analyses are recommended, but cycle-to-failure tests (using hydrogen) and design life limits may be required until data are available.

Tables and figures are used to display successful service data for storage, transport, portable, and fuel tank service. All metal vessels have service histories of 60+ years, with composites gaining acceptance in the last 5 to 10 years (mostly in vehicle fuel tank applications). The successful service data support the reduction of design margins for some metallic vessels, and also support the “performance standard” concept for composite vessels.

Part III - H_2 Piping and Pipelines: Study of Existing Data, Standards, and Materials

This study evaluates the potential use of four piping and pipeline codes (ASME B31.1, 31.3, 31.8, and 49 CFR 192) for up to 15,000 psi hydrogen service.

The study compares the codes and determines the existing design margins. Tables and figures are provided to display the design margins, and also to display successful service data for piping systems and pipelines built in accordance with the codes. Some service data dates back to the 1940s.

Commonly used materials are rated for their resistance to hydrogen embrittlement and crack growth. A table is provided that lists recommended materials for high-pressure hydrogen service. For pipelines, reference to European Industrial Gases Association/Compressed Gas Association (EIGA/CGA) 121/04/E is recommended. For small piping systems, 316L stainless steel (SS) is recommended.

Several special topics related to hydrogen service are covered: performance of welded and mechanical joints, post-weld and post-formed heat treatment, effects of surface finish, and hot and cold pipe/tube bending.

Recommendations are provided for design margins for systems constructed of materials that are resistant to hydrogen embrittlement. Where less optimum materials are selected, the same design margins can be used with adequate initial and in-service inspections.

Recommendations are made for future standards dedicated to high-pressure hydrogen service. The design rule recommendations account for the challenges of (1) pressures well above current common practice and (2) hydrogen with its material compatibility issues, flammability, and small molecular size.