POPULATING THE HYDROGEN COMPONENT RELIABILITY DATABASE (HYCRED) WITH INCIDENT DATA FROM HYDROGEN DISPENSING

Al-Douri, Ahmad[1], Groth, Katrina M.[1], Hartmann, Kevin[2], Saur, Genevieve[2], Buttner, William[2]
[1] Mechanical Engineering, University of Maryland, College Park, MD, USA
[2] National Renewable Energy Laboratory, Golden, CO, USA

ABSTRACT

Safety, risk, and reliability issues are vital to ensure the continuous and profitable operation of hydrogen technologies. Quantitative risk assessment (QRA) has been used to enable the safe deployment of engineering systems, especially hydrogen fueling stations. However, QRA studies require reliability data which are essential to collect to make the studies as realistic and relevant as possible. These data are currently lacking and data from other industries, such as oil and gas, are used in hydrogen system QRAs. This may lead to inaccurate results since hydrogen fueling stations have differences in physical properties, system design, and operational parameters when compared to other fueling stations, thus necessitating new data sources are necessary to capture the effects of these differences. To address this gap, we developed a structure for a hydrogen component reliability database, (HyCReD) [1], which could be used to generate reliability data to be used in QRA studies. In this paper, we demonstrate populating the HyCReD database with information extracted from new narrative reports on hydrogen fueling station incidents, specifically focused on the dispensing processes. We analyze five new events and demonstrate the feasibility of populating the database and types of meaningful insights that can be obtained at this stage.

1.0 INTRODUCTION

For hydrogen fueling stations, quantitative risk assessment (QRA) is an important tool for enabling their safe deployment and has been increasingly embedded in the permitting process. However, most QRAs to date have used data from other industries such as oil & gas, petrochemicals, and nuclear power plants. QRAs built on hydrogen-specific component and system reliability data will provide more robust insights; however, these data are lacking for hydrogen [2].

Failures in hydrogen systems can cause property damage, injuries, loss of life, and system downtime. If these occur during early deployments, this could irreparably damage public trust, which may in turn drive policymakers to curb further adoption of hydrogen in vital sectors that are hard to decarbonize otherwise. While the petrochemical industry has had a long experience in the safe use of hydrogen, much of that experience is proprietary and cannot be directly transferred to scenarios where the general public is in contact with hydrogen as well as new, highly integrated renewable energy applications. Thus, it is important to continue gaining theoretical, experimental, and computational information on the safety and reliability of hydrogen systems.

Currently, hydrogen QRA studies rely primarily on data from other industries such as chemical processing, offshore oil and gas, and nuclear power plants (e.g., [3], [4], and [5]). However, these data sources do not capture the challenges that arise from hydrogen properties including wide flammability limits, low minimum ignition energy, high laminar burning velocity, and high leakage probability [6]. While hydrogen has been used in industrial processes such as petroleum refineries for decades, the change in application of hydrogen from a process medium to an energy carrier and fuel requires adjusting existing use and handling practices. Further, public-facing hydrogen systems (e.g. fueling stations, fuel cell vehicles) introduce a fluid previously present in the industrial domain to public settings where access is not closely controlled and user training cannot be assumed to be required. Thus, using generic data from other industries is not the best choice for QRA for hydrogen fueling stations, because it can lead to uncertainties and inaccuracies in assessments of the safety and reliability of the stations.

Several recent studies have cited the need for hydrogen-specific reliability data as a requirement to improve QRA [7]–[9]. Due to the lack of hydrogen component reliability data, it is unclear how well the existing generic data can accurately predict failure rates for hydrogen systems and components. While creating hydrogen QRA with generic data was a necessary first step in order to facilitate the deployment of the first hydrogen fueling stations, it is time to start collecting and using hydrogen specific reliability data in QRA.

2.0 APPROACH

In a recently submitted paper, Groth et al. [1] showed the main data collection structures and defined a set of 25 data elements to be collected in a hydrogen component reliability database. These elements were based on a set of 23 requirements, developed by West (2021) [10], covering database characteristics and types of data (static and event) to be collected. The development of these requirements was based on the QRA data types identified by Moradi and Groth (2019) [11], the review of current hydrogen safety data collection tools by West et al. (2022) [12], and reliability data collection best practices extracted from study of reliability engineering sources including textbooks and reliability database documentation and guidelines from analogous industries ([13], [14], [15], [16], and [17].

In addition to the reported requirements, the article summarized the approach to developing a failure mode taxonomy for hydrogen components and a generic component hierarchy for hydrogen fueling stations, both originally developed by West (2021) [10]. Since hydrogen fueling stations are systems with a higher degree of technological maturity, they were chosen as the system for which HyCReD is piloted for. The component hierarchy detailed five major subsystems and 21 functional groups for a hydrogen fueling station. The subsystems include the following: bulk storage, compression process, intermediate storage, dispensing process, instrument air/nitrogen, and the cooling process.

In this work, we focus on demonstrating HyCReD and expanding the number of events in HyCReD by adding new event descriptions focused on the dispensing process. The dispensing subsystem involves four functional groups: pre-cooling, dispensing, process transport, and sensing and control. We extracted five events for the dispensing process from three sources: the Hydrogen Incident and Accident Database (HIAD) [18], [19], H2Tools Lessons Learned [20], and a data-providing partner at the National Renewable Energy Laboratory (NREL).

3.0 DATA TABLES DEVELOPED

The sources described above were examined to identify events that had more detailed descriptions, compared to others, of the failures that occurred in the dispensing subsystem of hydrogen fueling stations. The information presented in Table 1, Table 2, Table 3, and Table 4 demonstrate that the database structure can be partially populated given the information available from event reports and entries in HIAD [18] and H2Tools [20]. Essentially, the only fields left blank in Tables 1-4 are fields that were not included in these data collection tools. However, the event HyCReD 6 shows that these data are readily available from data providers and can easily be collected in future events. As such, we demonstrate that the set of requirements defined in [10] for database characteristics, static, and event data were met through the data fields in the structure.

Table 1 presents four data elements with system-level information on the events extracted. These elements characterize the facility from which the report originated, its operational environment and the context of the event being reported. Facility identification is a narrative field in which the name of the station where the event occurred is provided. Facility type and service/usage are to be selected from drop-down menus providing classifications of the facility in terms of access and operations, respectively.

Table 1: System data fields for five events involving the dispensing process in a hydrogen fueling station.

Event Number	Facility Identification	Facility Type	Service/Usage	Facility Nominal Working Pressure
HyCReD 4	Unidentified	Commercial, limited access	Heavy-duty	700 bar
HyCReD 6	HITRF	Research, limited-access	Both heavy- and light-duty	This is a 700-bar dispenser for light-duty use supplied by permanent, on-site gaseous storage of approx. 600 kg
HyCReD 8	Unidentified	Pre-commercial, limited-access	Unknown	700 bar
HyCReD 9	Unidentified	Unknown	Unknown	700 bar
HyCReD 10	Unidentified	Unknown	Unknown	700 bar

Table 2 provides eight data elements used to describe the equipment where the failure event occurred. This is to be completed using drop-down lists from the generic hydrogen station component hierarchy developed by [10]. Upon selecting a subsystem in which the event occurred, a dependent drop-down list for the functional groups contained under the subsystem is used to select the group. The same applies to components under the selected functional group so that the component where the failure event occurred can be selected. The “equipment description” data element is a narrative field where a data provider can add a description of the equipment and system involved in the event. Component nominal working pressure (NWP) and population are numerical data elements for describing the intended operating pressure range and number of similar components to the failed component.

Table 3 and Table 4 show the failure and maintenance event data, respectively, obtained from the descriptions. While most aspects of failure information were available, there were some gaps in older data sources. Since the events examined had detailed descriptions, it was easy to determine the appropriate failure mechanism for each event. In the case of less detailed descriptions, the presence of drop-down menus or pick lists for each component, its failure modes, and failure mechanisms will be essential to ensure accurate and consistent reporting across components from multiple facilities. In addition, no information on maintenance event start/end dates and station restart date (if applicable) was available in any of the five events. This information is vital to determine which component failures lead to the longest downtime durations for fueling stations.

Table 2: Equipment hierarchy data fields for five events involving the dispensing process in a hydrogen fueling station.

Event Number	**Equipment Description**	**Subsystem**	**Functional Group**	**Comp.**	**Component NWP**	**Component Population**	**Install. Date**	**P&ID Part No.**
HyCReD 4	Solenoid valves were not operating correctly	Dispensing Process	Sensing and control	Flow control valve	-	-	-	-
HyCReD 6	Medium-pressure manual isolation ball valve (normally open) on a high-pressure, light-duty H2 dispenser	Dispensing Process	Sensing and control	Manual valve	480-860 bar	5	Jan-19	HV-120A*
HyCReD 8	A needle valve used primarily for manual filling to control hydrogen flow rate from storage banks to the 70 MPa test system.	Dispensing Process	Sensing and control	Flow control valve	480-860 bar (assumed)	-	10/1/2005 (Two years, 400 fill operations)	-
HyCReD 9	High-pressure polytetrafluoroethylene-lined 4.0-meter hose.	Dispensing Process	Dispensing	Hose	850-875 bar (assumed)	1	06/01/2005 (Two years, 150 high-volume fill operations, 200-250 pressure-cycling occurrences)	-
HyCReD 10	Two fittings experienced failure: The first was a 0.25-inch NPT hose connection, and the second was a double-ferrule high-pressure connection	Dispensing Process	Dispensing	Fitting	700-875 bar	-	9/1/2006 (First fitting was in service for approximately 1 year without leakage)	-

Table 3: Failure event data fields for five events involving the dispensing process in a hydrogen fueling station.

Event Number	Date & Time of Event	Failure Mode	Failure Mechanism	Failure Root Cause Description	Failure Severity	H2 release?	H2 release size	Accumulation?	Detection?	Detect. notes	Ignition?
HyCReD 4	7/23/2013	Fail to operate	Binding/ jamming	Solenoid valves were not operating properly because a strap connector on an air line in the FC workshop came apart overnight.	Minor	No	Unk.	No	Yes	-	No
HyCReD 6	12/20/2021 11:45	External leak hydrogen	Mechanical failure	Appears to be O-ring extrusion/failure (sent to NREL for LRQA testing)	Minor	Yes	Small (1-2 kg)	No	Yes	Audible	No
HyCReD 8	9/19/2007	Fail open	Deformation; Material failure-general	Internal galling rendered the needle valve unusable, and this was caused by a stainless steel stem acting against a stainless steel seat.	Minor	No	None	N/A	-	-	No
HyCReD 9	6/11/2007	External rupture hydrogen	Corrosion; Mechanical damage	A sidewall burst failure of a high-pressure PTFE-lined hose occurred. Failure of the hose occurred while it was temporarily connected to a gas booster, after 1-2 hours of service at 750 bar. Examination of the hose determined that the failure occurred approximately 30 cm from the crimped end fitting. The hose contained 3 distinct kinks (bent areas) within the immediate area of failure.	Critical	Yes	Unk.	-	-	-	No
HyCReD 10	9/19/2007	External leak hydrogen	Deformation; Fatigue	Failure was noticed when system was pressurized during a filling sequence, and was discovered by an audible hissing noise during leak checking	Minor	Yes	Small	N/A	Yes	Audible	No

Table 4: Maintenance event data fields for five events involving the dispensing process in a hydrogen fueling station.

Event Number	Date & Time Repair Started	Date & Time Repair Completed	Date & Time Station Restarted	Maintenance Description
HyCReD 4	-	-	-	A snap connector that came off in the FC workshop was reconnected and air supply was restored.
HyCReD 6	-	-	-	-
HyCReD 8	-	-	-	The needle valve was replaced with a new valve in order to continue the test program.
HyCReD 9	-	-	-	The assumption is that the hose was replaced. This is because the Lessons Learned section recommended that hoses should be examined for signs of external damage (corrosion, abrasion, cuts and kinking) and that high-use fueling hoses should be replaced every 6 months.
HyCReD 10	-	-	-	The system was depressurized and the fitting was removed and replaced. Afterwards, the system was re-pressurized with no further leakage

4.0 DISCUSSION AND CONCLUSIONS

In this work, we demonstrated that we were able to successfully fill out most of the 25 data elements outlined in the HyCReD structure [1]. Some of the important information that could not be filled out were the station name, component population, component installation date, and maintenance event date and times. This information could have been obtained from their original sources, but our team does not have access to them. Thus, we recommend that future incident reports provide this information so that more complete data can be collected. For example, component population and installation date are important elements to be able to calculate useful data products, such as failure rates, from this database. Also, we determined that maintenance event start and end dates were very scarce as evidenced by the blank cells in Table 4. This information is vital to be able to calculate component repair rates and station downtime, which significantly impact station profitability and the possibility of increasing adoption of hydrogen as a transportation fuel.

For the five events described in Section 4, three involved valves located in the sensing and control functional group of the dispensing process. The two other events involved a hose and a fitting, both of which are part of the dispensing functional group. The dominant failure mode observed was an external leak of hydrogen to the environment. A variety of failure mechanisms were observed for the incidents including mechanical damage, corrosion, leakage and fatigue. In most events, the release was detected and no ignition occurred. Using the severity scale from the IEEE Standard 500-1984 [21], one incident was deemed to be critical since it required a shutdown of the station. This event involved the external rupture of a high-pressure polytetrafluoroethylene-lined hose. Since we only collected these six incidents, we caution against making statistical judgements given the small amount of available data. However, we believe this is a promising pathway to creating meaningful statistics about these stations.

Through the demonstrated HyCReD structure, we present a major step towards achieving the goal of having hydrogen component and system reliability data to support QRA, safety analysis, reliability analysis, and maintenance planning. While HyCReD is still under development, these early analyses show that the structure is usable and can be populated with readily available information by stakeholders. Our next steps are to collect more data to populate HyCReD with additional events for the dispensing process as well as the other five major subsystems in a hydrogen fueling station. To do so, we are seeking information and data-providing partners to support these next steps. Once we have a larger set of events, we can produce estimated failure rates for the various components in a hydrogen fueling station. Ultimately, these results can provide participants and stakeholders with tangible insights that enable prioritizing maintenance activities and targeting components with the highest failure probabilities, thereby eliminating costly downtime. This leads to improved station uptime, higher number of fills, and ultimately greater economic returns. Further, these insights will lead to improved station designs for the future and enable targeted component research and development activities improving the most failure-prone components. Additional future steps include developing component hierarchies for systems other than hydrogen fueling stations, such as electrolysis units, as a wider set of system descriptions and diagram become public for these systems.

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