Proceedings of the 35th European Safety and Reliability & the 33rd Society for Risk Analysis Europe Conference
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doi: 10.3850/978-981-94-3281-3_ESREL-SRA-E2025-P4136-cd

Towards a reliability database for hydrogen equipment

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Reliability databases for hydrogen equipment are essential for risk and reliability assessments of both established and new hydrogen facilities. Existing hydrogen event databases have significant limitations with respect to quantity and quality of data, hence providing limited value for rigorous assessments. There is a lack of standardization in the hydrogen sector when it comes to data collection and analysis. In addition, there seems to be a lack of stakeholder incentives to perform data collection and sharing. In order to obtain high-quality reliability data for hydrogen equipment, we argue that each of these challenges must be addressed in a structured and holistic manner. In particular, a systematic approach for collection and analysis of failure data should be investigated. Looking at the more mature petroleum industry for inspiration (the OREDA project), we propose a similar setup for hydrogen equipment. Hence, we present an adaptation of the OREDA approach to the hydrogen domain. As an example and test case, we explore the equipment type pressure swing adsorber (PSA) used for (blue) hydrogen purification. The PSA example is detailed in terms of equipment structure (i.e. subunits, components and boundary) as well as failure modes and their criticality.

Keywords: Hydrogen, reliability database, data collection

1. Introduction

Hydrogen has been recognized as an important energy carrier in reducing emissions. However, the use of hydrogen poses accident risks arising from hazard characteristics of hydrogen like high flammability, and it is therefore important to carry out risk and safety assessments for hydrogen systems for safer handing of hydrogen (Lee et al., 2022). A major challenge in performing such assessments is the lack of reliability databases for hydrogen-specific applications (Groth et al., 2023). Risk and reliability assessment for hydrogen facilities will require failure data like failure modes and estimated failure rates for hydrogen process equipment and safety systems. It is important that such failure data are as realistic as possible. Per today, however, data requirements for hydrogen facilities are not well established, in contrast to e.g. the oil and gas industry.

There seem to be three main challenges with hydrogen event data collection and sharing. First, there is a **lack of data** due to short operational time, missing registration and lack of sharing between stakeholders. Many hydrogen facilities are relatively new and have not yet produced substantial operational failure data. Furthermore, even if failures occur, they may not be registered – or registered in a way that make them less suitable for reliability assessments. Second, there is a **lack of standardization** in the industry when it comes to data collection, including a lack of definitions related to e.g. equipment types and failure modes. Standardization work would imply a collective effort from various stakeholders, requiring sufficient interest as well as funding. Third, there is also currently a **lack of**

stakeholder incentives to perform data collection and sharing due to market considerations, limited financing and the absence of regulations. Furthermore, the historical lack of high-profile accidents has not provided the necessary "push" towards increased safety work and collaboration, as we have seen in the oil and gas sector.

As a consequence, reliability data directly relevant for hydrogen applications are scarce and insufficient, so reliability data from the oil and gas industry has often been applied instead for hydrogen applications. This use of data from another sector contributes to data uncertainty in the reliability and risk analysis for hydrogen facilities, and this calls for better reliability databases for hydrogen equipment available in the future. To establish such a hydrogen reliability database, a systematic approach for collection and analysis of failure data is required. This paper suggests groundwork needed for the establishment of a systematic hydrogen reliability database and presents an example of how such groundwork can be applied to a use case for hydrogen equipment.

1.1. Existing hydrogen databases and tools

A handful of hydrogen databases and tools exist today, although the maturity of such databases in terms of data quality varies. Below we briefly introduce four existing hydrogen databases that are relevant for risk and reliability analysis of hydrogen equipment (West et al., 2022).

H2Tools Lesson Learned (H2LL) (H2Tools, 2025) is a public resource for sharing lessons learned from incidents (i.e. near misses and accidents) involving hydrogen. It contains data from various sources like historic databases, journal articles, media and self-reporting, mostly from the US. The database also facilitates voluntary reporting of incidents from hydrogen facilities. All identifying information is removed for enhancing anonymity. Currently there are 220+ safety event records in the H2LL database. However, the hydrogen equipment categories used in H2LL are not of a sufficiently detailed level to be used as a basis for reliability data for hydrogen equipment.

Hydrogen Incident and Accident Database (HIAD, 2025) is a public repository tool developed by the European Commission Joint Research Center and DNV (Galassi et al., 2012). HIAD represents one of the largest available collections of hydrogen specific data, with more than 700 entries. The data entry fields in the HIAD database are *Events*, *Facility*, *Consequences*, *Event Nature*, *Lesson Learnt* and *References*.

The National Renewable Energy Laboratory (NREL) Composite Data Product (**NREL CDP**) reports maintenance data for hydrogen equipment from different hydrogen fueling stations operating in the US. Maintenance data for equipment like compressors, dispensers, and sensors have been collected. The data are anonymized and is published twice a year. As of 2020, 44 hydrogen fueling stations operating in the US were the sources of the data.

The Center for Hydrogen Safety **(CHS) data collection tool** aims at developing failure rates specific to hydrogen components from anonymized data from refueling stations. CHS members can report failure data to obtain failure rates.

SAFEN (2025) is a recent joint industry project (JIP) where a number of industry stakeholders are collaborating to share experiences and address knowledge gaps in renewable technologies (hydrogen, ammonia, and carbon capture/storage). As part of the scope, a database specification has been developed focusing on loss of containment events.

None of the existing databases presented above can be regarded as reliability databases. They are useful to inform qualitative decisions regarding safety culture, planning, procedures and best practices rather than Quantitative Risk Analysis (QRA) or reliability studies. To a certain extent, each of the databases presented is not systematic enough to serve as a robust data source for quantitative reliability assessments. The main reason is that the data fields in most cases are predetermined options and not specific enough to be used to generate reliability data for specific equipment types. Open-end fields lead to a wide variety of possible input with significant user interpretation. Even the NREL CDP, which is perhaps the most structured data collection template, fails to adequately define failure modes and mechanisms. In other words, while safety databases can be used to support qualitative decisions regarding safety culture, planning, procedures and best practices, they have significant shortcomings when used as a basis for quantitative reliability assessments for hydrogen equipment and rigorous QRA for hydrogen facilities.

2. OREDA

For the purpose of establishing a rigorous reliability database for hydrogen equipment, inspiration may be drawn from comparable process industry practices. Looking to the petroleum industry, OREDA is a prominent example of a successful reliability database.

2.1. What is OREDA?

Oreda is a joint industry project (JIP) organization of (currently) 6 oil and gas companies that has been active since the early 1980-ies. Oreda is a forum for exchange and development of reliability methods and know-how within the oil and gas industry, and has been the “cradle” for the production of central ISO/API standards within the reliability field (ISO 14224, ISO 20815, ISO TR 12489, see reference list). Furthermore, Oreda builds and maintains a comprehensive databank of reliability data collected on topside and subsea equipment from offshore and onshore operations from all over the world (North Sea, GOM, WOS, Angola, Adriatic, Caspian, etc.). Based on this databank, a reliability data handbook for selected equipment types has been published regularly; the last paper edition came out in 2015, and the handbook is now entirely digital.

2.2. OREDA approach to data

For each equipment category the database is split into three separate database files: an Inventory part, a Failure part, and a Maintenance part. The information recorded in the OREDA database is partly based on numeric data, partly on codes selected from a predefined menu, and partly on free text (OREDA 2012).

The **Inventory** part contains a description of each Equipment unit for which data have been collected. This description contains technical data (e.g. capacity, size) as well as some operating and environmental data (e.g. operating mode, vibrations). The inventory description for each equipment unit is stored in an Inventory record in the database.

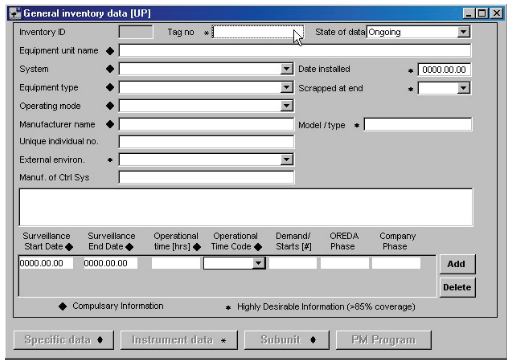

Figure 1. Example of OREDA data fields for equipment information (OREDA, 2012).

The **Failure** part contains information about the failures recorded for the equipment unit (inventory) during the period of surveillance; one record for each failure event. The failure events are always related to one equipment unit. In OREDA a failure event is defined as a physical failure of equipment. This implies that all events where a work order is issued, and some maintenance action carried out, would be considered as failure.

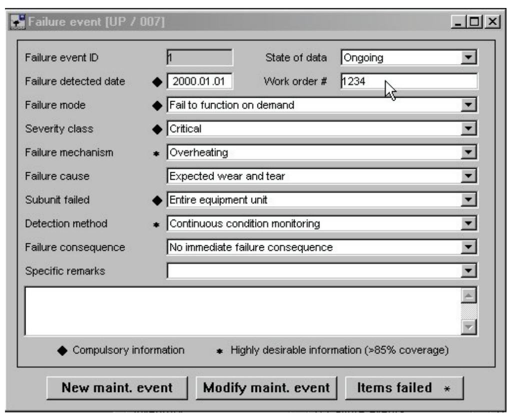

Figure 2. Example of OREDA data fields for failure information (OREDA, 2012).

The **Maintenance** part contains information about corrective and scheduled preventive maintenance program for each equipment unit (e.g. maintenance action, interval, manhours). Data on corrective maintenance is related to its preceding failure, while data on preventive maintenance is related to the equipment unit. Note that scheduled preventive maintenance is not mandatory when performing data collection, so the handbook does not contain such information.

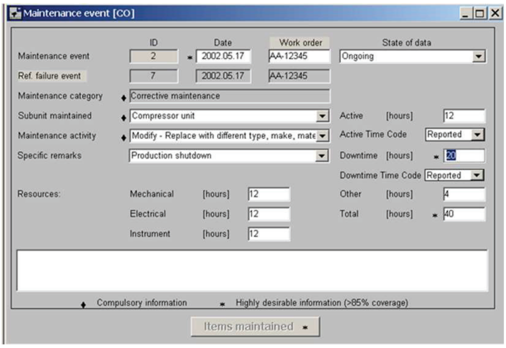

Figure 3. Example of OREDA data fields for maintenance information (OREDA, 2012).

Furthermore, each data field in Oreda is associated with a priority on three levels: *compulsory* (full coverage), *highly desirable* (at least 85 % coverage) or *no priority*. In the figures above, these priorities are indicated with the labels diamond, asterisk or no label, respectively. The point of prioritization is to make sure that the most important fields are always or almost always filled out, making it easier to aggregate and compare statistics. The OREDA database contains a substantial amount of data fields that are to be considered "nice to have", but where data might be difficult or time-consuming to obtain.

3. Going from OREDA to HYREDA

With OREDA as a starting point and model database, adjustments need to be made to better suit hydrogen needs. Although petroleum and hydrogen to some extent use similar equipment, there will be differences in content and setup within all the main data categories, i.e. inventory, failure and maintenance data.

4.1. Adjustments to OREDA

Some examples of possible adjustments (compared to OREDA) are given in the following.

Equipment types: Hydrogen will have some specialized equipment types, e.g. related to electrolysis, purification, etc.

Equipment boundary and subdivision: The boundary definition may be different, as well as the subunits constituting the equipment unit.

Process medium: Hydrogen will have other properties and process parameters, resulting in a different potential for e.g. corrosion, clogging, etc.

Failure modes: Hydrogen equipment may feature additional failure modes, and some failure modes may be irrelevant.

Criticality: The criticality of some failure modes may be different depending on equipment setup and characteristics.

Furthermore, there will be a need to review both the quantity and nature of the data fields, as well as the priority assigned to each field. Operating with an excessive amount of data fields, as well as assigning priority to too many fields, may prove discouraging to the data collection process. Hence, it might be advisable to start with a simpler collection scope focusing on the most essential data fields.

3.2. Potential challenges and questions

Apart form the general challenges to data collection and sharing described in the introduction (i.e. lack of data, standardization and incentives), there are some specific challenges and questions related to the process of going from OREDA to HYREDA.

As mentioned above, it could prove challenging to find the right level of detail in the data collection when it comes to the number of data fields and the prioritization of each field. Too many fields and too heavy prioritization will represent a substantial workload for the collector, which may affect the motivation as well as the ability to pay for the work.

Establishing a new reliability database will necessarily take some time, as operational reliability data on a standardized form gradually accumulates. Hence, patience and commitment need to be key traits of the stakeholders involved. Incentives to initiate and stay in the process must be present, as discussed in the introduction.

Why are existing data sources not sufficient?

Today, OREDA and other established data sources have been used for reliability calculations for hydrogen equipment, often enhanced with expert judgment. Some might argue that it is possible or even advisable to continue on this path. However, we believe that the uncertainty introduced by using data from another (although similar) sector should be avoided. In addition, specialized hydrogen equipment may not be found at all in sources like OREDA, making reliability estimates rely too heavily on expert judgment and biased manufacturer information.

Why not expand the Oreda scope instead of building a new database from scratch?
OREDA is an industry project funded by a handful of "traditional" oil and gas companies. Hence, hydrogen activities are outside their main scope of interest, and there are no real incentives to expand the database to include hydrogen equipment. Moreover, the data collection burden is already quite significant for these companies, as they struggle to fill all the existing equipment categories with sufficient and recent data.

One could envision the inclusion of hydrogen companies in the OREDA project to shift the focus towards hydrogen data needs, However, merging the two worlds will likely dilute the product and result in companies (participants and customers) experiencing that they pay for a product they do not need. It could be argued that part of the reason for OREDA's success is the homogeneity of the participants and the data collected.

4. Use case: Pressure Swing Adsorber (PSA)

In order to demonstrate the necessary transition from OREDA to hydrogen, a use case of a typical hydrogen process equipment has been selected: the Pressure Swing Adsorber (PSA).

4.1. What is a PSA?

A PSA plays an important role in separating hydrogen from impurities in synthesis gas. Adsorbents in PSA processes are typically silica gel/alumina for water removal, activated carbon for CO_2 removal, and 5A zeolite for the removal of CH_4, CO, and N_2. PSA systems are chosen for their low energy consumption, precision, and ease of operation, as they do not require rotating equipment or circulation solutions (Yang, 1987). PSA units function through four main stages: adsorption, depressurization, purge, and repressurization. Normally, multiple adsorbers ("polybed") are linked to maintain continuous throughput. Although additional beds improve performance, they also increase operational complexity. The first commercial PSA unit, featuring four adsorbers, was installed in 1966 (Yang, 1987), and currently there are approximately 1000 polybed PSA systems in operation worldwide.

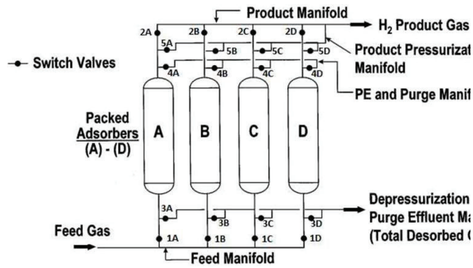

Figure 4. Process flowsheet of a 4-bed PSA system (Waldron, 2000).

Waldron (2000) provides a description of the flow process for methane removal in five steps (a)–(d). We include this description here to give an idea of the procedure and the equipment involved: "The CH_4 was adsorbed from the feed gas in step (a). It was desorbed and removed from the column in steps (d) and (e). The complementary step (b) is added to recover and internally recycle a part of the void and co-adsorbed H_2 that is present in the column at the end of step (a). The complementary step (c) also recovers a part of the void and co-adsorbed H_2 and uses it as H_2 purge gas during desorption. These steps increase the H_2 recovery by the process at the cost of increased adsorbent inventory. The H_2 purge and pressurization steps (e, f, g), push back the CH_4 impurities from the product end of the column so that a pure H_2 product stream can be obtained during the subsequent adsorption step. A part of the void gas H_2, the co-adsorbed H_2, as well as the purge gas H_2 is lost with the effluent waste gases produced during steps (d) and (e). This lowers the H_2 recovery by the process."

4.2. PSA-OREDA adaptation

In a recent work by Nguyen (2023) the PSA process is converted to a valve operation process where the PSA unit is directed by a system of 20 switch valves, with 5 valves for each of the 4 beds. The 4 adsorber lines are connected in parallel between the feed manifold and product manifold. The PSA process is converted to a RAM model as shown in Fig. 5.

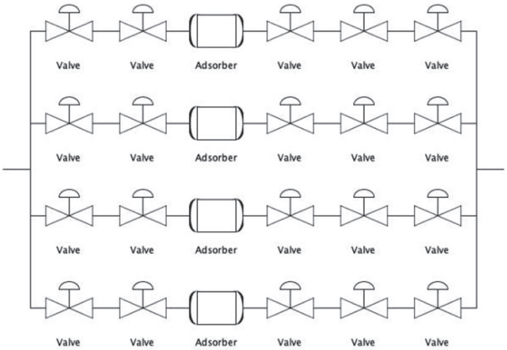

Figure 5. RAM model for the 4-bed PSA unit (Nguyen, 2023).

In (Nguyen, 2023) the failure rate for the 4-bed hydrogen PSA system is computed by assuming that any critical failure from the valves leads to the failure of the corresponding adsorber line, causing system failure. This assumption allows for the calculation of the mean failure rate of one line by summing the mean failure rates of the five corresponding valves. However, the detailed failure data for the adsorbers is not included in PSA failure rate calculations.

The partition into subunits, as well as the equipment boundary definition, is of importance to the reliability calculations. In (Nguyen, 2023), the adsorber is presented in a simplified manner without including detailed instrumentations and internals, etc. Furthermore, according to the vessel equipment boundary defined in OREDA, as shown in Fig. 6, the inlet, outlet, pressure relief and drain valves are specifically excluded from the failure data collected for vessels. The only valves included are calibration valves and instrument valves that form a pressure boundary (e.g. block valves, control valves, calibration valves, local indicators/gauges).

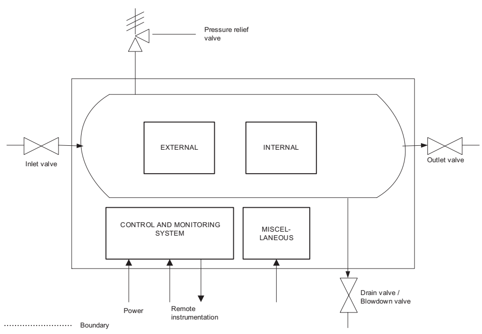

Figure 6. Vessel boundary definition in OREDA (OREDA, 2012).

Although adsorbers are part of the OREDA data taxonomy, no actual failure data have been collected on adsorbers in OREDA. Hence, we use general vessel data from OREDA for illustration purpose as data for adsorbers. The total number of registered critical failures for a vessel is 91 failures per 1 million hours. The critical failures modes distribution for a general vessel is shown in Table 1.

Table 1. Critical failures modes distribution for a general vessel in OREDA (OREDA, 2015).

Failure mode (critical)	No. of failures in 10^6 hours
Abnormal instrument reading	46
External leakage - Process medium	7
Fail to start on demand	1
Fail to stop on demand	1
Parameter deviation	24
Plugged/Choked	5
Spurious stop	1
Other	5
Unknown	1
Total	91

From the data, it is evident that over 75 % of critical failures in vessels are attributed to the control and monitoring systems. This insight is critical for evaluating maintenance mobilization time, spare part requirements, and maintenance planning. The failure distribution of control and monitoring system also indicate the need for robust maintenance strategies focusing on these systems to enhance reliability and reduce downtime.

5. Conclusion

Existing hydrogen databases and tools are useful to inform qualitative decisions regarding safety culture, planning, procedures and best practices, but have significant shortcomings when applied to Quantitative Risk Analysis or reliability studies. Hence, there is a need for the introduction of dedicated hydrogen reliability databases. We propose that a new hydrogen reliability database (HYREDA) should preferably be molded on the existing OREDA database used in the petroleum industry.

Necessary adaptations to OREDA will have to be made to better suit the hydrogen domain. This may include adjustments to the equipment units themselves – including their subdivision and defined boundary – as well as relevant failure modes and their criticality assessment.

HYREDA should arguably be made less comprehensive than the current OREDA solution to save effort in the data collection and encourage possible data contributors to "get started".

It will take some time to collect and share hydrogen event data in a standardized way with sufficient volume to be useful in reliability assessments. Hence, in a transition period, it will be natural to still consider OREDA data in calculations, as many types of equipment and operating conditions are comparable between the petroleum and hydrogen domain.

Industry stakeholders need incentives to collect and share hydrogen reliability data. This includes legislation, industry standardization and economic incentives. Furthermore, industry forums for dialogue and exchange of data should be established, e.g. through a JIP project.

This paper describes a use case where reliability aspects of a typical hydrogen equipment unit (PSA) is discussed, particularly in relation to OREDA. The use case highlights the currently high dependency on OREDA data in the reliability estimation.

Acknowledgement

The work is part of HYDROGENi (2025), a Center for Environment-friendly Energy Research (FME) funded by the Norwegian Research Council FME research program. HYDROGENi focuses on research and innovation for introducing hydrogen and ammonia at larger scale.

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