NanoSUN

Is Hydrogen Safe?

Hydrogen Refuelling Technology and Vehicles.

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OVERVIEW

There's been a lot of talk about hydrogen having a leading role in the journey to decarbonising transport and reaching net zero, particularly within the hard to decarbonise sectors such as maritime, aviation and road transport. However, like any other fuel source, there are safety concerns surrounding the use of hydrogen that need to be addressed if we are to accelerate the hydrogen economy within the transportation industry.

This paper takes a look at the various associated dangers of hydrogen and the unique properties that must be considered during the design of a project, particularly hydrogen refuelling technologies and fuel cell vehicles.

KEY TAKE AWAYS

- Hydrogen presents the same, if not less, dangers than other fuels due to its non-toxic and non-poisonous characters.
- An array of safety procedures and protocols must be implemented throughout each design stage of a product to ensure the safe performance of hydrogen technology.
- Hydrogen technology promises an efficient and economical solution when handled safely and appropriately.

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INTRODUCTION

There's been a lot of talk about hydrogen having a leading role in the journey to decarbonising transport and reaching net zero, particularly within the hard to decarbonise sectors such as maritime, aviation and road transport. However, like any other fuel source, there are safety concerns surrounding the use of hydrogen that need to be addressed if we are to accelerate the hydrogen economy within the transportation industry.

It's clear that hydrogen as an energy vector comes with a lot of advantages. Its high gravimetric energy density allows heavy duty applications, where weight is critical, such as ships, trucks, buses and trains, to significantly reduce the weight of the system compared to current battery-electric solutions. This meaning that hydrogen can, for example, enable the maximisation of a heavy-duty truck's payload and the range on its single tank. High-speed refuelling of hydrogen powered vehicles is also possible, minimising idle times of vehicle fleets and equipment without needing redundancy of battery storage, as is common for many warehouses utilising battery-powered forklift trucks.

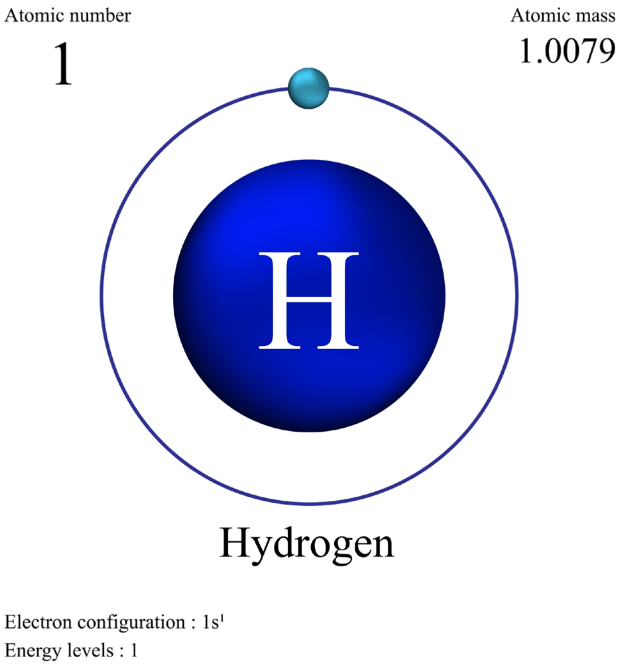
Yet, while the benefits of hydrogen are significant, there are a number of associated dangers that need to be taken into account. Hydrogen is equivalent in safety to other commonly used fuels when handled properly, but the unique properties of hydrogen must be considered, particularly during the design phase of a project.

PART 1: HYDROGEN PROPERTIES & SAFETY MEASURES

In its natural form, hydrogen is a gaseous substance that is colourless, odourless, and tasteless, meaning it can go easily undetected and its chemical structure makes it highly combustible. A small, common isotope consisting of two atoms, both sharing one electron and one proton, hydrogen has a simple chemical structure that allows for covalent bonding, causing high flammability and easy ignition when mixed with oxidising elements.

It is, however, the most abundant element on earth and is mainly generated from water and organic matter. Alongside its gaseous formation, it is available in various forms such as liquid hydrogen, solid and metallic, and unlike many other fuels it is non-toxic and non-poisonous. As a potential endless source of renewable energy in the globe's journey to net zero, it is widely becoming seen as a fuel of the future.

NanoSUN takes a look at hydrogen and the safety measures required throughout the design process of hydrogen technology and equipment.



FLAMMABILITY

Due to its chemical structure, hydrogen has a wide flammability limit when mixed with the air, ranging from 4% to 75% volume concentration. The flammability limit (otherwise known as the explosive range) is the range of concentrations hydrogen gas can have in the air, in which an explosion or flame will occur if the mixture is ignited at a fixed temperature and pressure (typically 20 degrees and atmospheric pressure).

It is therefore vital that precautions are taken to prevent leaks from accumulating, as they can quickly reach the Lower Flammability Limit (LFL) within the concentration range (4%). For this reason, ventilation must be a key consideration when designing high pressure hydrogen equipment. Fortunately, hydrogen is 14 times more buoyant than air, meaning natural ventilation is often sufficient to preventing accumulation, especially outdoors. However, forced ventilation is often a requirement in space-constrained or indoor systems, in conjunction with hydrogen gas detectors to provide further warning and options for automated shutdown in the event of malfunction.

IGNITION ENERGY

The hydrogen-air mix also presents a low minimum ignition energy, with hydrogen carrying a low ignition energy of 0.02mJ. It is therefore crucial that any sources of ignition located nearby a hydrogen system is removed. When hydrogen equipment is designed, it is essential that the system is analysed and the necessary calculations are conducted to determine the location and extent of any potential ignition sources of release. This leads to the generation of an ATEX zoning diagram.

ATEX is a European directive, which provides guidance on what electrical systems and equipment may be present in potential flammable atmospheres, to prevent ignition of releases. This significantly decreases the risk that people are exposed to, especially in situations where a technician needs to conduct maintenance on a system and needs to know the air is free of ignition sources. For this reason, it is mandatory for manufacturers of hydrogen technology to undergo the EU-Type Examination and acquire ATEX certification, verifying and ensuring the system's safe performance in an explosive environment.

POTENTIAL FIRES

External fires are a further concern for hydrogen systems, as they are for many different fuels. If for example, a hydrogen vehicle on the road was exposed to a liquid pool fire due to a nearby vehicle crash, this flame could compromise the integrity of the hydrogen storage tank and cause rupture; resulting in an explosion that could be extremely severe. It's therefore a requirement that transportable hydrogen systems and hydrogen powered vehicles are fitted with thermal relief devices, which releases the tank's contents upwards in response to an external fire. This averts a potential explosion but may cause a new concern of thermal radiation if this upwards jet ignites. The hazards of these two sources are a cause for serious consideration and must be balanced against each other to minimise the overall risk of the hydrogen system.

MATERIAL SELECTION

Material selection is key to ensuring the safety of any hydrogen fuelling technology. Hydrogen embrittlement is known to occur in many metals, where material strength is reduced after exposure to hydrogen. This can occur through many mechanisms, including hydrogen diffusing through grain boundaries, forming hydrides within a material, or blistering, where "bubbles" of hydrogen gas form within a material, causing cavities in the metal itself and allowing potential leakages.

The choice of material is therefore a critical stage within the products design process, as potential damage can be particularly susceptible. Austenitic stainless steels show good resistance to these forms of attack, and as such, 316L austenitic stainless steel is the most common material used for hydrogen service.

Brass is another material that is commonly used for hydrogen service, as it also shows a good compatibility with hydrogen properties Aside from the selection of primary pipework and component materials, it is also important to consider secondary material selection. For example, elastomeric seals (e.g. O-Rings) are often used within pressure-seals within components.

These seal materials must be both chemically, and environmentally compatible with hydrogen, the gas temperatures within hydrogen systems can reach temperatures well below 0°C and up to temperatures approaching 100°C. Ensuring seals don't become brittle and fail, or become soft such that they may move out of position is a critical design consideration.

PART 2: FUEL CELL VEHICLES & HYDROGEN FUEL

As previously highlighted, fast refuelling is a major advantage of Fuel Cell Electric Vehicles (FCEV) compared to Battery Electric Vehicles (BEV) when operating vehicle fleets. The fast turnaround of hydrogen fuel minimises idle time, without needing to store multiple backup batteries for each vehicle, as seen with forklift trucks.

In the case of light duty vehicles e.g. domestic cars, battery electric solutions can be very effective even with slow refuelling times in the order of a few hours, as leaving cars plugged into a charging point overnight is not an inconvenience. However, for heavier duty applications like buses, trucks or forklifts, where idle time translates directly into loss of revenue in some circumstances, long recharging times can be unacceptable and thus hydrogen vehicles become a more attractive solution. Yet, whilst hydrogen can be used as safely as other common fuels when handled properly, there are a number of unique safety factors that need careful consideration when it is utilsed within vehicles.

HYDROGEN STORAGE & REFUELLING

To ensure the safety of individuals operating hydrogen powered vehicles, FCEVs are typically installed with modern hydrogen storage tanks using type IV vessels. These vessels are composite tanks with plastic liners, which are then wrapped with either carbon fibre/epoxy or glass fibre/epoxy to give the tank the structural strength needed to control hydrogen under pressure. These plastic liners are normally limited to 85C in refuelling protocols to ensure they never reach their melting temperature, as this would lead to leakage through the cylinder wall if exceeded.

During a refuelling cycle, the temperature of hydrogen increases due to heat of compression. This is an inherent property of hydrogen gas and the faster the flow rate of hydrogen during refuelling, the greater the temperature increase is. It is therefore critical that a further safety parameter is put in place to manage the liner temperature. To do this, an average pressure ramp rate (APRR) methodology is used across the refuelling cycle to tightly control the mass flow rate of incoming fuel and the delivery of temperature of fuel into the receiving tank.

HYDROGEN EXPANSION & ELEVATED TEMPERATURES

Controlling the flow rate of fuel allows sufficient time for heat transfer between the gas and cylinder wall, where the cylinder wall itself acts as a heat sink, reducing the amount by which the liner temperature increases. In addition, the incoming gas stream temperature is usually cooled to reduce the amount by which the gas temperature would increase, allowing higher flow rates while keeping the liner temperature within allowable limits.

Under J2601 protocol, hydrogen refuelling stations are typically allowed to fill avehicle slightly above the nominal working pressure (NWP) so that when the vessel cools after refuelling, the settled pressure falls back down to the NWP, corresponding to an acceptably full state of charge (SOC). The main protocols followed are J2601 for cars, J2601/2 for heavy duty vehicles, and J2601/3 for hydrogen-powered industrial trucks (HPIT's or Forklifts). J2601/4 is a work in progress to ensure the safety of individuals and will describe protocol for ambient refuelling with no prechilling. There are also consortiums such as the European based PrHYDE project developing new protocols for medium and heavy-duty vehicles based on the current state-of-the-art technologies.

REFUELLING DESIGN TECNIQUES

When designing a refuelling system, like NanoSUN's mobile Pioneer Hydrogen Refuelling Station, it is important to consider the systems in place to prevent hazardous events, such as out of control refuelling. Tried and tested processes and industry techniques such as Design Failure Modes and Effects Analysis (DFMEA), Hazard and Operability (HAZOP) and Layer of Protection Analysis (LOPA) are ideal tools for this purpose.

DFMEA is a useful design tool, used throughout the design process, in order to ensure a design is capable of meeting the technical requirements which represent the required function and performance of the product. This can be used to risk assess a design throughout its generation and put mitigations or modifications in place where needed. This is critical in preventing both unplanned late change and in reducing the likelihood of discovering unexpected emergent behaviour at a later stage.

HAZOP studies a system in a methodical way, looking at sources of hazard in terms of deviations in flow, pressure, temperature, control etc., as well as external factors such as extreme weather, fire, lightning and possible misuse of the system. This helps to highlight what the most likely and high-consequence deviations are, and what safeguards a system already has in place against such deviations.

LOPA is a more targeted quantitative tool. After a HAZOP has been conducted and the more serious deviations identified, LOPA looks into the overall risk of a given event by examining the expected frequency of an initiating event, e.g. failure of a control system leading to haywire refuelling. LOPA then examines the barriers in place which are able to stop this hazardous scenario from escalating to cause a fatality and applying a modifier to the expected Frequency to take credit for these barriers. In order to prevent common cause failure taking out multiple safety systems, and double-counting safety systems in error, care is taken in a LOPA to only consider barriers that are truly independent of one another. Based on a LOPA, recommendations can be made to add safety instrumented systems to meet the risk target, for example redundant sensors, pressure switches, gas monitors etc. These recommendations once implemented ensure that a system design is as robust as possible to key hazards, ensuring hydrogen refuelling is as safe as possible.

CONCLUSION

When looking at hydrogen technology, in particular the introduction of innovative refuelling systems, like the Pioneer HRS, an understanding surrounding the safe use of hydrogen is critical if we are to succeed in implementing it as a key global fuel source.

Whilst it is understood that the properties of hydrogen present cause for concern, it is clear that a considerable amount of research and attention has been given to addressing the dangers the gas presents. An effective array of safety procedures and protocols have been created and are required to be implemented throughout each design stage of a product to ensure the safe performance of hydrogen technology and the protection of the individuals handling the equipment.

Like all other fuels, hydrogen poses a number of safety risks that will continuously need to be factored into the design phase of a project. However, it must be made clear to the transport sectors that hydrogen presents the same, if not less, dangers than other fuels due to its non-toxic and non-poisonous characters. We are already beginning to see the safe and successful build of various H2 technologies with the introduction of hydrogen powered vehicles like the Toyota Mirai, the development of fixed hydrogen refuelling stations with ITM Power and BOC, along with hydrogen buses recently being introduced across the UK. We must therefore continue to highlight the benefits of hydrogen as a fuel source, particularly within the hard-to-decarbonise sectors, where it is increasingly evident that hydrogen technology promises an efficient and economical solution when handled safely and appropriately.

Want to know more about NanoSUN's Pioneer Hydrogen Refuelling Station? Contact us!

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