HIDROGÉNÜZEMŰ GÉPJÁRMŰVEK KOCKÁZATELEMZÉSÉNEK ÁTTEKINTÉSE

REVIEW OF RISK ANALYSIS OF HYDROGEN POWERED CARS

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ABSTRACT

This research presents the methods used for risk assessment of hydrogen vehicles. The design of hydrogen-powered vehicles should be prioritized to ensure a safe powertrain (lowest risk). Vehicles should be usable under normal conditions in everyday life, and the risk to the user should be minimized. A literature review has shown that the greatest risk in the use of hydrogen powered vehicles is hydrogen leakage. Hydrogen leakage can occur in fuel systems (tanks, pipings), and risk assessment methods should be applied to address this issue. In the future, green hydrogen vehicles will play an important role in reducing greenhouse gas emissions, but safe operation will also be an important requirement. The risk assessment procedures under consideration will support the future application of this new technology.

1. INTRODUCTION

Four primary sources—natural gas, oil, coal and electrolysis—account for 48%, 30%, 18% and 4%, respectively, of the world's commercial hydrogen production. The main source of industrial hydrogen is fossil fuels. In general, hydrogen is produced by steam conversion of natural gas.

The following primary energy sources can be used: natural gas, solar, wind and biogas or biomethane. Biogas is a natural gas or biomethane that undergoes a thermochemical process called steam methane reforming, which results in a steaming reaction that produces a synthetic gas consisting primarily of hydrogen. To separate water into hydrogen and oxygen, a technique called electrolysis is used, which can use natural gas, solar energy or wind as the main energy source. Both methods result in the production of hydrogen [1].

- Primary energy source: The following primary energy sources can be used: natural gas, solar, wind, biogas or biomethane.
- Thermochemical conversion: Biogas natural gas, also known as biomethane, undergoes a thermochemical process involving the reforming of steam methane, which reacts with steam to produce a synthetic gas consisting mainly of hydrogen.
- Electrolysis: To separate water into hydrogen and oxygen, a technique called electrolysis is used, the main energy source of which can be natural gas, solar energy or wind.
- Final energy carrier: Both methods result in the production of hydrocarbons.

One way to incorporate hydrogen into energy fields is to use hydrogen as a fuel additive for hydrocarbons. Urban gases produced from coal and hydrocarbons always contain significant amounts of hydrogen. Today, the majority of waste gases are methane or natural gas. The addition of hydrogen to natural gas foreshadows a gradual shift to hydrogen as an energy source. Hydrogen can also be used as an additive for internal combustion engine fuels.

The incorporation of hydrogen into natural gas engines can improve their combustion performance and reduce pollutant emissions, especially during lean-burn operation. When this mixture is used as fuel, cars should emit significantly less nitrogen oxides, carbon monoxide and hydrocarbons. A hydrogen natural gas transport system could be a successful way to reduce environmental problems in metropolitan areas and to supplement energy infrastructure with hydrogen.

The concept of the hydrogen scale is illustrated in Figure 1, along with the many methods of producing and using hydrogen. In addition to the traditional uses of natural gas, such as electricity, heat, chemicals and industrial processes, including the production of metals and fertilizers, hydrogen can also be used to produce synthetic fuels or directly fuel hydrogen-powered cars [2].

The fuel system of a hydrogen car consists of several components. One possible concept for using hydrogen as a fuel for propulsion mechanisms is the use of hydrogen fuel cells. These materials are supplied with hydrogen from high-pressure tanks, the design of which has changed over the last several decades. The output of the hydrogen fuel cell is electrical energy stored in small batteries to power the engine control system (which ensures that it starts when the reaction in the fuel cell is not yet active), with the remaining energy used to power the car itself. Today's hydrogen cars can, to a good approximation, be considered electric cars; only the electricity

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comes from a different source—it is generated directly onboard the car. The advantage of such vehicles is that hydrogen can be quickly pumped into tanks (pumping hydrogen from the normal material takes the same time as pumping diesel or petrol—usually minutes). The negative consequence of this solution is that the hydrogen must be kept on board the vehicle, which increases the minimum risk requirement. It is also necessary to take into account that even classic fossil-fueled cars are flammable and have their own specific risk values.

The same applies to electric cars—batteries stored on the floor of the car are a safety case. Each car has different cubic values because of their different characteristics. The disadvantage of hydrogen is that it has a wide range of explosive properties in the event of a leak from a pressure vessel or distribution system. It is therefore necessary to determine the effects of a possible explosion on the environment and to define a safety zone around the container.

Several authors have worked in these areas. Shen et al. [3] carried out a real explosion of a pressurized tank. A hydrogen tank was blown up at 35 MPa pressure, after which the intensity of the pressure wave, thermal radiation and flying fragments were analysed to determine the safe zone. Zhang et al. [4] analysed the effects of temperature, pressure and velocity during a confined space hydrogen explosion using numerical simulation. Lidor et al. [5] analysed the explosion limits of the H_2-O_2 system. Li et al. [6] analysed the explosion mechanism of a mixture of methane and air in a closed vessel. Similarly, Wang et al. [7] investigated the numerical simulation of a methane explosion in a building and its effects on the structure.

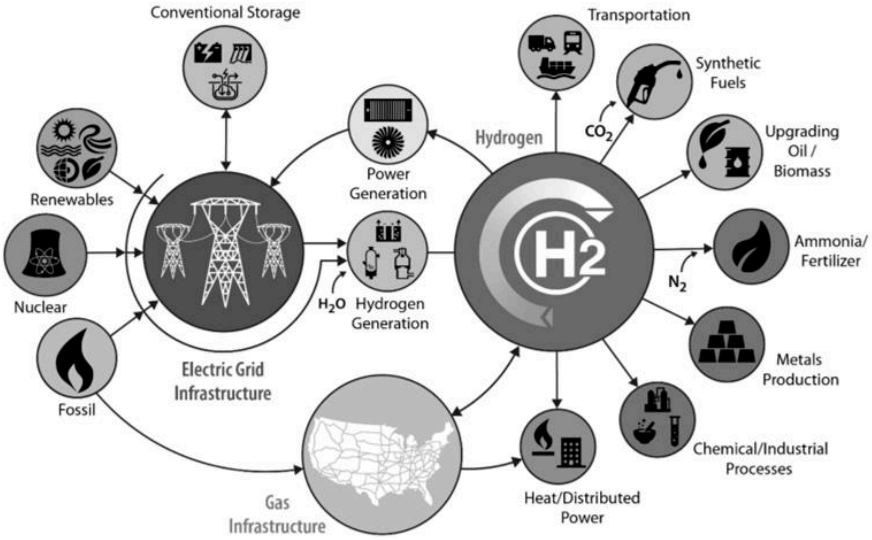

Figure 1. Hydrogen production and utilization pathway [2].

2. SAFETY ASSESSMENT [11]

The characteristics specific to the use of hydrogen as a fuel or energy carrier require that technical and operational measures be taken to reduce the risk of failure or accident to an acceptable level.

The basic risks for the operation of hydrogen propulsion systems are as follows:

1. Risk of combustion, ignition and explosion;
2. risk of over pressurization;
3. the risk associated with low operating temperatures;
4. the risk associated with hydrogen brittleness;
5. of risk from exposure to hydrogen in the human body [5].

2.1. Risk of burns, ignition and explosion

The risk of burns, ignition and explosion are the dominant risks of hydrogen systems. Hydrogen is highly likely to leak due to its physical and chemical properties. Leakage is directly related to the formation of a flammable mixture and can lead to ignition and explosion. This is also implied by the fact that hydrogen burns with a colourless flame that is practically invisible to the naked eye and emits UV radiation. The fact that the flame propagation speed is an order of magnitude greater than that of fossil fuels should not be ignored [8].

2.2. The risk of over pressurization

The risk of overpressure is based on the principle of operation of hydrogen technology. Due to the storage of large quantities of hydrogen at high pressure, the increased stress on all components of the high-pressure part of hydrogen technology must be considered. The existence of this type of risk and its increase are determined by the characteristic phenomenon of hydrogen brittleness [8].

2.3. Risk associated with low operating temperatures

The coefficient of variation associated with low operating temperatures is due to changes in the properties of the materials in the hydrogen system. A hazard arises when hydrogen is cooled to the temperature of liquid hydrogen (- 253 °C). As a consequence, during the cooling of the materials, changes occur in the strength properties of the structural nodes of the hydrogen system.

2.4. Risk from the brittleness of hydrogen

The risk from hydrogen brittleness is due to the specific interaction between hydrogen and the material used. The materials of tanks, pressure vessels and other equipment may lose their strength and properties during long-term exposure to hydrogen. Factors that influence this include, for example, the type of material, hydrogen concentration, operating pressure, temperature, type of material, type of hydrogen, hydrogen concentration, hydrogen content, operating pressure, temperature, type of stress on fuel system subassemblies, particle diameter as part of the microstructure and its thermal history, and moisture in the hydrogen [8].

2.5. Concerns about human exposure arising from exposure to hydrogen

The risk of human exposure to hydrogen is not life-threatening, but this risk must be taken into account. Direct contact with gaseous or liquid hydrogen can lead to local insensitivity and frostbite burns on parts of the human body. Hydrogen combustion, which produces high temperatures and a specific flame, also poses a health risk. Hydrogen has no direct toxic effects. However, it can cause asphyxiation, especially in confined spaces (e.g., in the passenger compartment of a car) [9,10].

3. RISK ANALYSIS

Hydrogen must be distributed and transported by pipelines to be used as an energy carrier. Using an existing pipeline and reservoir, hydrogen is transported cleanly through specific parts of the network. These parts have unique diameters, pressures and material characteristics and are focused on pure hydrogen. Two methods of producing hydrogen are water electrolysis (in combination with wind or photovoltaic energy) and steam methane reforming by gasification.

3.1. Compatibility, life-cycle emissions, and technoeconomic analysis [12]

1. Compatibility of pipelines with hydrogen: SNL and PNNL conduct assessments to estimate the service life of materials in metal and polymer pipelines and piping (e.g., steel and polyethylene). These information sources are incorporated into a publicly available model that can be used to estimate the service life of pipelines under key engineering assumptions.
2. Life cycle analysis: ANL will analyse the life cycle emissions of technologies using hydrogen as well as alternative routes such as synthetic natural gas.
3. Technoeconomic analysis: The NREL will quantify the costs and options for hydrogen production and alternative pathways such as synthetic natural gas.
4. A research effort to broaden the potential of hydrogen is the HFTO-led Hydrogen Materials Compatibility Consortium (H-Mat), led by SNL and PNNL, an internationally recognized framework for studying the compatibility of hydrogen materials.

4. MEASUREMENT TASK

As shown in section 3.1, it is necessary to test the precursors. At the university research centre, various tests are carried out on the tank materials used. The type of material tested is hypoeutectoid structural steel, of which the tank is made.

In the case of tests with pure hydrogen, it is necessary to specify how long the system (hydrogen-filled tank) must be left to rest to study the effects of hydrogen on the material properties. Several studies address the refinement of test parameters [13-16]. From the literature review, 2 samples were concluded to be needed. For the first test, the specimens were allowed to rest for 41 days at 128-130 bar. A longer period of time will also be needed, so a period of 3 months was chosen based on the literature (with a test duration similar to that of the previous samples).

At the university research centre, it is possible to study the tanks by flight. For safe testing, it is possible to crack test cranes at a maximum pressure of ~300 bar in an underground test facility. As shown in Figure 2, the crack test was successful, and a satisfactory end state was achieved.

The following two test methods were applied to the tanks:

1. cracked (without H_2, reference piece).
2. fatigue, cracking, and $+2\sigma$ bending load (H_2, 100%, 41 days, 128-130 bar).

Figure 2. Sample cracked.

After the crack tests, test specimens were cut out of the container at appropriate locations (both in the base material and seam section only).

The following tests will be carried out on the elaborated specimens: bending test, hardness test, tensile test, fabric structure test.

The results of these tests will provide the data for the risk assessment tests presented in the previous chapters.

Figure 3 shows the standard bending test equipment and the specimens tested in the university research laboratory.

Figure 3 Bending tests on samples.

The studies described above are currently in progress, and their results will be presented later.

5. SUMMARY

Hydrogen leaks from the car tank, and an explosion occurs. Storing hydrogen in a tank at high pressure poses a significant risk. The relevant information obtained by simulation will provide designers of hydrogen-powered cars with the necessary prerequisites for the following applications: the choice of the location of the hydrogen tank in the body compartment and the choice of the technologies to be used. the choice of the type of material to be used, the choice of the parameters of the body-in-engine component, the sizing of the connected components, the choice of the material of the valves and pipes used for hydrogen transport, and the choice of the material of the valves and pipes and the choice of the material of the tanks.

Obviously, different types of propulsion systems have different characteristics and risk values. The design of hydrogen propulsion systems must be based on a multifaceted decision-making process. It is assumed that the decisive parameter will be the minimization of all types of risk.

6. ACKNOWLEDGEMENTS

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