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Education in Hydrogen Technologies Area

HYDROGEN FILLING STATIONS

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CONTENT

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INTRODUCTION

This module focuses on hydrogen filling stations. The main objective of the module is to introduce the reader to the basic issues of design, construction and operation of filling stations. The introductory part introduces the reader to the history and development of hydrogen filling stations and their use in transport. Information is provided on the first hydrogen filling stations and their subsequent development. Basic information on hydrogen is also provided in this chapter, but only in the form of a basic overview. In the following sections this information is supplemented by a basic overview of the legislative requirements for the design and operation of hydrogen filling stations. This section also introduces the reader to a basic overview of the standards that affect the construction and operation of filling stations. The next chapter summarizes information on industrial gas filling stations and, in passing, on the production of hydrogen and its transport to the filling site. These issues are covered in depth in modules that focus on them. Other chapters deal with the division of filling stations, their construction, individual structural units and operational safety. Therefore, cases of accidents that have occurred during the operation of filling stations are also presented. The safety of operation not only of filling stations, but of hydrogen technology in general, is crucial for its future development and practical use. The last chapter is devoted to forecasts for the future development of refuelling stations and their use in transport.

INTRODUCTION – HISTORY

KEYWORDS

hydrogen, history, passenger and freight transport, filling stations, electric vehicle, infrastructure, refuelling, fuel cell, Iceland, emissions, environment, ecology

Hydrogen is the lightest gaseous chemical element, it is also the third most abundant element on Earth. Due to its high reactivity, it occurs almost exclusively as a compound in nature. A hydrogen atom consists of one proton in the nucleus and one electron in the shell. Hydrogen does not pollute the environment when it escapes, making it an emission-free energy source. Hydrogen is highly flammable but does not support combustion. Hydrogen was discovered in 1766 by Henry Cavendish, but at the time of its discovery, hydrogen had not found much use. One of the first uses of hydrogen in transportation came with the development of ballooning and airships, where hydrogen was used as a carrier gas alongside helium. As for the use of hydrogen propulsion today, we must distinguish between its use in fuel cells, or the discovery of the fuel cell itself, and in internal combustion engines.

The principle of the fuel cell was discovered in 1838 by the Swiss scientist Christian Friedrich Schönbein, and the first working prototype was built by the British scientist Sir William Grove. After the invention of the dynamo, the fuel cell fell into partial obscurity. "Its real "The fuel cell had its real renaissance in the 1960s. This was largely due to cosmic research, because the fuel cell has a more favourable ratio energy-to-weight ratio. For example, the Apollo spacecraft were equipped with them, but but they're also the power source for today's space shuttles." [3]

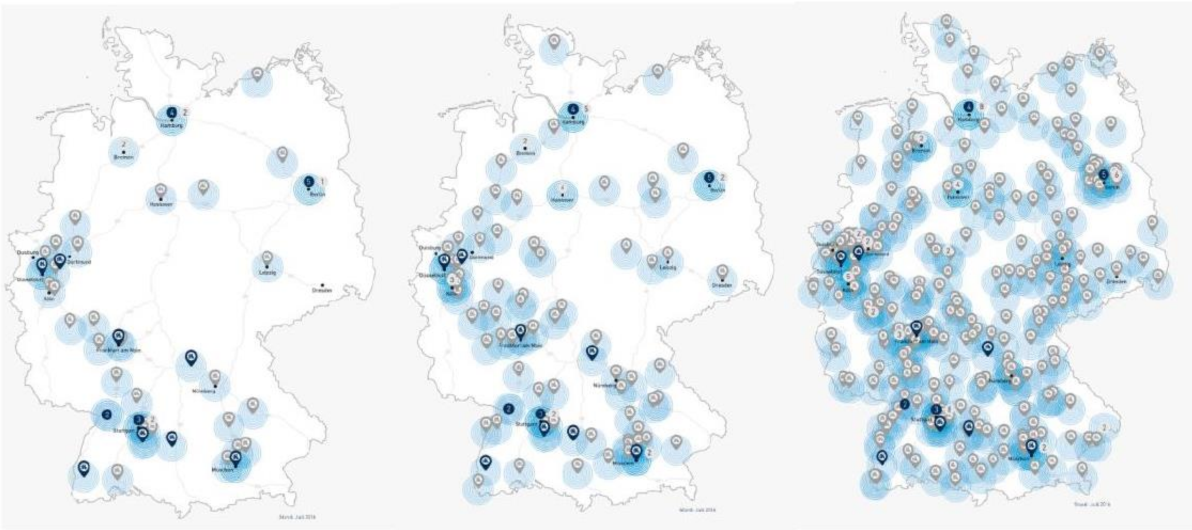
Although the hydrogen internal combustion engine was the first patented internal combustion engine, and as early as 1808, when a French patent was granted to retired Major Issac de Rivaz, its practical use dates back to a much later time. Hydrogen in Rivaz's engine was obtained by the electrolysis of water and "the design was ... unsettled and practically unworkable" [4]. The first working hydrogen internal combustion engine was not developed until a century after the first French patent, in the 1920. Its use was first tested in the airship engines of Ricardo and Maybach.

With efforts to reduce emissions in transport and the development of emission-free energy sources in transport, the use of hydrogen as an energy source is developing alongside electric mobility. To pump hydrogen into vehicles, special filling stations are required to ensure fast and safe filling of the car's tanks. Hydrogen is pumped in gaseous form and compressed to high pressure. The first hydrogen filling station was opened in 2002 in Reykjavik. [2] When Shell opened it in 2003, only one fuel cell car, a Mercedes-Benz Sprinter, and three Daimler Chrysler hydrogen buses were operating in Iceland as part of the European Union's first ever public transport programme.

Iceland was considered an ideal location for this pilot project because it has an abundance of cheap and clean hydro and geothermal energy that can be used to produce fuel by electrolysis with minimal carbon dioxide emissions. This made Iceland a pioneer in the transition to a hydrogen economy, with more than 40 vehicles on the road in 2007, mostly Toyota Prius hybrids, second only to California.

Japan currently has the largest number of hydrogen filling stations of any country in the world. In September 2021, there were 154 hydrogen refuelling stations in operation in the country. Japan's position as a leading provider of hydrogen automotive fuel is not surprising given that Japanese automakers Toyota and Honda are among only three automakers in the world that mass-produce hydrogen cars. [3]

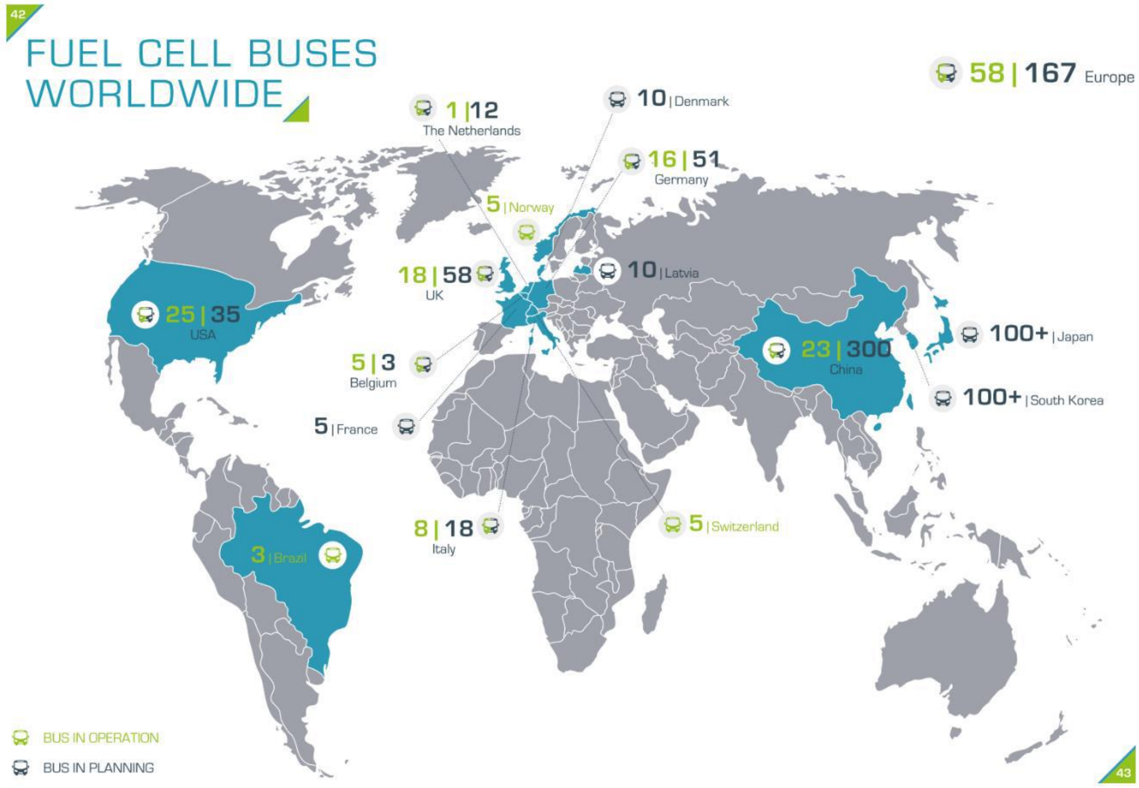
There are approximately 136 hydrogen filling stations in the European Union. The first hydrogen refuelling stations began to be introduced in 2016, but their expansion stalled until 2019, when the number nearly tripled in a single year. Hydrogen is seen as a critical resource for achieving emissions reductions and its use in transport is supported by many governments. In 2020, the EU saw a drop of 10 refuelling stations due to the UK leaving the EU.



Picture 1 Filling station network in Germany in 2016, 2018, 2023 [5]

The first non-public filling station was opened in the Czech Republic in 1999 in Neratovice, followed by another one in ÚJV Řež in 2020. In 2022, the first public filling station was opened in the Czech Republic in Ostrava.

Global demand for hydrogen after the Paris Agreement and more recently after COP26, the world is trying to find innovative technologies to replace fossil fuels and reduce greenhouse gas emissions. Hydrogen has emerged as one such alternative, particularly for the transport sector. Global demand for hydrogen totalled 71 million tonnes in 2019, with the refining sector being the main consumer. The IEA forecasts that by 2070, total demand could reach more than 500 million tonnes, with the transport sector expected to be the largest consumer of hydrogen. Where current infrastructure is failing, not only does technology need to advance, but the necessary infrastructure also needs to be developed for countries to meet their net zero targets. Only three countries in Europe have met the EU requirements for a sustainable taxonomy for hydrogen production using electricity from national grids. Most countries would produce hydrogen with high carbon intensity if they used grid electricity. In addition to the carbon intensity of the product, the biggest global challenges for hydrogen technology, according to the 2021 survey, were its complex distribution and inconsistent supply and storage issues.



Picture 2 Current status and outlook for the expansion of hydrogen-powered buses. [4]

Refuelling takes place at filling stations. The whole process is very similar to refuelling traditional fossil fuels. After connecting the filling gun to the tank valve, you flip a lever and the system does the rest. Filling the tanks takes 5 minutes and will give the car full capacity. So refuelling is similar to CNG/LPG vehicles, except that in the case of hydrogen it is compressed not liquefied gas. This difference is due to the fact that a temperature of -253°C is required to liquefy hydrogen. Achieving such a low temperature would be economically and technically very challenging.

1 COMPARISON OF A HYDROGEN CAR AND AN ELECTRIC CAR

Given the rapid development of electric vehicles and their associated infrastructure, a comparison between this type of propulsion and hydrogen propulsion is suggested. Although specific modules are devoted to this issue, it is worth mentioning here at least some basic information.

In the passenger car sector, the main advantage of hydrogen propulsion is the filling time, which, depending on the type of vehicle and filling station, is usually in the order of minutes (5-10 min). Another advantage is that a fuel cell vehicle does not have to carry as many batteries, so it is lighter than a pure electric vehicle. The lower weight translates into a longer range, which is almost comparable to that of fossil-fuel vehicles (about 450-700 km). One of the advantages of electric vehicles is the possibility to recharge the batteries at home. However, this advantage is dependent on the installation of a recharging facility and the need for a private parking space. The biggest disadvantage of hydrogen-powered passenger cars compared to electric cars is the lack of a network of refuelling stations and the small range of hydrogen-powered passenger cars.

Other areas of transport where hydrogen can be used as a fuel are in particular road freight transport, public transport, work and handling machinery and rail transport. In these areas, the use of hydrogen as an energy source appears to be more efficient than pure electricity. The main advantages of hydrogen propulsion are the significantly lower weight of these vehicles, the speed of filling and the simpler construction of a filling station compared to a charging station with the required power.

CONTROL QUESTIONS:

1) Where and when was the world's 1st hydrogen filling station opened? [Reykjavik, 2003]

2) Which country had the largest number of refuelling stations in the world in 2021? [Japan; 154]

3) Name at least two passenger car manufacturers that mass produce hydrogen powered vehicles. [Hyundai, Toyota, Honda]

2 LEGISLATION ON THE OPERATION AND MAINTENANCE OF FILLING STATIONS

KEYWORDS

Legislation, standard, ISO, IEC, SAE, HFS, hydrogen quality, communication, filling connection, nomenclature, standardization, validity, safety, filling process, protocol

This chapter focuses on the legislative basis for the operation and maintenance of hydrogen filling stations (HFS). The legislation related to the design of HFS is also related to this issue, therefore part of this chapter is also devoted to this issue. Compliance with legislative regulations is essential to ensure the safe operation of the HFS and to ensure its longevity. In this chapter, the reader is introduced to the basic terminology according to the current legislation and an explanation of the basic concepts. Legislation within the EU is determined by European standards, but some operational and technical details may be specified in national regulations, such as fire regulations. The main international organisations that issue technical standards are ISO (International Organisation for Standardisation), IEC (International Electrotechnical Commission) and SAE (Society of Automotive Engineers). Within these organisations, standards are developed by TC (Technical Committee) members of CEN (European Committee for Standardisation) and CENELEC (European Committee for Electrotechnical Standardisation) members. The development of legislative standards is very rapid and, in the context of the development of hydrogen technology, there is a constant evolution and amendment of existing standards and the creation of new ones. [17]

The main CEN/CENELEC TCs for hydrogen-related standards are:

CEN/CLC/TC 6 - Hydrogen

CEN/TC 23 Transportable gas cylinders

CEN/TC 69 Industrial valves

CEN/TC 185 Fasteners

CEN/TC 197 Pumps

CEN/TC 234 Gas infrastructure

CEN/TC 235 Gas pressure regulators and related safety equipment for use in the gas industry gas transmission and distribution;

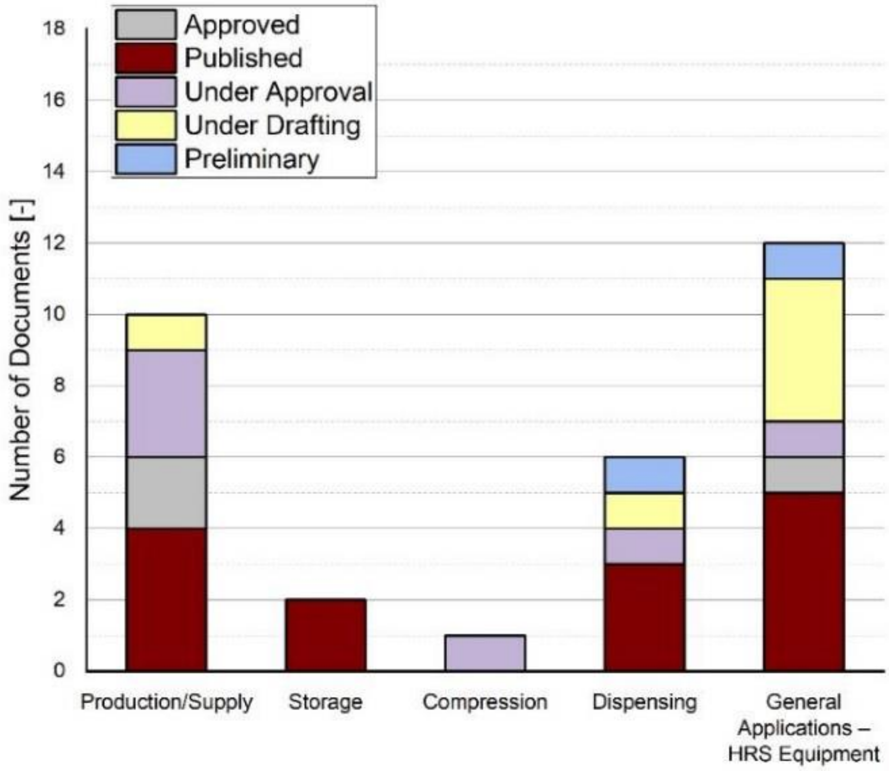
CEN/TC 236 Non-industrial manually operated shut-off valves for gas and gas distribution special valve combinations - other products

CEN/TC 238 Test gases, test pressures, appliance categories and gas appliances.

Types

CEN/TC 268 Cryogenic vessels and specific applications of hydrogen technology commission.

As the issues and scope of these standards are beyond the scope of this module, standards specifically related to the construction and operation of HFS will be described below. [17]



Picture 3 Status of development of CEN and CENELEC standards for HFS. [17]

Legislation on HFS in the EU is regulated mainly by the following standards [12]:

Hydrogen filling stations – EN 17127 - Outdoor dispensing hydrogen gas filling stations with filling protocols; ISO 19880-1:2020 - Hydrogen gas - Filling stations - Part 1: General requirements

Hydrogen properties – EN 17124 - Hydrogen fuel - Product specification and quality assurance for hydrogen gas dispensing stations - Proton exchange membrane (PEM) fuel cell applications for vehicles

Filling process – EN 17127 (refers to SAE J2601) - Filling protocols for light surface hydrogen gas vehicles

SAE J2799 – Hardware and software for communication between hydrogen surface vehicles and stations

Filling connections – EN ISO 17268 - Connection devices for filling hydrogen gas into surface vehicles.

Before discussing the individual standards, it is essential to become familiar with the basic terminology. For ease of reference, the Czech standard TPG 304 03 - Hydrogen gas filling stations for mobile equipment has been developed to simplify the basic orientation necessary for the design, construction, manufacture, operation and maintenance of HFS. From this standard, the necessary terms of basic terminology are elaborated. Knowledge of this terminology is necessary for correct orientation not only in legislative documents, but also in technical regulations and technical literature.

2.1 BASIC NOMENCLATURE ACCORDING TO TECHNICAL RULES TPG 304 03

Safe distance *– the distance between the source of the hazard and the target (persons, equipment, environment) that ensures acceptable risk to a foreseeable limit. The hydrogen filling station is both the source of the hazard and the target. The situation is the same with the equipment around the hydrogen filling station in relation to it. The safety distance can be reduced by additional safety measures.*

Safety distance *– the minimum distance between the source of a hazard and an object that is necessary to mitigate the effect of a likely foreseeable event and prevent a minor incident from escalating into a major incident.*

Hydrogen Filling Station Operation Risk Assessment *– Determination of a quantitative or qualitative risk value for specific situations and recognized hazards of a hydrogen filling station under normal operating conditions. The committee's risk assessment report is part of the project documentation.*

Compressor *– A device that compresses the hydrogen supplied through the suction line to at least the maximum operating pressure of the mobile equipment tank.*

Mechanical disconnect *– A device that prevents the filling hose from breaking, damaging the dispensing device and dislodging the filling quick coupling.*

Maximum Working Pressure (MWP) *- The maximum pressure to which the hydrogen filling station can be subjected in operation at a given process position, independent of the hydrogen temperature, before intervention by means of means to ensure that it is not safely exceeded or reduced, e.g. by safety valves.*

Contingency *– Any unplanned situation in the normal operation of a hydrogen filling station which may cause or will cause injury to health, damage or loss of property, materials, environmental damage or loss of business.*

***Danger Zone** – An area in which an explosive atmosphere exists or may occur in such quantity that special precautions must be taken in the design, installation, and use of the hydrogen filling station.*

***Non-public hydrogen filling station** – a station that serves a closed group of customers, e.g. a company station.*

***Nominal Working Pressure (NWP)** - the pressure to which the device is set at a hydrogen temperature of 15 °C; typical values for cars are 700 bar, for buses and trucks 350 bar*

***Operator** – a person qualified to operate the equipment*

***Hydrogen flow restrictor** – Device that shuts off the hydrogen flow when a predetermined hydrogen flow limit is reached, which is typically 60 g/s of hydrogen.*

***Filling overpressure** – The pressure at which the gas is supplied to the mobile equipment.*

***Filling connection** – A component of a dispensing rack or apparatus consisting of a flexible connection (filling hose), a mechanical disconnection and a filling quick coupling.*

***Hydrogen filling station** – A device for filling the pressure tanks of mobile equipment with compressed hydrogen. It consists of a hydrogen source, a compressor, a refrigeration unit, high-pressure storage tanks, dispensing equipment and, where appropriate, other accessories.*

***Slow filling station** – a filling station without a high-pressure compressed hydrogen storage tank, where the mobile equipment tank is filled directly from the compressor discharge line.*

***Working Pressure (WP)** - The highest pressure expected for a hydrogen filling station at a given process position in normal operation.*

***Non-explosion hazard area** – An area in which an explosive atmosphere is not expected to be present in such quantities that special precautions must be taken in the design, installation and use of the hydrogen filling station.*

***Operational pressure leak test** – A leak test carried out on equipment in operation.*

***Quick-fill station** – a filling station with a high-pressure compressed hydrogen tank, allowing rapid filling of the tank of one or more mobile devices simultaneously by overfilling.*

***Suction line** – the hydrogen supply line from the low-pressure tank to the inlet of the compressor.*

***Pressure leak test** – A procedure for verifying that the equipment under test meets the leak requirements.*

User *– The operator of the mobile equipment or the driver of the mobile equipment or the operator of the hydrogen filling station, i.e. a person over 18 years of age familiar with the operation of the compressed hydrogen filling equipment.*

Public hydrogen filling station *– a station that allows the sale of hydrogen to mobile devices to the general public in accordance with Act No 311/2006 Coll.*

Ventilation *– the exchange of air in a space by the action of natural convection (wind action, temperature gradient), forced convection (fan action) or a combination of both.*

Hydrogen *– a gas of the quality necessary for the operation of fuel cells; according to ISO 14687-2, the purity of hydrogen must be at least 99,97 %.*

Hydrogen filter *– a device for removing mechanical impurities from compressed hydrogen.*

Compressive strength test *– A procedure to verify that the equipment under test meets the mechanical strength requirements.*

Explosive atmosphere *– A mixture of air with combustible substances, e.g. hydrogen, in the form of gases, vapours, mists or dusts at atmospheric conditions ranging from the lower explosive limit (LEL) to the upper explosive limit (UEL) at which, after initiation, combustion extends to the volume of the entire unburned mixture.*

Dispenser *– a dispensing device that does not meet the definition of a dispenser, but which performs a function for dispensing compressed hydrogen in specific conditions (in-house facilities, small filling stations, development filling stations and other facilities for which this solution is appropriate).*

Dispensing rack *– a compressed hydrogen dispensing device which does not need to be opened for operation and which is equipped with a specified gauge for measuring the quantity of hydrogen dispensed for commercial purposes (in kilograms) and a control and safety device to ensure that the prescribed filling conditions are met.*

Dispensing equipment *– equipment for the dispensing and measuring of the quantity of compressed hydrogen removed; these are dispensing racks and dispensing devices.*

High-pressure storage tank *– a device used to store compressed hydrogen for rapid filling of one or more mobile devices simultaneously while reducing the number of compressors starts.*

Safety device *– A device to protect against a hazardous situation that automatically causes the filling of a mobile device to be interrupted if hydrogen leaks or the filling hose is broken.*

***Hydrogen refrigeration device** – a device that cools hydrogen; it is located downstream of the compressor discharge*

2.2 HYDROGEN FILLING STATIONS – EN 17127 - OUTDOOR HYDROGEN GAS DISPENSING STATIONS WITH FILLING PROTOCOLS

This document defines the minimum requirements to ensure interoperability of hydrogen refuelling stations, including refuelling protocols, that dispense gaseous hydrogen into road vehicles (e.g. fuel cell electric vehicles) that comply with the legislation applicable to these vehicles. The safety and performance requirements of the entire hydrogen refuelling station, addressed in accordance with existing relevant European and national legislation, are not included in this document. [13]

2.3 HYDROGEN FILLING STATIONS – ISO 19880-1:2020 - HYDROGEN GAS – FILLING STATIONS - PART 1: GENERAL REQUIREMENTS

It defines minimum requirements for the design, installation, commissioning, operation, inspection and maintenance, safety and, where applicable, performance of public and non-public HFS filling stations that dispense gaseous hydrogen for light road vehicles. The information contained in this document also includes guidelines and requirements for filling medium duty road vehicles. In addition, the information contained in this document can be applied to hydrogen refuelling stations with other uses such as:

- filling stations for motorcycles, forklifts, trams, trains, river and marine applications;
- indoor dispensing stations;
- residential applications for the propulsion of land vehicles;
- mobile filling stations
- non-public demonstration service stations.

However, this document does not address other specific requirements that may be necessary for the safe operation of these refuelling stations.

This document contains requirements and guidelines for the following elements of a refuelling station

- hydrogen production/delivery system:

- delivery of hydrogen by pipeline, delivery of gaseous and/or liquid hydrogen by trucks or trailers for storage of metal hydrides;

- on-site hydrogen generators using the water electrolysis process or hydrogen generators using fuel processing technologies;

- liquid hydrogen storage;

- hydrogen purification systems, as appropriate;

- compression;

- compression of hydrogen gas;

- pumps and evaporators;

- hydrogen gas storage;

- precooling equipment;

- hydrogen gas dispensing systems; [14]

2.4 HYDROGEN PROPERTIES – EN 17124 - HYDROGEN FUEL - PRODUCT SPECIFICATION AND QUALITY ASSURANCE FOR HYDROGEN GAS FILLING STATIONS - PROTON EXCHANGE MEMBRANE (PEM) FUEL CELL APPLICATIONS FOR VEHICLES

This document specifies the quality characteristics of hydrogen fuel dispensed at hydrogen refuelling stations for use in Proton Exchange Membrane (PEM) fuel cell vehicle systems and the corresponding quality assurance aspects to ensure the consistency of the hydrogen fuel. [15]

Total share of hydrogen and contaminant gases	
Minimum pure hydrogen content	99,97 %
Total amount of gases other than hydrogen	300µmol/mol
Maximum concentrations of individual contaminant gases	
Water (H_2O)	5 µmol/mol

Total carbohydrates (methan)	2 µmol/mol
Oxygen (O_2)	5 µmol/mol
Helium (He)	300 µmol/mol
Total nitrogen (N_2) a Argon (Ar)	100 µmol/mol
Carbon dioxide (CO_2)	2 µmol/mol
Carbon monoxide (CO)	0,2 µmol/mol
Total sulphur compounds (H_2S)	0,004 µmol/mol
Formaldehyd (HCHO)	0,01 µmol/mol
Formic acid (HCOOH)	0,2 µmol/mol
Amoniak (NH_3)	0,1 µmol/mol
Total halides	0,05 µmol/mol
Maximum particulate concentration	1 mg/kg

Table 1 Hydrogen quality requirements for hydrogen fuel cells [8]

2.5 FILLING PROCESS – EN 17127 (REFERS TO SAE J2601) - FILLING PROTOCOLS FOR LIGHT SURFACE HYDROGEN GAS VEHICLES

EN 17127 is based on SAE J2601 – Filling Protocols for Light Surface Hydrogen Gas Vehicles in the filling process. The SAE J2601 standard defines the protocol and process limits for refuelling hydrogen into vehicles. The process limits (e.g., fuel delivery temperature, maximum flow rate, final pressure, and rate of reaching it) are dependent on external factors such as ambient temperature, fuel delivery temperature, and the pressure of the tank into which the hydrogen will be filled. The SAE J2601 standard defines standard protocols for hydrogen refuelling. These protocols are either based on a lookup table that uses a fixed rate of pressure rise in the container, or on the use of a dynamic rate of pressure rise formula. In this case, the filling rate is calculated continuously during the filling process. When using the lookup table protocol, the hydrogen pressure value reached at the end of the filling process is known, in contrast, the protocol using the pressure rise rate formula defines the maximum hydrogen pressure value reached during the filling process. Both protocols allow hydrogen filling with or without communication (between the filling device and the vehicle). For filling with communication, SAE J2799 – Hardware and Software for Communication between Hydrogen Surface Vehicles and Stations must be used in addition to SAE J2601. A critical factor in the performance of hydrogen filling is the ability of the HFS to achieve the desired temperature of the hydrogen delivered. Depending on the temperature, the delivered hydrogen is divided into three categories, denoted by the letter, "T": T40, T30, T20. The T40 category is the coldest. The SAE J2601 standard defines filling protocols for pressure classes 350 bar and 700 bar and three categories of fuel delivery temperatures (-40 °C, -30 °C, -20 °C). It also defines two sizes of hydrogen storage systems. The first system operates with both 350 and 700 bar pressures and its volume is 49.7l - 248.6l and the second operates only with 700bar pressure and its volume is 248.6l and above. [16]

Parameter	**Limit**
Minimum hydrogen temperature	-40 °C
Maximum hydrogen temperature	85 °C
Minimum pressure in the dispenser	0,5 MPa
Maximum pressure in the dispenser	87,5 MPa
Maximum flow rate	60 g/sec.

Table 2 Performance and safety limits for hydrogen filling according to SAE J260

SAE J2799 – Hardware and software for communication between hydrogen surface vehicles and stations.

This standard specifies the communication hardware and software requirements for hydrogen fuelling of hydrogen surface vehicles (HSVs) such as fuel cell vehicles, but can also be potentially applied to heavy duty vehicles (e.g. buses) and industrial trucks (e.g. forklifts) with a compressed hydrogen storage tank. It includes a description of the communication hardware and protocol that can be used to refuel the HSV. The intent of this standard is to enable the harmonised development and implementation of interfaces for hydrogen refuelling.

2.5.1 FILLING CONNECTIONS – EN ISO 17268 - CONNECTION DEVICES FOR FILLING HYDROGEN GAS INTO LAND VEHICLES

This document defines the design, safety and operational characteristics of connectors for refuelling hydrogen gas into ground vehicles. This document divides refuelling connectors into the following three basic parts:

- Pressure and protective cover (vehicle mounted).

- Nozzle

- Communication device (communication between the filled vehicle and the HFS)

This document is intended for filling connections with a nominal working pressure up to 70 MPa.

The design and types of filling connections are dealt with in a separate section of the module.

CONTROL QUESTIONS:

1) What are the main international organizations that issue technical standards? (ISO, IEC, SAE)

2) EN ISO 17268 - Hydrogen gas filling connections for land vehicles is intended for equipment operating up to what nominal working pressure? (70 MPa)

3) What is the minimum pure hydrogen content for fuel cells? (99,97 %)

3 TECHNICAL GAS FILLING PLANTS

KEYWORDS

hydrogen, distribution, cylinders, cylinder bundles, filling, production, transport, storage, industrial gases, safety

Industrial gases are an everyday part of our lives as they are used to produce the vast majority of the items we use. Industrial gases are not only an essential part of manufacturing processes in industry, but are also indispensable in healthcare, food, electrical engineering, research and many other applications. Their use therefore affects not only everyone's life but also the environment in which we live. This module focuses on hydrogen and related technologies. In this part of the text we will look at other technical gases besides hydrogen. You will also find basic information on the production of industrial gases, their transport and distribution. Technical gas filling plants supply technical gases to customers, fill empty technical gas tanks and transport them.

The production and distribution of industrial gases is a process that is carried out by international companies with a global presence. The products of their activities are not only industrial gases, but also chemicals used in various industries, processing waste products of chemical production. The largest producers and distributors of hydrogen in the world are Linde, Air Products, Messer, Air Liquide International, Cummins and others.

In industrial gas filling plants, hydrogen is stored in above-ground or underground steel tanks. From these tanks, the hydrogen is further filled into transport or pressurised cylinders. The pressurised storage tanks can be replaced by large capacity underground tanks at suitable locations. These are usually underground spaces created by mining. The hydrogen storage pressure is approximately 110 bar; higher pressures are not used because of possible leakage of natural gas through the rock mass. Underground storage tanks have the advantage of a large capacity and do not take up space on the surface. The disadvantage of this type of storage is the selection of a suitable location due to the geological conditions. The expansion of hydrogen vehicles is conditional on a sufficiently dense network of filling stations, which must be easily accessible to users. For this reason, it is necessary to build filling stations in towns and around roads where there are no suitable sources of hydrogen. It is therefore necessary to import hydrogen to filling stations in a similar way to fossil fuel or LPG/CNG filling stations. At the point of production, the hydrogen is filled into suitable containers for transport and then transported to the final distribution point.

Due to the specific characteristics of hydrogen, a number of problems arise in its storage, transport and distribution, the most important being:

- Extremely low bulk density (3.2 times lower than natural gas and 2700 times lower than gasoline).

- Compressed hydrogen can be explosive – risk of explosion

- Hydrogen storage regulations are inconsistent around the world

- Difficult to mix hydrogen with natural gas when transporting it in existing pipelines

- Hydrogen can increase the brittleness of the materials from which transport and storage equipment is made [18]

3.1 TRANSPORT OF HYDROGEN

This part of the text introduces the reader to the transport of hydrogen to the final distribution point, the means of transporting it, and in relation to filling stations. Since the issue of transporting hydrogen from the point of production to the final filling point is of vital importance for filling stations, the following section will focus on the means of transporting hydrogen. In the case of filling stations, it is essential that there is a sufficient supply of hydrogen to cover daily consumption, even if these stations are located in dense areas with poor accessibility for trucks.

Three types of hydrogen transport in particular can be used for hydrogen filling stations:

1) Hydrogen transport by pipeline

2) Transportation of bottled hydrogen gas by road or rail

3) Transport of liquefied hydrogen

4) Transportation of hydrogen by pipeline in a mixture with natural gas

3.1.1 TRANSPORTATION OF HYDROGEN BY PIPELINE

Hydrogen pipelines are made of metal or plastic and are used to distribute hydrogen either through existing natural gas infrastructure or by building new pipelines solely for the transportation of hydrogen.

Building new hydrogen pipelines requires a significant initial investment, but it is probably the easiest way to distribute the gas. On the other hand, the use of existing natural gas infrastructure requires lower initial costs, but care must be taken to ensure that the right proportion of hydrogen is in the gas mix. Further investment in technology to separate the hydrogen from the natural gas once it reaches its destination is also required. [18] Transportation of hydrogen through pipelines is advantageous at the point of production to supply a hydrogen filling station designed for internal transport vehicles or to supply a public hydrogen filling station located in the vicinity of the hydrogen production.

3.1.2 TRANSPORT OF COMPRESSED HYDROGEN FOR ROAD OR RAIL

The transport of compressed hydrogen by road or rail is currently the most widely used mode of hydrogen transport. Hydrogen is transported in pressurised containers at a pressure of 200 bar (defined by the Agreement on International Carriage of Dangerous Goods by Road – ADR) [19] For an example of the use of hydrogen and petrol transport by truck, we can use the comparison published in the "Hydrogen Strategy of the Czech Republic". The same truck carrying compressed hydrogen can transport 500 kg of hydrogen (in cylinders at 200 bar pressure). This is because the cylinders have to withstand very high pressure. A truck with hydrogen weighs almost the same as a truck without hydrogen, the only difference is the 500 kg. The compressed hydrogen tank is robust. Because of the low amount of hydrogen transported in a single trailer, this method of transport is only economical up to a distance of around 150 km. [19] When transporting compressed hydrogen by road or rail, there is no need to build a transport infrastructure and the amount of hydrogen transported can be dosed appropriately. For the final distribution of hydrogen, transport containers can be used as mobile storage tanks for filling stations, thus eliminating the need to pump hydrogen into the filling station's storage tank. The disadvantages are the limited distance, especially in the case of road transport, and the risk of accidents. [19]

3.1.3 TRANSPORT OF LIQUEFIED HYDROGEN

An alternative route that could significantly increase the amount of hydrogen transported is to liquefy it. Liquid hydrogen is stored at a temperature of -253° C. This implies increased demands on the materials used and high energy requirements for liquefaction, thus a major disadvantage is the loss of around 40 % of the energy during liquefaction itself (Devinn, Irena).

Another option to increase the transported volume of hydrogen is to liquefy it. Liquid hydrogen is stored at a temperature of - 253° C. Achieving such a low temperature is associated with the high energy costs of liquefaction and the high demands on the materials used to store the liquefied hydrogen. Up to 40 % of the energy stored in the hydrogen is lost during liquefaction. [19] The advantage of this type of transport is the possibility of transporting large volumes of hydrogen over considerable distances (until suitable gas pipelines are built). The disadvantages are energy consumption and, in the case of road transport, the risk of accidents. [19]

3.1.4 TRANSPORTATION OF HYDROGEN BY PIPELINE IN A MIXTURE WITH NATURAL GAS

This type of transport uses the existing network of pipelines designed for transporting natural gas, to which a certain amount of hydrogen would be added. Currently, the gas network is technically prepared for hydrogen additions of up to 2 %. After technical modifications, it would theoretically be possible to transport up to 10% hydrogen. The main disadvantage of this type of transport is the need to separate hydrogen from natural gas at the end user. The advantage is the higher flow rate of the natural gas/hydrogen mixture through the pipeline. This mode of transport is cost-effective at high transport volumes and when a large number of customers are concentrated in one region. According to the German Hydrogen Strategy, 1 200 wagons, 600 ships or 82 cm diameter pipelines are required to transport 100 000 tonnes of hydrogen. [19]

3.2 SAFETY RULES FOR WORKING WITH INDUSTRIAL GASES

Working with industrial gases is extremely dangerous. Improper handling of these substances can have serious consequences, endangering health and life. Depending on the type of gas used, there are the following hazard categories:

- Toxic hazards,

- fire hazards,

- explosion hazard.

Working safely with gases should always start with the creation of a suitable infrastructure, such as internal and external gas installations, single – and double-sided and automatic gas expansion stations, high tightness installations made of copper or steel pipes, as well as additional equipment (pressure reducing valves, shut-off valves). Rooms in which an explosive atmosphere may be generated must first be equipped with active safety and ventilation systems. Laboratories or production halls should be equipped with detection systems suitable for the type of gas and effective exhaust systems for reaction gases. In addition, effective ventilation of rooms, gas cabinets and storage areas should be provided. Cylinders of compressed gases should be protected by against tipping, overheating and damage. When the work is completed, gas cylinders should be removed and moved to a location where they do not pose a hazard. Remember that there is a high risk of explosion in case of fire or improper transportation (special carts should be used for transportation). Furthermore, do not clean the cylinders by yourself. It is also forbidden to store flammable gases with incompatible substances, e.g. oxidizing gases with flammable or aggressive gases. Knowing the basic rules and regulations is the key to working safely with gases. It pays to know the rules and regulations and to educate each other about safety.

CONTROL QUESTIONS

1) Can you name at least three types of hydrogen transport? (Transportation by pipeline; Transportation of compressed hydrogen by road or rail, Transportation of liquefied hydrogen by road or rail, Transportation of hydrogen by pipeline in a mixture with natural gas)

2) Why is it necessary to build filling stations in urban areas or near roads? (because of easy accessibility)

3) What are the risks of handling industrial gases? (explosion risk, fire risk, toxic risks)

4 CONSTRUCTION PARTS OF THE FILLING STATION

The reader will learn about the main parts of a hydrogen filling station, their purpose and function. It also shows how the different parts of a hydrogen filling station are connected to form a functional and safe unit. Because a hydrogen filling station is a complex device that combines electrical, mechanical and high-pressure elements, it is essential to know the function of the individual parts and the safety regulations for their maintenance and repair.

4.1 THE MAIN PARTS OF A HYDROGEN FILLING STATION

A hydrogen filling station consists of the following parts:

- Hydrogen storage tank (underground, above ground)

- Compressor

- Heat exchanger

- High-pressure storage tank

- Cooling dosing device

- Dispensing rack

- Filling quick coupler

Hydrogen Storage Tank – The hydrogen that will be filled in the hydrogen filling station is vehicles are most often stored compressed in pressurized storage tanks. Due to the very small hydrogen molecule, it is necessary to select a material for the storage tanks that prevents hydrogen leakage through the material structure. Pressure vessels are most often made of steel or composite materials. In the case of composite containers, a steel or aluminium layer is placed inside the container to prevent hydrogen leakage. The hydrogen is stored in the tanks at a pressure of 200 bar. This hydrogen storage system has been proven and tested for a long time. The disadvantage is the considerable size of the tanks, especially in the case of filling stations that have to serve a large number of vehicles. The pressurised storage tanks can be a fixed part of the filling station and the hydrogen is piped in or transported to the site by trucks and then pumped into the tank. The other option is to use mobile storage tanks, where the hydrogen is filled at the industrial gas filling station and this tank is then transported by road or rail to the filling station. Pressurised steel or composite tanks can be placed on the surface or can be placed underground.

In some cases, it is possible to produce hydrogen on site, most often using electrolysis to produce hydrogen on site, in which case the cost of transporting the hydrogen to the filling station is eliminated.

The following two systems are mainly used for on-site hydrogen storage:

Bulk bundle – a rack containing gas cylinders. All gas cylinders of the bulk bundle are connected to each other by pipes and valves. This concept storage is ideally suited if the system is to be expanded later, as any number of volumes can be connected. Very small quantities can also be stored with this concept.

Picture 4 Bulk bundle [20]

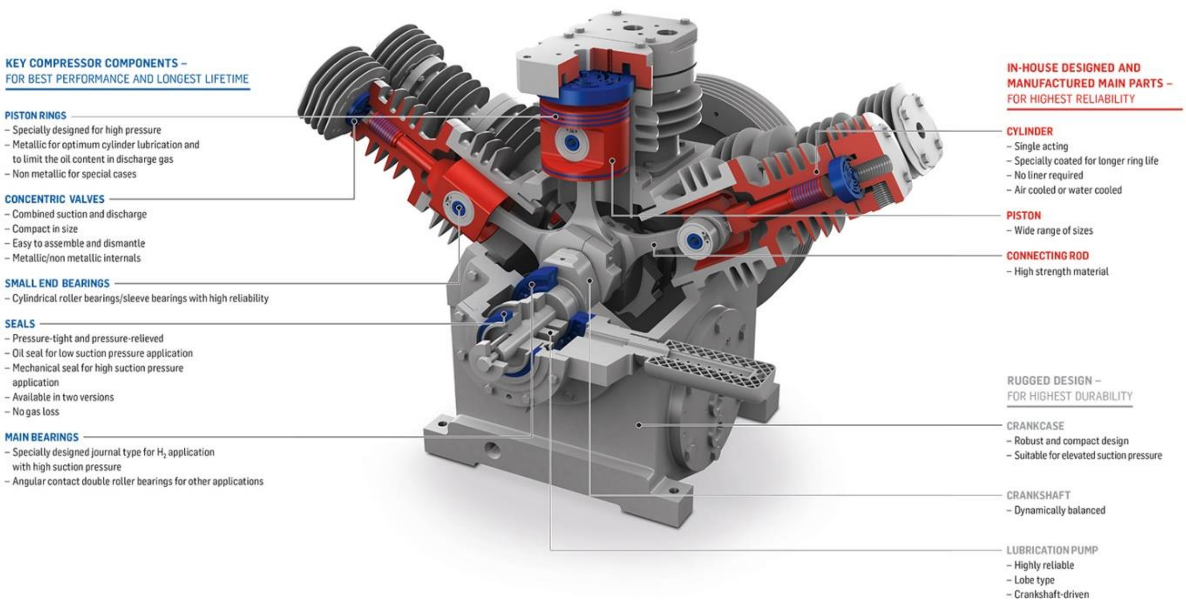
Tubular storage tank – these storage tanks consist of long storage units that are installed in a frame. A tubular storage unit is 6 or 12 metres long and can store large quantities of hydrogen.

Picture 5 Tubular storage tank [20]

Compressor – The compressor compresses the hydrogen to increase pressure and reduce volume, allowing more hydrogen to be stored in the system and for the gas to flow efficiently for dispensing. [22] At high-pressure filling (700 bar), the compressor is required to pressurize the hydrogen to about 950 bar. [23] At medium pressure filling, the hydrogen is compressed to a pressure of about 530 bar. [23] Dry-chain piston compressors with electro-hydrostatic drive are used for hydrogen compression. The compressor unit consists of two coaxial, vertical gas cylinders, each mechanically coupled and driven by a hydraulic cylinder. The space between the gas and drive cylinders prevents contamination of the medium with hydraulic oil.

The two drive cylinders are hydraulically connected to each other. Changes in stroke direction are made by contactless switches and the hydraulic cylinders are driven by a hydraulic power pack. When using a system with a control pump, the change in piston stroke can be infinitely controlled. Electro-hydrostatically driven dry-running reciprocating compressors compress gases such as hydrogen, nitrogen, helium, argon or ethylene completely free of lubricants and solids. The special arrangement and design of the gas piston seals and guide elements also makes it possible to dispense completely with the usual lubrication of the seal components in high and peak pressure applications.

Picture 6 Compressor for filling station [21]



Picture 7 High Pressure Compressor Diagram [20]

Heat exchanger – during the compression process, hydrogen is unwantedly heated, so the highly compressed hydrogen must pass through a heat exchanger where it is cooled.

High-pressure tank – The highly compressed gas is stored in a tank where it is ready to be filled into the vehicle. Storage is controlled by specially designed valves, fittings and electrical controls designed to regulate pressure and interact with the dispensing equipment and vehicle as required. [22]

Refrigerated dispensing equipment – For filling, the hydrogen is cooled to -40°C for fast and efficient filling to ensure safe hydrogen dispensing and compliance with filling protocols, i.e. J2601 protocol.

Dispensing Rack – Serves the same purpose as the dispensing rack on a conventional fueling station. Includes fill coupling, fill hose, display and control technology. The payment terminal can be located separately. Using the display, the user can conveniently start the refuelling process. A short step-by-step instruction is then followed until the filling coupling is firmly attached to the fuel filler neck of the vehicle. Hydrogen at temperatures down to -40 °C then flows through the filling coupling into the vehicle's hydrogen tank. The dispensing unit can fill the vehicle tank with a pressure of both 350 bar and 700 bar. [20]

Picture 8 Dispensing equipment [20]

The dispensers shall be installed in the open air under a shelter made of non-combustible materials, including roofing. They shall be located so that they are easily visible from the hydrogen filling station operator's position or controllable by CCTV and so that vehicles do not pass through the hazardous areas surrounding them. The shelter shall be designed for a wind speed of 160 km/h and a roof snow load of 100 kg/m², taking into account seismic resistance.

Filling quick coupler – connects the dispensing equipment and the filled vehicle. It shall provide a filling pressure resolution of 350 bar or 700 bar. For filling connections only filling hoses may be used, the design of which ensures a conductive connection to the mobile filling device, withstands hydrogen flow and operating pressure. The filling connection shall be no shorter than 3 m and no longer than 5 m. The design of the filling quick coupling shall preclude its use for purposes other than filling the tanks of hydrogen mobile equipment. Furthermore, it shall ensure that the hydrogen flow is only open when it is tightly connected to the filling connection of the mobile equipment and shall exclude unintentional disconnection. Disconnection of the filling quick coupling shall be possible only after depressurisation. If the mechanical stress exceeds a certain limit, it will disconnect and close the hydrogen supply from the dispenser and the hydrogen return flow from the tank of the mobile equipment being filled. The force required to disconnect is substantially less than the tensile strength of the filling connection hose or the force required to pull the filling quick coupling or damage the dispensing device. [24] The filling quick coupling shall allow a sufficiently fast gas flow for the shortest possible filling time of the vehicle and shall also allow data linking of the filled vehicle and the dispensing device to ensure data communication and optimum setting of the filling mode.

Picture 9 Filling quick coupling for 700 bar pressure. [25]

CONTROL QUESTIONS

1) What materials are most commonly used for compressed hydrogen storage tanks (steel or composite materials)?

2) What is the purpose of the compressor in a hydrogen filling station? (compresses the hydrogen from the tank to a high pressure, which will then be fed into the vehicle)

3) List at least four functions that must be ensured by the filling station (sufficiently fast gas flow, safe disconnection and depressurization, communication between the dispensing device and the filled vehicle, no confusion of filling pressures)

5 OPERATION AND MAINTENANCE OF THE FILLING STATION

KEYWORDS

safety, hydrogen, gas detection, inspection, maintenance, certification, qualification, safe distance, occupant protection, risks, explosion, leakage.

In order to ensure safety during the filling of vehicles and during the actual operation of the filling station, sufficient attention must be paid to operational checks and maintenance of the hydrogen filling station. This issue will be dealt with in this part of the text. The reader will be introduced to the various tasks involved in checking the condition of a hydrogen filling station, the safety regulations and the systems to ensure safe operation. Finally, cases of hydrogen filling station accidents will be presented, explaining their causes and consequences.

5.1 CONDITIONS FOR SAFE OPERATION OF A HYDROGEN FILLING STATION

Compliance with the operating instructions and operating rules of the plant is essential for the safe operation of the filling station. A diagram of the hydrogen filling station equipment, operating instructions, local operating regulations (fire regulations) must be available at the filling station site.

A sign prohibiting filling by unauthorised persons and instructions for filling shall be displayed in a prominent position in the vicinity of each compressed hydrogen dispenser. It is recommended that this prohibition be implemented in at least two world languages and, in border areas, in the languages of neighbouring countries. The engine of the mobile equipment must be switched off during filling and it must be secured against movement. Only the filled mobile device may be in the designated area of the dispensing device during the filling process. Smoking and open flames are prohibited in the area of the hydrogen filling station. This prohibition must be posted in a visible place. Safety signs and placards shall be used, their design and location being specified by the relevant legislation. These include warnings against the following types of hazards:

- areas where there may be an explosive atmosphere;

- flammable substances;

- compressed gases;

- risk of electric shock;

- blow-off of safety valves;

- hot or cold surfaces;

- mechanical hazards.

The dispensing equipment shall be secured against misuse during non-operating hours in the manner described in the local regulations.

Documentation of the hydrogen filling station in operation shall include an instruction manual detailing the proper procedures for the use of all parts of the hydrogen filling station. The instruction manual must identify the risks and hazards and specify safety precautions. The instruction manual must also contain a description and explanation of all warnings and markings used on the hydrogen filling station, particularly those relating to hazardous areas. The service manual shall be part of the technical documentation and shall contain instructions for the qualified maintenance of the process equipment, detailing the correct procedures for set-up, treatment, preventive checks and repairs. The service manual shall include recommendations for qualified maintenance, service intervals and records. Where methods of verifying correct operation are available (e.g. software testing programs), the use of these methods shall be described in detail. Qualified maintenance shall be performed by an authorised organisation. The provisions apply mutatis mutandis to the construction parts of hydrogen filling stations where the maintenance instructions are prepared by the construction contractor. [24] If there is a failure in the high-pressure section of the filling station, it is necessary to shut off the hydrogen supply, interrupting the hydrogen supply to the vehicle being filled, if connected. Subsequently, a controlled release of hydrogen from the pressurised parts into the surrounding atmosphere will occur.

5.2 OPERATION CONTROL OF THE HYDROGEN FILLING STATION

The hydrogen filling station shall be subjected to a periodic inspection at least once every 6 months, during which the following shall be carried out:

- a visual inspection of the condition of the entire installation;

- checking the functioning of the safety equipment and the remote-controlled valves;

- checking the operational status of the fire safety equipment

- checking the tightness of the connections during operation of the installation;

- visual inspection of the integrity of cable insulation;

- visual inspection of earthing and bonding devices (integrity of conductors, connection points free of corrosion and mechanical loosening, etc.).

Hydrogen filling stations shall be inspected regularly once a year:

- inspection of the gas equipment

- checking the passage and adjustment of pressure relief devices;

- hydrogen quality tests

- checking the compactness and marking of fire seals;

- checking the hydrogen mass flow meter

- operational inspection of electrical equipment in hazardous areas.

Hydrogen filling stations shall be subjected to periodic inspection once every three years:

- an operational inspection of the gas equipment, including a check of the operator's qualifications;

- an operational inspection of electrical equipment, including a check of the operator's qualifications.

Only persons over 18 years of age, medically fit, demonstrably trained, familiar with the local operating rules, trained in the event of an accident and tested to operate a hydrogen filling station may operate a hydrogen filling station.

5.3 HYDROGEN FILLING STATION ACCIDENTS

Despite all the safety measures to ensure the operation of hydrogen filling stations, a hydrogen filling station explosion occurred on 10 June 2019 in the Norwegian municipality of Bærum. Two people who were in a vehicle near the hydrogen filling station were injured in the accident. The explosion was so powerful that it triggered the airbags of vehicles in the vicinity. The manufacturer of the hydrogen filling station was NEL, it is the largest manufacturer of electrolyzers with a history dating back to 1927 and a leading manufacturer of hydrogen filling stations.

The owner of the affected hydrogen filling station is Uno-X Hydrogen, the station was opened in 2016. It was a Nel H2Station with on-site hydrogen production.

The main cause of the explosion was a poor tightening of the bolts on the hydrogen storage tank, which led to a gradual failure of the sealing system, followed by an uncontrolled leakage of hydrogen (time: 17.30) and then an explosion (time: 17.37). Subsequent investigation revealed an error in the assembly of the high-pressure storage unit, which consists of steel tanks and other components from subcontractors.

The investigation tested the high-pressure storage tanks used in this type of filling station and found the system to be completely safe in terms of material structure and design, but the assembly of the system was found to be unsafe. Inadequate tightening of the bolts can cause a hydrogen leak with fatal consequences.

Following this incident, NEL has tightened the control of the assembly of the pressure vessels even further, with the individual assembly steps being controlled as in the aerospace industry.

CONTROL ISSUES

1) Who is allowed to operate a hydrogen filling station? (Persons over 18 years of age, medically fit, proven to be trained, familiar with local operating rules, trained in emergency drills and tested to operate a hydrogen filling station

2) At what intervals are the hydrogen filling station inspected? (6 months, 1 year, 3 years)

3) What tasks are performed at the 1-year inspection? List at least four. (Check gas equipment, check pressure relief devices for clearance and adjustment, test hydrogen quality, check compactness and marking of fire seals, check hydrogen mass flow meter, operational inspection of electrical equipment in hazardous area.

6 TYPES OF FILLING STATIONS

KEYWORDS

technical conditions, hydrogen source, hydrogen filling station, storage, mobility, stationary station, internal transport, passenger cars, buses, trains, aircraft, compressed gaseous hydrogen, liquefied hydrogen, economics, refrigeration, availability, public

In the following, hydrogen filling stations are divided into several categories. This categorisation is intended to help the reader to understand the hydrogen filling stations and to summarise the main advantages and disadvantages of each solution. When selecting the type of a particular hydrogen filling station, the economic, technical and safety possibilities and the specific intended use for the filling station are crucial. After considering all these aspects, a study is carried out and the most suitable filling station design is selected. Here, hydrogen filling stations are classified according to the type of hydrogen used, the location of the station, the type of vehicles for which the station is intended and the source of the hydrogen distributed in the filling station.

6.1 CLASSIFICATION BY TYPE OF HYDROGEN

(1) Hydrogen filling stations for compressed gaseous hydrogen

2) Hydrogen filling stations for liquid hydrogen

Hydrogen filling stations for filling fuel cell vehicles with hydrogen in gaseous form are used for vehicles where the hydrogen is similarly stored as a gas in the vehicle's storage tank. There are generally two standards for gaseous hydrogen stations – refilling hydrogen at 700 bar (H70) or at 350 bar (H35). Passenger cars typically use H70 technology. Filling stations using liquid hydrogen are significantly less common. Hydrogen is only in liquid form at temperatures below -252.87 °C. A liquid hydrogen filling station requires an intensive refrigeration system which is very energy and technology intensive. [26]

6.2 DISTRIBUTION BY LOCATION

1) Stationary

2) Mobile

Hydrogen stations are generally a stationary system. The main function of a hydrogen refuelling station is to act as a hydrogen storage system with hydrogen storage and refuelling technology. In most cases, hydrogen is currently delivered to the station in cylinders or in specialized hydrogen containers on trucks. Some stations produce hydrogen directly at the hydrogen station by electrolysis (from wind or sun). Pipelines would be another efficient way to deliver hydrogen to these stations in the future. Mobile hydrogen refuelling systems are much smaller and are used for emergency refuelling or for some special mobile use cases. The advantage of mobile refuelling stations is that the station can be designed as a functional unit, which will be brought to the site from the industrial gas filling plant and replaced by a full station when emptied, while the empty station will be taken away to be filled. This system is suitable, for example, for intra-company transport. [26]. Hydrogen for passenger cars requires hydrogen refuelling stations that provide H70 (700 bar) pressure, while trucks and other special vehicles nowadays typically require H35 (350 bar) hydrogen refuelling stations. Liquid hydrogen could also be used for truck applications in the future; the advantage is the higher energy density of liquid hydrogen. Liquid hydrogen is planned to be stored in a hydrogen tank using state-of-the-art technology. Fuel cell buses are becoming increasingly popular because these types of hydrogen vehicles have high hydrogen consumption that is predictable. A fleet of several hydrogen buses can justify the investment in its own hydrogen refuelling station. Hydrogen consumption can be calculated and the station can be regularly replenished. Hydrogen fuel cell buses currently store hydrogen at 350 bar. Internal transport vehicles mainly use 350 bar technology because such a storage system requires less investment and, unlike cars, regular refuelling can be planned and carried out at a station built close to the general operating base (e.g. outside or inside the plant). Other modes of transport, such as trains, trams or even aircraft, can have hydrogen refuelling stations in a depot or hangar. [26]

6.3 CLASSIFICATION BY HYDROGEN SOURCE

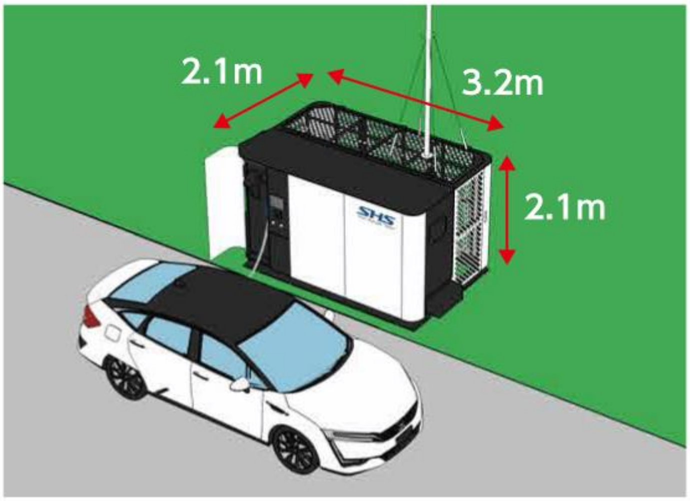
1) Hydrogen filling stations without their own hydrogen source

2) Hydrogen filling stations with their own hydrogen source

Most filling stations are built in locations where there are no suitable hydrogen sources and hydrogen has to be transported to these stations. Hydrogen filling stations with their own hydrogen source should be built at hydrogen production sites (e.g. production from landfill gas, hydrogen as a waste gas from chemical production, etc.). By building hydrogen filling stations at these locations, a considerable amount of costs associated with transporting the hydrogen and filling it into transport containers are saved. The disadvantage is that it is usually less accessible to the public. Therefore, this type of filling station is particularly suitable for local customers or for filling vehicles that operate in the production of this type of hydrogen.

Currently, the most common type of hydrogen filling station is for compressed hydrogen gas. These stations are stationary and similar in design to CNG filling stations. The filling pressure is set at 700 bar for passenger cars and 350 bar for trucks. In most of the refuelling stations already implemented, hydrogen is imported in tanks and is then pumped into a storage tank in the refuelling station.

As a point of interest, here is an example of a small hydrogen filling station which, thanks to the technology used and its small size, is very well suited for example to dense urban areas. Honda has quite a long history with hydrogen cars, with the first FCX clarity model appearing on the market back in 2007. At the same time, it has also spent a long time developing a better hydrogen refuelling station. In 2014, the first prototype SHS station appeared - a station that houses everything needed to produce hydrogen in the smallest possible space. In 2015, it came up with a revolutionary technology for hydrogen production using high-pressure electrolysis with its own device called the Power Creator. The SHS station is a very compact way to, produce, store and refill hydrogen, all with only a connection to water and electricity. The energy supplied is expected to be mainly from renewable sources, thus reducing CO2 emissions even when producing hydrogen. By using the power creator system, high pressure hydrogen is produced and therefore there is no need to use compressors which take up space and thus the electricity consumption of the whole plant is also reduced, according to the Honda website the electricity consumption has been reduced to 1/4. At the same time there is no need for such large tanks to store more hydrogen. All these improvements have made it possible for the station to occupy a space of 3.7m x 2.25m x 2.57m and can be placed almost anywhere.



Picture 10 Honda SHS [27]

CONTROL QUESTIONS

1) What are the advantages and disadvantages of hydrogen filling stations built on-site? (Advantages: eliminates the cost of filling hydrogen into transport containers and transporting it from the point of production to the point of filling; disadvantages: less accessible to the public, more suitable for local distribution)

2) What is the main disadvantage of hydrogen filling stations for liquid hydrogen? (energy and technical complexity, for liquefied hydrogen it has to be maintained at temperatures below -258°C.)

3) What is currently the most common type of hydrogen filling station? (stationary for compressed hydrogen gas with a filling pressure of 700 bar for passenger vehicles and 350 bar for trucks, without its own hydrogen source).

7 FORECASTS IN DEVELOPMENT

KEYWORDS

future, development, efficiency, use, research, availability, environment, European Union, subsidies, emissions, fuel cells, refuelling stations, independence, hydrogen, ecology, trucks, cars

The future of hydrogen filling stations is closely linked to the development of hydrogen production and the infrastructure for transporting it to the point of refuelling. The next necessary steps will be to switch to green energy sources for hydrogen production and to increase the efficiency of fuel cells. The increasing number of hydrogen powered vehicles will put pressure on the growing number of refuelling stations and their increased availability.

To give a few examples, the Japanese carmaker Toyota launched its first hydrogen car in the form of the Mirai, and in early December introduced the experimental GR Yaris with a hydrogen internal combustion engine. Both cars ingeniously demonstrate two different approaches to the use of hydrogen in transport: while the Mirai uses chemical reactions in fuel cells to generate electricity for electric propulsion, the GR Yaris burns hydrogen in a modified conventional engine. Both have undeniable environmental advantages: using hydrogen in a fuel cell produces only non-mineralised water as waste, and even burning it in a conventional engine results in only relatively small amounts of harmful NO_x. "The hydrogen fuel cell is significantly easier to recycle, with the disadvantage of using very rare metals such as platinum or iridium".

When the European Commission put forward its hydrogen strategy in 2020, it set the goal of creating a full hydrogen ecosystem in the EU to help decarbonise all sectors of concern. Two years on, concrete legislation is being born at EU level to help translate the targets into practice. Hydrogen is covered, for example, by the well-known Fit for 55 climate legislation packages, which defines the production of renewable hydrogen and includes measures to encourage its consumption. These include the construction of refuelling stations and related infrastructure. In the new REPowerEU energy plan, which is designed to help the EU break its energy dependence on Russia and ensure affordable and clean energy for the EU-27, the Commission has proposed an increase in hydrogen targets. Europe is not only thinking of hydrogen as another clean energy source, or energy storage, but also as an alternative fuel for vehicles. Although hydrogen transport projects are in their infancy, they have potential.

There are already hydrogen-powered cars, trucks, buses, trains and even ships. But they are far from widespread. And some of them may not even live to see it. Transport experts say hydrogen will catch on for freight rather than passenger transport. In the case of cars, batteries lead the way. If we are talking about passenger transport, battery power has almost a decade's head start, which also shows that the introduction of hydrogen in transport in general, and passenger transport in particular, seems to be a complementary solution rather than the main one. In freight transport, however, hydrogen has a number of advantages over batteries. One of the advantages is the lower weight of the vehicles, as well as the fast refuelling in 20 minutes and the reliable and higher range, which should not decrease significantly even in cold conditions. For this reason, too, hydrogen is seen as a solution, especially for long-distance freight transport and where the vehicle needs to be continuously loaded. It is likely that batteries and hydrogen will be replenished and coexist. Hydrogen also makes sense from the point of view of ČESMAD BOHEMIA (the association of hauliers). "The prototypes (of hydrogen vehicles) tested seem to be suitable for long-distance transport, their range is comparable to diesel vehicles and better than battery electric vehicles."

But the expansion of hydrogen propulsion is still the music of the future, and several question marks remain to be resolved. One of them, for example, is where to install the bulky hydrogen tanks that trucks need. Whether Europe can manage to produce enough pure hydrogen also remains a key question mark. Hydrogen production from fossil fuels would certainly not lead to carbon neutrality. If we are talking about so-called green hydrogen, the main stumbling block is the scale of production needed. To develop hydrogen-powered transport, it is of course also necessary to build enough filling stations. The construction of refuelling stations is not only financially but also technically demanding. For example, the Czech filling station, which has been in operation since June 2022 in Ostrava, cost about CZK 15 million. The Czech Republic is planning to build about 80 of them domestically by 2030. Another obstacle that will hinder the rapid development of hydrogen vehicles is the assumption of a very high price of hydrogen vehicles. If the EU wants to achieve its goals of making transport emission-free, hydrogen refuelling stations should be available at least every 150 kilometres along the trans-European car transport network by 2030. This would create a sufficiently dense network of hydrogen refuelling stations to ensure adequate EU cross-border connectivity and support the 60,000 hydrogen trucks expected to be on EU roads in 2030. The 60,000 hydrogen trucks reflect the results of a 2020 study commissioned by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), which concluded that fuel cells "are a very promising solution for emission-free propulsion for heavy goods transport. The study concluded that hydrogen fuel cell trucks could become cost competitive by 2027 if the price of hydrogen falls to €6/kg. The study also highlighted the high operational flexibility and relatively short refuelling times of hydrogen trucks. However, a legislative framework will be essential for hydrogen trucks to take hold in the market. "Without the EU's flagship climate package Fit for 55, only 3 000 hydrogen trucks would be on Europe's roads by 2030," a European Commission official told EURACTIV. However, with current proposals to meet the EU's climate ambitions, this number is set to rise to 60 000. The study outlines a scenario in which 17 % of new trucks sold in 2030 would run on hydrogen. However, two key criteria must be met – hydrogen should be sold at a price below €6/kg and the costs associated with hydrogen technology should fall. If this were to happen, it would mean that around 60,000 hydrogen trucks would be running on European roads by 2030. In 2030, green hydrogen could cost as little as €1.8/kg. The cost of the technology could be put on a promising downward trajectory by joint EU and industry research funding.

For hydrogen filling stations, the future focuses mainly on building a sufficiently dense network of filling stations, solving the hydrogen supply problem and reducing filling times. One option under consideration is to increase the filling pressure, but this will lead to even greater demands on safety, quality of materials and design of both filling stations and vehicles. As the number of filling stations increases, the price of filling stations will decrease, making it possible to increase their number even further.

In order to make the construction and operation of hydrogen refuelling stations more efficient and cost-effective, the Department of Energy Technology at the University of Duisburg-Essen (UDE) and the Centre for Fuel Cell Technology (ZBT) are currently developing simulation models of refuelling station components in order to analyse and evaluate designs. Researchers from UDE and ZBT are looking at the basic components of a hydrogen filling station. On the ZBT test bed, they examine the fuel pump, tank size and pressure, feed the results into simulations and calculate the relationships between the components to make refuelling efficient. Critical to the design of a hydrogen filling station is its intended use. Filling stations in small towns or businesses and stations located along highways will be completely different.

Another issue that will need to be addressed is the losses in the hydrogen production and distribution chain. The more efficient the process, the lower the final price of hydrogen. Hydrogen is also significantly more expensive than fossil fuels. Project leader Dr. Jürgen Roes of the Department of Energy Engineering says: "Nevertheless, hydrogen from solar and wind energy is an important energy storage device of the future because it does not pollute the environment." It therefore makes sense to use the resource as efficiently as possible and to start thinking about how to use it as economically as possible. [28]

CONTROL QUESTIONS

1) In which mode of transport is hydrogen expected to be the main use? (freight transport and city buses)

2) What are the advantages of hydrogen powered vehicles compared to electric vehicles? (lighter weight, longer range, range independent of outside temperature, faster refuelling)

3) What percentage of new trucks sold in the EU in 2030 should run on hydrogen (17 %)?

8 SUMMARY

The purpose of this text is to familiarize the reader with the basic issues of hydrogen filling stations, their history and operation. The reader should be familiar with the basic legislative issues and technical regulations that affect both the actual design and construction of filling stations and the rules for their operation and maintenance. In the following sections, the reader will become familiar with the types of hydrogen filling stations, their basic characteristics and intended use. The text concludes with an assessment of the future development of hydrogen filling stations as well as the general use of hydrogen as an energy source in transport.

The issue of hydrogen technology is very broad and undergoing dynamic development, so it is not possible to cover all the information related to this issue in one educational text. For a perfect orientation in the issue of hydrogen and its use it is necessary to get acquainted with other modules and to follow the developments in the field of hydrogen technology. In general, hydrogen technologies can be considered very promising, although their widespread deployment will be accompanied by a considerable number of problems and will be costly.

9 SOURCES

[1]: https://finmag.penize.cz/veda-a-technika/430830-je-vodik-palivem-budoucnosti-nastupujici-trend-ocima-expertu

(2) https://www.wired.com/2007/11/checking-in-on/

(3) https://www.statista.com/statistics/1026719/number-of-hydrogen-fuel-stations-by-country/

[4] *CHIC » Fuel cell electric bus project CHIC launches final project report as tool for cities and bus operators* [online]. [vid. 2017-01-19]. Dostupné z: http://chic-project.eu/newsevents/news/fuel-cell-electric-bus-project-chic-launches-final-project-report-as-tool-for-cities-and-bus-operators

[5] H2-Stationen. *H2 Mobility* [online]. [vid. 2017-02-10]. Dostupné z: http://h2-mobility.de/h2-stationen/

[6] https://www.iberdrola.com/sustainability/hydrogen-stations

[7] https://www.sciencedirect.com/topics/engineering/hydrogen-refuelling-station

[8] TPG 304 03 www.cgoa.cz

[9] https://hydro-tech.hennlich.cz/produkty/kompresory-a-plnici-stanice-vodiku-14468.html

[10] https://www.sultrade.cz/standardni-vysokotlake-kompresory/

[11] https://www.products.pcc.eu/cs/blog/vyznam-technickych-plynu-v-prumyslu/

[12] https://www.technicka-zarizeni.cz/sbornik-prednasek-kh-2021/vystavba-a-provoz-vodikovych-plnicich-stanic-a-nektere-souvislosti/

[13] https://www.technickenormy.cz/csn-en-17127-venkovni-vydejni-vodikove-cerpaci-stanice-na-plynny-vodik-s-plnicimi-protokoly/

[14] https://www.iso.org/standard/71940.html

[15] https://standards.iteh.ai/catalog/standards/cen/90016399-7325-4ffa-a34f-058be6306350/en-17124-2022

[16] https://www.sae.org/standards/content/j2601_202005/

[17] Comparative study of Global, European and Italian Standards on Hydrogen Refueling Stations

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DOI: https://doi.org/10.1051/e3sconf/202233409003

[18] https://www.tuvsud.com/cs-cz/odvetvi/energetika/konvencni-energie/vodikova-energie/skladovani-preprava-a-distribuce-vodiku

[19] Vodíková strategie České republiky, *Ministerstvo průmyslu a obchodu*

[20] https://www.sultrade.cz/standardni-vysokotlake-kompresory/

[21] https://hydro-tech.hennlich.cz/produkty/kompresory-a-plnici-stanice-vodiku-14468.html

[22] https://www.haskel.com/en-us/blog/how-does-a-hydrogen-refuelling-station-work

[23] https://hdsam.es.anl.gov/index.php?content=hrsam

[24] TPG 304 03

[25] https://www.weh.us/weh-fueling-nozzle-tk17-h-70-mpa-for-fast-filling-cars-singlehanded-operation-selfservice.html

[26] https://hyfindr.com/hydrogen-refueling-station/

[27] https://global.honda/innovation/FuelCell/smart-hydrogen-station-engineer-talk.html

[28] https://fuelcellsworks.com/news/filling-station-of-the-future-using-hydrogen-more-efficiently/

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