Safety using of hydrogen as vehicle fuel: A review

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Abstract—**Hydrogen today has become an acceptable fuel for many energy applications and systems. It is necessary to define basic safety specifications, and ways to deal with this fuel. It is important to be able to use hydrogen in the same proportion as other fuels, without any added risks. The identification of hydrogen safety should include understanding of its important combustion phenomena. Because hydrogen has low liquid state temperature (-212°C), it is sensitive to the vessels and containers' walls, and it could cause thermal decline and condensation to it. The identification of safety hazards for any fuel is a very complex mission and requires analysis of high-quality technical information, compared with information similar to other types of fuel. The conditions of ignition, fire, and explosion should be carefully studied and evaluated to ensure that the fuel is actually safe to be used. From here, it can be said that hydrogen may be safer than conventional fuels when used in some applications, and may become more dangerous than most of them in other applications.Because of the depth and importance of this subject, it has been dealt with in great depth. Scientific literature is filled with very large numbers of papers that are taught and addresses several safety points and safety considerations when using hydrogen. In the following pages, efforts were made to summarize and explain what many researchers have studied in the field of hydrogen safety.**

Index Terms— Hydrogen, safety aspects, detonation, deflagration, Ortho-Para conversion.

I. Introduction

WThe world today suffers from many of the problems that resulted from negative human events during the last two centuries, which were directly reflected on current generations [1]. The burning of fossil fuels, whether coal, natural gas, oil for energy production and transport, has caused pollution of the environment and the high level of greenhouse gases to an alarming level [2]. Global warming, which has caused a serious climate change, started to pose many problems and great suffering to some societies [3]. Fossil fuel is depleted in the near future despite the new discoveries of many natural reservoirs, but it cannot compensate for the rising consumption of it in transportation and power generation [4]. It has become clear that fossil fuels need to be replaced in the near future with environmentally friendly energies such as solar, wind and geothermal [5, 6, 7]. The relentless search to find clean fuel for internal combustion engines has also suggested using bio-fuels such as bio-ethanol or biodiesel as well as hydrogen [8, 9, 10].

Many readers may not know that hydrogen was the first option of Diesel experiment in his famous engine, which its failure caused to transition to the fuel named by hid name. Ricardo also carried out several practical experiments to use hydrogen in spark ignition engines in 1920 [11]. Since then, global interest in hydrogen has not ceased to fuel cars, planes, and rockets. But this interest increases in periods especially when there are problems for the oil market in the world, such as in 1973 war and the event of fluctuation of global oil prices for the period from 2008 to 2014 [12].

Hydrogen has been widely used in the heat treatment industry as an element in the furnace atmosphere and recently as a primary component or carrier gas in the heat treatment environments of glass plants [13]. Hydrogen reacts with many metal oxides in heat treatment temperatures and acts as an excellent oxygen control. Hydrogen also has the lighter gas molecule and has a very high thermal conductivity, both of which provide the possibility of increasing heat transfer between the surrounding envelope and the operating piece, whether metal or glass [14]. The many advantages of H2 in heat treatment applications have led to increased use of pure H2 or N2-H2 mixtures in applications such as copper brazing, sintering, and ferrous strip annealing [15].

Also, hydrogen is a good fuel as it doesn't emits no air pollutants when combust except of tiny concentrations of NOx [16]. Hydrogen was used as fuel in spark ignition engines alone [17], or added to NG [18], LPG [19], and gasoline [20]. Also, it was used in diesel engine added to diesel fuel [21], or to biodiesels [22]. When hydrogen is added, all hydrocarbon emissions such as HC and CO are clearly reduced [23, 24]. Hydrogen has an important advantage, which is the rapid spread of flame [25]. The hydrogen has the highest laminar burning flame velocity compared to all known fuels, as it is the fastest oxidation fuel [26]. This feature has made a mixture of other types of gaseous fuels with hydrogen can work in higher flame speed [27, 28]. In addition to its combustion at very poor mixtures that cannot be reached without the added hydrogen [29].

Hydrogen today is the main fuel for the fuel cells that work with no emissions [30].

When talking about hydrogen fuel immediately opens the issue of safety. Many people first think of the famous Hindenburg air balloon in 1937 [30]. When dealing with hydrogen as fuel, the main interest becomes possibility of burning it in closed areas, and its susceptibility to explosion. However, in previous generations after Hindenburg, hydrogen is routinely used in a many industrial applications. Hydrogen is generated and being used in the same plant or using transport pipelines from the production plant at specified

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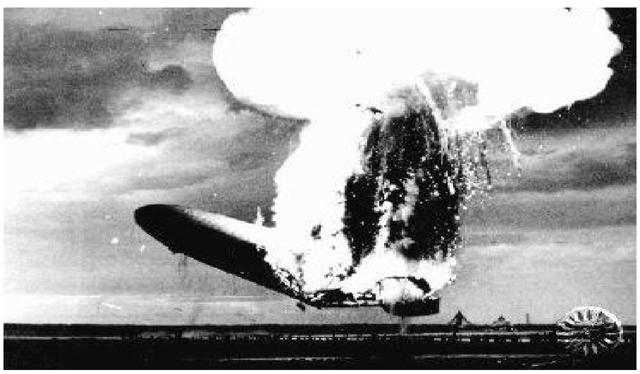
distance. Today, more than 100 million gallons of cryogenic hydrogen are transported on North American highways only each year [31].

II. THE HINDENBURG

The Hindenburg disaster was the most famous accident (actually, the only famous) containing hydrogen directly occurred in Lake Hurst, New Jersey in 1937. Thirty-five people died in the tragedy, but a subsequent analysis showed that 27 of these deaths were caused by people jumping from the burning balloon in the air. Eight other people were killed by burning with upholstery vapors or diesel [30]. The latest research, conducted by hydrogen specialists at NASA, showed that the explosion was caused by high-volatile coatings used to paint the outer part of the balloon-something resembling a rocket-propelled grenade. Although hydrogen was on fire when caught fire, 62 people remained on the boat and avoided toxic smoke from the furnishings [31]. Studies have shown that hydrogen combustion occurred within one minute of ignition, while diesel fires continued to burn for up to ten hours after ignition [32].



III. THE CHALLENGER SPACE SHUTTLE AND THE H-BOMB

Many people have their unexplained fears of using hydrogen as a result of an incorrect vision linked to the 1986 Challenger space shuttle or a hydrogen bomb explosion. NASA's engineering and safety studies have shown that the Challenger disaster was not caused by hydrogen. The hydrogen bomb uses tritium, a completely different form of hydrogen. During the explosion of the hydrogen bomb in a process similar to that of the sun's energy is repeated. This process occurs at astronomical temperatures and pressures, and the reactions here are nuclear and not chemical reactions [33].

IV. HYDROGEN GENERAL SPECIFICATIONS

Talk about the safeness of the hydrogen use should start by identifying and studying the basic physical properties of this gas [34].Table 1 provides comparative information for hydrogen, methane and gasoline. Some characteristics identify specific situations that pose relatively greater or lesser risks to hydrogen and the other fuels. Since safety is indeed dependent on the effectiveness of the system design and its work in dealing under these circumstances, it can be said that it is too early to conclude that a certain type of fuel is better than other types, or that this or that type is somewhat safer in a particular application by simply examining the characteristics table [35, 36 and 37].

TABLE I
FLAMMABILITY, DETONABILITY AND IGNITION PROPERTIES OF FUELS[38]

Fuel	H_2	CH_4	C_3H_8	Gasoline
Flammability limits				
Lower (%fuel per volume)	4.0	5.3	2.1	1.0
Upper (% fuel per volume)	75.0	15.0	10.4	7.8
Detonability limits				
Lower (%fuel per volume)	18.3	6.3	3.4	1.1
Upper (% fuel per volume	59	13.5	6.7	3.3
Ignition energy (mJ)	0.02	0.29	0.31	0.24
Thermal autoignition (ºC)	520	630	450	
Minimum Heated laminar air jet (1mm d)	640	1040	885	
Heated Nichrome wire (1mm d)	750	1220	1050	

Hydrogen is the lightest of all elements. It is colorless, odorless, tasteless, and nontoxic, but can be suffocated when oxygen is shifted into the air. In liquid form H2 can freeze liquid nitrogen, cause mineralization, and frostbite. Appropriate materials should be selected for the very low temperature of the H2 liquid service [35]. H2 is highly flammable and lighter than air. In the absence impurities with H2, it burns with a colorless flame. The physical properties of H2 and several other gases are listed in Table 2.

The minimum discharge required for hydrogen is 13% -18%, which are double the natural gas and 12 times higher than gasoline [39]. If we recall that the hydrogen fuel combustion limits are 4%, the explosion of the hydrogen container is only under unusual circumstances and a detonation capsule must be present. As an example, hydrogen has to accumulate up to 13% in the air and in a closed area without a source of ignition during the accumulation period, and then, in these very special circumstances the ignition source must be initiated [40, 41 and 42]. In the case of hydrogen explosion, the hydrogen contains the least explosive energy per unit of energy stored in the fuel. The explosive energy in a certain amount of hydrogen is 22 times less than the same volume filled with gasoline vapors. Hydrogen fire and flame are almost invisible, which makes them dangerous in terms of safety standards, because people in the vicinity of the hydrogen flame may not even know of a fire [43]. To remedy this, chemicals must be added that can provide the necessary gloss [44]. Here, we must emphasize that the low temperatures resulting from the emission of the hydrogen flame will lead to the material and people who are close to the hydrogen fire will be less vulnerable to combustion and the harm that can be obtained will be due to heat transfer by radiation. Smoke from gasoline fires poses a danger to those who inhale this smoke, but the hydrogen fires produce only water vapor (if the secondary materials do not burn on site) [45, 46].

TABLE II
PHYSICAL PROPERTIES OF SELECTED GASES [39]

Gas Synbol, mole weight	**Nitrogen N2 28.0134**	**Helium He 4.0026**	**Hydrogen H2 2.01594**	**Air - 28.96**
Spec. Gravi. (air=1) 70ºF, 1 atm	0.9669	0.13796	0.0695	1
Spec. Vol. Ft3/lb 70ºF, 1 atm	13.803	96.71	192.00	13.30
Density, lb/ ft3 70ºF, 1 atm	0.0724	0.0103	0.00521	0.0749
Boiling point ºF	-320.36	-451.10	-423.00	-317.80
Heat of Vab. BTU/llb	85.6	79.0	191.7	88.3
Spec. Heat BTU/lbºF	0.2488 @77ºF	1.2404 @77ºF	3.4202 @77ºF	0.2406 @77ºF
Therm. Cond. @ 32ºF BTU/ft^2. hr	0.0139	0.08266	0.1076	0.0139

V. Properties of the Cryogenic Liquid

In standard atmospheric conditions, liquid hydrogen boils at -252.9°C. The transition from liquid to gaseous conditions in standard conditions causes the hydrogen expansion to be approximately 850 times in size [47]. This fertility has implications for safety though they are simple. People who deal with cryogenic hydrogen should be provided with equipment that protects them from low-frost chew, from frostbite and cold injury. Cold hydrogen vapor breathing is also dangerous [48]. If the containers that store liquid hydrogen are not perfectly isolated, the heat can enter, which may cause the liquid hydrogen to boil and steam build up pressure. To avoid this catastrophic failure, liquid hydrogen tanks are equipped with sealed valves and can release the gas that is formed when the pressure is increased to a certain degree so that the released amount of the tank does not represent a direct risk of fire or explosion [49]. This accumulated vapor can be released into the atmosphere or used in some applications (small fuel-cells are suggested as well as the use of catalytic burning). In some special cases, long ventilation paths may increase the possibility of building up a sufficiently flammable mixture and increasing the risk of explosion [50]. When venting from the storage container (100% hydrogen, 0% air) to the atmosphere (approximately 0% hydrogen, 100% air), there will certainly be some local areas with flammable hydrogen/air mixture ratios. In such circumstances, attention should be paid to good ventilation that will reduce this flammable volume and ignition sources should be avoided in this area [51]. Unusual conditions such as external fires or container discharge failures should be taken into consideration when designing ventilation arrangements. This procedure should also be used in compressed gas storage systems and metal hydrates containers, where pressure relief should be provided in accident conditions. In such circumstances, venting rates should be relatively rapid [52]. **Table 3** lists the cryogenic properties of liquefied gases at their normal boiling point that are relevant to safety. Liquefied gases may create additional hazards because of their low boiling temperatures and the possibility of liquid spills [53]. The classification of hydrogen as a hazardous substance was based on its flammable and explosive properties. Therefore, when working with hydrogen, whether liquid or gas, priority must be given to different safety aspects, in order to ensure that the system of transfer and using this material adequately addresses all these aspects of safety [54].

TABLE 3
CRYOGENIC PROPERTIES OF LIQUEFIED GASES [53]

Liquified gas	**Boiling temp. K**	**Liquid density kg/m^3**	**Gas density kg/m^3**	**Heat of vaporization J/g**
Hydrogen	20.3	70.8	1.34	454.6
Helium	4.2	125.0	16.89	20.6
Methane	111.6	422.5	1.82	510.4
Nitrogen	77.3	808.6	4.53	198.6

VI. Ortho-Para conversion

The hydrogen molecule exists in two forms, which differ with respect to the orientation of their nuclear spins. Ortho-hydrogen has parallel spins, and Para-hydrogen has antiparallel spins. While at room temperature the Ortho modification outnumbers the Para modification by a factor of 3 to 1, liquid hydrogen at its boiling point at equilibrium consists almost entirely of Para-hydrogen. This Ortho-Para conversion at cryogenic temperature is a very slow exothermic process, and in the absence of a paramagnetic catalyst, can take several days to complete. Hydrogen heat of conversion is 715.8 kJ/kg, which is 1.5 times the heat of vaporization. This problem is alleviated in liquid hydrogen plants by catalytically converting normal hydrogen to Para-hydrogen during liquefaction [55].

VII. Interaction of hydrogen with metals

Care must be taken to select materials that are appropriate for the intended purpose. The main concern associated with the use of certain metals in connection with hydrogen is hydrogen embitterment and hydrogen attack [53].

VIII. Hydrogen embitterment

Many substances are subject to hydrogen embitterment at temperatures close to ambient temperature. Some of these materials are those that have a structural formation that form the metal structure. This problem occurs when using many types of steel and get in cases where the material is subjected to mechanical stresses. Hydrogen can enter the material in its atomic form so that it can be within the metal structure. In order to prevent surface or other imperfections that are likely to be formed when using stressors, it is preferable to resist metal degradation. The introduction of hydrogen atoms into the metal structure makes hydrogen sulfide impurities more easily separated than molecular hydrogen [53].

In general, the hydrogen embitterment can be lowered using any of the following points:

a) The strength level of the used material hardness can be restricting to a safe value;
b) Control the applied stresses and prevent them from exceeding pre-defined limits.
c) Reduce residual stresses by using heating or cold worked formation.
d) The reduction and avoid of cold plastic deformation from manufacturing processes such as cold bending or forming.

In components that are subject to periodic cyclic loading, it will be important to avoid conditions that may cause local fatigue as hydrogen is known to greatly accelerate the spread or initiation of cracks in the structure. Austenitic stainless steel is generally less affected by hydrogen embitterment, and today it is used in the construction of hydrogen equipment. Austenitic stainless steel has a remarkable capability even at very low temperatures [55].

IX. Hydrogen attack

At temperatures higher than 200 °C, some materials manufactured from low-plate structural steel may be exposed to another state of reaction with hydrogen existence known as hydrogen attack. In this case, the chemical reaction between the hydrogen stored in the container and the carbide particles in the steel produces methane gas. This process, which is non-reflective degradation, happens in the microscopic structure of the steel [56].

Increasing temperatures and pressure may cause increasing the hydrogen attack intensity. It is important to look for practical engineering solutions to avoid hydrogen attack. From these solutions, the use of steel alloys that contain very little or no carbide stabilizers to reduce the interaction between carbon and hydrogen absorption as a result of halting the hydrogen attack [57].

X. Organic materials

The use of fiber reinforced polymers (FRPs) has become more important and more widely used as pressure vessel materials. Most polymers do not cause any problems with storing and transporting hydrogen. However, hydrogen may be able to diffuse through these materials more easily than the use of metallic materials. Normally, the leaks of the container are not sufficient to reach the proportion of flammable air-fuel outside the container, but at the same time they can cause a loss of the amount of gas stored over a long period of time, and can spoil the vacuum insulation of the container [58].

XI. Effect of low temperatures

Most materials undergo a sharp reduction in their ductility and specific heat when cooled to liquid hydrogen temperatures. Therefore, when dealing with storage and transport of liquid hydrogen, care should be taken to ensure that the structure of the material from which the container is stored maintains a certain degree of ductility. The ductility behavior of metals and alloys is controlled in low temperature conditions through the metal mesh structure. Many metals and alloys have a cubic structure as austenitic steel (of these metals aluminum, copper, and nickel alloys exhibit only a moderate decrease of their solubility in cryogenic temperatures) [59].

Composite materials, which have fiber-reinforced materials and microfiber structures that use glass, polyamide or carbon can also be used to provide satisfactory behavior when operating at ultra-cooled temperatures [60]. There are significant differences in the method of linear shrinkage of different metals with polymers that must be taken into consideration, as the latter are exposed to much larger contractions than minerals. This situation must be taken into account when designing hydrogen equipment and containers that operate under high pressures and at very low temperatures [61].

XII. Critical situations

A. Gas leaks

Hydrogen gas is difficult to detect if it does not produce audible noise, because it has no distinctive color and no odor. The leaking hydrogen gas can be easily mixed with air to produce a flammable mixture, especially if the leak is in an enclosed, unventilated place [62]. Active or passive ventilation for closed rooms containing equipment for handling or storing hydrogen shall always need to install a detection device to avoid the buildup of a flammable mixture [39].

All system components and connecting elements that carry hydrogen should be designed to minimize leaks. Threaded connections and flanges should not be used. Wherever possible there must be replaced by welded or brazed joints [63].

B. Liquid spills

If liquid hydrogen is spilled, the existence of an ignitable mixture of vaporized gas and air is certain. In case of the evaporation of liquid hydrogen, it generates a white cloud of condensate water which is heavier than hydrogen. Many references indicate that the expansion of this dense water cloud be seen as an approximate guide to extending the flammable gas-air mixture cloud. This unsupported evidence does not necessarily mean that it is taken as a basis for safety measures. The properties of the clouds may differ from each other depending on their formation conditions. However, cryogenic cooling caused by low-temperature hydrogen evaporation of indirectly cooled objects results in the loss of their flexibility, causing further damage [64].

If liquid hydrogen is impregnated, the flow must be cut by closing the upstream valves. No measures may be taken in the vicinity of the spill site, and the area adjacent to it must be evacuated until such time as the liquid evaporates and the gas disintegrates into concentrations below the flammability range. Dams or other trapped devices must be used very carefully due to the event-related explosion effects that may develop into an accident [65].

C. Frozen impurities in liquid hydrogen

Liquid hydrogen tanks that are frequently filled and emptied shall be regularly checked for the accumulation of impurities such as oxygen. Oxygen particulate build up in liquid hydrogen may detonate. Solid air in a liquid hydrogen piping system can plug lines and orifices and may interfere with the operation of valves and other equipment [66].

D. Oxygen enrichment in the environment

Liquid hydrogen is usually transported in isolated and vacuumed lines. In the case of hydrogen flowing through non-thermally insulated pipes, it can easily cool the surrounding air to less than 90 Kelvin. This causes oxygen to rise in the air to 52%. This air enriched with oxygen enhances the permeability of flammable materials and makes the usually non-flammable materials ready for flammability. Therefore, if hydrogen transport lines cannot be isolated for any reason, the area below should be abandoned from any organic material, including road blocks of bitumen and similar materials. This issue should be considered particularly alarming when transporting large quantities of hydrogen [67, 68].

XIII. Hydrogen vehicle onboard hazards

The presence of hydrogen on board may pose a direct safety hazard. Here, circumstances and risks should be considered, including situations where the vehicle is inoperable, when the vehicle is in normal operation, and in collisions. The most important potential risks are fire, explosion, and toxicity. The latter can be ignored where neither hydrogen nor it fires' smokes can be considered to be toxic. Hydrogen becomes a source of fire or explosion in many areas, including fuel storage, fuel supply lines, or fuel cells. Hydrogen and oxygen can also combine on the catalyst surface and create ignition conditions, but the potential damage will be limited due to the presence of a small amount of hydrogen in the fuel cell and fuel supply lines [69]. So, the largest amount of hydrogen can be considered at any time is the one in the tank. Several ways of failure of the tank during the normal operation of a vehicle or collision can be considered, such as:

A catastrophic rupture in the hydrogen tank due to defects in manufacturing; fault due to intensive handling, or transferring of the tank, or fracture due to stress; puncture of the tank with a sharp instrument; external fire accompanied by failure of the pressure relief device in its operation.

A large leakage of hydrogen can result from an idle relief valve that starts by releasing hydrogen into the air without justification or high pressure in the tank. It also can be caused by a hole with a sharp tool such as a pullet [70]. The slow leakage can occur due to cracks in the lining of the tank, error in the work of the pressure relief device, or a faulty connection from the tank to the feeder line, or the openings of the fuel line [71].

Similar failure situations due to high pressure storage, and low pressure fuel lines can be analyzed and studied in practice and theoretically. Ford Motor Company cooperated with Directed Technologies Inc., to conduct a study to assess the probability of failure conditions for the above cases. The results of the study showed that the condition of the catastrophic rupture is a difficult condition and it is difficult to happen to a large degree. The study identified several types of large hydrogen leakage or slow leakage of normal operating conditions or in collisions and accidents [72]. The above-mentioned failure patterns can be mostly avoided or reduced by the following:

• Proper design of the system and choose the appropriate equipment to prevent leakage and do all the necessary tests and investigations. It should include the system's ability to withstand shocks and vibrations by careful research, the optimal location of the pressure venting system, the protection of high pressure lines, and the installation of a valve on all feeder lines.

• Improved fire protection by using an automatic separation system for batteries connections and eliminating all electrical spark sources that are responsible for most of the gasoline fires by 85% after any collision. This process needs to design fuel supply lines so that they are automatically-separated from all electrical devices, batteries, motors and wires as much as possible. A system of active and passive ventilation that allows hydrogen to escape must be designed to the highest and prevent its accumulation in the storage area [73].

• The risk is usually defined based on the probability of occurrence and its consequences. The study conducted by Directed Technologies Inc. that is mentioned above conducted detailed analysis and assessment of the risk probability in many of the most likely accident scenarios involving hydrogen, such as:

• Fire in the fuel tank or explosion in open spaces is not limited

• Fuel tank fire or explosion in tunnels

• Fuel line leakage in non-confined areas

• Fuel leakage due to accidents at the refueling station or in the garage [74].

The study concluded that the probability of the hazard and its consequences for the above cases are similar if not less than those produced using other types of fuel such as gasoline or natural gas.

XIV. Relative advantages of using hydrogen

In this part of the study we will review the important issues related to the safe storage and circulation of hydrogen that can be performed in hydrogen cars and trucks. The most important safety issues for a vehicle may be in situations such as refueling, fuel storage on board, and operation. Currently there are three options for hydrogen storage on board that has priority: compressed gas, cooled liquid and metal hydrides. Hydrogen storage systems using metal hydrates are associated with the use of many metals, including iron, magnesium, nickel, manganese, and titanium. These hydrates react with hydrogen and then release it as gas when heated.

Recently, the use of finely-activated carbon has begun, as this substance adsorbs hydrogen to its surface. Here, hydrogen adsorbs and stores at low temperatures that is higher than its boiling point, and it is also released as gas by activated carbon heating [75].

In many applications hydrogen can be considered safer fuel than gasoline or diesel. Since hydrogen stores large amounts of energy, work with it requires certain safety precautions like any other fuel. So, hydrogen can be safer than gasoline if used correctly. Hydrogen is very light, it is the lightest elements in existence, and so it spreads and floats up in the sky, unlike gasoline that will stay waiting for ignition. If hydrogen leaks into the soil, it will not contaminate groundwater or cause environmental disaster, unlike fossil fuels such as gasoline and diesel [76].

The tests were carried out by a group of researchers at the University of Miami's Faculty of Engineering to see if hydrogen would ignite in the car. In these experiments, 3,000 cubic feet per minute of hydrogen was leaked from a car tank and ignited. During the hydrogen combustion period the temperature sensors inside the car did not measure any increase more than 1 or 2°C anywhere in the vehicle [77, 78]. The temperature of the outside of the car did not exceed the case of a car sitting under the sun. At first glance, these results may seem unjustified. However, when burning carbon fuels such as gasoline, it burns the hot incandescent particles that emit into the surrounding environment. Since hydrogen does not contain any carbon, it will not leave any traces of hot soot, and it combustion will result in small radiation energy. From here, the researchers concluded that the victim of a hydrogen fire accident must be practically in the torch in order to get burned. The compressed hydrogen tanks are made to withstand the enormous pressures and effects and are designed to avoid failure.

To date, many critics still refuse the use of hydrogen in vehicles as the ability of this fuel to explode. Certainly this is possible. But, these critics ignore the large explosive capabilities of natural gas reservoirs in their own cars [79]. Numerous practical tests have been conducted for technical bodies, companies, and institutions that consider the safety of compressed gas hydrogen storage. A car crash going at a speed of 55 m/s has been tested, but the hydrogen tank remained intact after the accident.

BMW also tested the hydrogen tanks it manufactures in a variety of accidents including collision, fire, and rupture of the tank to ensure the safety of the hydrogen vehicles it manufactures. In all tested cases, hydrogen cars have given positive and comparable results to conventional gasoline cars. Car companies rely on a fundamental principle that hydrogen-powered vehicles are designed with a fundamental priority: to prevent hydrogen from leaking into the car [80, 81].

XV. Conclusions

Hydrogen had been considered as alternative fuel for all fundamental fuels; it will continue penetrates these markets with time. Reasonable accidents must be assumed, to develop detailed faults, to deliver particular information about expected hazards. Hydrogen has been considered as essential substance in many industrial processes; it had been handled and transferred successfully for many generations. In industry using hydrogen is a routine matter, and there is no additional safety problems exist. Transferring hydrogen by pipes for hundred kilometers is used for many years successfully. Electricity industry used hydrogen successfully for cooling rotors and stators in large generators turbines, without any mentioned problems. Hydrogen is considered one of the most important alternative fuels. It can be used for vehicles, buses, locomotives, marines, airplanes and containers. In general, gases filled with hydrogen (like city gas, coal gas.. etc.) used successfully in Europe, to carry out residential requirements in nineteenth century, which show us that there is a high percentage of safe usage to hydrogen.

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