Safety in High Pressure Hydrogen Storage and Handling in Hydrogen Plant- A Review

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Abstract

Hydrogen is one of the most reliable source of energy after the fossil fuels. The rich availability of this gas and its ability to produce and transfer energy makes it one of the most suitable forms of fuel which can be used in near future. The fields in which the hydrogen can be used as a potential fuel are very wide. Even though hydrogen has a very high potential, the safety is a major concern when using it. The features like flammability, invisible flame, odourless, colourless and density makes the gas very unsafe to handle and use. The following literature reviews focuses on the factors which has to be considered while handling and storing hydrogen.

Keywords: *Hydrogen storage, Flammability, Handling, Engineering Controls*

For the past several years after the first energy crisis hydrogen was considered as the best form of energy carrier if the petroleum products deplete. The range of application and the areas in which hydrogen can be used is very vast, but they are also limited due to its instability and the hazards which they may cause. Hydrogen only requires combustion energy of 142mj/kg which makes it extremely volatile and hard to handle and store. Any leak or unexpected situations in while handling and storing hydrogen gas may cause catastrophic effects like fire and explosion. Some of the major factors of concern in a plant where hydrogen is produced in large quantities by a common method like electrolysis are

- Storage of pressurised hydrogen gas.
- Hydrogen embrittlement on welded joints in pipelines.
- Self ignition of hydrogen gas.

The risks and hazards involved in a hydrogen plant can be evaluated and eliminated by using evaluating methods like risk analysis. Risk analysis helps in systematically evaluate and hence find the areas of hazard in a plant if there is and hence eliminate it or reduce its rate of severity. There are several risk assessment systems like HAZOP, JSA, and HIRA which are used to identify the hazards and assess the effect of the hazard and probability for the hazard to occur and severity of the hazard.

Risk assessment and risk analysis are a set of systematic methods to:

- Identify hazards
- Quantify risks
- Determine components, safety measures and human interventions important for plant safety

I. RISK ASSESSMENT

A crucial part of any safety and health program is the identification, evaluation, elimination and/ or the control of hazards in the workplace. It is impractical to prevent all hazards, so the aim is to reduce the severity of the hazard to a level that it is no longer a major problem in order to protect workers from getting hurt. This is called risk assessment, and it is the evaluation of hazards to determine their potential to cause an accident.

When people hear of the term risk assessment, most of them think of it as some other forms of insurance this is mainly due to lack of proper knowledge and implementation at the right place at the right time. In reality, all most all of the people implement risk assessment in their day to day life. For example, while a person is driving he adjusts his speed by assessing the conditions and circumstances on the road; while playing we seek cover when caught in rainstorm. Because of this, we should be more informed on various risk assessment techniques available to us and should have sufficient knowledge on how they can be properly used and implemented on different scenarios.

The risk assessments tools like failure mode and effects analysis (FMEA) or management oversight risk tree (MORT) analysis, Petri net analysis (PNA), fault tree analysis (FTA) are more complex when compared to other techniques and are best used in formal situations for specific purposes.

The intent of this review paper is to analyze and review all the papers on hydrogen safety. The review paper will cover the major areas where high safety issues occur in a hydrogen plant and will try to suggest improved and safer techniques.

II. HYDROGEN GAS STORAGE

Storage of hydrogen is a major task which has to designed and constructed carefully during the installation of a plant. There are various factors to be considered while designing the storing facilities in a plant containing pressurized hydrogen gas. Safety distance is an important factor which has to be always considered while deciding a place for setting up the storage vessels in a hydrogen plant. The calculation of separation distances for hydrogen infrastructure is mainly done by considering the severity of reacting and non-reacting jets, most of which will be in the momentum controlled regime. The safety distance can be calculated by mainly two methods NFPA 55 standard and hydrogen safety engineering, after calculation it was found that hydrogen safety engineering was more reliable than NFPA55(saffers and molkov, 2011). While considering storage of hydrogen its storage in solid state must also be considered.

Hydrogen cars are the future of automotive industry, the increases oil process and its shortage are increasing the demand for hydrogen driven vehicles day by day. One of the major hurdles faced by the automobile industries is the successful establishing of hydrogen filling stations throughout a country. In comparison with other transport 'fuels', safety distances in the Netherlands for gasoline (20–25 m), CNG and hydrogen (10–15 m) are of the same order of magnitude. Safety distances for LPG are larger: 15m for the dispenser, 25m for the underground buffer, and, depending on annual sales, 45–110m for the filling point on the LPG tank trailer. The capacity of a hydrogen filling station does not appear to have a large influence on the safety distance. For this reason a filling station for gasoline can also be equipped with a filling unit for hydrogen without increasing the external safety distances (Matthijsen and Kooi, 2006). Also by improving the type and design of vessels used for storing hydrogen, any potential hazards caused by these storing vessels can be solved. It is proposed that risks can be mitigated and controlled by taking different measures, such as optimizing vessel structure, proper selection of materials, mitigation of ignition sources, on-line safety monitoring, safe operation and management. Also, it was recently proven that multi-layered stationary hydrogen storage vessels are more safer than compared to single layered vessels. This type of vessels which have been developed in China, are now safely in action (Xu, Zheng, Chen, Kai and Li, 2009).

An easiest way of storing hydrogen gas was in its solid or cryogenic state. Characterized by its high gravimetric energy content and clean conversion, hydrogen is considered as a very promising alternative. Cost effective, efficient and safe means of storage and delivery of hydrogen is essential to make this a reality. Hydrogen can be converted into solid state by compressing the gas at very high pressures (about 700 bar) or liquefaction at cryogenic temperatures (20 K), this presents several safety and design challenges. But storing hydrogen in its solid state emerged as a safe and feasible alternative, especially for mobile and portable applications (Murthy and Kumar, 2013).

III. SELF IGNITION OF HYDROGEN GAS

Self ignition is one of the factors which cause accidents in a hydrogen plant. Due to the extreme flammable nature of hydrogen it is possible that the gas may get ignited even in the absence of an external ignition source when it forms a flammable mixture with oxygen. The chemistry behind the combustion of hydrogen is very simple and less complex when compared to other fuels. The reason for this decreased complexity is that only two main gases mainly hydrogen and oxygen take part in combustion (Williams, 2007). It has been explained by several papers that hydrogen is capable of getting ignited inside a pipeline. By using the high speed direct and shadow photography flow visualization has been created and investigated for understanding the self ignition capacity of high pressure hydrogen. By using a diaphragm a flow of high pressure hydrogen is allowed to propagate into a tube which contains air, as hydrogen enters it forms a hydrogen-air mixture which gets ignited even in the absence of an external ignition source. From the study it is been understood that the self ignition capacity of hydrogen mainly depends on the factors like pressure, length, diameter, type of cross section of the pipe and the location of the sensors. The test was conducted pressure ranging till 11.3Mpa and it was found that the self ignition started occur from 7.5Mpa (Kim, Lee, jeung, and Kim, 2013). Similarly, the ignition capacity of hydrogen was evaluated by releasing pressurised gas into open atmosphere. An experiment was setup in such a way that the hydrogen gas was pressurized to a range of 30Mpa and made to exit through two different types of nozzle having diameter of 5mm and 10mm and varying pipe length. From the experiment it was conclude that the diameter of the nozzle and length had direct effect on the self ignition of hydrogen. As the length of the pipe and the pressure increases the chances of self ignition also increases, short pipes are also capable of causing self ignition if the pressure is high(Mogi, Kim, Shiina and Horiguchi, 2008).

The changes in self ignition temperature of hydrogen gas when other gases were evaluated. This evaluation was necessary since other gases were added to hydrogen to enhance its performance as a fuel. In order to safely use this mixture the self ignition of the mixture was very important to be found out. The gases like methane and hydrogen were mixed and tested at various scenarios and concluded that the effect of hydrogen substitution in methane is dramatic and the effect is more at higher pressure(Golub, Baklanov, Bazhenova, Bragin, Golovastov, Ivanov and Volodin, 2007). Also hydrogen-oxygen-helium mixtures were tested to understand the behavior of the gases at different temperature and pressures. The obtained data can be very useful by providing information which would help in avoiding dangers from occurring when different gases are mixed with hydrogen (Liu, Zhang, Ma, Shi and Huang, 2014)

The similar experiments were also carried out numerically under simulation and also it was concluded that the length of the tube and the pressure at which the hydrogen gas exits has direct effect on its self ignition (Xua, L. Himaa, Wena, Dembelea,. Tamb and Donchev, 2008). Another type of ignition which was tested was called diffusion ignition. This was tested by both numerical and experimental methods; the release of high pressure gas produced a shock wave that led to triggered ignition even though the overall temperature of hydrogen was below the auto ignition temperature. It was postulated that it was caused by a temperature increase of combustible mixture due to mass and heat diffusion between hydrogen and shock-heated oxygen. Apart from the factors like length, diameter and gas pressure other factor like occurrence of a wall in the path were the gas was released was also tested to find whether it played any role in the self ignition. After the experiment it was proven that regardless of the length, height and distance, wall did not play any role in self ignition of gas, but had its influence by changing the direction of flame propagation (Ki, Lee, Kim and Jeung, 2012).

IV. HYDROGEN EMBRITTLEMENT ON WELDED JOINTS IN PIPELINES.

While considering various factors which causes safety issues in an hydrogen plant there are very less chances that authorities may concentrate on hydrogen itself and the safety issues hydrogen can cause on the plant. Hydrogen is a type of gas which has the ability to slowly degrade and cause damage to metal parts which it is in contact with. The most common metal parts which hydrogen are in contact with are metal pipelines which carries highly pressurised hydrogen at different temperatures.

Hydrogen induced stress cracking (HISC) plays a major role in causing fractures and cracks in pipelines. The three main reasons which cause HISC are hydrogen source, microstructure of the pipe material and tensile stress. HISC mainly affects the heat induced areas in a pipeline which are mainly created as a result of welding (Capellea, Dmytrakhb, Azaria and Pluvinagea, 2014). The hydrocarbons which are being transported through pipelines by petroleum industries are complex and cannot be separated electrically as result most of the materials transmitted contains sufficient amount of hydrogen molecules to initiate HISC. In order to limit the damages and accidents due to hydrogen embrittlement, after conducting extensive studies and experiments a precautionary procedure or experiment is being proposed by the paper, DNV-RP-F112 is a series of experiments and procedure through which every material used for the manufacture of hydrogen carrying pipeline should be taken through (Solnørdal, Wästberg, Heiberg and Hauås-Eide, 2009).

V. DISCUSSION AND CONCLUSION

- Identification of Hazards in hydrogen plant plays a vital role in preventing Explosions, Fire and major accidents.
- Several papers have studied about various causes for accidents to occur in an hydrogen plant and also suggestions have been mentioned to prevent accidents.
- Several causes for self ignition of hydrogen gas has been identified and analyzed
- Causes for hydrogen embrittlement and its effects have been discussed.

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