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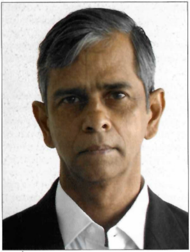
SPECIAL ISSUE



HYDROGEN - PRESENT AND FUTURE

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The advancement of hydrogen technology is driven by factors such as climate change, population growth, and the depletion of fossil fuels. Rather than focusing on the controversy surrounding the environmental friendliness of hydrogen production, the primary goal of the hydrogen economy is to introduce hydrogen as an energy carrier alongside electricity. Water electrolysis is currently gaining popularity because of the rising demand for environmentally friendly hydrogen production. Water electrolysis provides a sustainable, eco-friendly, and high-purity technique to produce hydrogen. Hydrogen and oxygen produced by water electrolysis can be used directly for fuel cells and industrial purposes. The review is urgently needed to provide a comprehensive analysis of the current state of water electrolysis technology and its modelling using renewable energy sources. While individual methods have been well documented, there has not been a thorough investigation of these technologies. With the rising demand for environmentally friendly hydrogen production, the review will provide insights into the challenges and issues with electrolysis techniques, capital cost, water consumption, rare material utilization, electrolysis efficiency, environmental impact, and storage and security implications. The objective is to identify current control methods for efficiency improvement that can reduce costs, ensure demand, increase lifetime, and improve performance in a low-carbon energy system that can contribute to the provision of power, heat, industry, transportation, and energy storage. Issues and challenges with electrolysis techniques, capital cost, water consumption, rare material utilization, electrolysis efficiency, environmental impact, and storage and security implications have been discussed and analysed. The primary objective is to explicitly outline the present state of electrolysis technology and to provide a critical analysis of the modelling research that had been published in recent literatures. The outcome that emerges is one of qualified promise: hydrogen is well-established in particular areas, such as forklifts, and broader applications are imminent. This evaluation will bring more research improvements and a road map to aid in the commercialization of the water electrolyser for hydrogen production. All the insights revealed in this study will hopefully result in enhanced efforts in the direction of the development of advanced hydrogen electrolyser technologies towards clean, sustainable, and green energy.

Supply security and climate change are two important concerns for the future of the energy sector, posing the issue of determining the most efficient approach to reduce emissions while also supplying the energy needed to sustain economies. Fossil fuels are finite; hence alternative energy sources are required Carbon pricing is one of the alternatives that has an important role in facilitating energy transitions, such as the transformation from high-carbon energy (coal and oil) to low-carbon energy (natural gas) and clean energy (renewable resources). The carbon market can minimise the cost of emission reduction in society, boost investment in green and low-carbon industries, and regulate capital flow by allocating carbon emission reduction resources optimally [8]. Future energy sources must meet the conditions of being carbon-free and renewable for the long-term treatment of climate change and reducing reliance on oil imports. In terms of cost, electrolyser production costs vary based on size, materials, and volume, and have been decreasing, but must decrease further to in its gaseous form by road or rail in high-pressure cylinders.

Hydrogen is used in its gaseous form but stored and transported in liquid form. However, there are also several applications for liquid hydrogen:

The aerospace industry is one of the major users of liquid hydrogen. As stated earlier, this industry uses liquid hydrogen to launch rockets.

Currently, there is a growing interest in superconductivity (the state in which material has virtually no resistance when transporting electricity), in which liquid hydrogen plays an important role. This provides another potential use for the liquid gas.

Lastly, the development of heavier trucks and extended-range ships is also considering the use of liquid hydrogen in the tanks.

The use of hydrogen, whether in gas or liquid form, is not without risks. When hydrogen reacts with the right amount of oxygen gas, a massive amount of energy is released, causing an explosion. In addition, hydrogen has a relatively low combustion temperature and is therefore highly flammable.

Furthermore, because hydrogen is colourless and odorless, a leak in a system is hard to detect. Even a hydrogen flame is almost invisible, and therefore difficult to extinguish. Liquid hydrogen is also extremely cold (-252.9 °C) and will cause freezing on contact. Finally, oxygen can condense if the hydrogen is insufficiently insulated, forming an increased fire hazard.

There is some debate as to how the above risks compare to other fuels. In fact, research shows that hydrogen poses a slightly higher fire risk than gasoline or natural gas. What this increased risk means for the future of hydrogen remains to be seen. However, all other fuels are not without their dangers either, and with the proper infrastructure and information, hydrogen can be managed well and safely.

Fortunately, hydrogen has been used in various industries for a long time, and infrastructures and security measures have improved significantly over the past few decades. Sophisticated sensors now exist that immediately indicate a leak from a hydrogen infrastructure. Hydrogen tanks, pipelines, and applications are also subject to rigorous testing standards. This equipment is exposed to high pressure and extreme temperatures before it can be put into service.

With the proper infrastructure in place, hydrogen can be safely managed without any problems if the end-user also handles the gas responsibly. In this respect, providing correct information plays an important role. The better the user follows the instructions and is made aware of possible dangers, the smaller the risk will be. Liquid hydrogen requires a higher quality of insulation than some other liquid gases. The main reason for this is the extremely low temperature of the gas. If, for example, hydrogen is transported through a pipeline with foam insulation, a small rupture in the foam may be the source of oxygen condensation due to the extreme cold emitted by the liquid hydrogen. A fire or explosion will ensue should this condensed oxygen come into contact with hydrogen or any other combustible material.

Fortunately, there is a form of insulation that provides optimal insulation. The vacuum technology method is the solution for safely transporting, storing, and using liquid hydrogen. Vacuum insulating is as much as 15 times better than other insulation materials (for example, PIR/PUR, or Foamglas, Armaflex, Perlite, and Misselon) and can be used for pipes as well as fittings, tanks, and cryogenic equipment.

Vacuum technology uses vacuum or high-vacuum to insulate transfer lines or systems optimally. A vacuum environment is created by encapsulating these lines or systems with a double wall and vacuumize the space between the two walls. The vacuum ensures that heat transfer cannot occur (since most molecules have been extracted) between the warm outside and the cold inside.

Vacuum insulation for hydrogen systems is not only safe but also meets the strict requirements for hydrogen infrastructures. For example, liquid hydrogen transfer lines on ships are expected to be equipped with a double-containment for extra safety (should the process line have a leakage, the extra-containment will be in place). If the pipelines are provided with vacuum insulation, the vacuum tube also functions directly as a double-containment. As such, vacuum insulation kills two birds with one stone.

CcH2 is stored in insulated pressure vessels that are filled with cold H gas at up to 400 bar pressure. The gas is then discharged as the vehicle drives, which cools the tank.

Cryogenic hydrogen storage, which involves cooling hydrogen to extremely low temperatures (around −253°C), presents the main challenge of maintaining this temperature. Liquifying hydrogen is a time- and energy-intensive process, resulting in energy losses of up to 40% compared to the 10% energy loss in compressed hydrogen storage. Cryogenic storage is primarily used for medium to large-scale storage and transportation, such as truck deliveries and intercontinental hydrogen shipping. A cryogenic tanker can typically hold 5000 kg of hydrogen, five times the capacity of compressed hydrogen gas tube trailers. The safety of cryogenic vessels is ensured by their extra protective layer (vacuum jacket) in the event of accidents, and hydrogen has low energy for adiabatic expansion at cryogenic temperatures . In case of a leak or tanker rupture, there will not be a significant explosion unless the gas is ignited. Low temperatures of leaked hydrogen gas can cause malfunction and damage to nearby valves or pressure relief devices not designed for such conditions. An example of this happened in a cryogenic hydrogen lab in 2016, where a pressure relief valve failed to function because it was in an area that was not rated for cryogenic temperatures.

Cryogenic insulation has advanced in several ways, including:

- New materials
  New materials have enabled improvements in thermal insulation systems for transferring and storing cryogens.

- Multi-layer insulation blankets
  Also known as super insulation, these blankets are widely used for high-performance insulation.

- Vapor cooled shields
  These shields use the boil-off vapor of a cryogenic fluid to create temperature zones in a vacuum space.

- Testing and apparatus
  New test apparatus and methods have led to new technical standards for cryogenic insulation systems.

- Understanding heat transfer

A better understanding of heat transfer characteristics has contributed to advancements in cryogenic insulation in a cryostat with vapor cooled thermal shields, cold vapor evaporating from the liquid space is used to cool the thermal shields and thereby reduce the heat load on the cryogenic liquid. Vapor cooled thermal shields, or shrouds, are often associated with liquid helium Dewars. However, the same principle can be applied to any cryogenic liquid. Liquid nitrogen Dewars with carefully designed vapor cooled thermal shields have been used to achieve very long holding times in instruments for space flight and balloon borne applications. Vapor cooled thermal shields may be constructed by diverting all or part of the cryostat boil-off through cooling coils attached to thermal shields. In sub-Kelvin cryostats, for example, vapor from an evaporation stage may be drawn off to cool a 1K heat shield while vapor from a separator pot cools an outer 4K heat shield. In storage dewars it is more common to heat sink nested heat shields at the dewar neck. Boiling a gram of liquid helium at 4.5K absorbs 21 J of heat. Warming a gram of helium vapor from 4.5K to 300K requires 1550 J of heat. Effectively using the enthalpy of the cold helium vapor allows liquid helium vessels to achieve very low boil-off rates. Traditionally, many laboratory liquid helium cryostats and magnet dewars have employed liquid nitrogen cooled thermal shields to intercept heat from surrounding 300K surfaces. Typically, we would expect the heat flux from 300K to an 80K surface insulated with a thick MLI blanket and with a good isolation vacuum to be about 1W/m2. If this 80K surface surrounds a 4K surface, which is also well insulated, then we typically expect a heat flux of about 0.1W/m2 on the 4K surface. The liquid nitrogen cooled thermal shield, in effect, absorbs 90% of the heat flux at a much lower cost than would be achieved if the 4K surface were not shielded. The major concern in selection of proper insulation system is to minimise the heat in leak from ambient. The basic objective is always to minimize the radiative energy transfer or heat inleak. Along with to minimize the convective heat transfer and of course the conductive heat transfer.