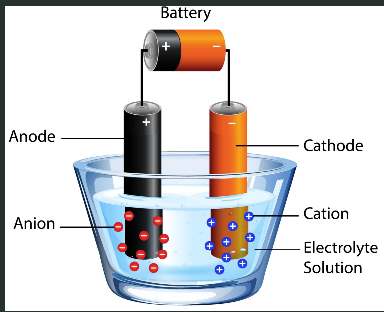


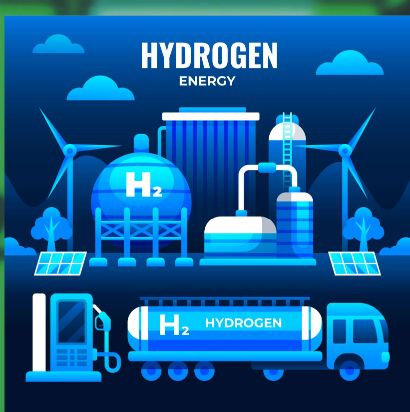
Draft Study Material

Green Hydrogen Plant Technician

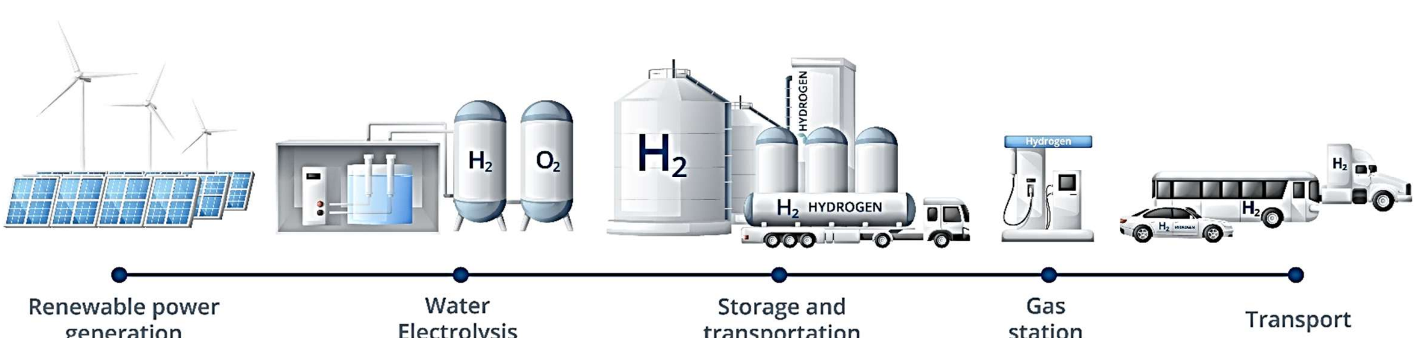
(Job Role)

QP: Ref. Id. SGJ/Q0120

Sector: Green Jobs



Textbook for Class XII



Green Hydrogen Plant Technician

(Job Role)

Qualification Pack: Ref. Id. SGJ/Q0120
Sector: Green Jobs

Textbook for Class XII

PSS CENTRAL INSTITUTE OF VOCATIONAL EDUCATION, SHYAMLA HILLS, BHOPAL, M.P., INDIA

PREFACE

Vocational Education is a dynamic and evolving field, and ensuring that every student has access to quality learning materials is of paramount importance. The journey of the PSS Central Institute of Vocational Education (PSSCIVE) toward producing comprehensive and inclusive study material is rigorous and time-consuming, requiring thorough research, expert consultation, and publication by the National Council of Educational Research and Training (NCERT). However, the absence of finalised study material should not impede the educational progress of our students. In response to this necessity, we present the draft study material, a provisional yet comprehensive guide, designed to bridge the gap between teaching and learning until the official version of the study material is made available by the NCERT. The draft study material provides a structured and accessible set of materials for teachers and students to utilise in the interim period. The content is aligned with the prescribed curriculum to ensure that students remain on track with their learning objectives.

The contents of the modules are curated to provide continuity in education and maintain the momentum of teaching-learning in vocational education. It encompasses essential concepts and skills aligned with the curriculum and educational standards. We extend our gratitude to the academicians, vocational educators, subject matter experts, industry experts, academic consultants, and all other people who contributed their expertise and insights to the creation of the draft study material.

Teachers are encouraged to use the draft modules of the study material as a guide and supplement their teaching with additional resources and activities that cater to their students' unique learning styles and needs. Collaboration and feedback are vital; therefore, we welcome suggestions for improvement, especially by the teachers, in improving the content of the study material.

Deepak Paliwal

(Joint Director)

PSSCIVE, Bhopal

Date: 20 July 2025

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Table of Contents

MODULE 1: INSTALLATION OF WATER FEED SYSTEM

Module Overview

Water is the key ingredient for making green hydrogen through electrolysis. A well-designed water feed system ensures a clean and steady water supply to the electrolyser, facilitating smooth operation. This system comprises pipes, storage tanks, filters, and control valves to deliver water at the desired purity level demineralised (DM) for alkaline electrolysers or ultrapure for PEM electrolysers. Proper treatment and monitoring (including pH, flow rate, etc.) prevent damage and leaks while maintaining optimal efficiency.

In this module, you will learn how to install, maintain, and monitor this system while following safety best practices for reliable hydrogen production.

Learning Outcomes

After completing this module, you will be able to:

1. Describe the importance of water feed systems in green hydrogen production.
2. Identify the quality requirements for water used in alkaline and PEM electrolysers.
3. Explain various water purification processes such as pre-treatment, reverse osmosis, distillation, and deionisation.
4. Install and maintain piping systems and water treatment units for hydrogen production.
5. Monitor critical water quality parameters (pH, conductivity, resistivity) and maintain logs.
6. Perform basic troubleshooting and apply safety precautions while handling the water system.
7. Adjust water supply and treat water for consistent electrolyser performance.
8. Use appropriate tools and instruments to set up and test the input water system.

Module Structure

Session 1: Input Water System for Electrolyser

Session 2: Various Parameters Essential for Water as Feedstock

Session 3: Understanding the Piping System

Session 1: Input Water System for Electrolyser

In a Green Hydrogen production facility, water is essential and can be classified into three primary categories based on its usage:

1. Water for Green Hydrogen Production: This is the main input required for the electrolysis process, which generates hydrogen through the splitting of water molecules. The purity of this water is critical to ensure optimal efficiency and hydrogen yield.

2. Water for General Plant Purposes: This category includes water utilised for various operational needs within the plant, such as cooling systems, cleaning, and maintenance activities. While this water may not require the same level of purity as that used for electrolysis, it should still meet certain quality standards to prevent operational issues.

3. Quality of Water: The required quality of water varies significantly depending on the electrolyser technology employed, namely alkaline electrolysers and Proton Exchange Membrane (PEM) electrolysers. Each technology has specific specifications and tolerances for impurities, which can affect performance and longevity.

The diagram below illustrates the different quality standards needed for each type of electrolyser, highlighting the importance of using the appropriate water quality for efficient and sustainable hydrogen production.

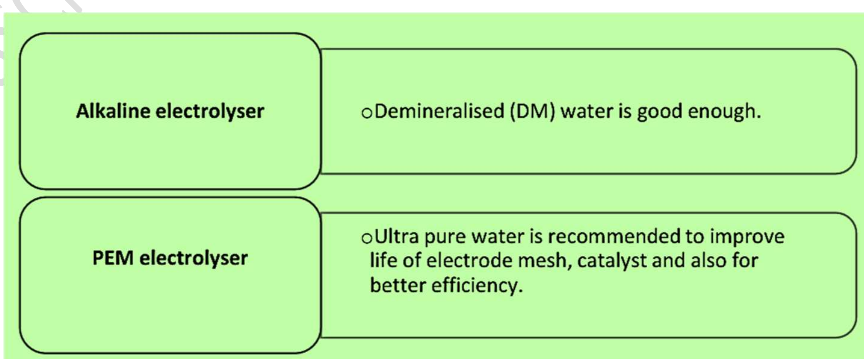

Fig. 1.1: Quality of Water Required for Alkaline and PEM Electrolysers

Source and Quantity of Water for Hydrogen Production

Access to a good water source is vital for producing hydrogen because water is the main ingredient used in electrolysis. Possible water sources include the municipal supply from the local government, water from the Irrigation Department, or deep bore wells, as long as they have enough water and follow local rules. It's important to get the right agreements and permits from the necessary authorities to secure these water sources.

The amount of water needed depends on how much hydrogen you want to produce. Roughly, you need about 10 liters of water to make 1 kilogram of hydrogen. Therefore, if you aim to produce 100 kg, 1,000 kg, or 10,000 kg of hydrogen per day, you will need 1,000 liters, 10,000 liters, and 100,000 liters of water each day, respectively.

For large-scale hydrogen production, especially for a plant producing around 1 GW (1,000 MW), it's best to locate the facility near large water bodies like rivers, lakes, or reservoirs. This helps ensure a steady and ample water supply, which is crucial for continuous operation.

Also, consider not just the estimated water needs but also extra water that might be lost due to evaporation, system inefficiencies, and water used for maintenance and operations. Typically, losses can range from 60 to 90 kg of water for every kilogram of green hydrogen made. However, much of this lost water can be recovered through condensation and treatment processes, which allows for recycling and can lower the overall demand for new water.

Water Treatment

The given figure represents the water flow diagram of a hydrogen production plant with a PEM electrolyser, which has the following four stages of water treatment:

1. Pre-treatment
2. Reverse osmosis
3. Storage and distribution
4. Pure water

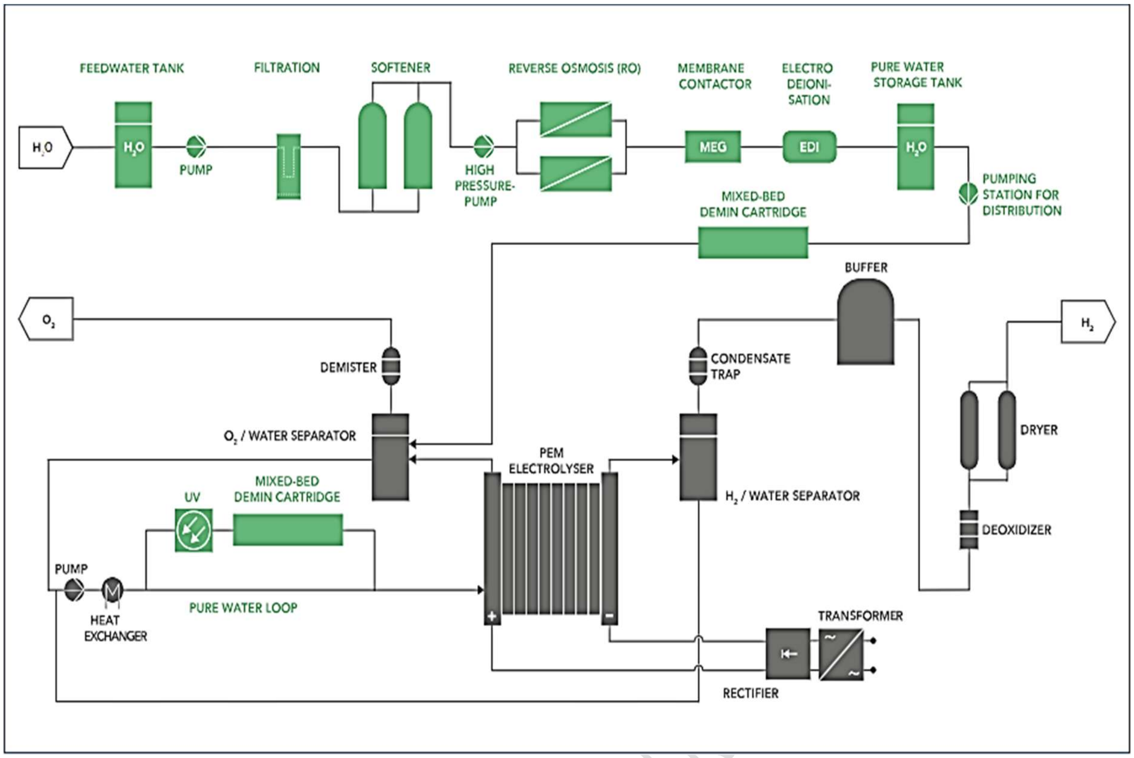

Fig. 1.2: Water flow diagram of a hydrogen production plant with PEM electrolyser

Let's discussion the first stage of water treatment plant in Hydrogen production.

1. Pre-Treatment

The pre-treatment phase of water purification is critical and encompasses several essential tasks:

- Feed Water Tank: Raw water, collected from natural sources or municipal supply, is first stored in the feed water tank. This tank serves as a reservoir where the water is retained before being transferred to the filtration plant. Efficient pumping systems ensure a steady flow of water for subsequent treatment processes.

- Filtration: This step aims to enhance water quality by removing a range of impurities. Sediment filtration systems are employed to allow heavier solid particles to settle out, while additional filtration methods, such as microfiltration or ultrafiltration, eliminate undesirable microorganisms, sediment, and chemical contaminants like chlorine and heavy metals.

- Softener: Hard water can lead to scaling and reduced efficiency in plumbing and appliances. Water softening systems utilize ion exchange processes to replace hard minerals, specifically calcium and magnesium, with sodium or potassium ions, thereby producing soft water that is less likely to cause scaling.

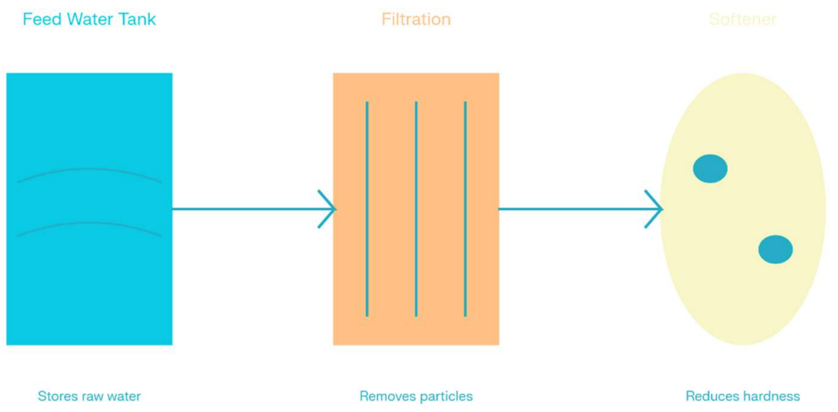

Fig. 1.3: Water Pre-Test Flow

2. Reverse Osmosis

Reverse osmosis (RO) is a sophisticated water purification technology that utilises a semi-permeable membrane. This membrane selectively allows solvent molecules (such as water) to pass through while blocking a wide range of contaminants, including dissolved salts, heavy metals, and other large particles. This process effectively reduces the concentration of unwanted substances, yielding purified water suitable for various applications.

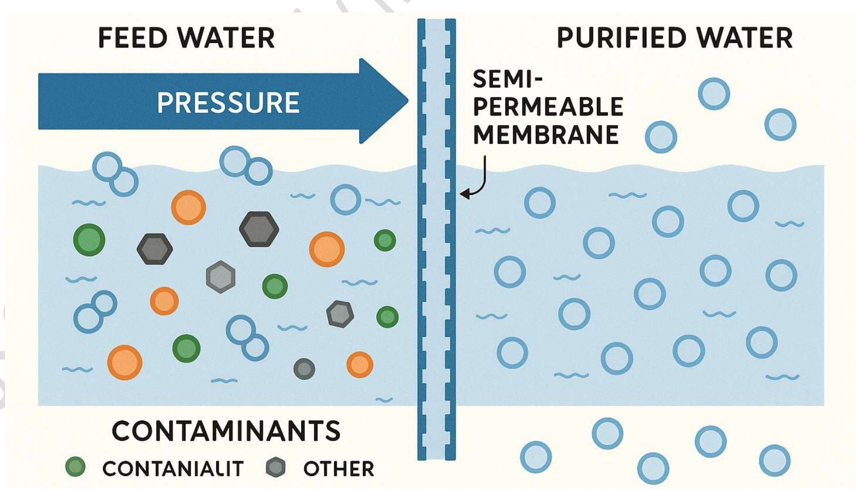

Fig. 1.4: Reverse Osmosis

3. Storage and Distribution

After the reverse osmosis treatment, the purified water undergoes an electro-demineralisation process, which further enhances its quality by removing remaining ionic contaminants. The resulting high-quality water is collected in a storage tank, designed to maintain purity until distribution. Adequate measures are implemented to ensure that the water remains free from contaminants throughout the storage phase.

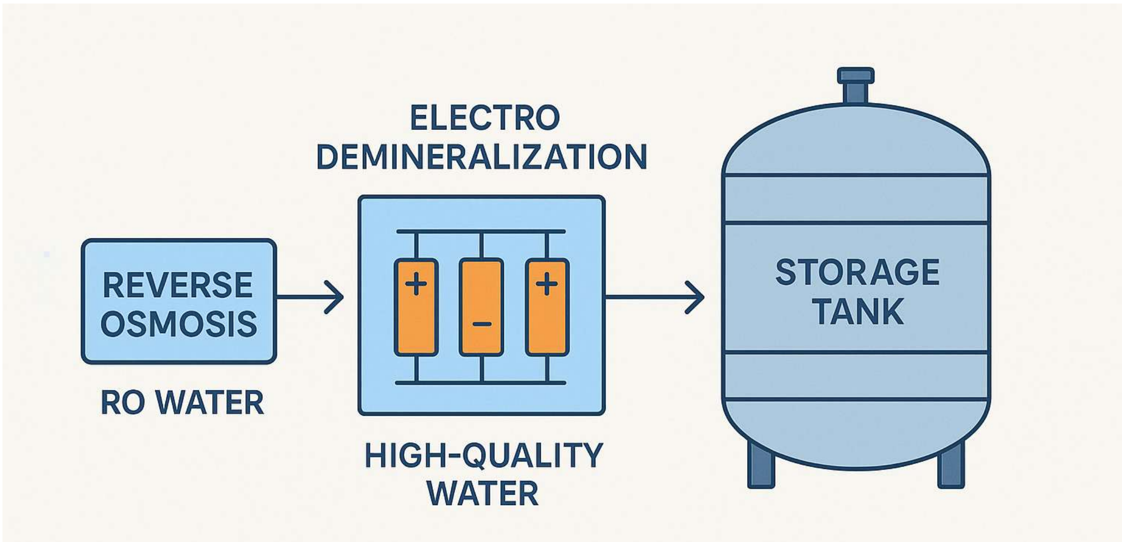

Fig. 1.5: Storage system after Reverse Osmosis

4. Pure Water Treatment

Once stored, the water typically undergoes a double-bed demineralisation process. This advanced treatment phase includes passing water through two layers of ion exchange resins that remove remaining ions and provide high-quality demineralised water. Subsequently, the water is subjected to a UV (ultraviolet) treatment, which delivers a specific dosage (measured in J/m^2) for the reduction of total oxidizable carbon (TOC). The UV treatment is crucial as it effectively destroys and/or removes oxidizable carbons, ensuring the water is not only pure but also safe for consumption.

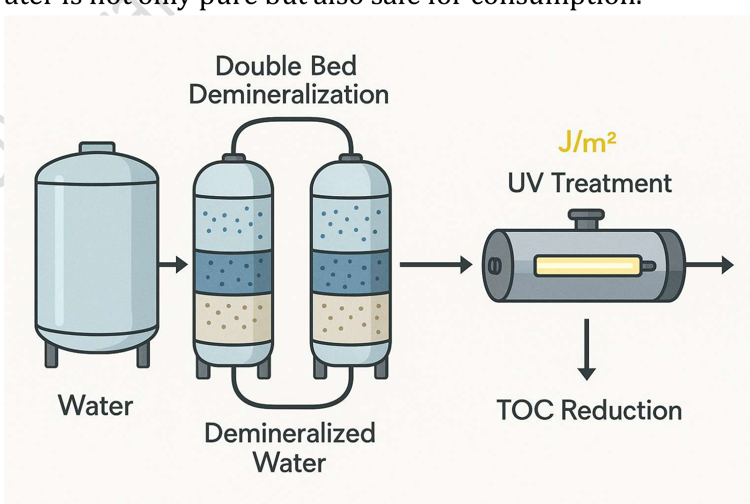

Fig. 1.6: Advance Water Purification

Sampling and Quality Checking

To ensure the ongoing quality and safety of the water, regular testing and monitoring are paramount. It is recommended to collect samples of the demineralised or ultrapure water every hour and test various parameters, particularly the pH value. The pH of pure water should ideally be around 7, which is neutral. Regular checks help in the early detection of any anomalies and maintain the reliability of the water treatment system.

Water Feedstock

Processes for Treating Water Supply for Feedstock Purposes

Natural water usually contains a mix of dissolved mineral salts. To produce green hydrogen, it's important to use water that is free from these minerals. The process of removing these minerals is called demineralisation.

Natural water can have many minerals that may disrupt hydrogen production. Therefore, it's crucial to achieve a high level of purity. Demineralisation ensures that any unwanted minerals are removed, allowing for the use of clean water in hydrogen generation.

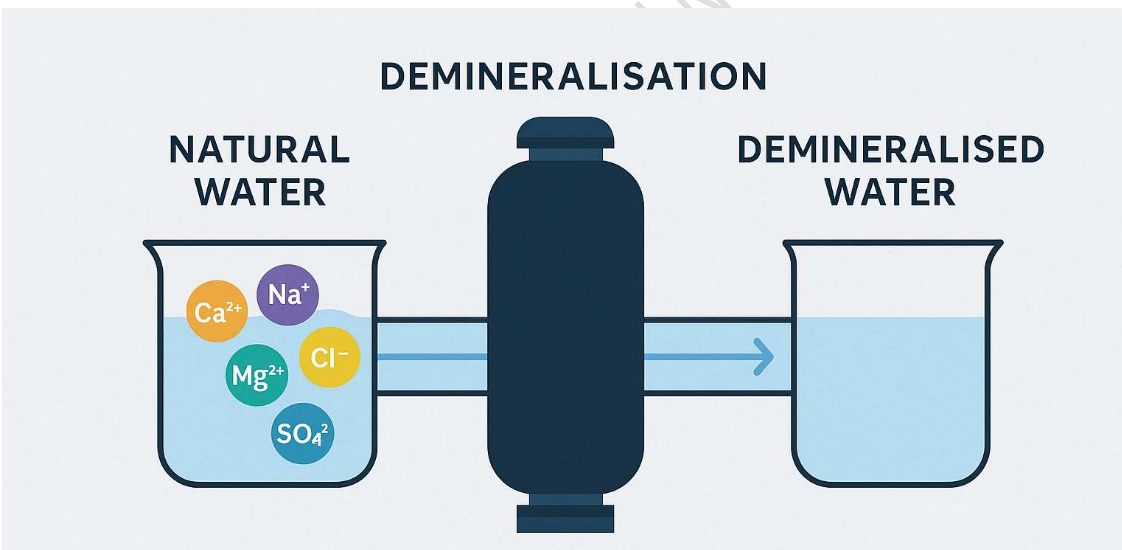

Fig. 1.7: Demineralisation

Distillation

Distillation is a common method for purifying water. This technique heats the water to turn it into steam, separating it from impurities. During distillation, the contaminated water is boiled. As it turns into steam, larger and non-volatile substances stay behind.

The steam is then collected in a separate container and cooled down. As it cools, the steam turns back into liquid water, resulting in purified water that is free of the original contaminants. This process uses heating and cooling to purify water, making distillation a key step in ensuring high-quality water for green hydrogen production. A diagram can show the steps of evaporation and condensation, illustrating how pure water is separated from impurities.

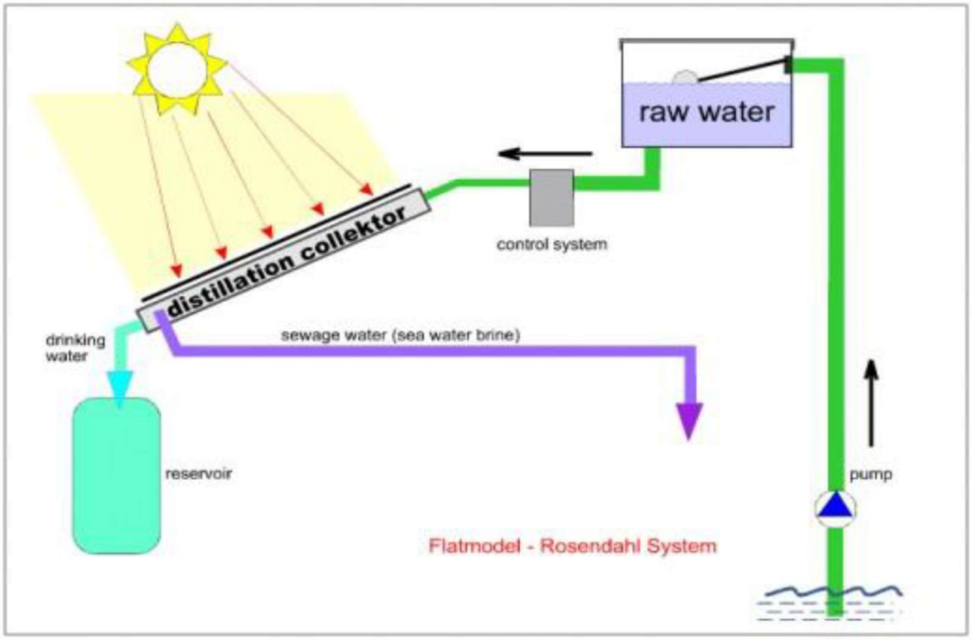

Fig. 1.8: Impurity removal by distillation

Reverse Osmosis

Reverse osmosis is a method used to purify water. It works by using a special membrane that only allows water to pass through. First, water is put under pressure, which is stronger than osmotic pressure. This pressure forces the water through the membrane, separating it from impurities, minerals, and contaminants. As a result, clean water comes out on one side, while the impurities stay behind on the other side. People use reverse osmosis to turn seawater or brackish water into drinking water and also to create high-quality water for industrial processes.

The following figure represents the reverse osmosis process.

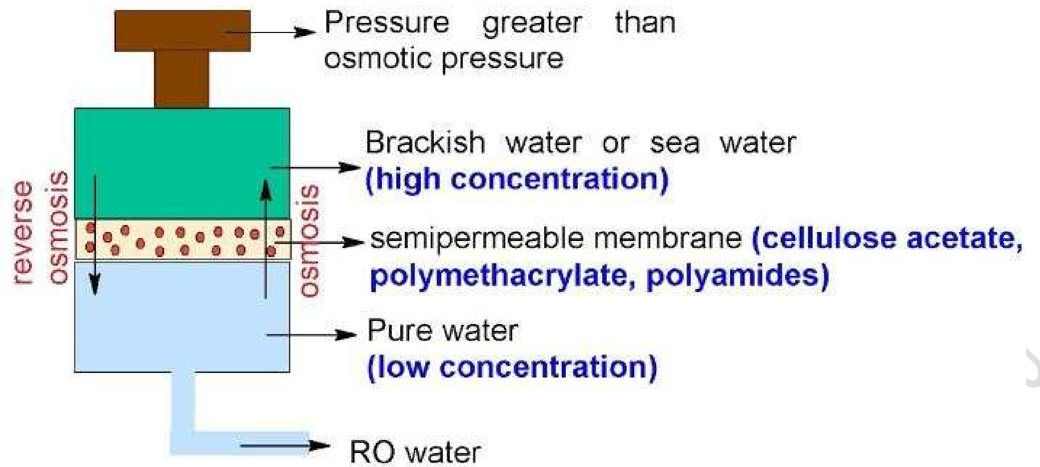

Fig. 1.9: Reverse Osmosis Process

Electrodialysis

Electrodialysis is a water treatment process that removes ions from water. It uses electric current and ion exchange to separate these ions. Unlike reverse osmosis, it does not use pressure. Instead, it relies on electric current to move ions through special membranes. This process effectively separates ionic components from the water.

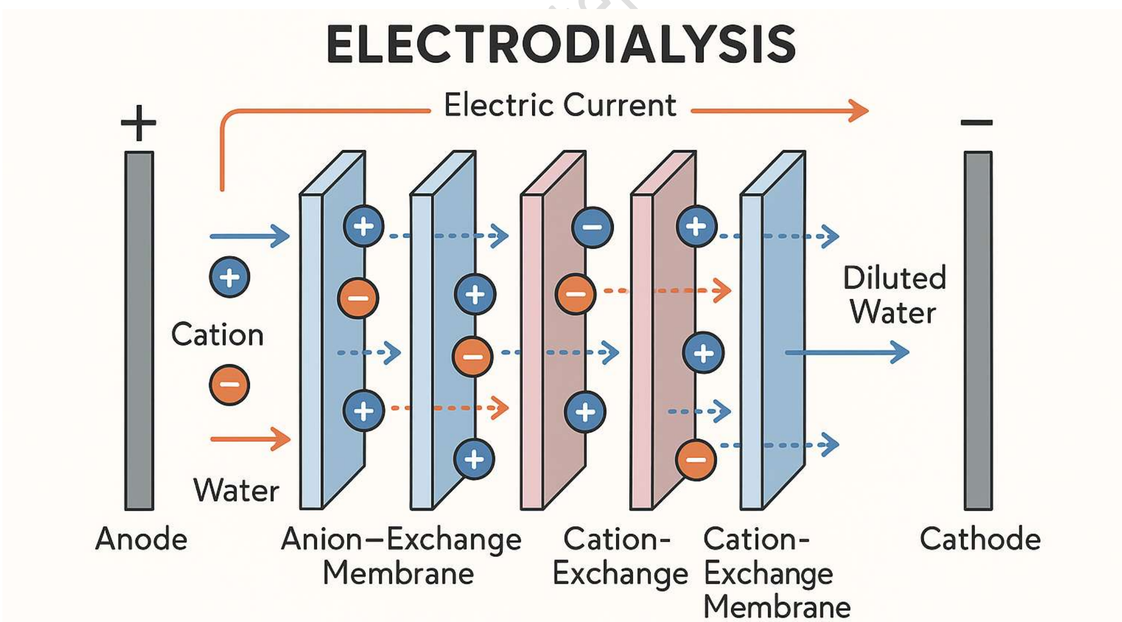

Fig. 1.10: Electrodialysis process for water treatment

Deionisation

Deionisation and demineralisation are often used to mean the same thing. Deionisation is a method that removes almost all ionic mineral pollutants from water. Demineralised water contains no mineral ions, including:

- Cations (positive ions): sodium (Na+), calcium (Ca2+), potassium (K+), magnesium (Mg2+), etc.
- Anions (negative ions): chloride (Cl-), sulphate (SO42-), nitrate (NO3-), carbonate (CO32-), etc.

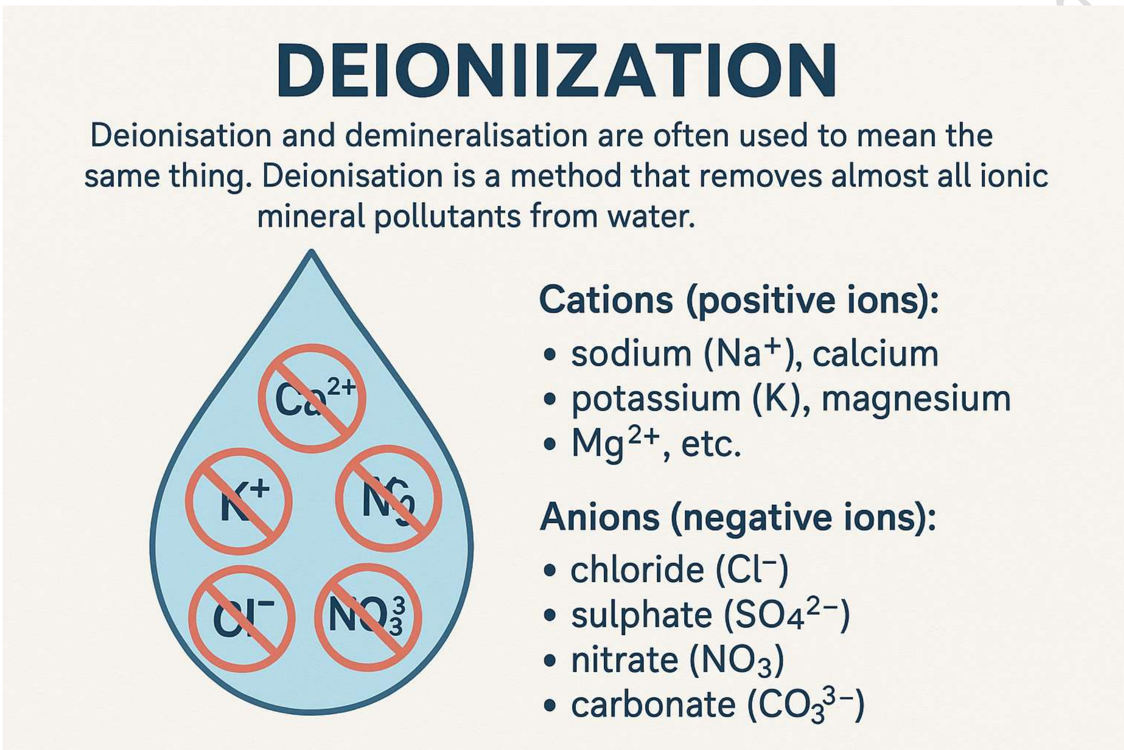

Fig. 1.11: Deionisation process removes all ionic mineral pollutants from water.

Ion-exchange Process

Demineralisation uses special ion exchange resins to treat water. These resins replace mineral salts in water with hydrogen (H+) and hydroxyl (OH-) ions. There are two main types of resins:

- Cation-exchange resins: These release hydrogen ions or other positive ions, replacing impurity cations in the water.
- Anion-exchange resins: These release hydroxyl ions or other negative ions, replacing impurity anions in the water.

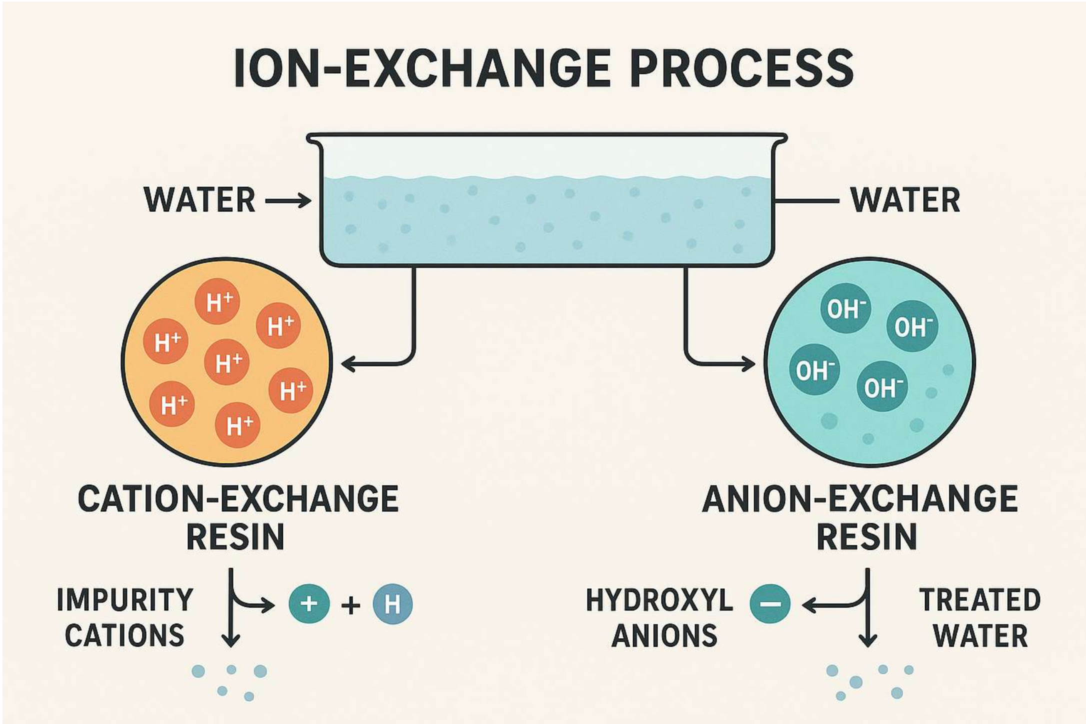

Fig. 1.12: Ion Exchange Process

During demineralisation, pressure is applied to push water through a membrane. After ion exchange, the process includes degasification to remove dissolved gases and polishing to eliminate any remaining suspended solids.

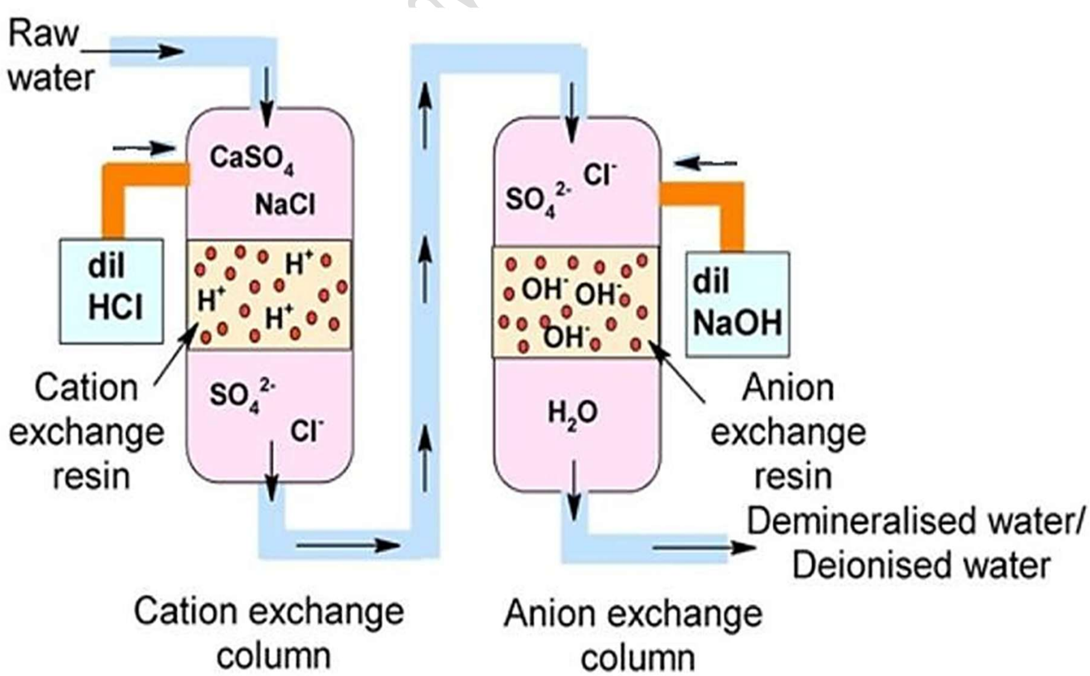

Fig. 1.13: Schematic of Demineralisation Water Plant

DM Plant Specifications

The following table lists the specifications of a small DM water treatment plant:

Components	Specifications
Flow rate	50 to 80 Litre/hr
Space requirement	Compact, 1 m x 1m
Power	Not required (raw water pump provides required pressure) Minimum inlet pressure 0.5 kg/cm2
Output TDS	Less than 10 ppm
Output DM quantity	500 Lit at 100 ppm TDS (Total dissolved solids)

Check Your Progress

A. Multiple Choice Questions (MCQs)

1. What is the minimum purity level required for water used in PEM electrolysers?
A. Tap water
B. Rainwater
C. Ultrapure water
D. Sea water

2. How much water is approximately needed to produce 1 kg of hydrogen through electrolysis?
A. 10 litter
B. 5 liters
C. 1 liters
D. 50 liters

3. Which stage of the water treatment process removes dissolved salts using a membrane?
A. Pre-treatment
B. Reverse osmosis
C. Filtration
D. Distillation

4. Which of the following is a common method used to purify water through phase change?
A. Deionization
B. Reverse osmosis
C. Distillation
D. Electrodialysis

5. In the pre-treatment stage, what is the function of a water softener?
A. Increase temperature
B. Remove heavy metals
C. Add chlorine
D. Replace calcium and magnesium with sodium or potassium

B. Fill in the Blanks

1. Water used in green hydrogen production through electrolysis must be ______ to prevent damage to the electrolyser.
2. In a PEM electrolyser, the water should be treated to achieve ______ water quality.
3. The process of removing mineral salts from water is known as ______.
4. Reverse osmosis uses a ______ membrane to remove impurities from water.
5. The ideal pH value for ultrapure water used in electrolysers is around ______.

C. Short Answer Questions

1. Why is ultrapure water required for PEM electrolysers?
2. What is the role of the feed water tank in the pre-treatment phase?
3. How does distillation purify water?
4. What is the significance of the softener in water pre-treatment?

D. Long Answer Questions

1. Explain the different categories of water used in a green hydrogen production facility.
2. Describe the four major stages in the water treatment process for PEM electrolysers.
3. Why is it necessary to locate large hydrogen plants near water bodies, and how much water is typically needed?
4. Discuss the differences between demineralisation, deionisation, and reverse osmosis in water purification.

Session 2: Various Parameters Essential for Water as Feedstock

During the production of green hydrogen through electrolysis, it is crucial to monitor the conductivity of purified water. Conductivity is the opposite of resistivity. Typically, demineralised water is used in this process. However, this water has a pH level of around 7, which means it is not very conductive. For example, distilled water is a poor conductor of electricity, while tap water, which contains minerals and impurities, can conduct a small amount of electricity. To improve the conductivity of water during electrolysis, it is essential to add specific substances. Adding baking soda (sodium bicarbonate) can significantly increase the rate of electrolysis by enhancing conductivity. However, using table salt (sodium chloride) in the water solution is more effective for conducting electrolysis.

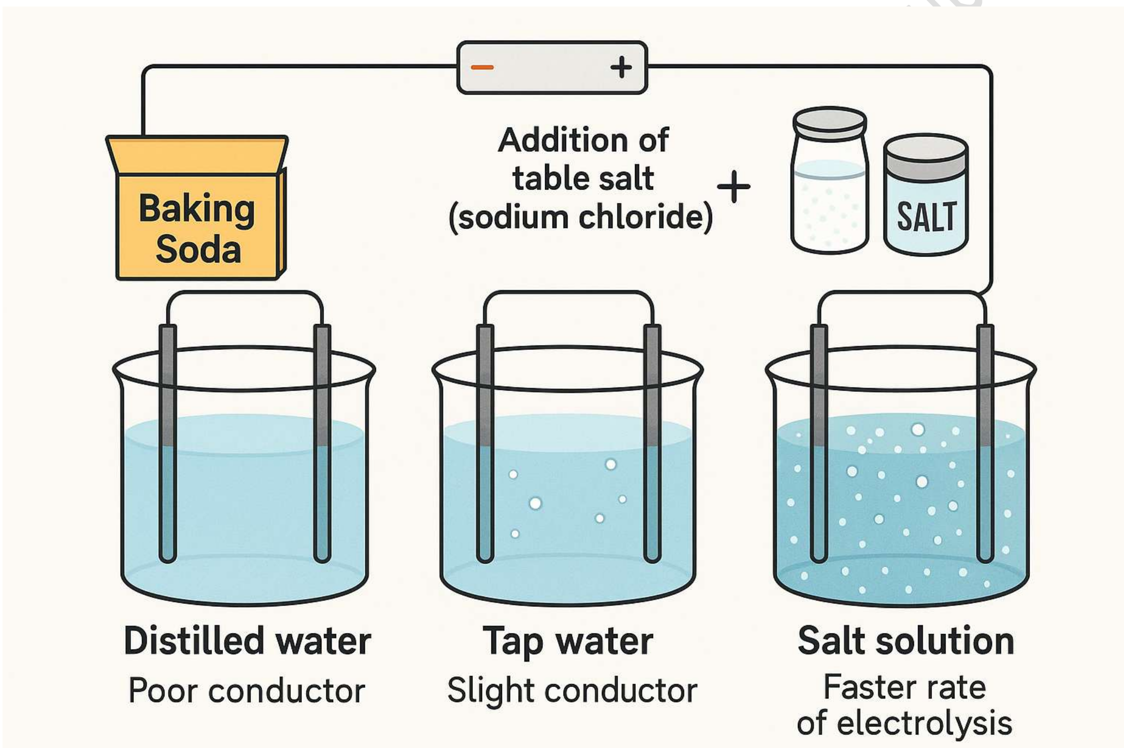

Fig. 1.14: Adding impurity in Distilled Water results a change in the conductivity of electrolysis

Electrolyser suppliers often recommend adding substances like potassium hydroxide (KOH) or sodium hydroxide (NaOH) to the water. When dissolved, these substances break down into charged particles called ions, which are crucial for conducting electric current through the electrolyte solution. You can measure the conductivity of the solution with an electrical conductivity meter (EC meter) and determine the pH level using a pH meter.

Preparation of Electrolyte

Preparing the electrolyte is a critical step in electrolysis. An electrolyte is a substance that dissociates in water to create charged particles, known as cations (positively charged ions) and anions (negatively charged ions). For effective electrolysis, it is essential to use high-quality deionised water that is free from minerals and contaminants. This typically requires potable-grade water, along with additional purification systems.

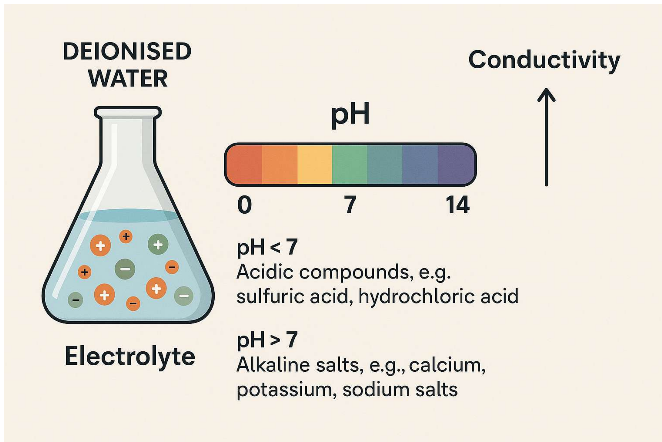

Fig. 1.15: pH Value of Water

Different salts or acids can greatly affect the pH levels and conductivity of the solution. A pH above 7 means the solution contains alkaline salts, like calcium, potassium, or sodium salts, which improve conductivity. A pH below 7 indicates acidic compounds, such as sulfuric acid or hydrochloric acid, which result from reactions between solubilised compounds and hydrogen ions (for example, H_2SO_4 and HCl).

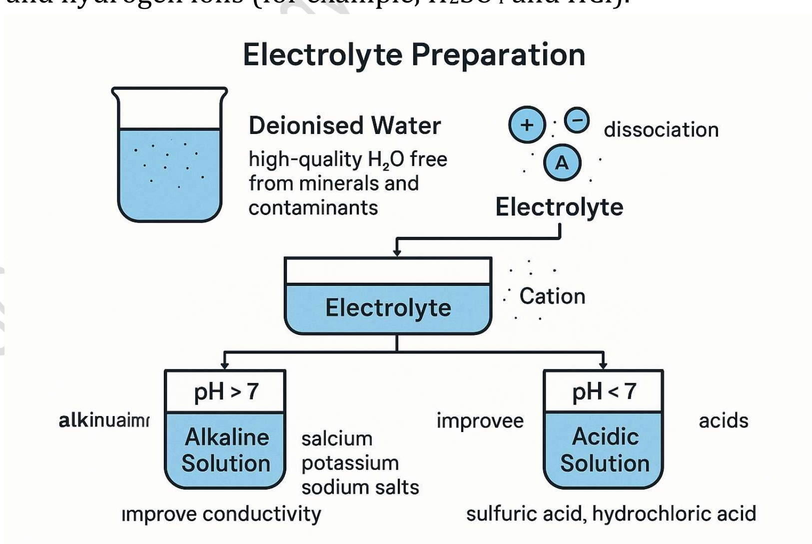

Fig. 1.16: Preparation of Electrolyte

The table given below lists the values of resistivity and conductivity of electrolytes prepared by using DM water. The processes followed in the production of electrolyte are also mentioned. The Table gives the acceptable values for the electrolysers of different makes.

Table: Quality of treated water

Quality	Ultra-Pure Water	Pure Water	Purified Water
Typical Resistivity	10-18 MΩcm	1-10 MΩcm	1-0.02 MΩcm
Conductivity:	0.1-0.0555 µS/cm	1.0-0.1 µS/cm	1-50 µS/cm
Produced By:	Polishing the mixed-bed stem e.g. nuclear grade resins.	Strongly basic mixed-bed system	Weakly basic mixed - bed system.

Selection Parameters for Selection of Water Quality for Hydrogen Production

Selection of Water

In the process of hydrogen production through electrolysis, water plays a very important role. To produce just 1 kilogram of hydrogen, about 9 litres of high-quality DM (De-mineralised) water is required. However, to get this amount of DM water, approximately 60 litres of regular or raw water is needed. The total amount of raw water required depends on the capacity of the hydrogen production plant. For small-scale hydrogen plants, water from the city supply is usually suitable. In general, water for hydrogen production can be taken from many sources such as city pipelines, rivers, reservoirs, tube wells, and even seawater. But if the water contains many impurities, it needs to be purified using special processes, which increases the cost of production.

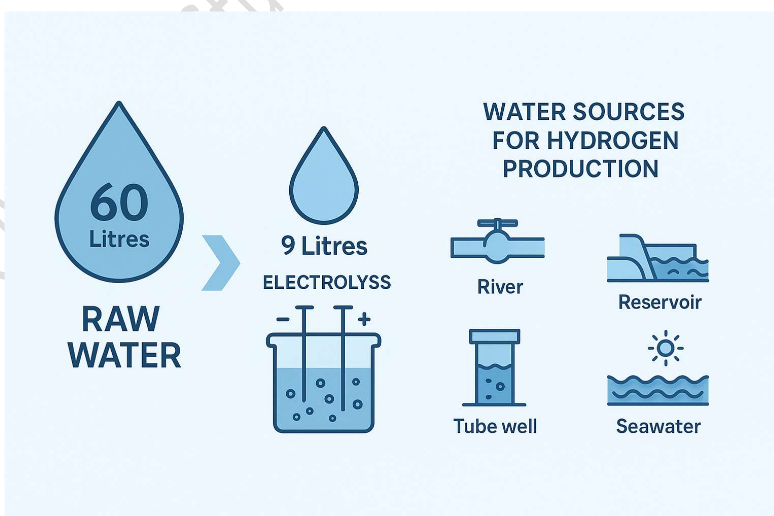

Fig. 1.17: Need of Water for Hydrogen Production

The type of water required also depends on the kind of electrolyser being used in the plant. In the case of an alkaline electrolyser, DM water is sufficient for smooth functioning. However, if a PEM (Proton Exchange Membrane) electrolyser is used, ultrapure water is needed. Ultrapure water means water that is free from all types of salts, minerals, and impurities. It is more refined than DM water and is necessary to protect the sensitive components of the PEM electrolyser.

Importance of Water Selection

Using the right quality of water is very important because it directly affects the life and performance of the electrolyser. Good quality water helps protect key components such as the electrode mesh, catalyst, and filter mesh. It also helps maintain a good hydrogen production rate, reduces the frequency of maintenance, and lowers the amount of wastewater generated. If poor-quality water is used, sediments can form, filters may get blocked, and the electrolyser may get damaged. This leads to higher operating costs and more downtime for repairs.

Ultrapure water is especially important for producing high-quality hydrogen and keeping the electrolyser running efficiently. If water is not treated properly, it can reduce the overall performance of the plant and may even harm the electrolyser. Therefore, proper water treatment is essential. The selection of electrolyser technology and the source of water determine how much purification is required.

Effect of pH Value

Another important factor to consider is the pH value of the water, which shows how acidic or basic the water is. If the pH is too low (acidic), it can damage the electrodes, increase the corrosion of containers, and lead to higher consumption of chemicals like KOH (potassium hydroxide) or NaOH (sodium hydroxide) used in the process. On the other hand, if the pH is too high (basic), it may cause the formation of unwanted chemical deposits, reduce the efficiency of the system and require more cleaning. Therefore, it is important to regularly check and control both the pH level and the conductivity (ability of water to carry electricity) to ensure the proper functioning of the electrolyser.

Monitor the Quality of Water Feedstock for Input to the Electrolyser

In hydrogen production, it is very important to check and monitor the quality of the water used in electrolysers. This water, known as feedwater, must meet specific standards to avoid damaging the system and to ensure smooth operation. The two main indicators of water quality are pH value and resistivity. Ideally, the pH value of the water should be 7, which means the water is neutral, not too acidic or too basic. The resistivity should be between 10 to 18 mega-ohm centimeter (MΩ· cm) for ultrapure water and 1 to 10 MΩ· cm for DM (de-mineralised) water. Another way to check water quality is by measuring its conductivity, which is the opposite of resistivity. Good quality water should have low conductivity, meaning it doesn't allow electricity to pass through easily, which is a sign of fewer impurities.

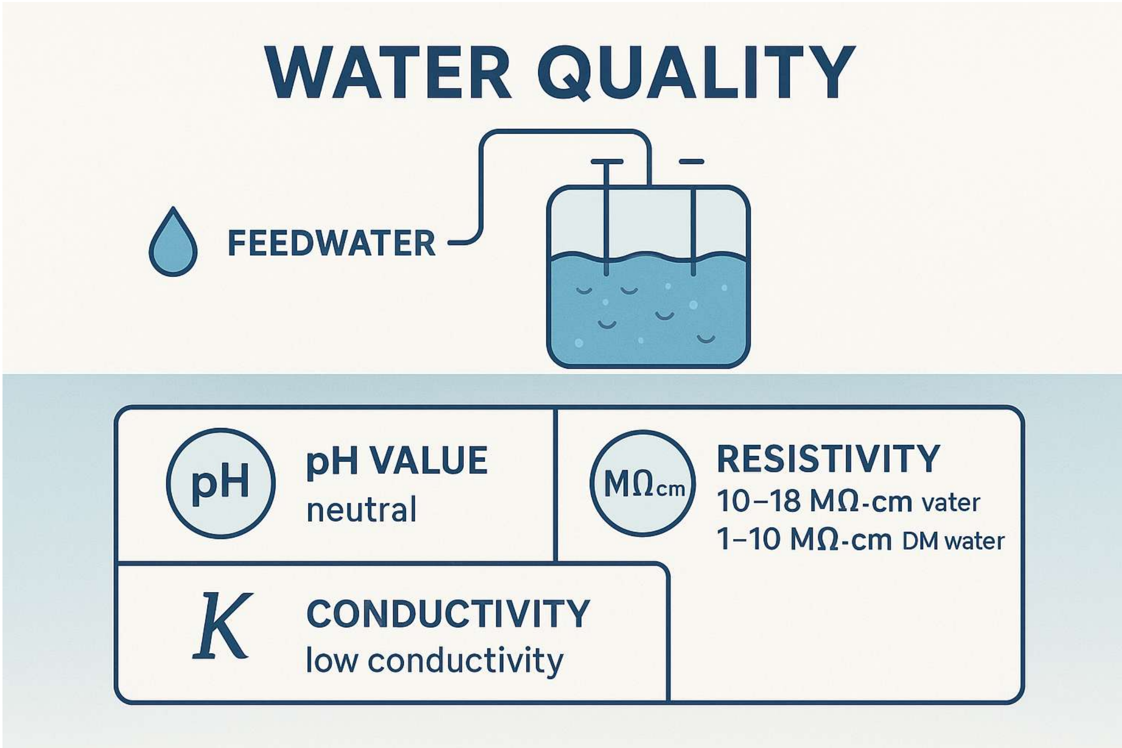

Fig. 1.18: Feed-Water Quality Standards

To monitor water quality, regular samples should be taken from different points in the system. These include water stored in the DM water tank and water coming out of the electrolyser outlet. If the water from the DM storage tank does not have the correct pH or resistivity, it means the chemical treatment of raw water needs to be adjusted. This might involve changing the amount of chemicals added during purification until the correct pH (around 7) and conductivity levels are reached, as specified by the electrolyser manufacturer.

If water samples taken from the electrolyser outlet show sudden changes in quality, such as increased impurities or unusual conductivity, this could be a sign of a problem in the piping system. For example, raw water might be mixed with clean water due to leaks or faults in the pipes. In such cases, the pipelines should be thoroughly checked and repaired.

It is also necessary to test the electrolyte solution, which is a mixture of DM water and a chemical like potassium hydroxide (KOH). This mixture should usually contain about 30% KOH. If tests show that the concentration is too low or too high, the amount of KOH or DM water being mixed must be adjusted. Maintaining the correct electrolyte quality is important because poor-quality electrolyte can damage the electrodes, remove precious metal coatings, or reduce the efficiency of the catalyst. Additionally, if unwanted chemical salts enter the system, they can react with the electrolyte and form solid particles. These particles may clog filter meshes and reduce the flow of electrolyte, affecting the overall performance of the system.

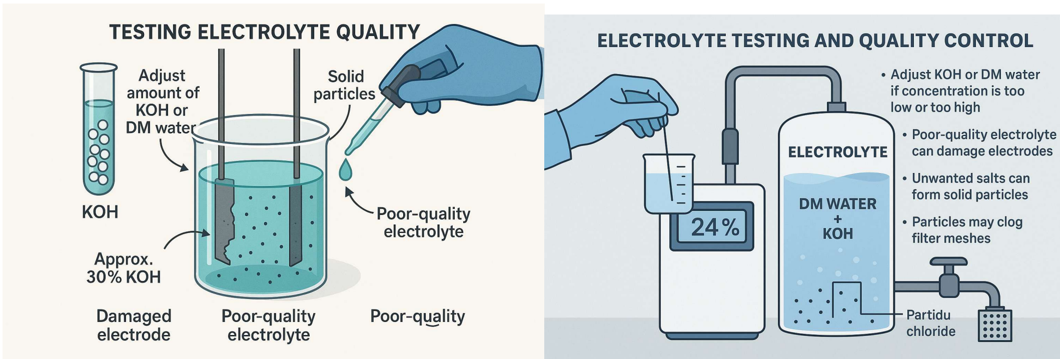

Fig. 1.19: Electrolyte testing and Quality Control

Even though it's not possible to completely prevent deposits from forming on the electrodes and other components, regular monitoring of pH and conductivity can help manage the situation. It also helps determine how much chemical dosing is needed to keep the electrolyte within the safe and recommended limits.

Check Your Progress

A. Multiple Choice Questions (MCQs)

1. What is the typical pH value of demineralised (DM) water used in electrolysis?
A. 5
B. 9
C. 7
D. 3

2. Which chemical is commonly added to improve water conductivity for electrolysis?
A. Table sugar
B. Sodium chloride (NaCl)
C. Vinegar
D. Calcium carbonate

3. What is the ideal resistivity range for ultrapure water used in PEM electrolysers?
A. 1–10 MΩ·cm
B. 0.02-1MΩ·cm
C. 0.1–1 MΩ·cm
D. 10-18 MΩ·cm

4. What is the effect of low pH (acidic) water on the electrolyser?
A. Improves electrode performance
B. Increases corrosion of components
C. Prevents scaling
D. Reduces electrolyte conductivity

5. What does a sudden change in water conductivity at the electrolyser outlet indicate?
A. Leak or contamination in the pipeline
B. Good performance of the filter
C. Water is of high quality
D. Increase in hydrogen production

B. Fill in the Blanks

1. Conductivity is the opposite of ______ in water.
2. ______ is commonly added to water to improve conductivity during electrolysis.
3. High pH (basic) in the water can lead to unwanted chemical ______.
4. To monitor water quality, measurements of both ______ and ______ are essential.

C. Short Answer Questions

1. Why is pH monitoring important in the electrolysis process?
2. How does adding KOH or NaOH affect water conductivity?
3. What can sudden increases in conductivity at the electrolyser outlet indicate?
4. What role does deionised or ultrapure water play in hydrogen production?

D. Long Answer Questions

1. Explain the relationship between conductivity, resistivity, and water quality in electrolysis.
2. Why is it necessary to monitor the electrolyte concentration in the electrolysis

process?

3. Describe the quality standards and classification of treated water used in electrolysis.

4. Discuss the significance of water source selection and treatment for green hydrogen production.

Session 3: Understanding the Piping System

The source of raw water for a green hydrogen plant can vary depending on the location. It may come from natural sources, irrigation canals, municipal water supply, or bore wells. Because of this, the design of the raw water supply and treatment system may be different at each site. However, once the water is treated and converted into DM or ultrapure water, the layout of the piping system from the treatment plant to the electrolyte tank is usually similar in most hydrogen plants.

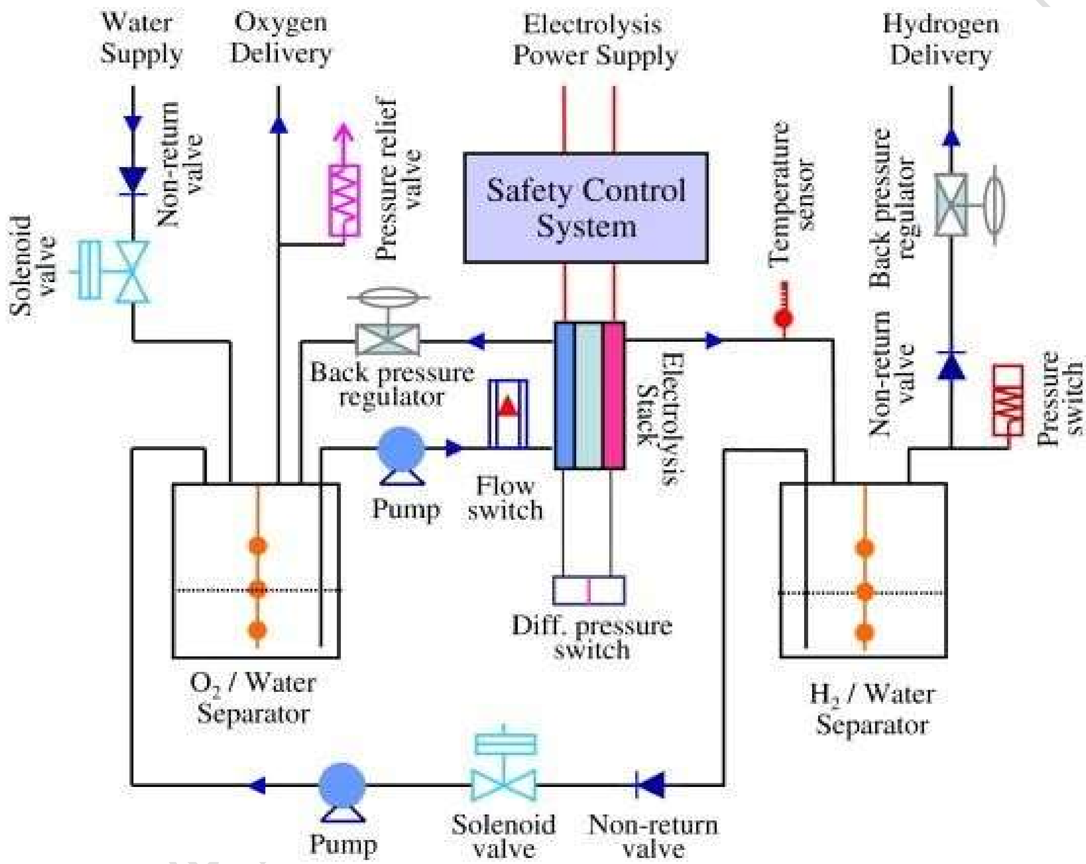

Fig. 1.20: Water piping in a PEM electrolyser

In a typical layout, as shown in the diagram of a PEM electrolyser, the input water first enters a separator tank, which helps separate hydrogen gas from the water. There is also a dedicated hydrogen-water separator tank for safety and efficiency. The system includes water circulation pumps to move the water through the electrolyser, and non-return valves and solenoid valves are installed to control the flow and prevent backflow.

An important safety feature of the piping system is the ability to quickly drain water in case of flooding due to pipe leakage or equipment failure. The system should also be designed so that sections of the water supply can be maintained or repaired without shutting down the entire plant. This helps in better operation and easier maintenance, ensuring the plant runs smoothly and safely at all times.

Install the Piping and Piping Accessories for Supplying a Controlled Quantity of Water to the Electrolyser

To supply the right amount of water to an electrolyser for hydrogen production, a well-designed piping system is very important. The water piping system includes many components such as valves, reducers, and pipe fittings. These parts must be installed properly so that if any part gets damaged or needs replacement, it can be removed easily without disturbing the rest of the system. Enough space should be left around each component to carry out maintenance safely. Also, high-quality O-rings, gaskets, sealing tapes, and proper tightening of pipe joints must be ensured to avoid water leaks, which could cause frequent shutdowns of the plant.

Laying the Pipelines

Constructing pipelines requires careful planning and preparation. First, engineers should evaluate different possible paths for the pipeline and select the most suitable one. The pipeline layout usually starts from the raw water source, such as an underground borewell, irrigation canal, or municipal water supply. If raw water comes from a reliable supplier, storage may not be required. But it is still recommended to have a raw water storage tank, especially when using groundwater. In the storage tank, alum (a chemical) is added to help settle down dirt and impurities at the bottom. Proper arrangements must be made to remove this sediment regularly.

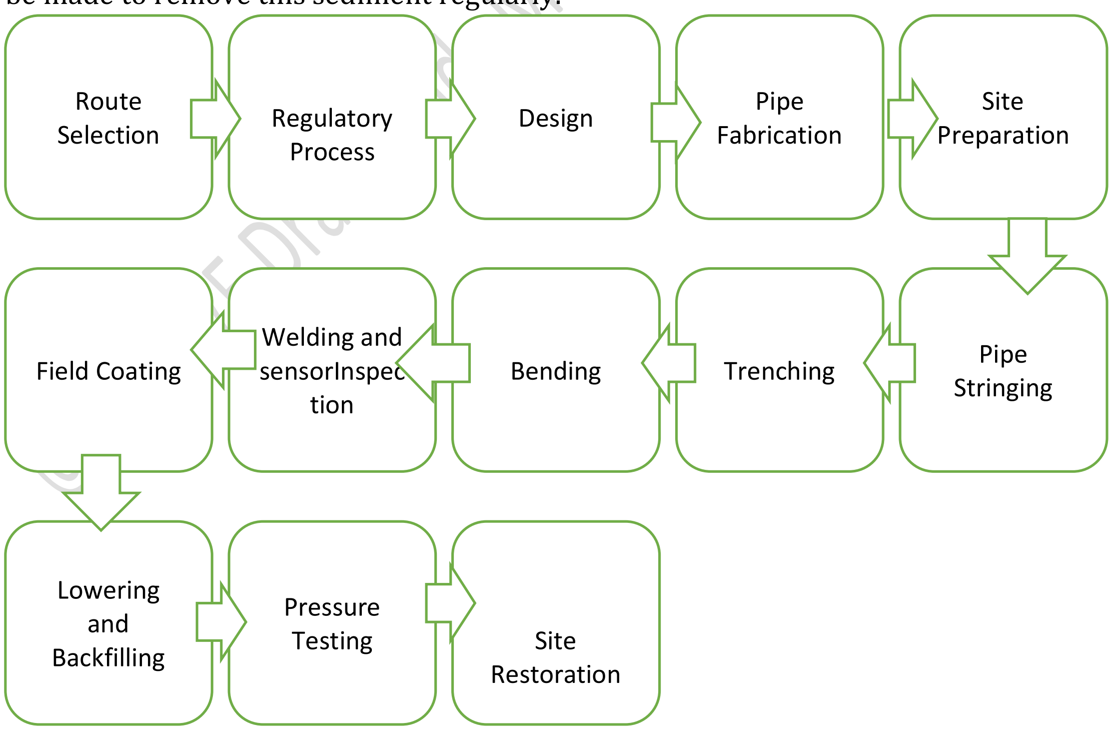

Fig. 1.21: Sequence of Laying of Pipelines

The clean water, after sediment removal, is pumped to the DM (demineralisation) treatment unit, where it is purified. Then, the DM water is mixed with 30% potassium hydroxide (KOH) to create the electrolyte, which is finally supplied to the electrolyser as needed. A typical layout of a DM water treatment plant and its piping system is used to guide installations.

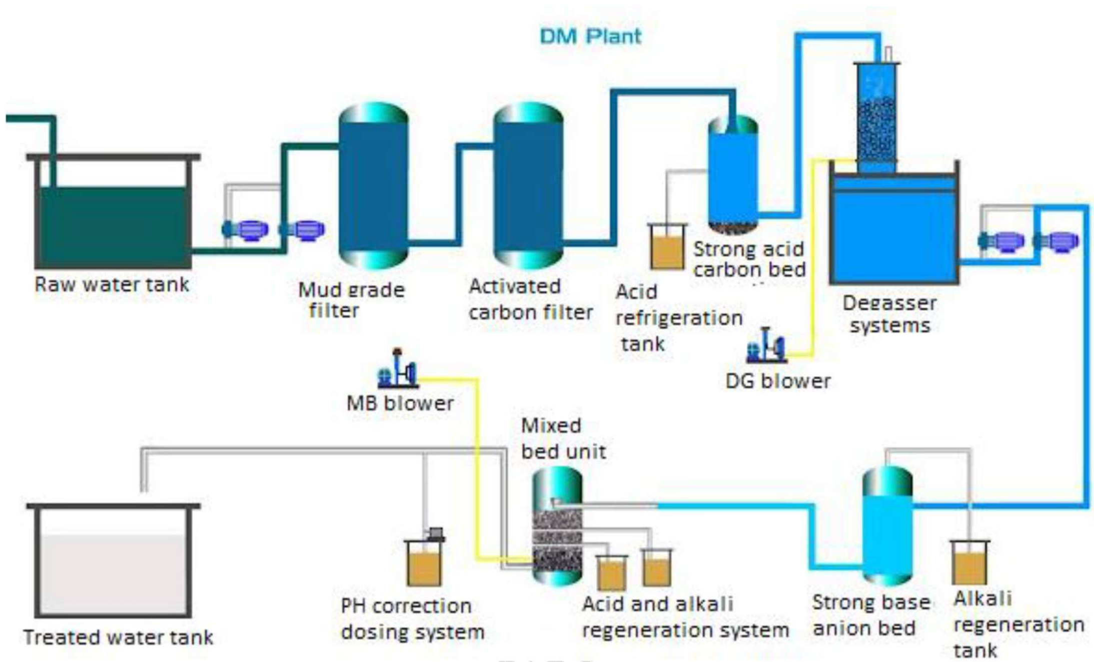

Fig. 1.22: An indicative DM water treatment plant

Important Points to Consider When Laying Pipelines

- All water pipes should be placed underground in trenches.
- The trench should have a slight slope so that any leaking water flows away from the plant towards a drainage pit.
- In small plants, a single pipeline is enough. But in large plants with many electrolysers, dual pipelines may be required.
- Valves should be installed in the system so that certain parts of the plant can be shut down for repair or maintenance without stopping the whole system.
- Electrolyte tanks should have two sections so that one section can be repaired while the other keeps working.
- Every tank must have a proper drainage system for safely disposing of used water or electrolyte.

- If any leak occurs, the sloped floor or trench should guide the water to a pit, from where it can be pumped out safely.

Measuring Instruments for Controlled Water Supply

To control and monitor the water supply properly, different instruments are used to measure flow, level, temperature, and water quality. Some common instruments include:

- Flow Measurement: Turbine meters, ultrasonic flow meters, magnetic flow meters, and Coriolis mass flow meters.
- Level Measurement: Radar gauges, tank gauges, and capacitance level instruments.
- Temperature Measurement: Thermowells.
- Quality Measurement: Water analysers, water-cut meters, and sampling probes.
- Control Components: Control valves, pressure relief valves, and emergency shutoff valves.

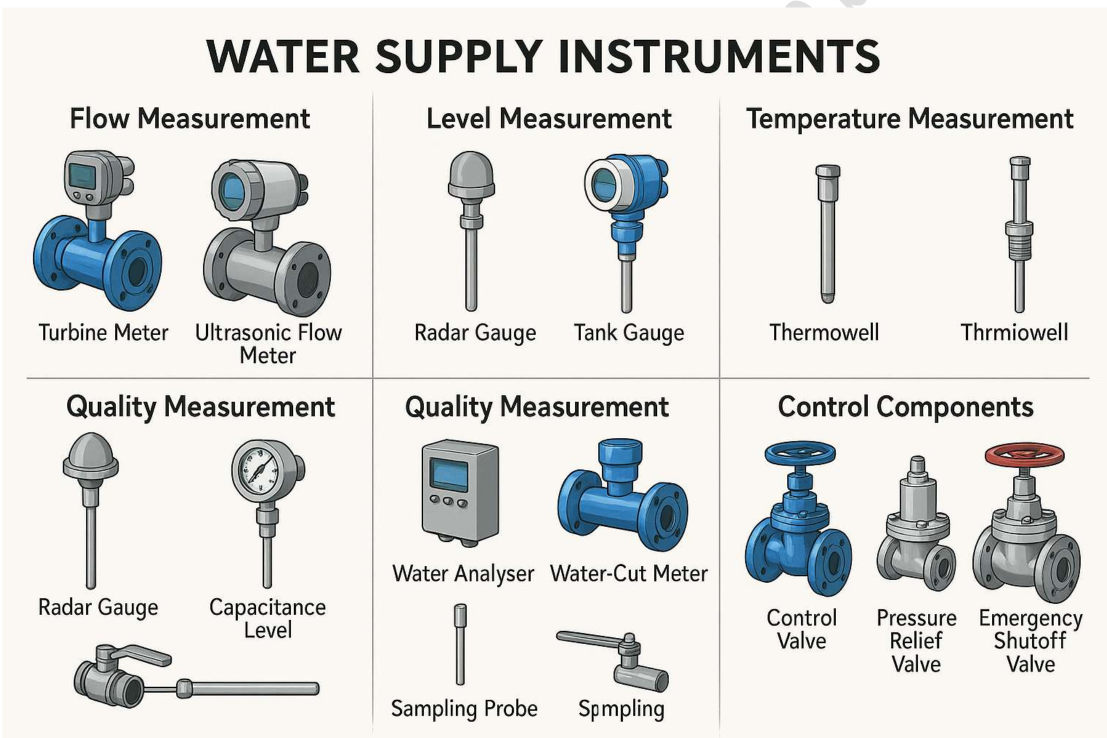

Fig. 1.23: Control and Monitoring Instruments of the Water Supply

These instruments ensure that the correct quantity and quality of water is supplied to the electrolyser and that the system works efficiently.

Water Supply Adjustments During Operation

During daily operations, the amount of hydrogen produced might change due to problems such as electricity supply issues, compressor faults, or maintenance activities. In such situations, the water supply to the electrolyser must be adjusted. To do this, valves need to be throttled (partially opened or closed). For automatic adjustment, motorised valves are used, which can be controlled from a remote-control panel.

ACTIVITY
Tools and Tackles Required To set up and operate the feed water system, technicians use various plumbing tools such as: • Pipe wrenches • Spanners • Pipe cutters • Teflon tape • Sealant • Measuring tape • Pipe bending tools Students should be able to identify these tools by name and use. A hands-on activity or video can help students learn this better.

Dos and Don'ts in Water Supply System Installation

Proper installation and handling of the water supply system ensures safe and trouble-free operation. Here are a few important Do's and Don'ts:

Do's	Don'ts
✅ Regularly check all pipelines, joints, valves, and connections.	❌ Do not operate the water system without the supervisor's permission.
✅ Clean the drainage paths and remove sediments to prevent blockages.	❌ Do not begin maintenance without ensuring enough raw and DM water is stored.
✅ Clean coarse and fine raw water filter stacks regularly.	❌ Do not open any pipelines near electrical cables without proper drainage arrangements.
✅ Perform water supply maintenance only when the plant is shut down.	❌ Do not mix electrolyte and DM water without proper measuring equipment.
✅ Maintain a reserve stock of essential chemicals and plan.	❌ Do not allow raw water to mix with DM water avoid any wastage.
✅ Keep extra stock of gaskets, sealing tapes, pipe joints, valves, etc.	❌ Do not waste water. Reuse or return excess water to the raw water storage if

	possible.
✅ Check the direction of flow before opening any valves.	

Record Results, Organise Data, and Perform Basic Computations to Set Up and Operate an Input Water System

Setting Up and Operating the Input Water System

Setting up the input water system involves several steps. Firstly, the raw water needs to be tested once every day to monitor any changes in quality, such as pH value or dissolved salts. Based on this, the water treatment process (like chemical dosing) can be adjusted to maintain the correct quality of demineralised (DM) water, which should have a pH of 7. This treated water should be checked every 3 to 6 hours.

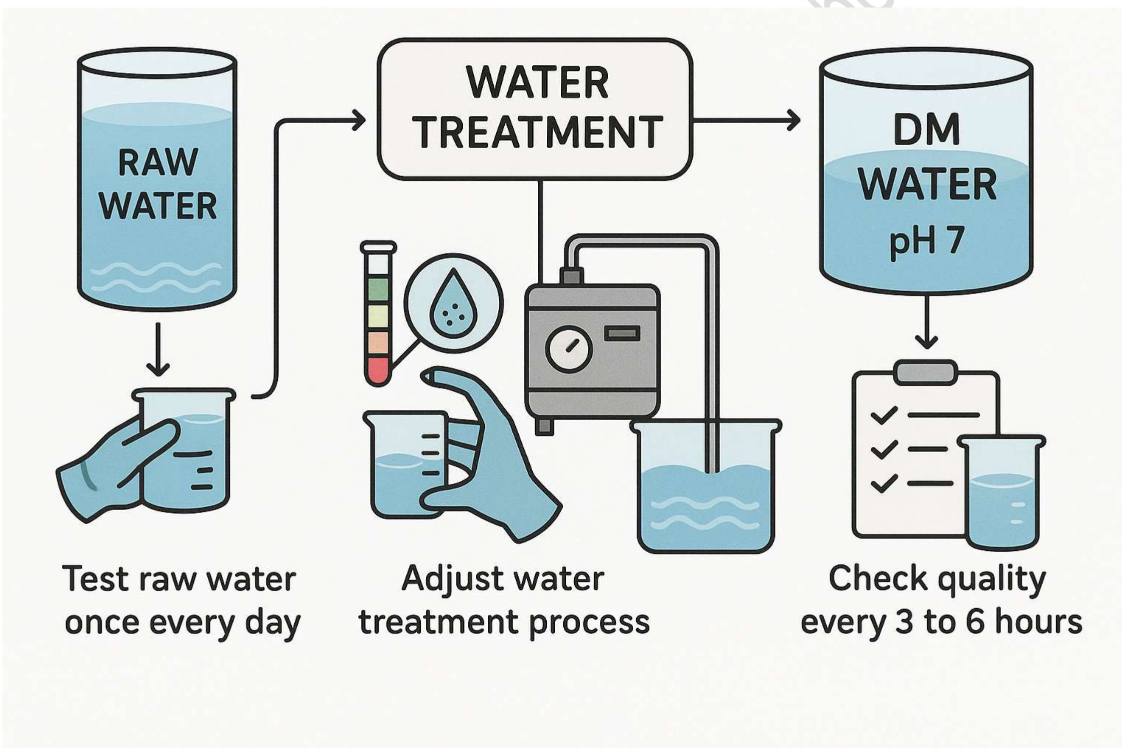

Fig. 1.24: Setting up the input water system

The feed water going into the electrolyser also needs regular testing, at least once every 6 hours, especially if the DM water quality is fluctuating. The purity of the hydrogen produced must be monitored daily to check if the water quality is affecting the final product. If any unusual changes are observed, corrective action must be taken. Major components like electrodes and catalysts should only be checked during plant shutdowns, as these checks also help detect any problems, such as leakage of raw water into the feed line.

All daily data regarding the quality of DM water, electrolyte mixture, hydrogen output, and energy used should be recorded. This helps in evaluating how the quality of water and electrolytes affects hydrogen production.

Total Water Quantity

To produce 1 kilogram of green hydrogen, a minimum of 9 litres of pure water is required chemically. However, in practice, the total water needed is much higher due to additional factors. For example, the cooling systems used in electrolysers can require 30 to 40 kg of water per kg of hydrogen, especially in evaporative cooling systems. Also, multi-stage compressors used for compressing hydrogen for storage consume water for cooling through intercoolers.

During raw water treatment, around 20 to 40% of water is wasted, depending on the quality of the incoming raw water. When we consider all these uses, including process losses and cooling demands, the total water requirement goes up to around 60 to 95 kg per kg of hydrogen produced. A large portion of this, about 60 to 70%, is due to cooling water needs.

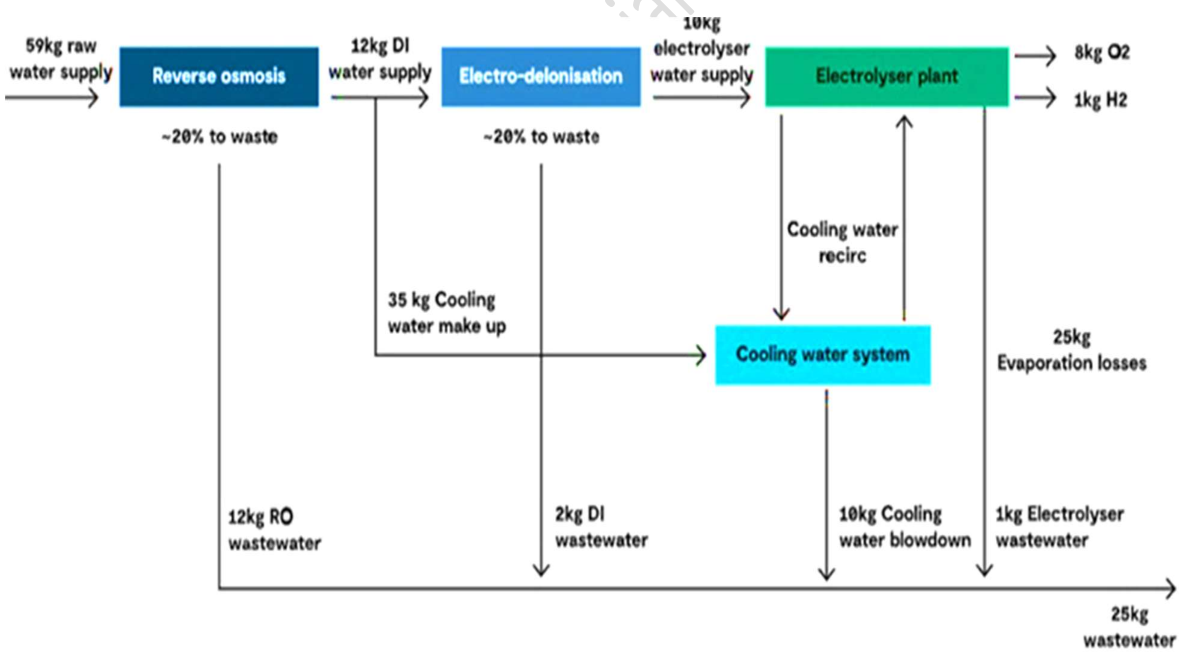

Fig. 1.25: Break-up of water demand for green hydrogen production

Note: Since water is a precious resource, efforts should be made to reuse and recycle as much water as possible. Water lost through evaporation can be recovered using condensation methods like distillation. Similarly, wastewater from the plant can be treated and reused in non-critical areas.

Recording Water System Readings

Accurate recording of readings is essential for the smooth operation of the water system. These readings include pH value, resistivity or conductivity, flow rate, and temperature at different points in the system. These should be recorded at regular intervals as recommended and compared with standard values to make any necessary adjustments. Daily comparison of water parameters with hydrogen purity levels helps in maintaining system efficiency. A sample format or log sheet is usually used for keeping these records.

Parameter	Raw water	Decarbonized water	DEMI water	Required values
Total hardness (°N)	13.34	4.37	0.00	0.00
Carbonate hardness (°N)	12.44	2.8	0.00	0.00
Noncarbonate hardness (°N)	0.90	1.57	0.00	0.00
Ca^{2+} (mg/L)	64.9	14.2		
Mg^{2+} (mg/L)	17.5	10.3		
Na^{+} (mg/L)		6.9		
K^{+} (mg/L)		1.9		
Fe total (mg/L)	0.056	0.2	<0.01	≤0.01
SiO_2 (mg/L)	4.54	1.7	<0.01	≤1
Cl^{-}, (mg/L)	7.86	3.5		
SO_4^{2-} (mg/L)	50.3	52.0		
HCO_3^{-} (mg/L)		31.0		
pH	7.79	10.4	6.5–7.3	9.1 ± 0.1
Conductivity (μS/cm)	448	237	0.05	≤0.1
Suspended solids (mg/L)	25.6	14.0		
$KMnO_4$ demand (mg/L)	11.28	5.53		

Fig. 1.26: Indicative recording of water parameters and required values

Check Your Progress

A. **Multiple Choice Questions (MCQs)**

1. What is the purpose of the hydrogen-water separator tank in the piping system of a PEM electrolyser?
   A. To store excess hydrogen
   B. To mix water and hydrogen
   C. To cool down the system
   D. To separate hydrogen gas from water

2. What component is used to prevent backflow in the water piping system?
   A. Pressure relief valve

B. Non-return valve
C. Flow meter
D. Level gauge

3. Why is it recommended to install the water pipes in underground trenches with a slope?
A. To prevent freezing
B. For easy access
C. To guide leaking water to a drainage pit
D. To reduce pressure

4. Which of the following tools is used to seal joints in a water supply system?
A. Spanner
B. Pipe cutter
C. Teflon tape
D. Thermowell

5. Which instrument is used to measure water flow in the piping system?
A. Turbine flow meter
B. Thermowell
C. Radar gauge
D. Sampling probe

B. Fill in the Blanks

1. In the piping system, ______ valves are used to control water flow and prevent backflow.
2. All water pipelines in a hydrogen plant should be laid in ______ trenches.
3. During operation, ______ valves allow for remote control of water flow.
4. Regular monitoring of water includes parameters like flow rate, temperature, pH, and ______.

C. Short Answer Questions

1. Why is a sloped trench necessary for pipeline installation in a hydrogen plant?

2. What are the key components in a water piping system used for hydrogen production?
3. How is DM water quality monitored during operation?
4. What role do flow meters and thermowells play in the water system?

D. Long Answer Questions

1. Describe the sequence of setting up the water piping system from the source to the electrolyser.
2. Explain the importance of installing valves and having dual sections in the electrolyte tanks.
3. What instruments are used to measure and control the water supply, and how do they contribute to efficiency?
4. Discuss the total water requirement for producing 1 kg of hydrogen and ways to reduce wastage.

MODULE 2 HYDROGEN CONDITIONING AND COMPRESSION

Module Overview

This unit teaches you how to prepare green hydrogen for safe storage, transport, and use. Hydrogen produced through electrolysis or other methods requires purification, drying, and compression. This process ensures safety and efficiency for its use in applications such as fuel cells, industry, and energy storage systems.

You will learn about the main parts and how hydrogen purification systems work, including de-oxo systems, dryers, and compressors. You will also study the properties of hydrogen gas, compression technologies, and best practices for installing systems. Safety standards for handling high-pressure gas are a key focus, along with the importance of the Material Safety Data Sheet (MSDS) to understand hydrogen's hazards and safety guidelines.

This module provides clear steps on designing, installing, and maintaining a complete hydrogen conditioning and compression system. It highlights safe working practices, how to choose the right equipment, and quality assurance.

Learning Outcomes

After completing this module, students will be able to:

1. Understand the need for hydrogen purification and conditioning in green hydrogen applications.
2. Explain the working of De-Oxo systems, dryers, and the overall hydrogen conditioning process.
3. Describe the types, working principles, and installation of hydrogen compressors.
4. Interpret hydrogen safety data (MSDS) and follow safety protocols during operation and maintenance.
5. Select suitable compression systems and estimate storage needs based on pressure and flow requirements.

Module Structure

Session 1: Conditioning/Purification of Green Hydrogen

Session 2: Hydrogen Conditioning System

Session 3: Material Safety Data Sheet (MSDS)

Session 4: Selection of Compression System

Session 1: Conditioning/Purification of Green Hydrogen

To use hydrogen properly, we need to make sure it is very pure. This is called the purification process. The amount of purity depends on where the hydrogen will be used. For example, if hydrogen is used as a fuel, 99% purity is usually enough. But for very sensitive uses like in semiconductor factories, the hydrogen must be almost 100% pure – around 99.9999%. This level is called parts per million (ppm) purity. When we prepare hydrogen for transport or storage, we also do something called conditioning. This includes making it ready to be stored as a high-pressure gas or as a very cold liquid. So, purification is just one part of a bigger process called hydrogen conditioning.

Hydrogen Conditioning:

Hydrogen conditioning is the process that makes hydrogen clean and ready for safe storage. This includes removing any leftover oxygen, water drops, and electrolytes, drying the hydrogen, and then compressing it so it can be stored. A special machine called a hydrogen purifier is used to clean the hydrogen. If the hydrogen is made from fossil fuels like natural gas, it needs to be cleaned even more, especially if it will be used in PEM fuel cells or the electronics industry.

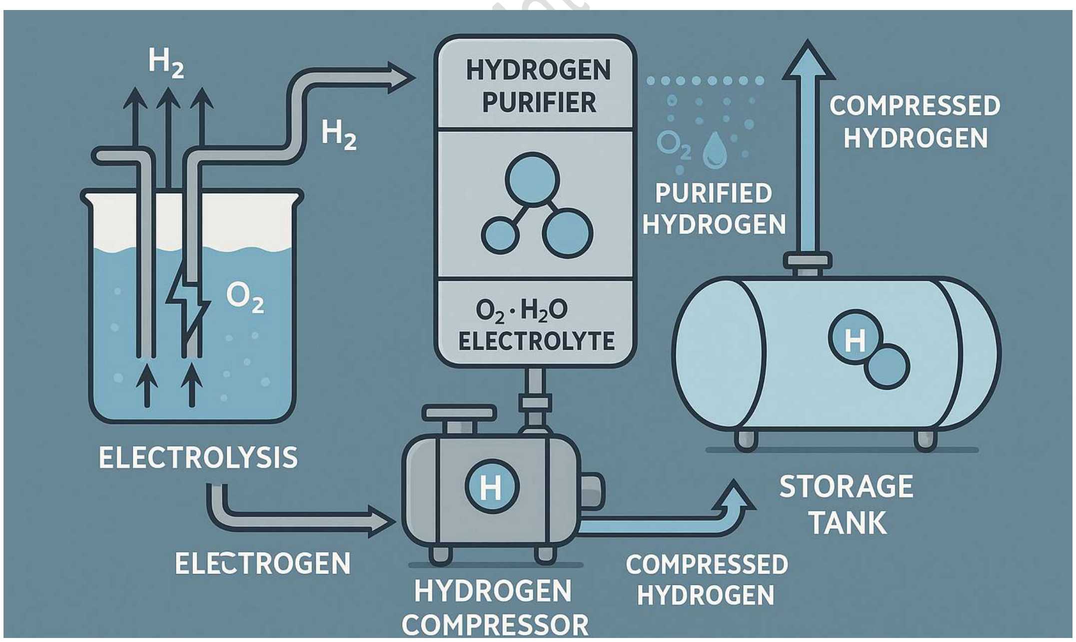

Fig. 2.1: Hydrogen Conditioning

When hydrogen is made using electrolysis (splitting water using electricity), it is already quite pure about 99.99%. During this process, hydrogen forms at the cathode and oxygen at the anode, and the pressure of hydrogen is kept higher than that of oxygen. This stops oxygen from mixing with the hydrogen, which helps keep the hydrogen pure. Because of this, hydrogen made from electrolysis usually needs less purification, which also saves money.

De-Oxo System:

In the electrolysis process, water is split into two gases hydrogen and oxygen. But both gases still carry some water vapour and tiny droplets, which need to be removed. Also, the hydrogen gas may have a small amount of oxygen mixed in it, which must be taken out to make the hydrogen pure.

To remove this unwanted oxygen, we use a special method called the De-Oxo process, which means deoxygenation. In this process, the extra oxygen in the hydrogen reacts with the hydrogen itself to form water vapour. This water vapour is then removed using a dryer. The De-Oxo system uses a catalyst (a substance that helps the chemical reaction) made from Palladium (Pd). This process is very important when we want high-purity hydrogen, especially for delicate industries like semiconductors.

Note: *Compressor throughput* means how fast a compressor can compress hydrogen, usually measured in **kilograms per hour (kg/h)**.

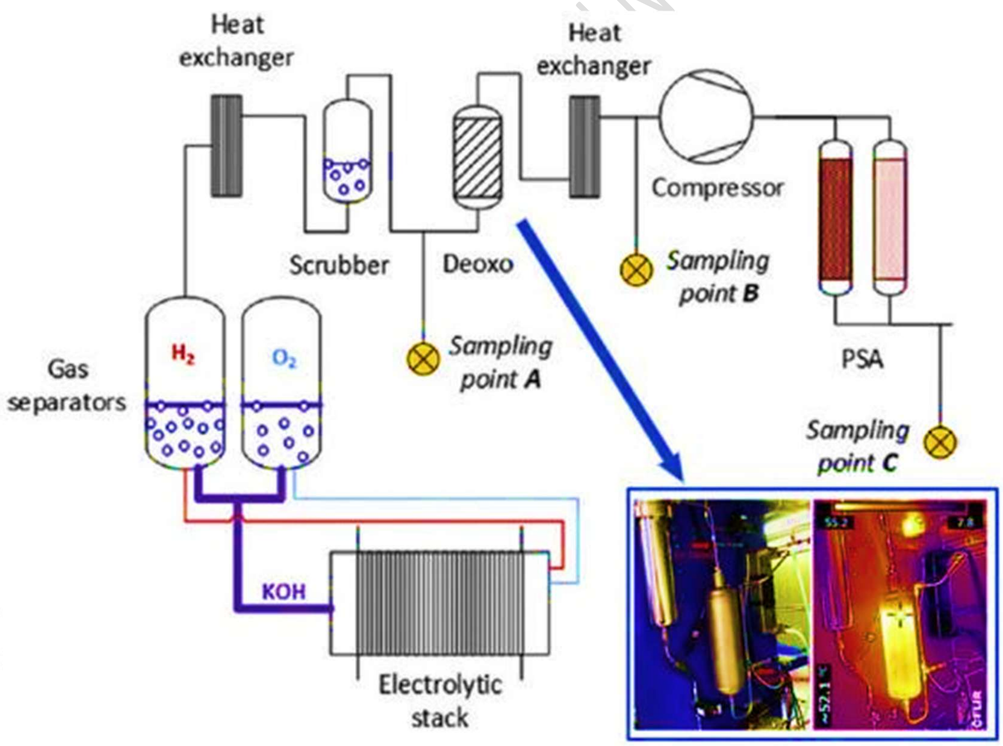

Fig. 2.2: De-oxo system for hydrogen purification

In a hydrogen plant that uses electrolysis, only hydrogen is purified. The oxygen gas is usually released into the open air because we don't need it for special uses, so no purification is done for oxygen. However, water or electrolyte droplets that get mixed in the gases are removed in a process called water separation. This separated water or electrolyte is cleaned and sent back into the system to be used again.

In industries that need very high-purity hydrogen (as pure as parts per million or ppm level), only a small amount is required. So, it is common to buy regular commercial hydrogen and then purify it at the user's own workplace. This helps in making high-quality products like tiny parts used in the semiconductor industry, where even a small impurity can cause problems.

Dryer System:

The dryer system is used to remove water vapour and moisture from hydrogen gas before it is finally compressed and stored. This step is very important because hydrogen must be dry and clean before it goes into storage.

To remove moisture, the dryer uses electric heaters and a special material called silica gel crystals. These crystals can absorb water from the hydrogen gas. When the silica gel absorbs moisture, its colour changes to blue, showing that it is full of water. The good thing is that silica gel can be used again after drying it in the sunlight.

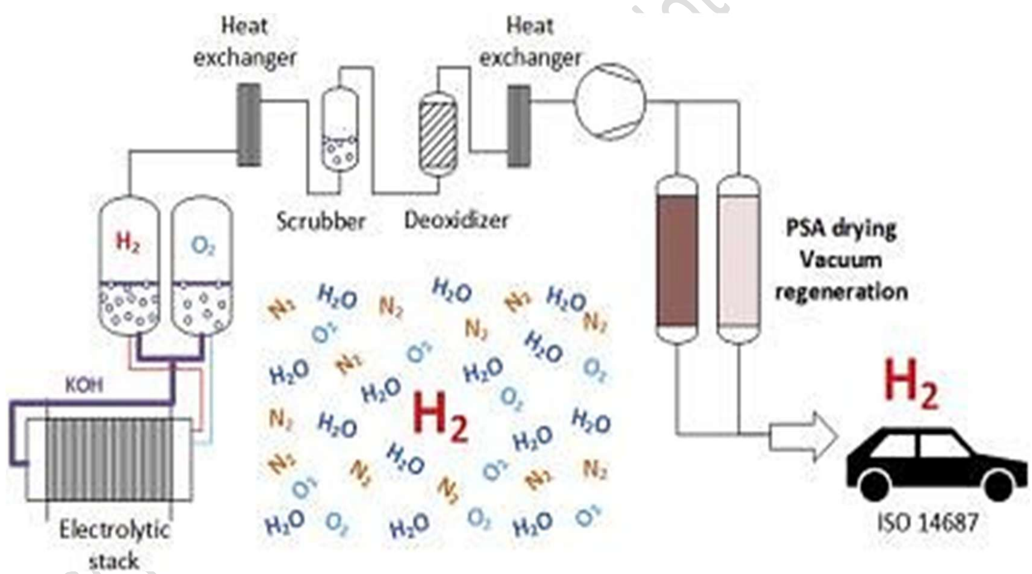

Fig. 2.3: Hydrogen dryer (scrubber) and purifier (deoxidiser)

The picture below (Fig. 2.3) shows a hydrogen dryer (also called a scrubber) and a purifier (also called a deoxidiser).

The size or capacity of the dryer depends on how much hydrogen is to be dried and compressed every day. Some extra capacity is also kept in case of emergencies or if a fault develops in the system.

It is important to note that there is no storage tank for hydrogen between the dryer and the next step (compression). So, if the dryer stops working or develops a problem, the entire hydrogen conditioning process, including compression, will be affected immediately. That is why it is important to have a backup system (redundancy) and to monitor the dryer closely all the time.

Check Your Progress

A. Fill in the Blanks

1. The process of removing water vapour and oxygen from hydrogen gas to make it suitable for storage is called ________________.
2. The ________________ process uses a **palladium catalyst** to remove oxygen by reacting it with hydrogen to form water vapour.
3. Hydrogen generated from____________ is already quite pure, usually about **99.99%**.
4. The **dryer system** uses **silica gel crystals** to remove moisture from hydrogen gas before it is compressed.

B. Multiple Choice Questions (MCQs)

1. **What is the primary purpose of hydrogen conditioning?**
   a) To increase the temperature of hydrogen
   b) To add water to hydrogen
   c) To prepare hydrogen for safe storage
   d) To reduce the volume of hydrogen

2. **What is the role of silica gel in the hydrogen drying system?**
   a) To add oxygen
   b) To absorb moisture
   c) To reduce pressure
   d) To cool the gas

3. **Which material is used as a catalyst in the De-Oxo system?**
   a) palladium
   b) Copper
   c) Iron
   d) Platinum

4. **What happens to the silica gel when it absorbs water?**
   a) It melts
   b) It changes colour
   c) It evaporates

d) It turns into liquid

5. **In hydrogen plants using electrolysis, what is usually done with the oxygen gas?**
   a) Released into open air
   b) Sent for purification
   c) Compressed and stored
   d) Used in fuel cells

C. Short Answer Questions

A. What is the difference between hydrogen purification and hydrogen conditioning?

B. Why is hydrogen from electrolysis considered purer than hydrogen from fossil fuels?

C. Why is it important to remove water vapour from hydrogen gas before storage?

D. What does the De-Oxo process do and how?

D. Long Answer Questions

1. Explain the complete process of hydrogen conditioning.
2. Describe how hydrogen is purified using the De-Oxo system and why it's important.
3. Discuss the role and importance of the dryer system in hydrogen conditioning.
4. Why is redundancy and constant monitoring important in hydrogen conditioning systems?

Session 2: Hydrogen Conditioning System

The hydrogen conditioning system is used to prepare hydrogen so it can be used safely and effectively in different applications. To make hydrogen ready, we need to perform several steps removing water or electrolyte droplets, drying, removing oxygen, compressing the gas, and finally checking the purity of hydrogen.

The following process is in the Step-by-Step Setup of the Hydrogen Conditioning System and is described below:

a) Water/Electrolyte Removal Unit

The water/electrolyte removal unit is the first part of the hydrogen conditioning system. It must be installed exactly as the supplier recommends. After setting it up, a hydrogen sample is tested to check if the water and electrolyte have been removed properly. The process is quite simplehydrogen gas is passed through water and a scrubber. This helps to remove tiny droplets of water or electrolyte from the hydrogen. The hydrogen is kept at a low pressure (just a few bars) during this step. The water that is collected from this process is not wasted. It is cleaned using the DM (De-mineralised) water system and then used again in the system. This helps in saving water and keeping the process efficient.

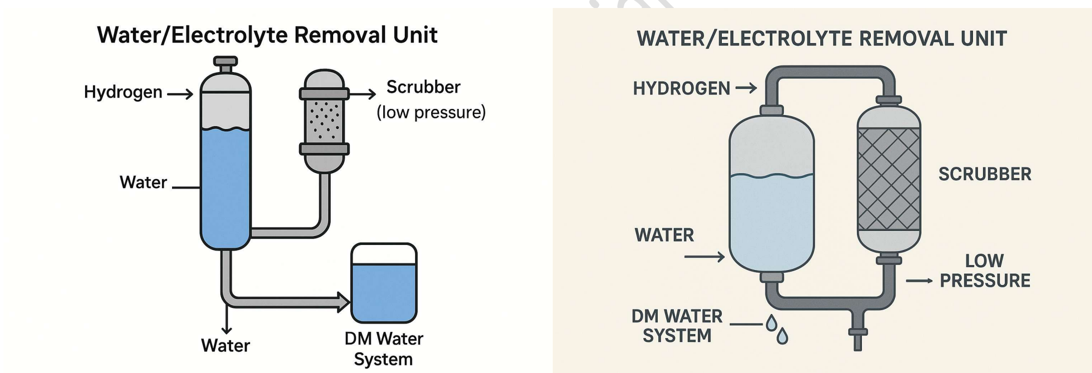

Fig. 2.4: Water Removal Unit

b) De-Oxo Unit

The De-Oxo unit is used to remove oxygen from hydrogen. It should be installed properly, as per the supplier's instructions. After setting it up, a sample of hydrogen is tested to make sure the oxygen has been removed to the required level.

In the De Oxo unit, hydrogen gas is passed through special chemicals or catalysts that absorb the oxygen. Sometimes, the unit needs to be kept at a higher temperature to help the reaction work better.

The condition of the chemicals or catalyst must be checked regularly, especially after producing a certain amount of hydrogen. Based on this, we decide whether to recharge (refill) or replace the chemicals and also if the catalyst needs cleaning. This helps the De-Oxo unit to keep working properly and give pure hydrogen.

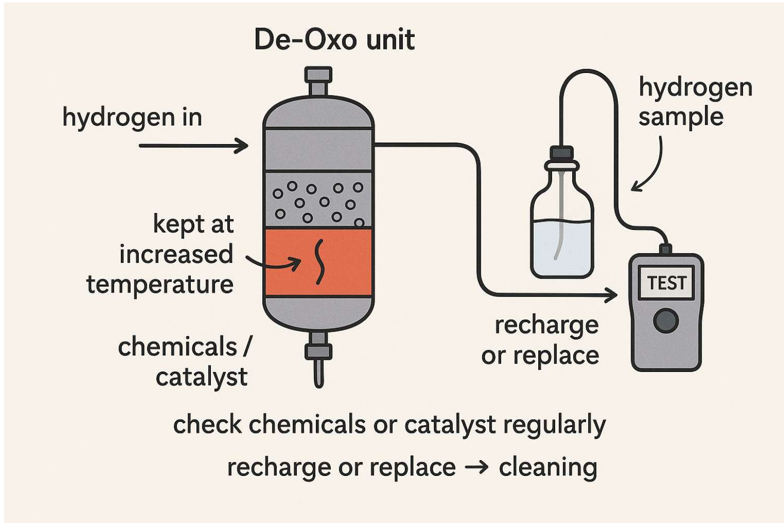

Fig. 2.5: De-Oxo Unit

c) Dryer Unit

The dryer unit is used to remove moisture (water vapour) from hydrogen gas. It should be installed as per the supplier's instructions. After setting it up, a hydrogen sample is tested to check if it is dry enough.

The dryer has heating elements and materials like silica gel that absorb moisture from the hydrogen. It may also have a catalyst to remove small traces of oxygen that may still be present. This step ensures that the hydrogen is completely dry and clean before moving to the next stage of conditioning.

Fig. 2.6: Dryer Unit

d) Compressor Unit

The compressor unit is used to compress hydrogen gas for storage or further use. It must be installed exactly as per the supplier's instructions. Before using hydrogen, the compressor is first tested with air or nitrogen to check its performance. During this test, important things are checked, such as:

- Rated capacity (how much gas it can compress),
- Power used,
- Working of valves,
- And the pressure it can build.

After the performance test, the compressor is purged (cleaned) using nitrogen or CO_2. Then, a pressure test is done using hydrogen gas. During this test, it is very important to carefully check for any hydrogen leakage, as hydrogen is a very light and flammable gas. For pressure testing, the inlet and outlet valves are kept closed, and the safety valve is set about 10% higher than the rated pressure of the compressor to ensure safe operation.

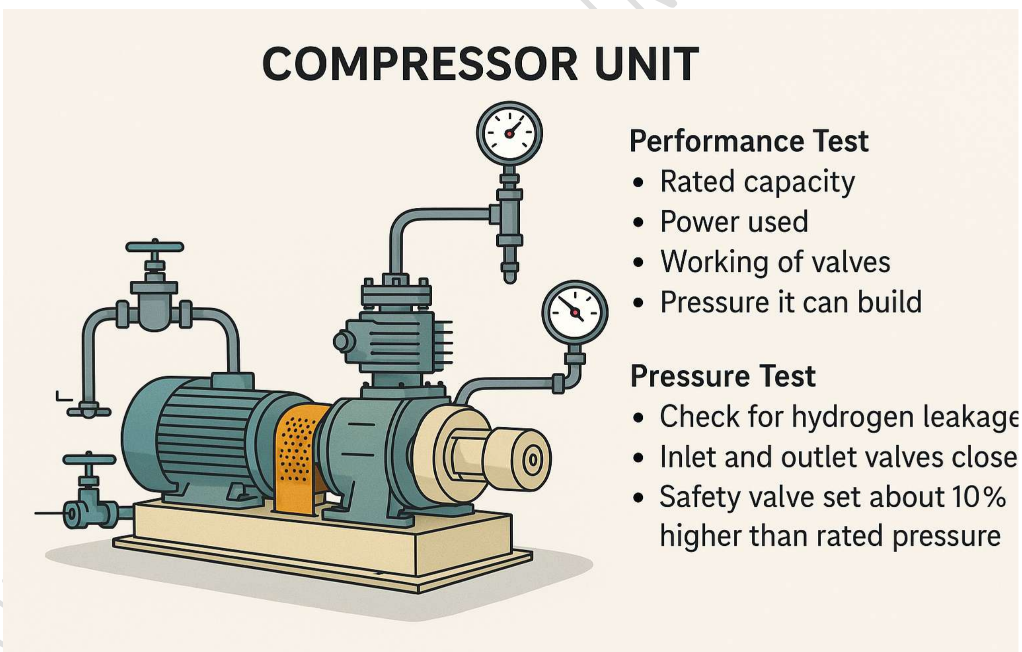

Fig. 2.7: Compressor Unit for Hydrogen Gas

Balance of Plant

The Balance of Plant (BOP) includes all the supporting systems that are needed for the smooth working of a green hydrogen production plant using an electrolyser. These systems help the main plant to work safely, efficiently, and continuously.

Some examples of BOP items are:

- Water purification systems
- Cooling systems
- Pumps and piping
- Control systems
- Power supply units, etc.

These parts may not directly produce hydrogen, but they are very important for the overall performance of the plant.

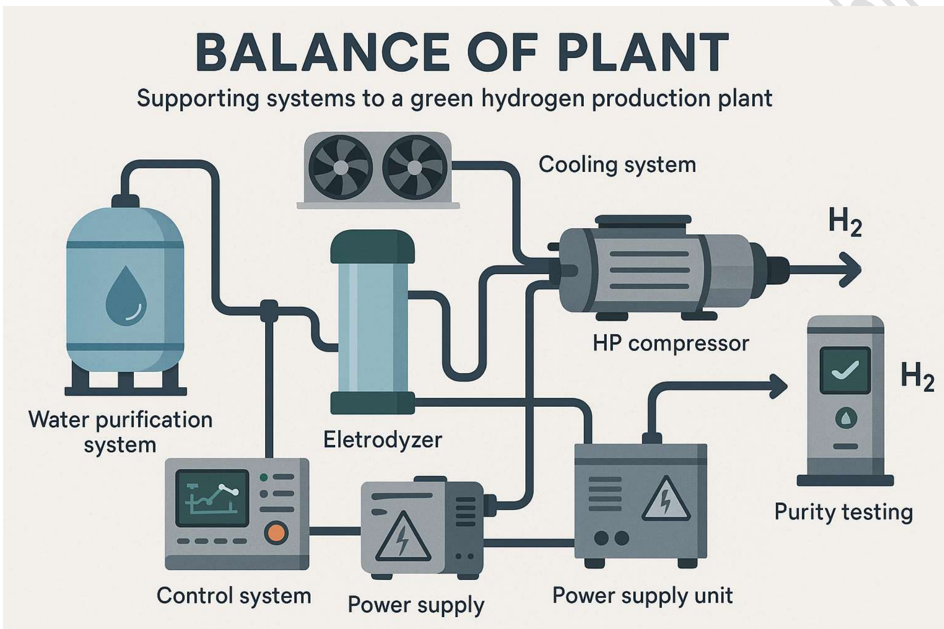

Fig. 2.8: Balance of Plant

After the complete conditioning of hydrogen, a final purity test is done. This test checks if there are any traces of lubricating oil or vapour that may have entered the hydrogen gas from the high-pressure (HP) compressor. This ensures the hydrogen is pure and safe to use, especially in industries like fuel cells or semiconductors.

Check Your Progress

A. Fill in the Blanks

1. The first step in hydrogen conditioning is the removal of **water or electrolyte droplets** using a **scrubber**.
2. The **De-Oxo unit** removes **oxygen** from hydrogen using special **chemicals or catalysts**.

3. The **dryer unit** uses **silica gel** to absorb **moisture** from hydrogen gas.
4. The **compressor** is first tested using **air or nitrogen** before testing with hydrogen.
5. The **Balance of Plant (BOP)** includes systems like **cooling, water purification, control, and power supply** that support the main plant.

B. Multiple Choice Questions (MCQs)

1. **Why is a water/electrolyte removal unit important in hydrogen conditioning?**
   a) To increase hydrogen pressure
   b) To heat hydrogen gas
   c) To add oxygen to hydrogen
   d) To remove water and electrolyte droplets

2. **What is used in the De-Oxo unit to remove oxygen from hydrogen?**
   a) Water
   b) Electricity
   c) Chemicals or catalysts
   d) Nitrogen

3. **Which material is used in the dryer to absorb moisture?**
   a) Activated carbon
   b) Silica gel
   c) Sand
   d) Iron powder

4. **What is tested before using the compressor with hydrogen?**
   a) Performance with air or nitrogen
   b) Colour of hydrogen
   c) Noise level
   d) Quantity of oxygen

5. **Which of the following is NOT part of the Balance of Plant (BOP)?**
   a) Electrolyser
   b) Cooling systems
   c) Power supply

d) Control systems

C. Short Answer Questions

1. What is the purpose of the water/electrolyte removal unit in hydrogen conditioning?
2. Why is the condition of the De-Oxo catalyst monitored regularly?
   How does the dryer system work in hydrogen conditioning?
3. What is the role of the final purity test in hydrogen conditioning?

D. Long Answer Questions

1. Explain the step-by-step setup of the hydrogen conditioning system.
2. Describe how the De-Oxo unit functions and why it is critical in hydrogen purification.
3. What safety checks and tests are done before and during hydrogen compression?
4. What is the role of the Balance of Plant (BOP) in a hydrogen production plant?

Session 3: Compression Process and Installation of Compression System

Hydrogen is usually produced at low pressure, around 20 to 30 bar. It has the highest energy per kilogram compared to other fuels, but its energy per volume (space it takes up) is the lowest.

Hydrogen has two types of energy values, called lower calorific value and higher calorific value. Even the lower calorific value of hydrogen is very highabout 120 MJ per kg. For comparison, petrol has only about 44.3 MJ per kg. This means hydrogen can give much more energy for the same weight.

However, hydrogen is very light and takes up a lot of space. At normal temperature (20°C) and 1 bar pressure (which is atmospheric pressure), 1 kilogram of hydrogen occupies around 11 cubic meters. This is a large volume compared to petrol or diesel, which are liquids and take up much less space.

For example, petrol or diesel has an energy density of about 30 MJ per litre, while hydrogen gas at 25°C and 1 bar has only about 0.010 MJ per litre. This means hydrogen gas has about 3000 times less energy in the same volume compared to petrol or diesel.

Because hydrogen takes up so much space, there are two main ways to store it more efficiently:

1. Liquefied Hydrogen: Hydrogen is cooled and turned into a liquid. But this process is very expensive because it needs special equipment and a lot of energy. Also, storing liquid hydrogen requires cryogenic tanks that keep it very cold, and there is some loss of hydrogen due to evaporation called boil-off loss.
2. Compressed Hydrogen Gas: Hydrogen gas is stored under very high pressure. At 700 bar, the energy density of hydrogen reaches about 4.6 MJ per litre, which is much better but still less than petrol or diesel. With new materials, if hydrogen is compressed to 900 bar, its energy density can increase to about 5.5 MJ per litre.

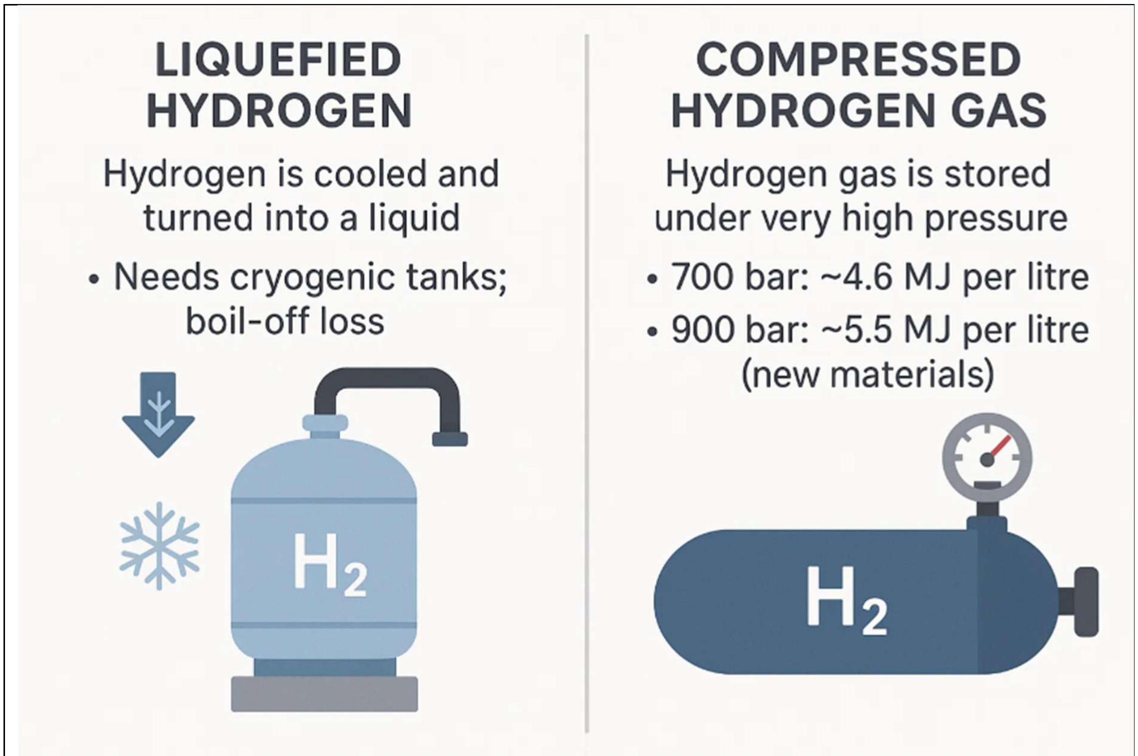

Fig. 2.9: Types of Compression system

Compression Process

Compression is mostly done on gases. Compression is a process in which something is squeezed or pressed to reduce its size or volume. It is just pressing and reducing the space between their molecules. Which may increase the pressure of the container. Example: You can think of it like many people staying together in a small roomthe more people in the same room, the more crowded it feels. Similarly, when gas is compressed, the molecules come closer, and pressure goes up.

At the beginning of compression, the pressure is low (only a few bars), so the compressor doesn't have to work much. But as the pressure builds up, the compressor has to work harder and use more power. You can think of pressure like voltage in electricity, and the flow of gas like electric current.

In the compression process, two important valves help build up pressure: a directional valve on the high-pressure (HP) side of the compressor and a non-return valve at the inlet of the storage tank. It is very important to make sure these valves are properly sealed and regularly checked to prevent leaks.

When gas is compressed, its temperature rises as the pressure increases. To control this heat, cooling water is sprayed frequently on the storage tank. The temperature of the high-pressure gas must be continuously monitored to keep it safe.

The compressor parts, like shaft seals in rotary compressors or piston rings in reciprocating compressors, also need regular inspection and maintenance because hydrogen can leak through faulty seals or rings. To avoid dangerous leaks, hydrogen leak detectors are used at these places.

Good ventilation is very important in the compression area to keep the environment safe. In case of emergencies, nitrogen or carbon dioxide cylinders are used to safely purge (clean out) the hydrogen gas from the system.

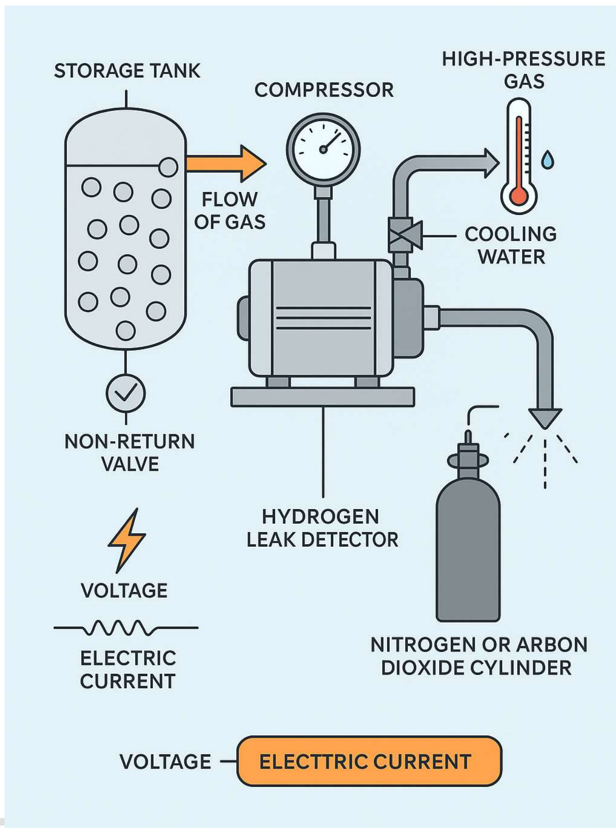

Fig. 2.10: Process of Compressor System

Installation of Compression System

The compression system must be installed following the instructions and drawings provided by the supplier. Here is a simple guide to understand the important steps:

1. **Receipt of Compressor**

   As soon as the compressor arrives, carefully check the unit and all its parts for any damage that might have happened during shipping. Also, verify that all the items listed in the Bill of Materials have been received. Keep the spare parts and consumables (items that get used up) stored separately and safely.

2. **Location**

   Place the compressor in a dry, well-ventilated, and well-lit area. The location should allow easy access for inspection and maintenance.

3. **Foundation**

   The compressor must be fixed securely on a concrete foundation built according to the foundation details provided by the compressor supplier. Epoxy-based grout is used to firmly attach the compressor skid (base frame) to the concrete foundation, ensuring it stays stable and strong.

4. **Inlet Piping & Inlet Filtration**

   The inlet piping may carry gas at a pressure higher than the normal atmospheric pressure. Therefore, the pipes must be strong enough to handle 10 to 20% more pressure than the highest pressure of the gas entering the system. However, the minimum pressure for the inlet should be about 5 bars. The piping system should also have a safety valve that is correctly sized and set to open at 3 to 4 bars above the maximum operating pressure, but below the maximum pressure the pipe can safely handle.

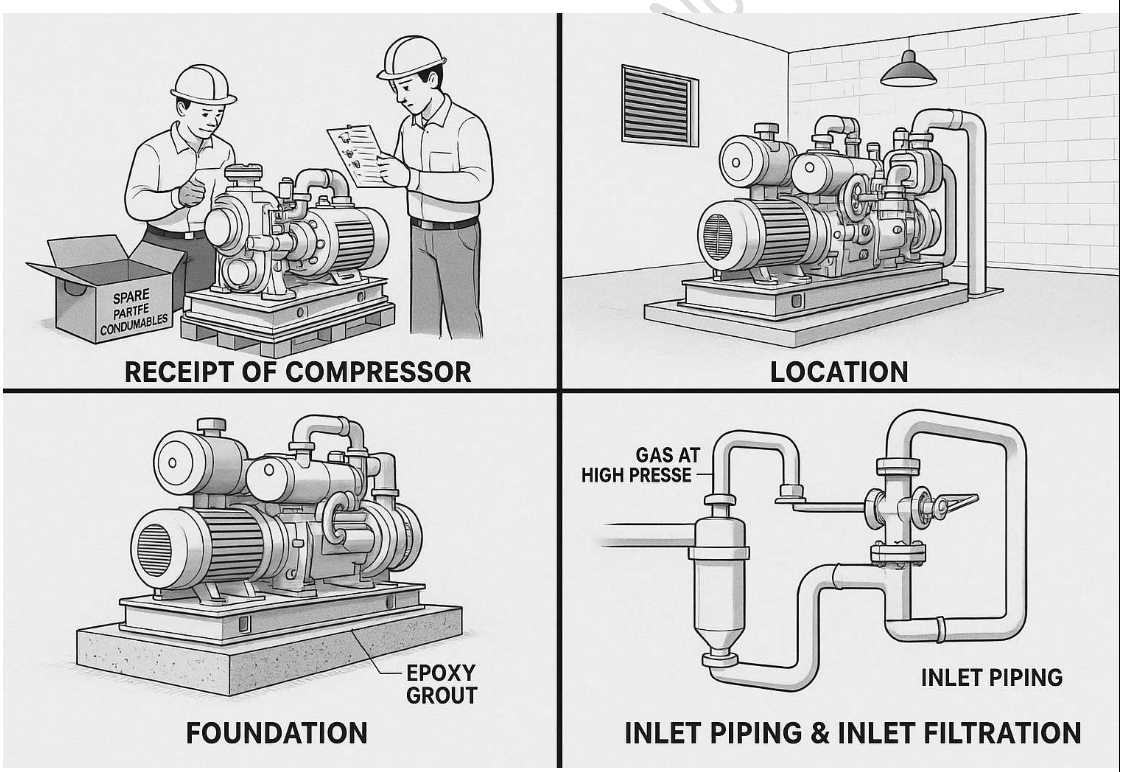

Fig. 2.11: Installation of Compression System

An inlet filter with a size of 1.0 micron or smaller must be installed in the inlet line. This filter cleans the gas or air before it enters the compressor, ensuring only clean gas goes into the booster.

Note:

- The compressor lasts longer when it receives clean, dry, and cool gas at its inlet.
- The lubricating oil system must be properly maintained, and the oil should be changed whenever needed.
- Compressors are designed to pump gases, not liquids. Pumping liquids can damage the compressor.

5. Discharge Piping

It is recommended to install a compressor aftercooler, a discharge safety valve, a discharge check valve, and an air receiver in the discharge piping system.

A properly sized safety valve must be installed at the discharge receiver before the aftercooler. This safety valve should be set to open at a pressure 10% higher than the maximum operating pressure, but still below the maximum pressure that the system components can safely handle. This ensures the system operates safely by preventing excessive pressure build-up.

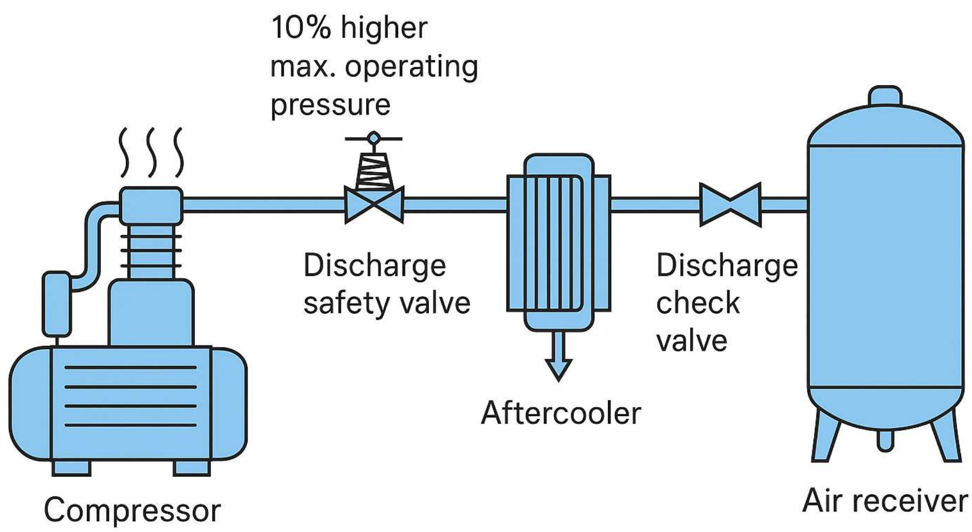

Fig. 2.12: Discharge Piping System

6. Receivers

Reciprocating compressors cause pressure pulses in the gas flow at both the inlet and discharge sides. To reduce these pressure fluctuations, compressors work better when there is a pulsation tank before the compressor (upstream) and a receiver tank after the compressor (discharge side). These tanks help smooth out the pressure changes and make the compressor operate more efficiently.

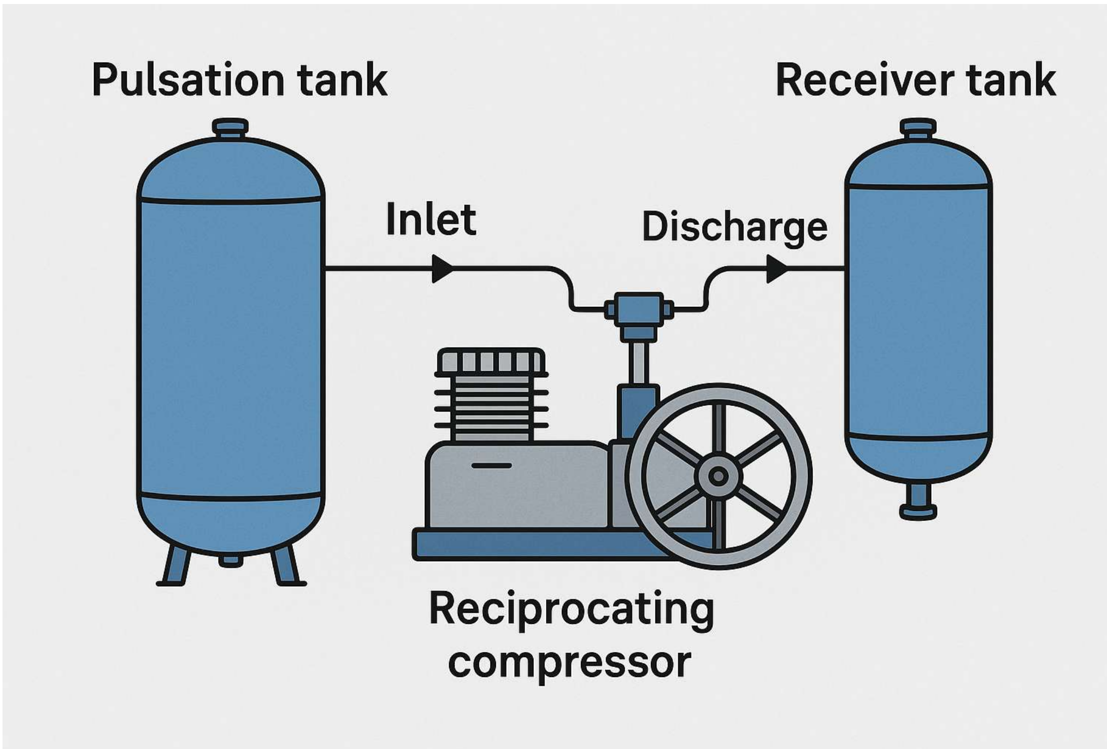

Fig. 2.13: Receiver of Reciprocating Compressor

7. Compressor Cooling

Air Cooling: An air-cooled compressor uses the movement of air (convection) to remove heat from the compression cylinder and head. The compressor must operate within the temperature limits set by the manufacturer. It is best to install air-cooled compressors in shaded or cool indoor areas where there is good air circulation to help with cooling.

Important: Air cooling is not suitable for hydrogen compressors.

Water Cooling: A water-cooled compressor uses circulating water that flows through heat exchangers to carry away the heat and keep the compressor cool.

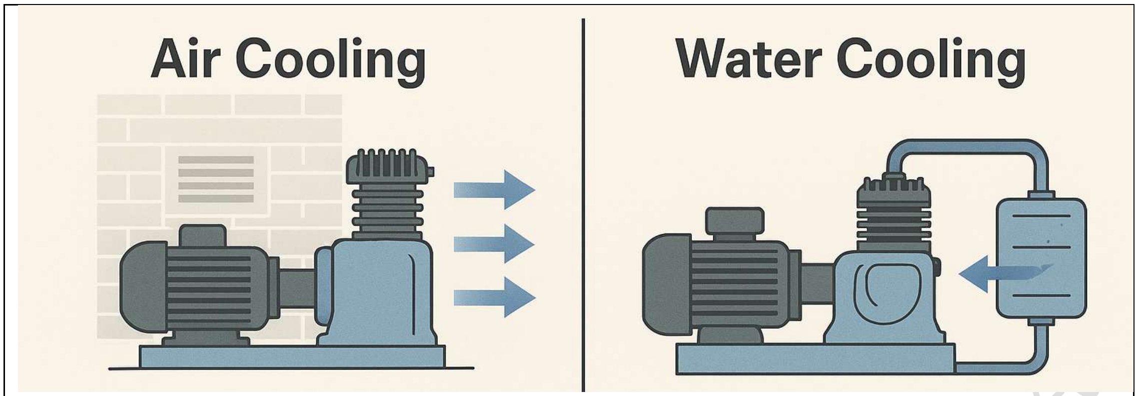

Fig. 2.14: Types of Coolong Systems Used in Compressor

8. Control Panel

The control panel of a compressor usually includes several important components housed within a protective enclosure. This enclosure protects the controls and electronics from dust, moisture, and damage, ensuring safe and reliable operation of the compressor system.

Fig. 2.15: Control Panel of Hydrogen Compressor

9. Motor Starter

The motor starter is a device that controls the starting and stopping of the compressor motor safely and efficiently.

- ***Gas Pressure Transducers:*** These sensors monitor the gas pressure and send feedback to the control system. This helps maintain the gas pressure at the desired levels automatically.

- **Unloader Device:** The unloader helps to manage the compressor's load by allowing it to load and unload smoothly. This prevents the compressor motor from starting and stopping too often every time the pressure changes, which helps protect the motor and improve its lifespan.

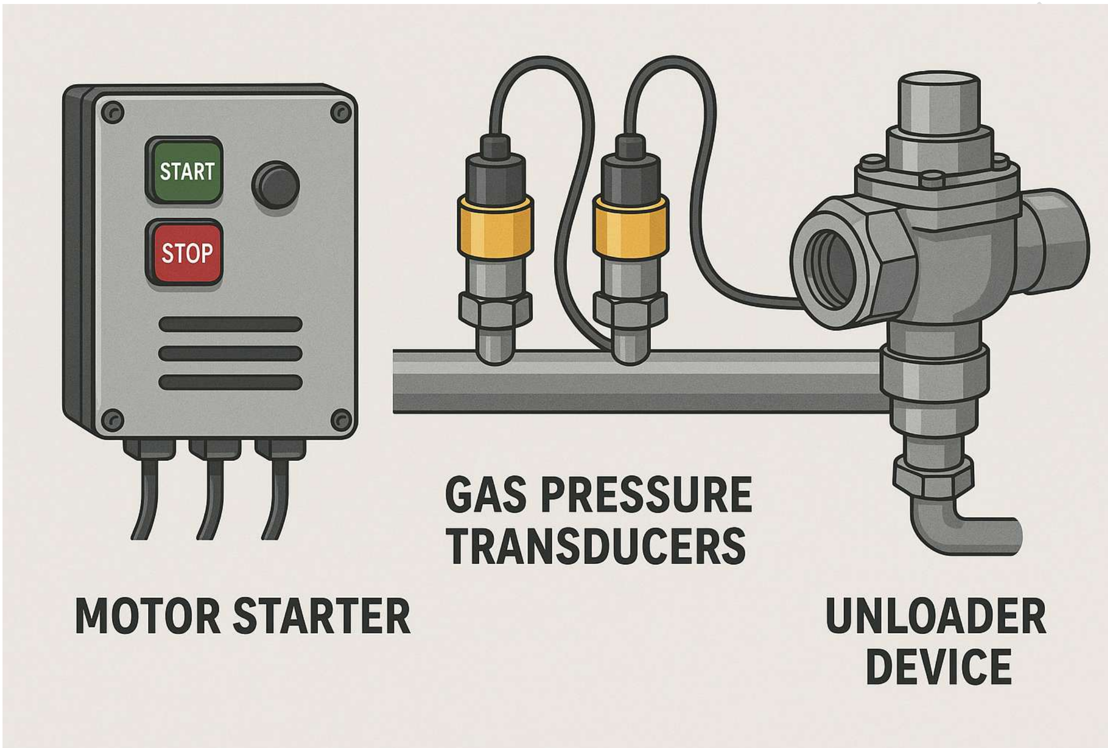

Fig. 2.16: Motor Starter controls the starting and stopping of the compressor motor

10. Safety Devices

A compressor system usually includes several important safety devices to protect both the equipment and the people working around it. If these devices are missing or not properly installed, they can cause serious damage or accidents.

a) **Temperature Sensor:** This sensor monitors the temperature of the gas leaving the compressor. If the temperature becomes too high, it can damage the compressor parts. The sensor is set to automatically shut down the compressor if the temperature goes above the safe limit.

b) **Low Oil Pressure Sensor:** The compressor needs oil for lubrication. If the oil pressure drops too low, it can cause severe damage to the compressor. This sensor detects low oil pressure and will shut down the compressor to prevent damage.

c) **Pressure Safety Valve:** This valve prevents the system from becoming too pressurised, which can be very dangerous. If the pressure gets too high, the valve releases some gas to lower the pressure. Properly sized safety valves are essential to avoid accidents, property damage, or injuries.

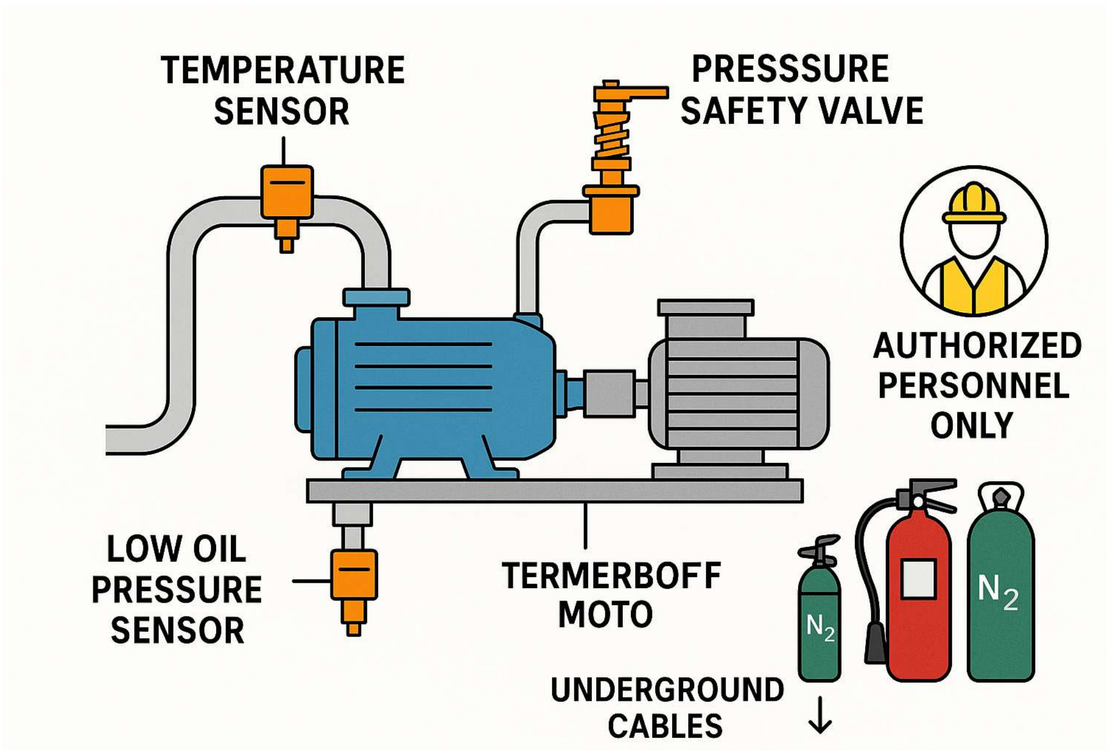

Fig. 2.17: Sensors in Compressor

The motor's terminal box must be both flameproof and airtight to ensure that no sparks escape from it. All cables should be installed underground for added safety. Firefighting equipment, along with nitrogen and carbon dioxide cylinders, must be readily available on-site. Only authorised personnel equipped with proper safety gear should be allowed to enter the compressor room or area. Additionally, precautions should be taken to prevent vibrations from being transmitted to other components such as valves, pressure gauges, and test point outlets, as this could cause false tripping of the system.

Types of Hydrogen Compressors

Hydrogen is usually produced at low pressures, around 20 to 30 bar, and needs to be compressed before it can be transported. Most current compressors for hydrogen are either positive-displacement compressors or centrifugal compressors. Positive displacement compressors can either be reciprocating or rotary. The choice of compressor type depends on the pressure at the inlet and outlet, as well as how much hydrogen needs to be handled each day. If the pressure is very high, above 200 bars, multi-stage compressors may be necessary. Multi-stage compressors can be more cost-effective than single-stage ones.

1. **Reciprocating Compressors**

In reciprocating compressors, a piston is used to compress the hydrogen gas. As the piston moves back and forth within a cylinder, it reduces the volume of the gas chamber, thereby increasing the pressure of the hydrogen gas.

Key Features:

- **Working Principle**: The piston draws hydrogen gas into the cylinder during the intake stroke. On the compression stroke, the piston pushes the gas into a smaller space, increasing its pressure before it is discharged.
- **Efficiency**: These compressors are highly efficient and offer consistent performance over time.
- **Durability**: Known for their robust construction and long life, making them suitable for demanding conditions.
- **Applications**: Ideal for low to medium-pressure applications (typically up to 200 bar), and commonly used in hydrogen refuelling stations, industrial plants, and pilot-scale hydrogen production facilities.

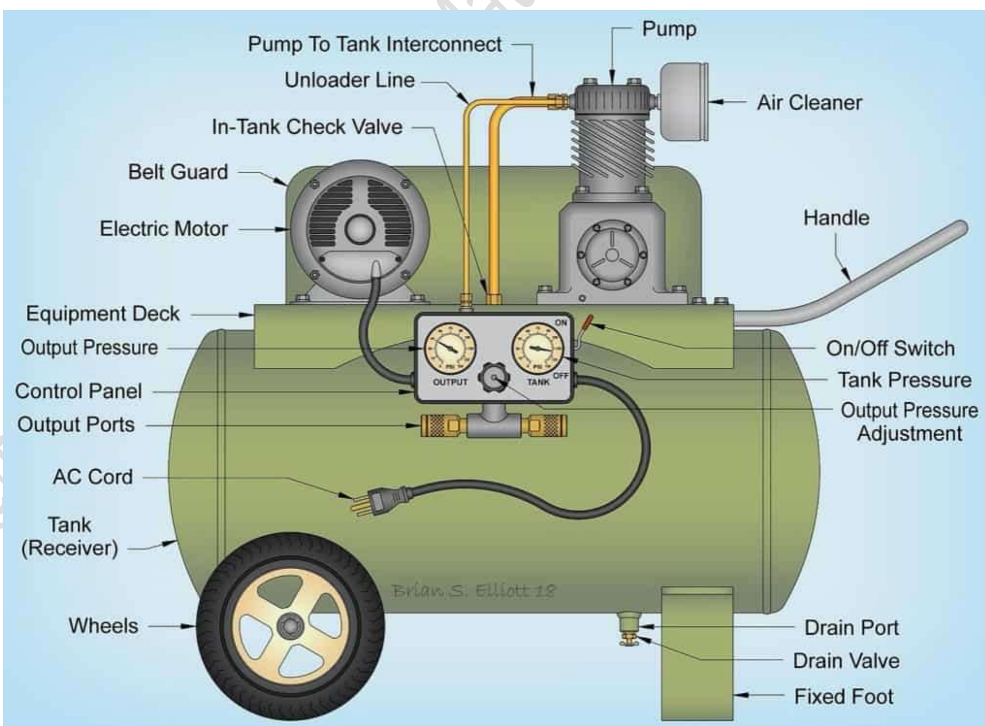

Fig. 2.18: Reciprocating Compressors

2. Ionic Compression Technology and Centrifugal Compressors

Ionic compression represents the next generation of hydrogen compression technology, designed for safe, fast, and efficient fuelling.

- Working Principle: In an ionic compressor, a column of ionic fluid is in direct contact with hydrogen gas. The ionic liquid acts as a piston, compressing the hydrogen without mixing with it.
- Advantages:
  - High performance
  - Low maintenance
  - Continuous operation
  - Lower operating costs
- Applications: Ideal for hydrogen vehicle fuelling stations, especially where quick and repeated fuelling is required.

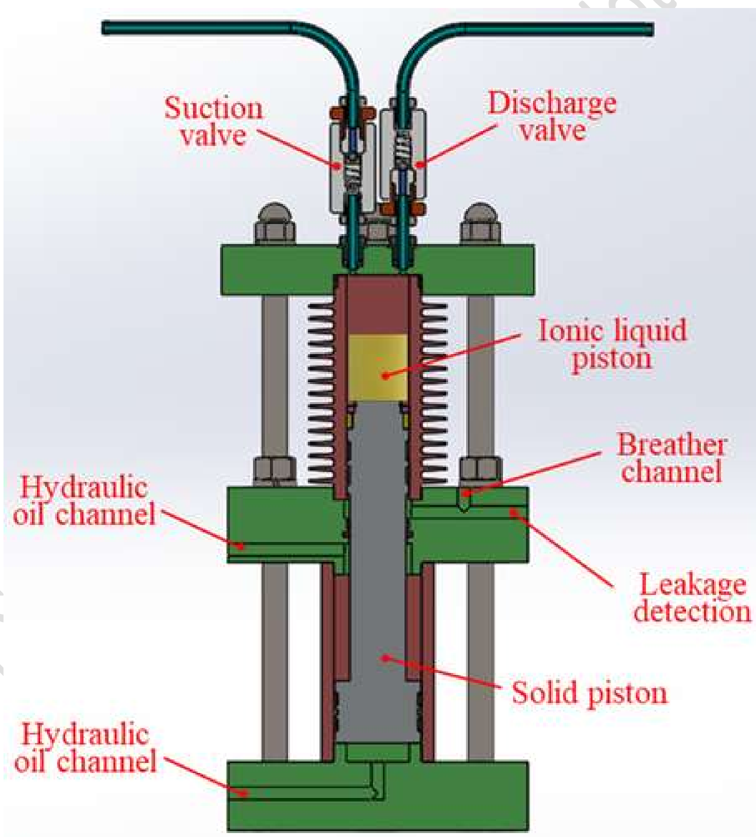

Fig. 2.19: Ionic Compressor

3. Centrifugal Compressors

Centrifugal compressors are dynamic compressors that use a high-speed rotating impeller to compress hydrogen gas.

- Working Principle: The rotating impeller accelerates the hydrogen gas to a high velocity. This kinetic energy is then converted into pressure using a diffuser.
- Advantages:
    - High throughput
    - Compact size
    - Efficient at high flow rates
- Applications:
    - Suitable for pipeline applications
    - Used in low- to moderate-pressure applications
    - Preferred when a high-pressure hydrogen compressor is needed with a moderate compression ratio

Both technologies play a crucial role in modern hydrogen infrastructure, each offering unique benefits depending on the specific application requirements.

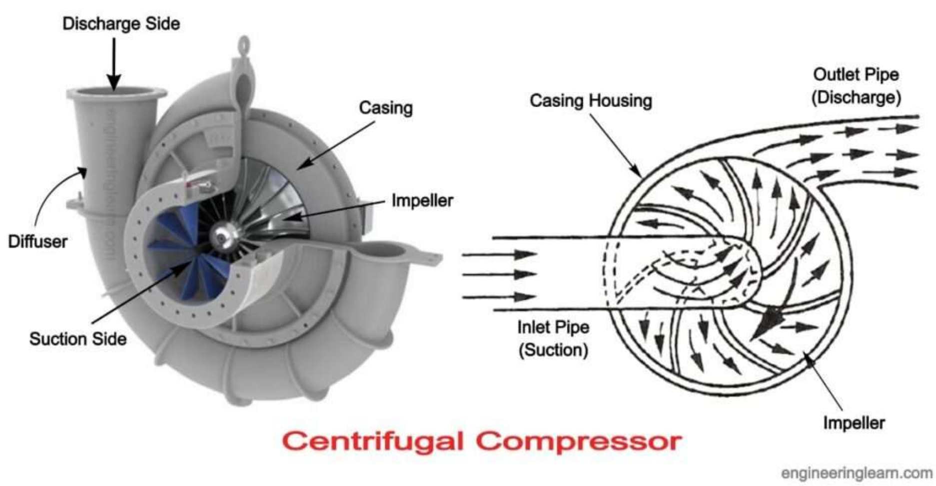

Fig. 2.20: Centrifugal compressors

4. Diaphragm Compressor

A diaphragm compressor is a specialised type of reciprocating compressor that uses a flexible diaphragm instead of a piston to compress gas. It is designed to ensure clean and leak-free compression, making it ideal for handling high-purity or hazardous gases, such as hydrogen.

Working Principle:

- A crankshaft and rod mechanism move the diaphragm back and forth.
- This flexing motion compresses the gas inside the chamber without direct contact between the gas and any lubricated parts.

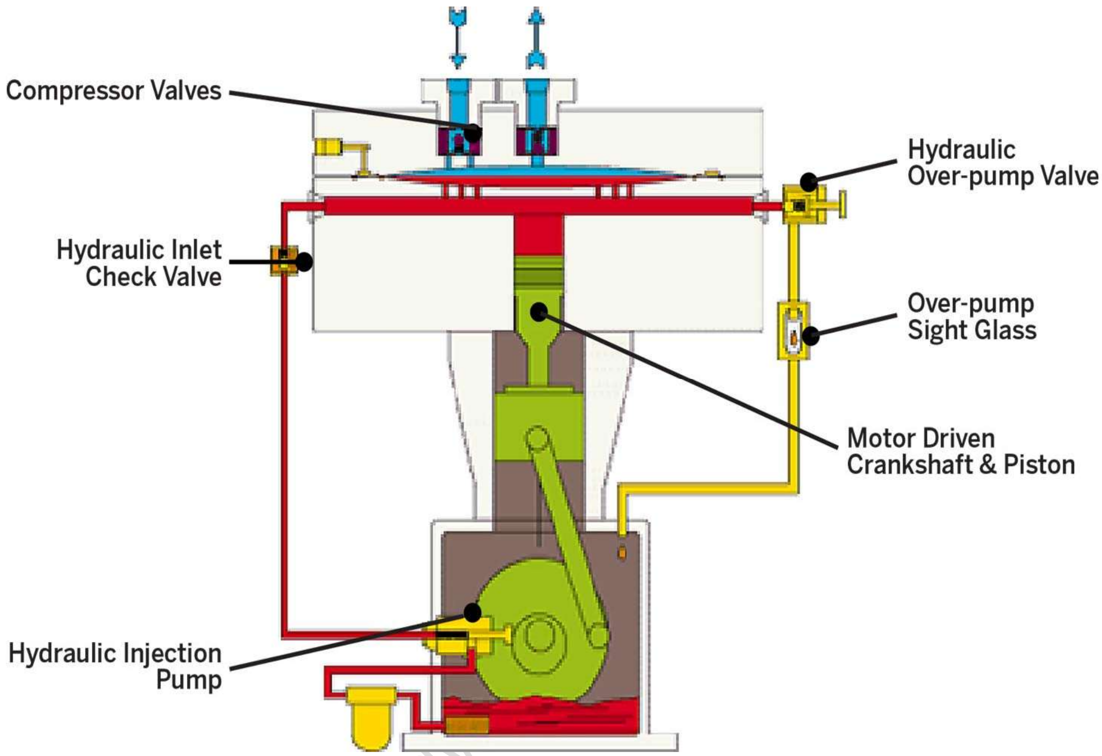

Fig. 2.21: Diaphragm Compressor

Key Features:

- No contamination: As the gas does not come into contact with the crankcase oil or piston parts.
- Low noise and vibration: Quiet operation due to the absence of metal-to-metal contact.
- **Leak-proof design**: Ensures high safety and gas purity.

Applications:

- Suitable for low-pressure hydrogen applications.
- Widely used in the chemical, pharmaceutical, and research industries, where gas purity and safety are critical.

Diaphragm compressors are especially preferred for hydrogen, where contamination must be avoided and minimal leakage is essential.

Check Your Progress

A. Fill in the Blanks

1. Hydrogen has a very high energy per kilogramits **lower calorific value** is around **120 MJ/kg**.
2. At normal conditions (20°C, 1 bar), **1 kg of hydrogen occupies about 11 cubic meters** of space.
3. In the **compression process**, pressure increases while the **volume decreases**.
4. Hydrogen gas can be stored either as **liquefied hydrogen** or **compressed hydrogen gas** to save space.
5. **Diaphragm compressors** are leak-proof and do not contaminate hydrogen because there is **no contact with lubricated parts**.

B. Multiple Choice Questions (MCQs)

1. Why is hydrogen gas compressed or liquefied before storage?
   a) To reduce its weight
   b) To make it less flammable
   c) To reduce its temperature
   d) To increase its volume

2. Which compressor type uses a piston to compress hydrogen gas?
   a) Diaphragm compressor
   b) Ionic compressor
   c) Reciprocating compressor
   d) Centrifugal compressor

3. At what pressure does compressed hydrogen reach an energy density of about 5.5 MJ/litre?
   a) 900 bar
   b) 600 bar
   c) 700 bar
   d) 200 bar

4. What is the main advantage of diaphragm compressors for hydrogen?
   a) They prevent contamination and leakage
   b) They produce more power
   c) They are very cheap

d) They compress gas faster

5. Which of the following is NOT a safety device in a hydrogen compression system?
   a) Temperature sensor
   b) Unloader device
   c) Pressure safety valve
   d) Low oil pressure sensor

C. Short Answer Questions

1. Why is hydrogen considered to have low energy density by volume?
2. What happens to the temperature of gas during compression?
3. What are the two main methods to store hydrogen efficiently?
4. What is the function of a directional valve and a non-return valve in compression?

D. Long Answer Questions

1. Explain the working principle of a reciprocating compressor and its applications in hydrogen systems.
2. Describe the safety precautions and devices used in a hydrogen compression system.
3. Compare the characteristics of diaphragm, reciprocating, centrifugal, and ionic compressors for hydrogen.
4. Explain the step-by-step installation procedure of a hydrogen compressor system.

Session 4: Material Safety Data Sheet (MSDS)

Material Safety Data Sheets (MSDS) are important documents created by the manufacturers or suppliers of dangerous chemicals. These sheets provide details about the physical and chemical properties of the substance, its potential risks, and safety instructions for handling it. They also include guidelines on how to use, store, and transport the material safely, along with emergency steps in case of accidents. In short, an MSDS is a complete guide for working safely with hazardous materials.

For example, hydrogen is considered a dangerous substance. To understand its risks and safety measures, we can refer to an MSDS provided by a company called Airgas. This sheet contains all the necessary information about hydrogen, such as its properties, hazards, and precautions to take while using it.

- Section 1. Identification
- Section 2. Hazards identification
- Section 3. Composition/information on gradients
- Section 4. First-aid measures
- Section 5. Fire-fighting measures
- Section 6. Accidental release measures
- Section 7. Handling and storage
- Section 8. Exposure controls/personal protection
- Section 9. Physical and chemical properties
- Section 10. Stability and reactivity
- Section 11. Toxicological information
- Section 12. Ecological information
- Section 13. Disposal considerations
- Section 14. Transport information
- Section 15. Regulatory information
- Section 16. Other information

Understanding Material Safety Data Sheets (MSDS)

An MSDS (Material Safety Data Sheet) is a detailed document that provides important safety information about hazardous chemicals. After reading an MSDS, you will learn:

1. Hazardous Ingredients & Properties – It lists dangerous substances in a product, along with their physical and chemical properties (like flammability or explosive nature).

2. Health Effects – It explains how the chemical can harm human health (e.g., skin irritation, breathing problems).
3. Reactivity – It warns about other chemicals that may cause dangerous reactions.
4. Safety Precautions – It gives guidelines on safe handling, storage, and exposure control.
5. Emergency Steps – It includes first aid measures, spill control methods, and firefighting procedures.
6. Updates – The MSDS must be updated whenever new safety regulations or health risks are discovered.

Why is MSDS Important for Workers?

Employers and employees use MSDS to stay safe while handling chemicals. By following these guidelines, workplaces can reduce accidents, injuries, and illnesses caused by chemical exposure. Since the Hazard Communication Standard (HCS) was introduced, MSDS has helped workers understand risks and take proper precautions.

Example: Hydrogen MSDS

After studying the MSDS for hydrogen (a highly flammable gas), necessary safety steps must be taken, such as:

- Proper operation and maintenance procedures.
- First-aid measures in case of exposure.
- Providing safety gear (like gloves, goggles, and masks) for workers.
- Placing warning signs and caution boards in work areas.

By following the MSDS carefully, workplaces can ensure a safer environment for everyone handling hazardous materials.

Check Your Progress

A. Fill in the Blanks

1. An **MSDS** is a document that gives important **safety information** about hazardous chemicals.
2. Hydrogen is considered a **highly flammable gas** and requires proper handling and **storage precautions**.
3. The MSDS lists **health effects**, including problems like **skin irritation** or **breathing issues**.

4. The **Hazard Communication Standard (HCS)** ensures that workers understand the **risks** of chemicals.
5. An MSDS must be **updated** when new **safety regulations** or health risks are discovered.

B. Multiple Choice Questions (MCQs)

1. **What does MSDS stand for?**
   a) Material Standard Data Sheet
   b) Manufacturing Safety Data Sheet
   c) Material Safety Data Sheet
   d) Mechanical Safety Document Sheet

2. **Which of the following is NOT typically found in an MSDS?**
   a) First-aid instructions
   b) Marketing information
   c) Storage guidelines
   d) Health effects

3. **Why is it important to regularly update an MSDS?**
   a) To include promotional content
   b) To match the colour scheme
   c) To reflect new safety regulations or risks
   d) To reduce production costs

4. **How can an MSDS help workers?**
   a) By entertaining them
   b) By preventing legal disputes
   c) By reducing accidents and exposure to harmful chemicals
   d) By replacing safety officers

5. **Which of these is a key safety step listed in a hydrogen MSDS?**
   a) Use of bright lights
   b) Wearing loose clothing
   c) Using gloves, goggles, and masks
   d) Storing it in plastic bottles

C. Short Answer Questions

1. What is the purpose of a Material Safety Data Sheet (MSDS)?
2. List three types of information you can find in an MSDS.
3. How does an MSDS help in preventing workplace accidents?
4. Why must employers ensure MSDS availability in work areas?

D. Long Answer Questions

1. Explain the key components of an MSDS and how each contributes to workplace safety.
2. Describe how an MSDS for hydrogen helps ensure safe usage of this gas in industrial settings.
3. Why is it important for MSDS documents to be updated, and who benefits from these updates?
4. How does the Hazard Communication Standard (HCS) relate to the use of MSDS in workplaces?

Session 5: Selection of Compression System

When choosing a hydrogen compressor, there are several important factors to consider:

1. Pressure Range: Select a compressor that can handle the pressure needed for your specific use. The pressure can range from 100 to 900 bars.
2. Flow Rate: Choose a compressor with a suitable flow rate for your application. Each electrolyser stack typically requires a flow rate between 1 m^3/hour and 11 m^3/hour.
3. Efficiency: Look for a compressor with high efficiency. This means it uses less energy to compress hydrogen, which helps lower costs. The compression efficiency is usually around 70%.
4. Reliability: A reliable compressor is crucial for safety and performance. Make sure to pick one that has a strong track record of lasting performance.
5. Durability: The compressor should be built to last and handle tough conditions in a hydrogen system.
6. Size and Weight: Ensure the compressor fits in the available space and meets weight requirements. Typical capacities go up to 200 m^3/hour.
7. Discharge Pressure: For lubricated compressors, the discharge pressure should be over 400 bars. For non-lubricated compressors, it should be up to 225 bars.
8. Cost: Finally, consider the cost. It is important to balance cost with performance when selecting a compressor.

Important: When planning a compression system, always choose standard and proven compressor models. Manufacturers charge high prices for non-standard models because they must develop new designs, create tools, and conduct costly type tests.

The selection of a compression system mainly depends on the needs of the end users, how those needs may change, the quantity of hydrogen to be supplied daily, and any transportation limitations.

You may need to choose and install different types of compressors based on the pressure and amount of hydrogen required. It's also essential to consider overall costs. Here are the key points for selecting and installing a hydrogen compression system:

- Ensure very good ventilation and eliminate any potential for mechanical or electrical sparks.

- Place the output valves of the compressor's delivery pipe under hydrogen leakage detection. If necessary, use upward ventilation near these valves to quickly carry away any leaked hydrogen.
- Store hydrogen in a separate room equipped with proper leakage detection devices.
- The compressor's capacity should match the daily requirements for hydrogen cylinders. It may be beneficial to have two compressors, each at 50 to 75% capacity, to ensure continuous hydrogen compression.
- Compressors are similar to those for other gases but differ in seal rings, the number of levels, non-return valves, safety valves, and setups for rapid upward diversion of hydrogen. A high safety factor is crucial.
- The hydrogen needs to be dry for proper compression.
- Ensure the availability of nitrogen or carbon dioxide cylinders for purging in case of emergencies.
- Include a device to check the purity of hydrogen after compression to detect any oil vapours mixed during the process.

Reference data

The following table gives data on compressors in NTPC projects for reference.

Project	**Hydrogen/ammonia production**	**Compressors**
GH2 mobility, Leh	80 kg/day, 11 hours	2 x 22 kW
GH2 Simhadri, AP	50 kg/day, 8 hours	2 x 37 kW
GH2, Mobility, Delhi	260 kg/day, 10 hours	2 x 110 kW
Green ammonia	9,100 kg/day, 24 hours	1 x 433 kW

Table: Compressors in Green hydrogen and green ammonia projects of NTPC

Precautions

Normally permit card (issued by operating personnel) system is followed to carry out any maintenance work. A compressor is a precision, high-speed mechanical piece of equipment. They require caution in operation to minimise hazards to themselves and their property.

Always follow these safety precautions:

- Never service the compressor or accessories while the unit is running.
- Always turn off the main power disconnect switch and lock it out before you work on the unit.

- Release all pressure from the system before servicing any part of the unit.
- Do not operate the unit if any safety guards, shields, or screens are removed.
- Do not take down any warning signs or the manufacturer's nameplate.
- Regularly check pressure relief valves to ensure they work properly.
- Only change the compressor operating settings with approval from the supplier. Contact the supplier for any changes.

Key components to consider are:

- The safety factor must be greater than 2. This means all parts should be able to handle at least double the storage pressure.
- Change seals after a certain number of hours of storage or when operating under pressure.
- Valves are crucial for a compressor's function. A reciprocating air compressor relies heavily on the suction filter, valves, and piston rings, so they need careful attention. Valves should be inspected and maintained regularly.
- The inlet or suction valve allows air to flow into the cylinder but prevents it from flowing back out. Failures of suction valves are the most common issues in a reciprocating compressor. Unloaders might be part of the suction valve assembly.

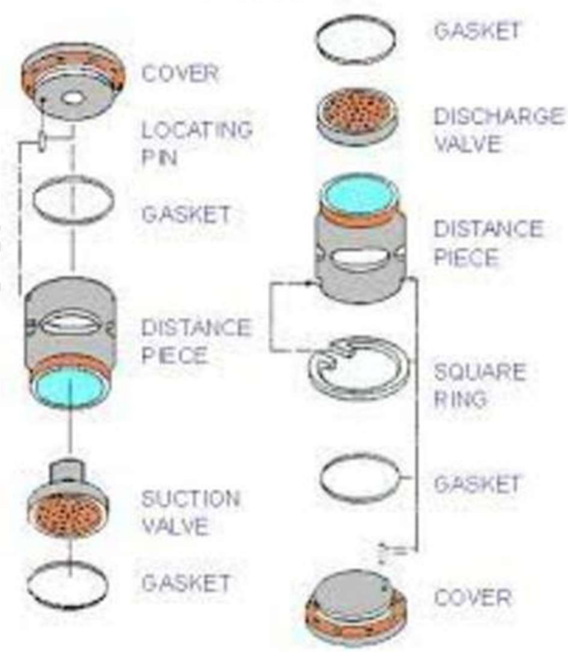

Fig. 2.22: Suction (inlet) and discharge (outlet) valves of reciprocating compressor, Outlet or discharge valve

The valve allows hydrogen to flow out of the cylinder but prevents it from coming back in. The most common failures in a reciprocating compressor are the suction and discharge valves. Sometimes, unloaders are part of the suction valve setup.

Pressure relief valve

A pressure relief valve keeps the pressure from going over a set limit. If the pressure exceeds this limit, the valve opens and releases excess hydrogen. The hydrogen pressure triggers the valve, so it doesn't need any electrical power to operate.

Once the pressure returns to normal, the pressure relief valve closes, stopping any further release of hydrogen.

Fig. 2.23: Hydrogen pressure relief valve Source:

Check the safety valve regularly to ensure it doesn’t leak. Keep in mind that the information provided is just an example. It might be different for hydrogen because it is very light.

Tank size

The size of the tank depends on how much hydrogen you need to store and the pressure in the tank. At normal pressure, 1 kg of hydrogen takes up 11 m^3 of space. If you increase the pressure in the storage tank, you can store a smaller volume of hydrogen.

$$P_1V_1 = P_2V_2 \text{ OR } P_1/P_2 = V_2/V_1$$

Based on this information, we determine the pressure and capacity of the storage tank. The pressure gauge on the storage tank helps us monitor hydrogen leaks over time. If the pressure decreases, it means that hydrogen is leaking.

Placement of the tank

You can place storage tanks outside or in a room, depending on available space and tank size. Make sure to leave enough space between storage tanks and keep high-pressure piping to a minimum. You must also install systems to monitor hydrogen pressure, firefighting systems, and CCTV monitoring.

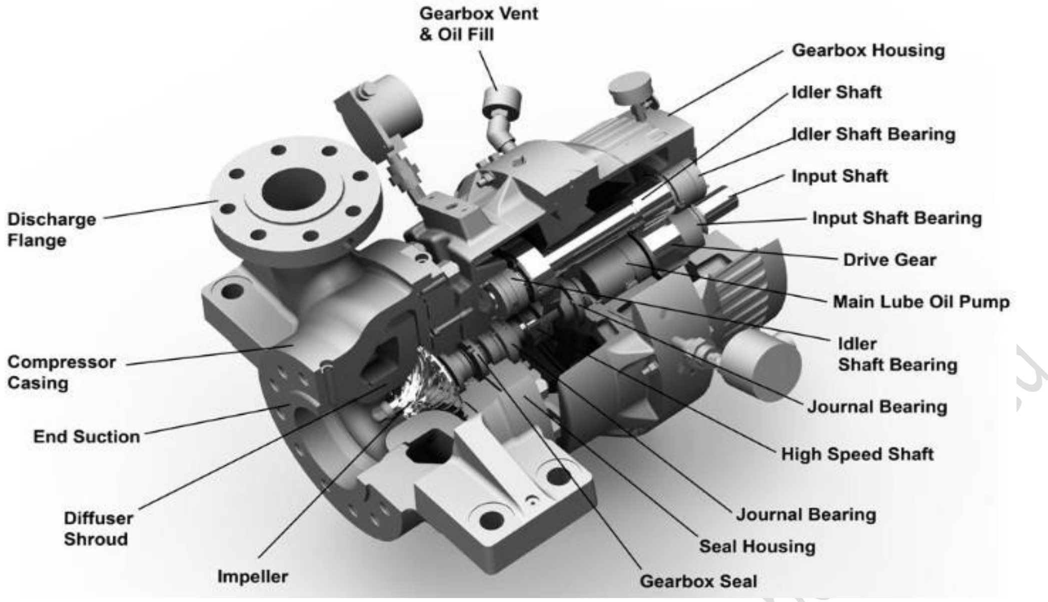

Fig. 2.24: Parts of a Centrifugal Compressor

Check Your Progress

A. Fill in the Blanks

1. The pressure range for hydrogen compressors can vary between **100 to 900 bars**.
2. Hydrogen must be **dry** before compression to ensure proper function and safety.
3. The **suction (inlet) valve** allows hydrogen to enter the compressor cylinder.
4. A **pressure relief valve** prevents the system from becoming over-pressurised.
5. The safety factor for compressor parts must be greater than **2**.

B. Multiple Choice Questions (MCQs)

1. **What is the minimum discharge pressure for lubricated hydrogen compressors?**
   a) 400 bar
   b) 225 bar
   c) 100 bar
   d) 900 bar

2. **Which of the following is NOT a valid safety precaution while working on a compressor?**

a) Lock out the main power before maintenance
b) Remove warning signs and labels
c) Check pressure relief valves regularly
d) Do not service the unit while it is running

3. **What is the function of the unloader in a reciprocating compressor?**
a) To clean hydrogen
b) To increase tank size
c) To reduce wear during start-stop operation
d) To ignite hydrogen safely

4. **Which component of a reciprocating compressor is most prone to failure?**
a) Suction and discharge valves
b) Pressure gauge
c) Motor
d) Tank foundation

5. **Why is good ventilation required in compressor installation areas?**
a) To make workers comfortable
b) To reduce energy bills
c) To increase flow rate
d) To remove leaked hydrogen safely

C. Short Answer Questions

1. Why is a safety factor important in hydrogen compression systems?
2. What are the two most common causes of failure in a reciprocating compressor?
3. How does a pressure relief valve work in hydrogen storage?
4. What considerations are important when selecting a hydrogen compressor?

D. Long Answer Questions

1. Explain the process of selecting a suitable hydrogen compressor for a green hydrogen plant.
2. Describe key safety precautions for operating and maintaining a hydrogen compressor.

3. Discuss the importance of tank size and pressure monitoring in hydrogen storage.
4. Compare different compressor setups used in NTPC green hydrogen projects.

MODULE 3 STORAGE UNIT

Module Overview

This module introduces the world of hydrogen storage. This module explains how hydrogen is safely stored and managed in different systems. Understanding what hydrogen storage is and why it's so important, especially in applications like fuel cell vehicles and clean energy solutions. Then, we discuss how to set up a hydrogen storage system step-by-step, including how the piping and storage layout is designed to ensure safety and efficiency. The module will also cover the different types of storage cylinders such as Type I, II, III, and IV and how to properly install them. We will explore various depressurisation methods, which help safely reduce pressure inside the system when needed. Finally, through key precautions and safety guidelines to follow when working with hydrogen, helping us to understand how to handle this powerful fuel smartly and securely. By the end of this module, we understand the hydrogen storage systems and how to work with them confidently and safely.

Learning Outcomes

On completion of this module, you will be able to:

- Understand the importance of hydrogen storage.
- Identify challenges in storing, handling, and transporting hydrogen.
- Choose and install the right hydrogen storage system.
- Follow key precautions for safe hydrogen storage.
- Apply safety standards and guidelines effectively.
- Understand the basic layout and piping arrangement of storage systems.
- Explain various hydrogen storage methods and setups.
- Describe safe depressurisation methods like water seals and vent stacks.

Module Structure

Session 1: Hydrogen Storage
Session 2: Setting Up a Hydrogen Storage System
Session 3: Architecture of Piping and Storage Layout
Session 4: Type of Cylinders and their Setting Up Method
Session 5: Depressurisation Methods of Hydrogen Storage System
Session 6: Precautions and Safety Guidelines for Hydrogen Storage

Session 1: Hydrogen Storage

Hydrogen is the lightest element on Earth. Unlike hydrocarbon fuels (like gasoline or natural gas), hydrogen is not usually stored as a liquid or gas. It has the highest energy content by weight, meaning it packs a lot of energy for its size. However, it has the lowest energy content by volume, making storage and transport difficult. To use hydrogen as a clean energy source, we need cost-effective storage solutions. Right now, storing hydrogen is more expensive than storing traditional fuels.

A global plan is underway to produce green hydrogen, made using renewable energy (like wind and solar) to power electrolysis (splitting water into hydrogen and oxygen). But renewable energy isn't always availableit changes with weather and location. This means hydrogen production must match when energy is available, creating uncertainty in supply.

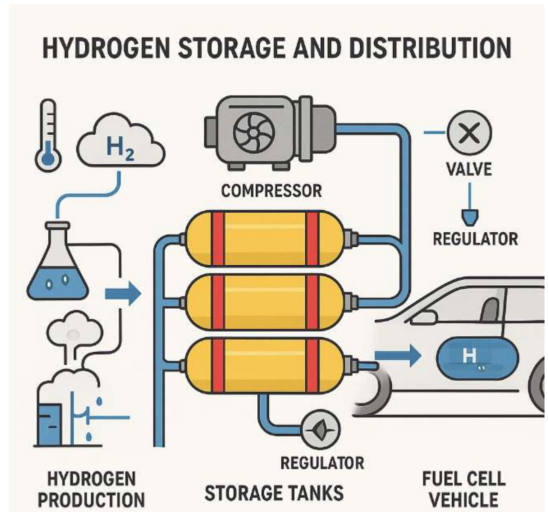

Fig. 3.1: Hydrogen storage and distribution

To solve this, we need good storage systems. One idea is to build fixed storage facilities near hydrogen production plants. These would store extra hydrogen when production is high and release it when needed, ensuring a steady energy supply.

Hydrogen storage is a key technology for advancing hydrogen and fuel cell systems. Without effective storage, hydrogen cannot replace fossil fuels in many applications. There are different ways to store hydrogen, depending on its use:

Types of Hydrogen Storage:

1. Stationary Storage – Used in places like:
    a. Power plants
    b. Refuelling stations
    c. Hydrogen production facilities
2. Portable/Mobile Storage – Used for vehicles, such as:
    a. High-pressure tanks in buses and trucks
3. Transportation Storage – Used to move hydrogen safely, including:
    a. Liquid hydrogen in cryogenic (super-cooled) tanks
    b. Compressed gas in tanker trucks

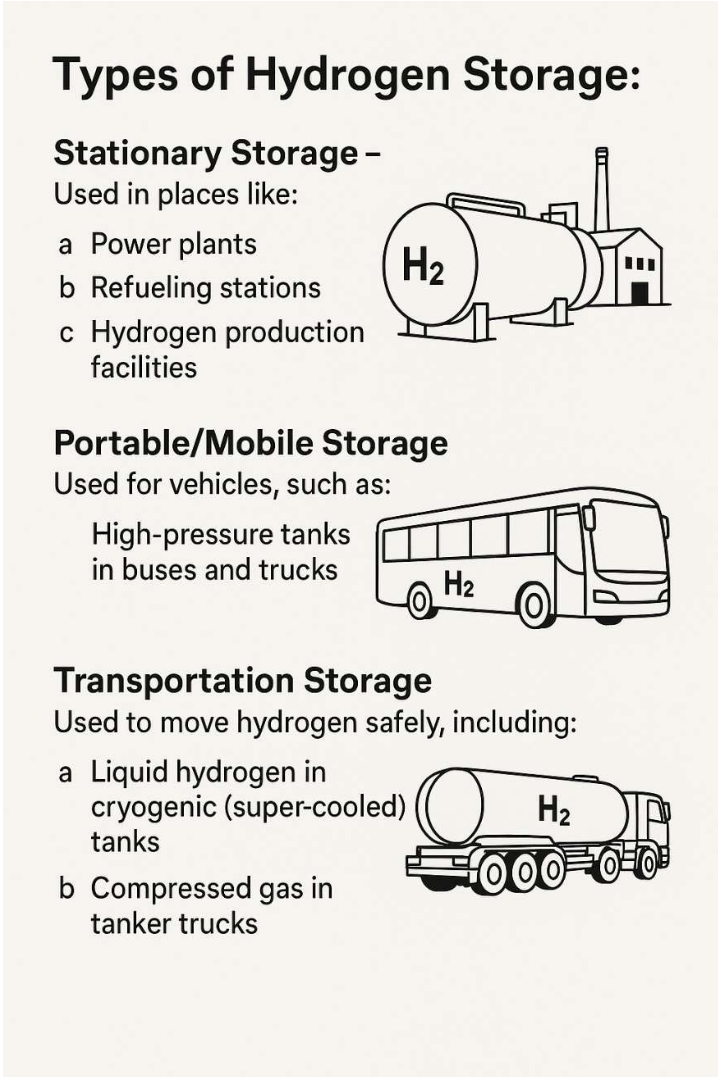

Fig. 3.2: Types of Hydrogen Storage

Hydrogen could replace fossil fuels in many industries, but it must be stored safely and efficiently first. The hydrogen storage market was worth $14.72 billion in 2021 and is expected to grow to $26.94 billion by 2030, at a 7.1% annual growth rate.

Challenges in Storing Hydrogen

Storing hydrogen is difficult because it is an extremely light gas. To store it efficiently, we need to keep it at very low temperatures or under high pressure, both of which require advanced technology. Currently, compressed hydrogen gas is stored in metal tanks, but this leads to a problem called hydrogen embrittlement, where the metal becomes weak and brittle over time, increasing the risk of leaks or ruptures.

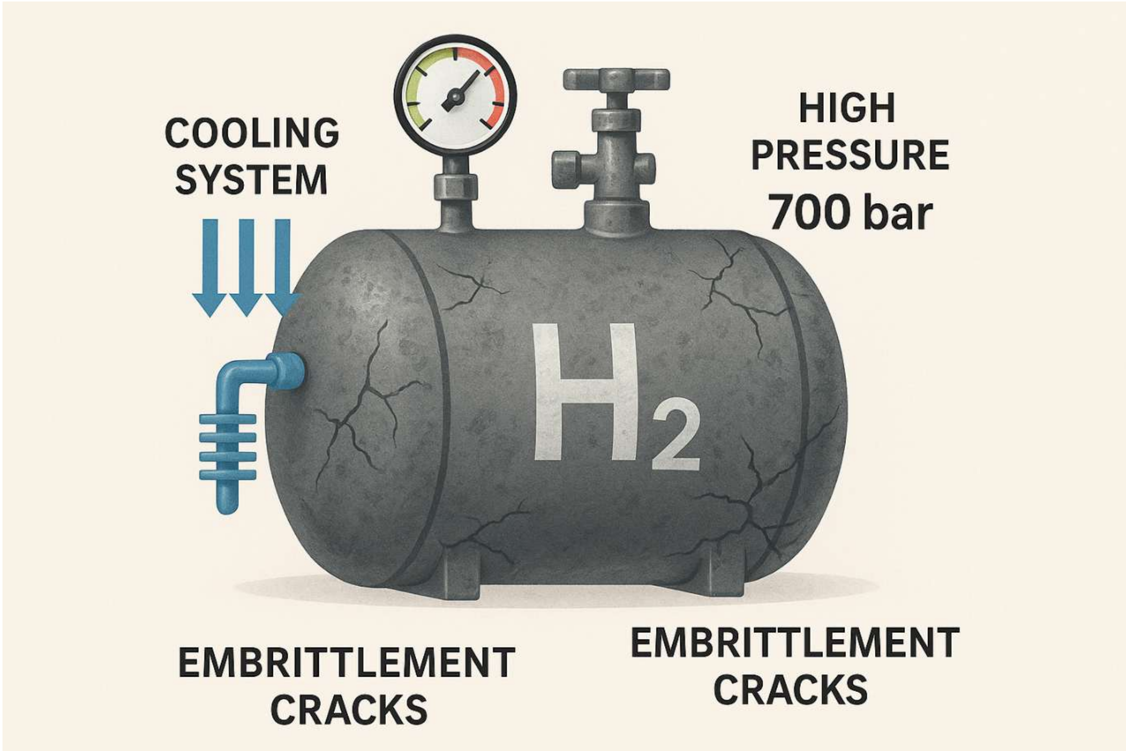

Fig. 3.3: Challenges in storing Hydrogen

Safety is a major concern because embrittlement weakens storage tanks. To detect this issue, modern inspection methods, like magnetic sensors and digital cameras, are needed to check for damage. Researchers are working on better storage solutions to prevent these problems and make hydrogen tanks safer and more reliable.

Another challenge is high-density storage, especially for vehicles. Most current storage systems take up too much space because hydrogen is stored as a gas. For large vehicles (like trucks or buses), this isn't as big of an issue, but for smaller cars, fitting enough hydrogen for a 500 km driving range is difficult. Some fuel-cell vehicles today use high-pressure tanks made of strong composite materials, but these are bulky and heavy.

Hydrogen has three times more energy per kilogram than gasoline, but it takes up much more space. For example, while gasoline holds 32 megajoules per liter (MJ/L), liquid hydrogen only holds 8 MJ/L. To match the range of gasoline cars, a hydrogen vehicle needs 5–13 kg of hydrogen stored onboard.

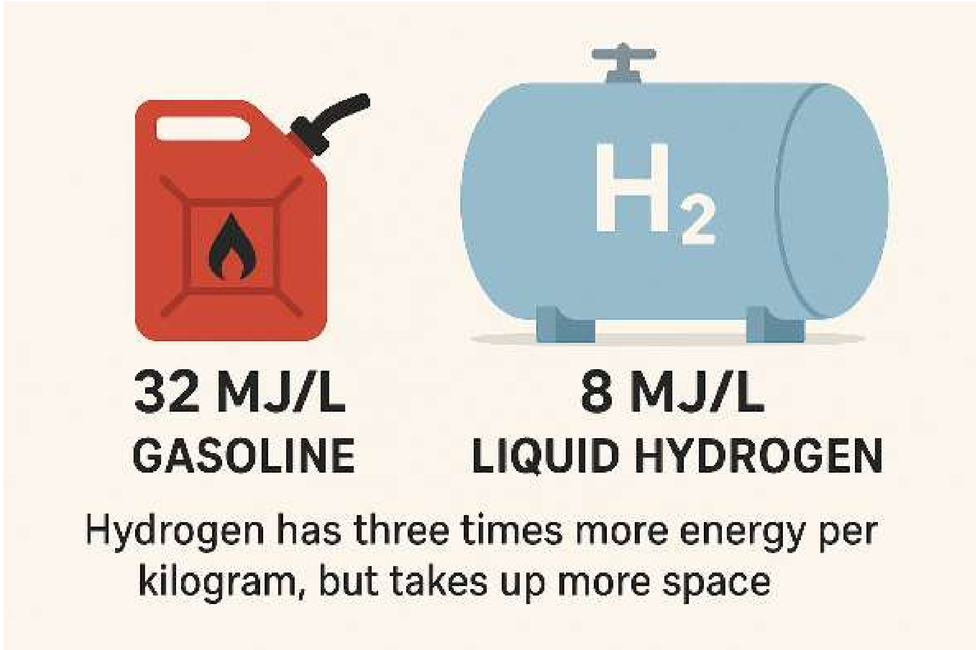

Fig. 3.4: Hydrogen has three times more energy per kilogram than gasoline

However, the tanks required for this add significant weightup to 100 kg for just 5 kg of hydrogenand must withstand extreme pressures (500–700 bars), making them expensive and potentially risky. Researchers continue to explore better storage methods to overcome these challenges and make hydrogen a practical alternative to fossil fuels.

The following figure shows the effect of pressure on the volume of hydrogen:

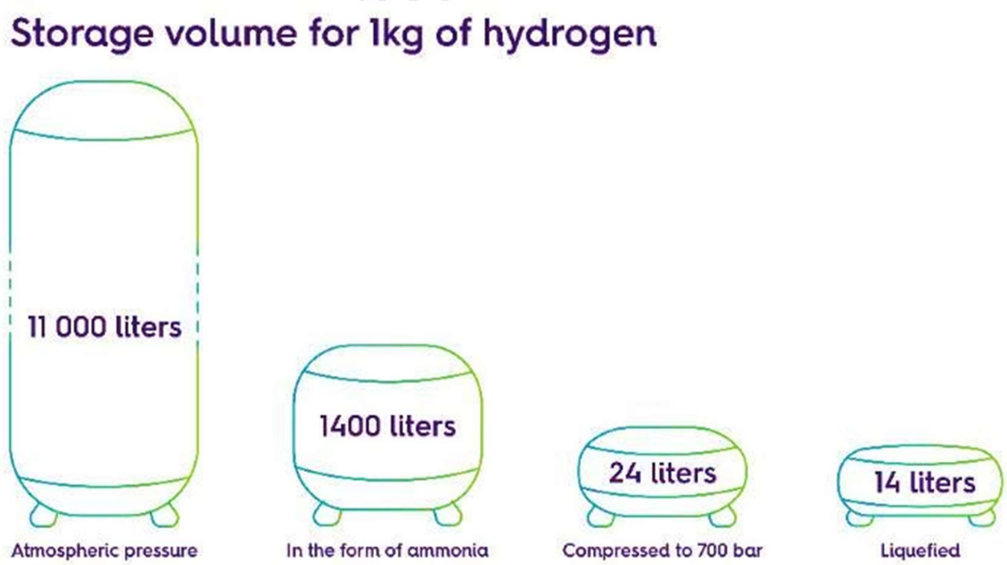

Fig. 3.5: Storage volume of 1 kg of hydrogen at NTP

The challenges in handling and transporting hydrogen are:

Handling hydrogen is not as easy as it may seem. Although hydrogen is a clean and powerful fuel, it has a very low energy density by volume. This means it takes up a lot of space unless it is compressed. To use hydrogen in vehicles, it must be stored in tanks at very high pressuresbetween 350 bar and 700 bar. Just to travel around 600 kilometres, a car needs about 5 to 6 kilograms of hydrogen. That may not sound like much, but safely packing that amount into a small tank is a big challenge. Besides storage, transporting hydrogen from the production site to the point of use brings more difficulties. The main goals are to lower the transportation cost, improve energy efficiency, keep hydrogen pure and prevent any leakage. A small leak during storage or transportation can be dangerous and waste valuable fuel.

In a country like India, using pipelines to transport hydrogen could be the most affordable and efficient option in the future. However, building a nationwide pipeline network requires huge investments and advanced technology. These are big hurdles that need to be overcome. The processes like Liquefaction, Refrigeration and Regasification are costly and energy-intensive. So, while hydrogen has great potential as a clean fuel, storing and moving it around is still a major technical and economic challenge.

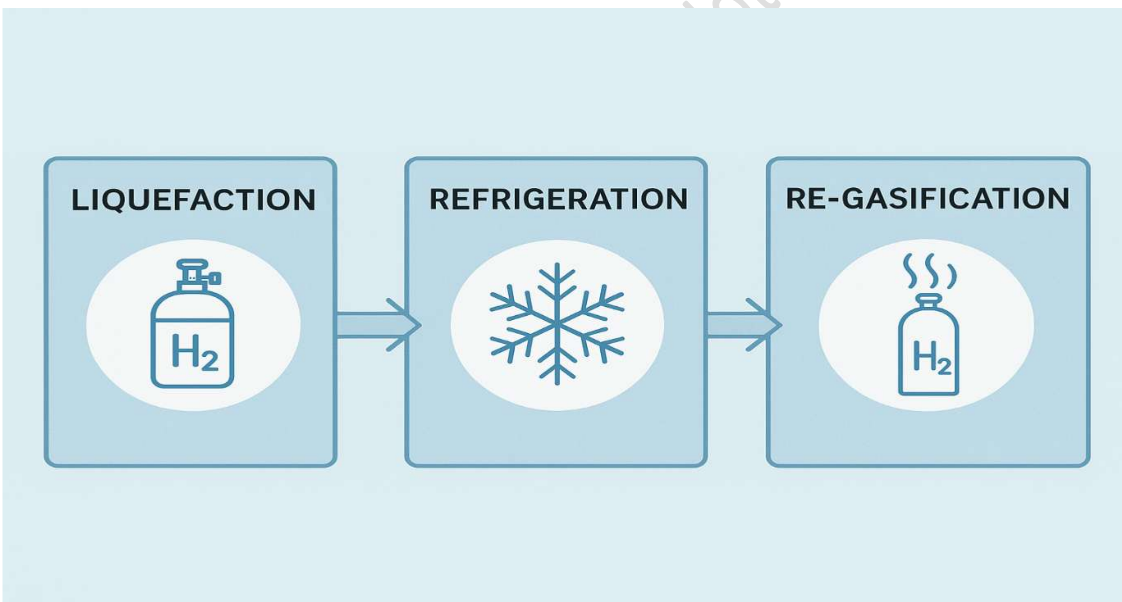

Fig. 3.6: Liquefaction, Refrigeration and Regasification

The process of turning hydrogen into a liquid form is known as ***Liquefaction.***

*K*eeping the hydrogen in a cold condition during shipping is known as ***Refrigeration.***

Converting Hydrogen back into a gas is known as ***Regasification.***

The table illustrates a comparison of various modes of transportation based on distance and the quantity of hydrogen utilised.

Technology	Year	Cost (Rs/kg)	Remarks
Transportation pipeline	2020	2.2	Distance 50 km, 1000 t/day
	2050	1.5	Distance 50 km, 1000 t/day
Distribution pipeline	2020	6.7	Distance 50 km, 100 t/day
	2050	5.2	Distance 50 km, 100 t/day
Truck	2020	11.8	Distance 50 km, 700 kg capacity
	2020	40.0	Distance 50 km, 200 kg capacity

One of the biggest roadblocks to building a successful hydrogen economy is the lack of good storage options. Without safe, efficient, and affordable ways to store hydrogen, it is hard to use it widely in vehicles or other systems. Right now, there are several key challenges that need to be solved. The durability of the materials used for storing hydrogen must last long and perform well over time, but many current systems wear out too soon. Then there's efficiency that storing and distributing hydrogen often wastes energy, and the process is not always reliable. Another issue is refuelling time. For hydrogen-powered vehicles to be practical, they need to be refuelled as quickly as petrol or diesel vehicles, but that's not yet possible in most cases. The cost is also a major concern. Storage systems for vehicles are still too expensive, making hydrogen an unrealistic choice for most people. Lastly, the volume and weight of storage systems are high, which affects how far a hydrogen vehicle can travel. To make hydrogen truly useful, we need storage systems that are lighter and more compact, yet still strong and affordable.

Check Your Progress

A. Multiple Choice Questions (MCQs):

1. Why is hydrogen storage considered challenging?
   A. Hydrogen has a low energy content by weight
   B. Hydrogen requires no special storage conditions
   C. Hydrogen is heavy and hard to move
   D. Hydrogen has low energy content by volume

2. Which of the following is a major challenge in hydrogen storage systems?
   A. Hydrogen is too expensive to produce
   B. Hydrogen embrittlement in metal tanks
   C. Hydrogen cannot be liquefied
   D. Hydrogen reacts with solar energy

3. What is the process of converting hydrogen into gas after being stored as liquid called?
   A. Compression
   B. Electrolysis
   C. Regasification
   D. Refrigeration

4. Which of the following storage methods is suitable for vehicles like buses and trucks?
   A. Stationary storage
   B. Liquid cryogenic tanks
   C. High-pressure mobile storage
   D. Underground pipelines

B. Fill in the Blanks:

1. Hydrogen has the highest energy content by weight, but the **lowest energy** content by volume.
2. The process of turning hydrogen into a liquid is called **Liquefaction,** and converting it back to gas is called **Regasification.**
3. One of the major risks in hydrogen storage is hydrogen **embrittlement,** which weakens metals over time.
4. In India, **pipelines** are considered a future affordable method for transporting hydrogen.

C. Short Answer Questions

1. Why is hydrogen considered a powerful fuel despite its storage challenges?
2. What are the main uses of stationary hydrogen storage?
3. What is hydrogen embrittlement and why is it dangerous?
4. Why are current hydrogen vehicle storage systems not suitable for small cars?

D. Long Answer Questions

1. Discuss the key challenges faced in the storage and transportation of hydrogen.
2. Explain how green hydrogen is produced and why its production needs effective storage systems.

Session 2: Setting Up a Hydrogen Storage System

Hydrogen Storage Methods

Hydrogen can be stored in different ways, and the method chosen depends on several factors, like whether the hydrogen will be used in a stationary setup (such as a power plant) or in moving vehicles (like buses and trucks). For example, storing hydrogen as compressed gas is a common method for road vehicles such as passenger cars, buses, and heavy-duty trucks. On the other hand, liquid hydrogen, which is stored at extremely low (cryogenic) temperatures, is used to launch rockets into space, and this method has been in use for many years. The choice of storage also depends on the infrastructure available. For instance, road vehicles need hydrogen refuelling stations, which influence the type of storage systems used.

Some of these are shown in the following figure:

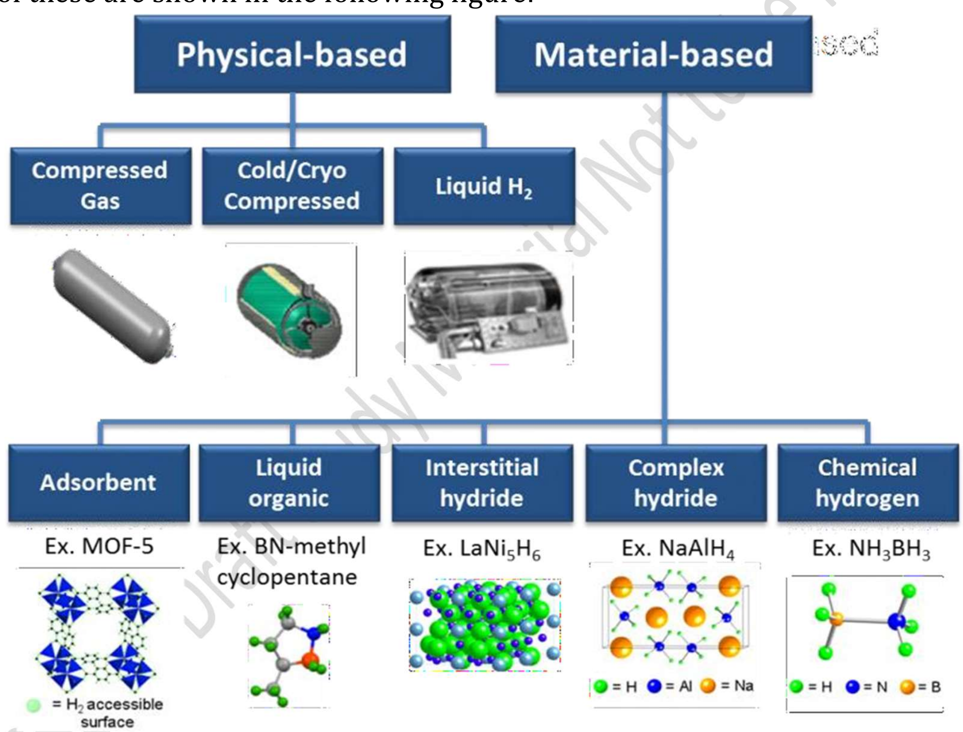

Fig. 3.7: Hydrogen storage methods

Different Methods for Storing Hydrogen

The way hydrogen is stored can vary depending on who produces and uses it. Factors like quantum aspects may also play a role. For example, if a thermal power plant both produces and uses hydrogen, its storage solutions might change based on its specific needs.

It is important to carefully place hydrogen storage tanks for safety, ensuring they are far away from homes. A good example is the NTPC Simhadri Thermal Power Plant in India, which runs a green hydrogen project that produces 50 kg of hydrogen each day. This project shows the progress being made in hydrogen storage and use on a large scale in India.

The accompanying figure shows a truck that carries 48 Type 1 cylinders, each holding 100 kg and weighing 149 kg. This gives us an idea of the logistical side of hydrogen storage solutions.

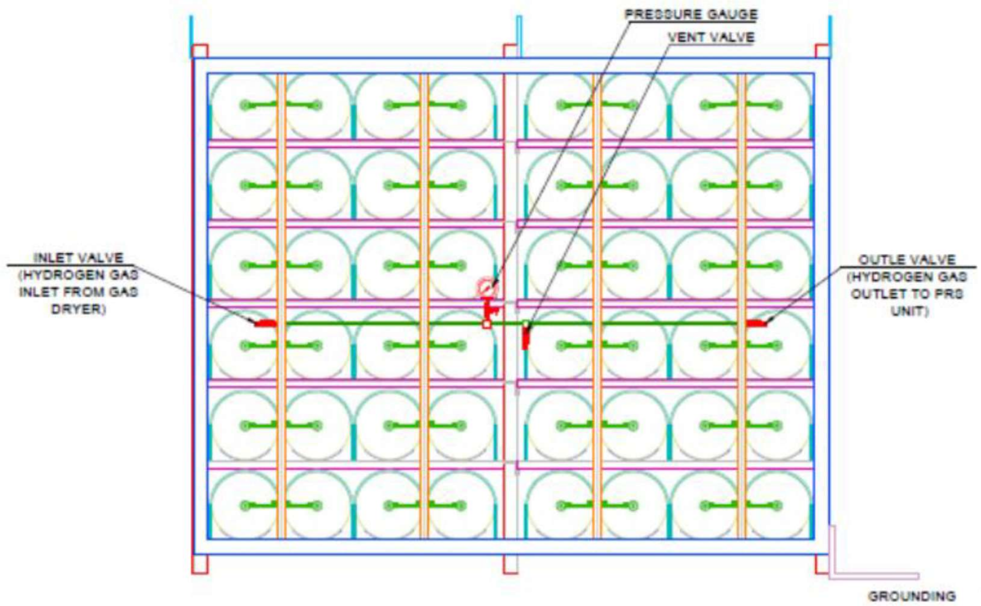

Fig. 3.8: Hydrogen gas cylinders loaded on a trailer

The NTPC mobility project in Leh aims to produce green hydrogen. It generates 80 kg of hydrogen per day and operates for 11 hours. To store the hydrogen, the project uses two compressors, each with a power capacity of 22 kW.

Cascade Filling System

This system efficiently stores high-pressure gas cylinders and is used to refuel smaller compressed gas cylinders. Typically, large cylinders are filled using a compressor, but the Cascade Filling System allows smaller cylinders to be filled without a compressor. This system enables a low-capacity compressor to fill multiple small cylinders quickly and efficiently. It also reduces how often the main compressor has to start and stop, helping to keep it working well and last longer. You can see a similar setup in the compressor tank used at a puncture shop.

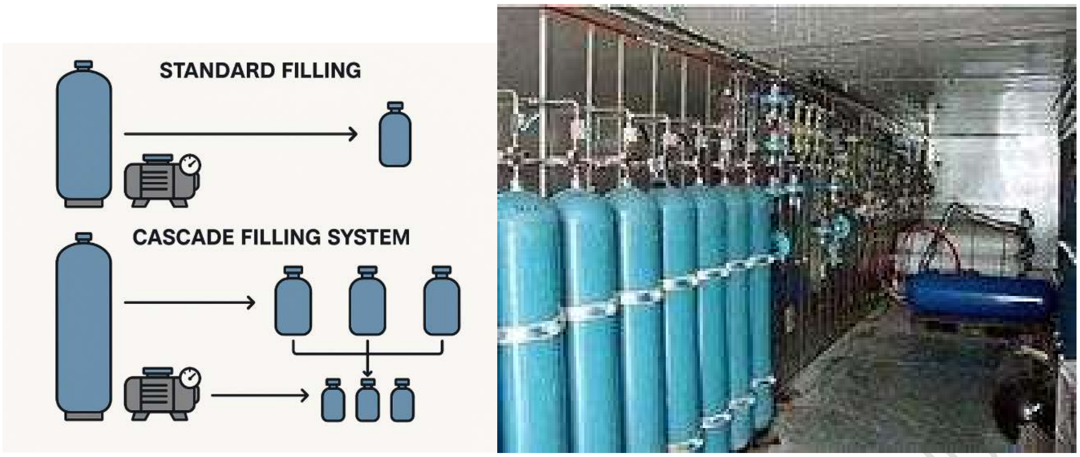

Fig. 3.9: Hydrogen cylinders cascade filling

Portable Storage

Physically, hydrogen can be stored as a liquid or a gas:

- **Gas**: Hydrogen should normally be stored in high-pressure tanks operating at 350–700 bars.
- **Liquid:** Hydrogen should be stored as a liquid at cryogenic temperatures of 252.8°C at 1 bar.
- **Solid (Chemical):**
    - **Adsorption:** Hydrogen is stored on the surface of solids
    - **Absorption:** Hydrogen is stored within solids.

The following figure shows hydrogen in gaseous form, being refuelled in high-pressure storage portable tank:

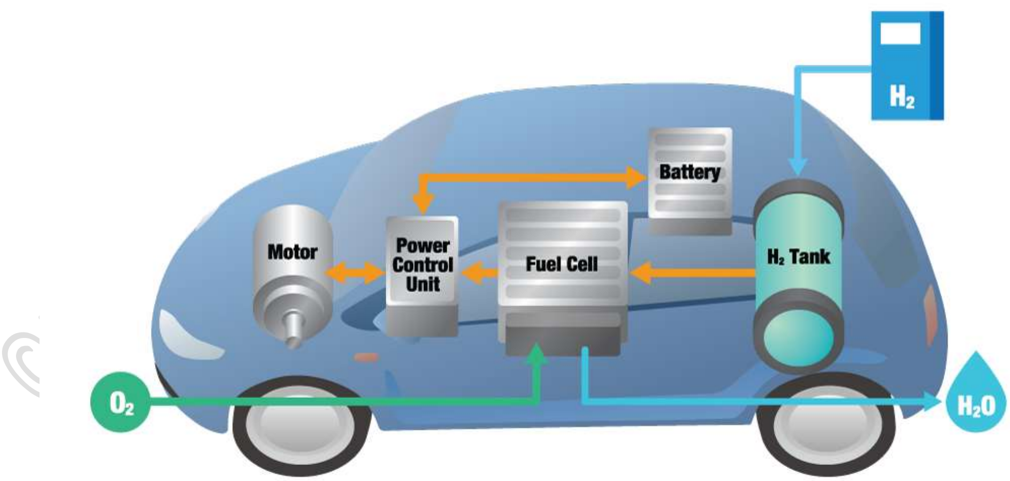

Fig. 3.10: Hydrogen gas refuelling in a high-pressure storage portable tank

Hydrogen Tube Trailer

Hydrogen tube trailers are semi-trailers that comprise 4 to 36 cluster high-pressure hydrogen tanks. These tanks vary in length from 6 to 16 metres, approximately and can be used to carry 4 to 36 cluster high-pressure hydrogen tanks.

Fig. 3.10: Hydrogen tube trailer

Selection of Hydrogen Storage System

Choosing a hydrogen storage system mainly depends on how much hydrogen you need to store. For most situations, compressing hydrogen gas is a cost-effective choice. However, if you need to store more than 5 tonnes of hydrogen per day, it is usually cheaper to store it in liquid form. Economic and safety considerations are key factors in deciding on a hydrogen storage method, along with the potential losses linked to each method. Storage options fall into two categories: mobile and stationary.

Losses in Hydrogen Storage

Here are the losses associated with different hydrogen storage methods:

S.No.	Storage Capacity	Storage Mode	Type of Loss	Loss per Day
1	50 m^3	Liquid	Boil off	0.4%
2	100 m^3	Liquid	Boil off	0.2%
3	20,000 m^3	Liquid	Boil off	0.06%
4	Applicable to s.no. 1, 2, 3	Liquid	Uploading	5%

A. Stationary Storage:
This type of storage is commonly used at production plants, gas filling stations, and by small-scale users like those in the food and semiconductor industries. Bulk users typically install stationary storage tanks that are designed based on how they receive hydrogen.

B. Mobile Storage:
Mobile storage is vital for transporting hydrogen in bulk and for hydrogen-fueled

vehicles. Cylinder-type storage is flexible and can be used for both stationary and mobile needs, making it easy to refill cylinders as they are used. Hydrogen producers who also use hydrogen often select super thermal power plants for storage.

Installation of Hydrogen Storage Systems

When installing a hydrogen storage system, specific requirements depend on its type:

A. Stationary Storage:

Stationary hydrogen storage systems are used at fixed locations like hydrogen production plants, refueling stations, and power generation units. To set up such a system safely and effectively, the first step is to prepare a strong and stable foundation that can support the weight of the storage tanks and related equipment. Once the foundation is ready, protective structures and a proper layout for water spray cooling must be arranged, especially in case of overheating or fire.

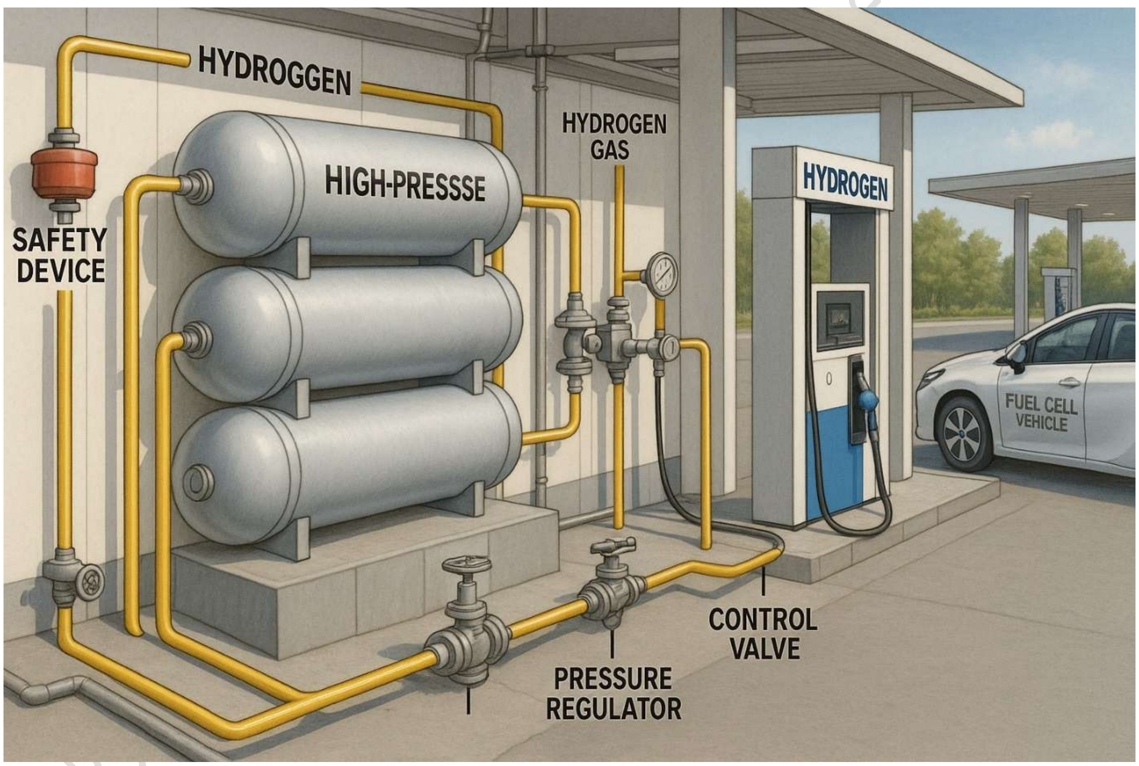

Fig. 3.11: Stationary hydrogen storage

One of the most important safety features in a stationary hydrogen storage system is the hydrogen leak detection system. Since hydrogen is a highly flammable gas, even a small leak can be dangerous. Therefore, detectors should be placed near all key areas, especially around joints, valves, and pipelines where leaks are more likely. These detectors must be sensitive enough to identify not only leaks from faulty valves but also those caused by material degradation over time due to hydrogen embrittlement (a process where metal becomes weak and cracks due to long-term hydrogen exposure).

The system should also include input and outlet valves, safety relief valves, pressure gauges, and alarm systems. The alarms must be capable of signaling high-pressure conditions (to prevent explosions) as well as low-pressure situations (which could indicate a leak or system failure). Automatic tripping mechanisms should shut down operations in case of excessive pressure or hazardous leaks.

The following figure shows the stationary storage of compressed hydrogen gas in open air.

Fig. 3.12: Storage of compressed hydrogen gas in open air

B. Mobile storage:

Mobile hydrogen storage refers to the storage of hydrogen in transportable units, such as cylinders or tanks mounted on trucks or trailers. These systems are designed to safely deliver hydrogen from production sites to places where it is needed, like refuelling stations or industrial facilities. While they follow safety monitoring standards similar to stationary storage, such as leak detection, pressure control, and alarm systems, they also have additional requirements due to their mobile nature.

Fig. 3.13: Mobile hydrogen storage

One key requirement is the easy and safe removal and replacement of hydrogen cylinders. The system should be designed in a way that allows operators to connect and disconnect the cylinders quickly and safely without risking gas leaks or injury. Secure mounting and proper labelling of each cylinder are also important.

Since these units are constantly on the move, the installation setup must be shock-proof and jerk-proof to prevent damage during transportation on rough roads or in case of sudden stops. The entire system should also be flame-proof and spark-proof to avoid any risk of ignition, especially during loading, unloading, or in case of an accident.

Fig. 3.14: Shock proof

Mobile storage units should have proper ventilation, temperature control, and fire suppression systems. Operators must be trained to handle emergencies, and vehicles must carry safety documents, warning signs, and emergency contact information.

Check Your Progress

A. Multiple Choice Questions (MCQs):

1. Which hydrogen storage method is typically used for launching rockets?
   A. High-pressure cylinders
   B. Liquid hydrogen at cryogenic temperatures
   C. Solid-state storage
   D. Cascade filling system

2. What is the key function of the cascade filling system in hydrogen storage?
   A. Liquefy hydrogen for long-term use
   B. Store hydrogen in underground tanks
   C. Fill small cylinders efficiently using larger cylinders
   D. Compress hydrogen into solid form

3. At what pressure range is hydrogen usually stored in portable high-pressure tanks?
   A. 350–700 bar
   B. 150–300 bar
   C. 50–100 bar
   D. 800–1200 bar

4. Why must mobile hydrogen storage systems be shock-proof and jerk-proof?

A. To reduce the cost of hydrogen transport
B. To allow remote monitoring
C. To store more hydrogen in less space
D. To prevent damage during transportation

B. Fill in the Blanks:

1. Hydrogen in liquid form is stored at **cryogenic** temperatures of -252.8°C at 1 bar pressure.
2. Mobile storage is used for transporting hydrogen using **cylinders** or trailers.
3. In stationary hydrogen storage, hydrogen **leak detectors** are essential for safety, especially around valves and pipelines.
4. **A cascade filling** system helps fill smaller cylinders without the constant need for a compressor.
5. Storage systems for hydrogen must be flame-proof and spark-proof to ensure safety during transportation and operation.

C. Short Answer Questions

1. What is the purpose of using a cascade filling system in hydrogen storage?
2. Why should hydrogen storage tanks be placed away from residential areas?
3. What are the key differences between mobile and stationary hydrogen storage systems?
4. Why is ventilated and temperature-controlled storage important in mobile hydrogen units?

D. Long Answer Questions

1. Describe the safety features required in a stationary hydrogen storage system.
2. Explain the characteristics and safety measures required for mobile hydrogen storage systems.

Session 3: Architecture of Pipes and Storage Layout

Piping Arrangement

In a hydrogen storage system, the piping arrangement is typically divided into two main sections: before storage and after storage. The piping before storage is used to carry the hydrogen gas right after it is produced, for example, from an electrolyser, to the storage tanks. This part of the pipeline handles freshly generated hydrogen and must be designed to ensure safety and efficiency.

The piping after storage is used to transport hydrogen from the storage tanks to consumers. This may include local distribution within the plant or delivery to external users. This section of piping is generally short, simple, and located near the exit gate of the facility. Its main function is to ensure that the stored hydrogen reaches the end user safely.

Importantly, output pipelines are often installed at a higher elevation. This safety feature helps any leaked hydrogen rise and disperse into the atmosphere quickly, since hydrogen is lighter than air. Because of this, smoking, open flames, or any spark-producing activities near these pipelines are strictly prohibited. To prevent physical damage, the pipelines are also well shielded and supported.

Fig. 3.15: An indicative piping of a hydrogen storage and transport system

As shown in Fig. 3.15, hydrogen pipelines must be carefully designed to support safe storage and transport. As per the Hydrogen Pipelines needs to be on overcoming technical concerns related to pipeline transmission

- Hydrogen can weaken the steel and welds used in the pipeline over time, a phenomenon known as hydrogen embrittlement.
- Preventing hydrogen leaks and gas penetration through materials is essential to avoid accidents.

- There is a growing need for affordable, reliable, and durable compression technologies to safely transport hydrogen over long distances.

In industries where hydrogen is consumed, usually small-scale storage and piping systems are used. These setups must be installed at a safe distance of at least 5 meters from the main hydrogen utilisation area.

The user point (where hydrogen is finally used) must be completely free of any fire, sparks, or ignition sources. Every area where hydrogen is stored or used must have proper ventilation to prevent gas buildup. Also, only trained and authorised personnel should monitor the use of hydrogen and respond to any safety concerns. Regular inspection, testing, and monitoring are critical for ensuring that the hydrogen storage and pipeline system remains safe and functional at all times.
The following figure shows an example of the layout of a hydrogen production plant and its consumers.

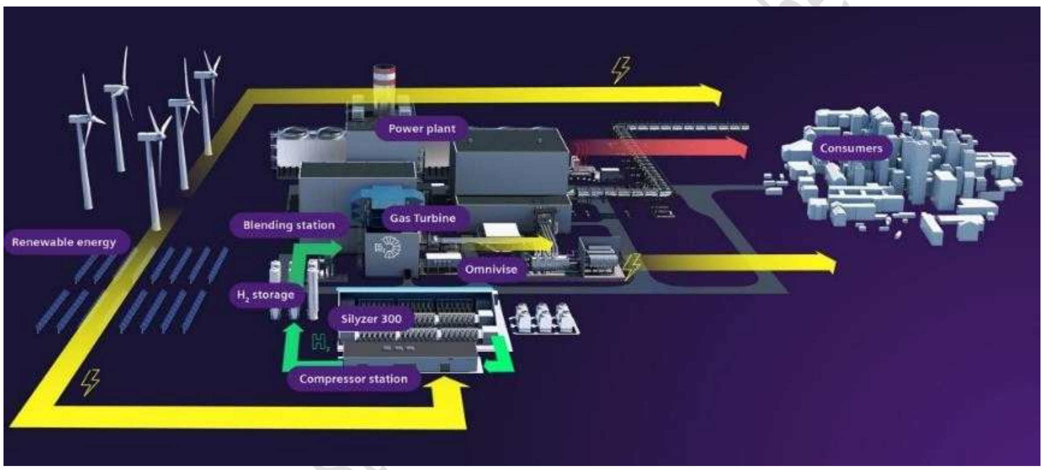

Fig. 3.16: Green Hydrogen production plant and gas power plant with hydrogen storage

Check Your Progress

A. Multiple Choice Questions (MCQs):

1. Why are hydrogen output pipelines installed at a higher elevation?
   A. To avoid corrosion
   B. To reduce storage pressure
   C. To allow leaked hydrogen to rise and disperse
   D. To increase flow speed

2. What is the phenomenon where hydrogen weakens metal pipelines over time called?
   A. Hydrogen corrosion
   B. Hydrogen leakage
   C. Hydrogen diffusion
   D. Hydrogen embrittlement

3. What is strictly prohibited near hydrogen pipelines?
   A. Painting
   B. Open flames and sparks
   C. Welding support brackets
   D. Noise-generating equipment

4. What is a major challenge in long-distance hydrogen transport via pipelines?
   A. Lack of colour coding
   B. Compressing hydrogen reliably and affordably
   C. Too much space requirement
   D. Overheating of hydrogen

B. Fill in the Blanks:

1. Hydrogen output pipelines are often placed at **higher elevations** to help leaked hydrogen disperse quickly into the atmosphere.
2. Only trained and authorised **personnel** are allowed to monitor and handle hydrogen storage and piping systems.
3. A **minimum** distance of 5 meters must be maintained between the hydrogen storage system and the point of hydrogen use.
4. Proper ventilation is necessary to avoid hydrogen gas buildup in storage or usage areas.

C. Short Answer Questions

1. What are the two sections of piping in a hydrogen storage system?
2. Why is it important to shield and support hydrogen pipelines?
3. What kind of safety features should be present in areas where hydrogen is used?
4. Why must hydrogen pipelines be regularly inspected and monitored?

D. Long Answer Questions

1. Explain the importance of proper piping arrangement in a hydrogen storage system.
2. What are the key safety challenges in the hydrogen pipeline system, and how can they be addressed?

Session 4: Type of Cylinders and their Setting Up Method

Types of Hydrogen Cylinders

Hydrogen can be stored in different types of cylinders depending on the pressure requirements and how the storage material reacts to hydrogen. The selection of the right cylinder type depends mainly on how long hydrogen needs to be stored and at what pressure. Hydrogen storage cylinders are commonly used at production plants, fuel stations, and in industries or vehicles that use hydrogen as a fuel.

There are four main types of hydrogen cylinders, each with different construction materials, features, and suitable applications:

Cylinder Type	Materials	Features	Applications	Hydrogen storage pressure and mass percentage (wt%)
Type I	All metal (usually steel or aluminums)	Very heavy but strong. No corrosion up to 20 bars of hydrogen pressure.	Suitable for industrial uses, but not fit for vehicles due to weight.	17.5–20 MPa; around 1 wt% hydrogen by weight
Type II	Metal liner with hoop-wrapped fiber composite	Still heavy. Limited lifespan due to internal corrosion.	Not suitable for vehicles	26.3–30 MPa
Type III	Metal liner with full composite fibre wrapping	Much lighter, high burst pressure, no hydrogen leakage, but may have galvanic corrosion between metal and fiber.	Good for vehicular use (like hydrogen cars and buses). Offers 25–75% higher capacity than Type I or II.	At 35 MPa: 3.9 wt% At 70 MPa: 5 wt%
Type IV	Plastic liner with full composite fiber wrapping (usually carbon fiber)	Lightweight, durable, resistant to damage from repeated filling and emptying (no creep fatigue). Some hydrogen permeation can occur.	Ideal for modern vehicles and long-term use	70 MPa; more than 5 wt%

Construction of Hydrogen Cylinders

The structure of these cylinders varies by type. The following diagrams (Fig. and Fig.) show:

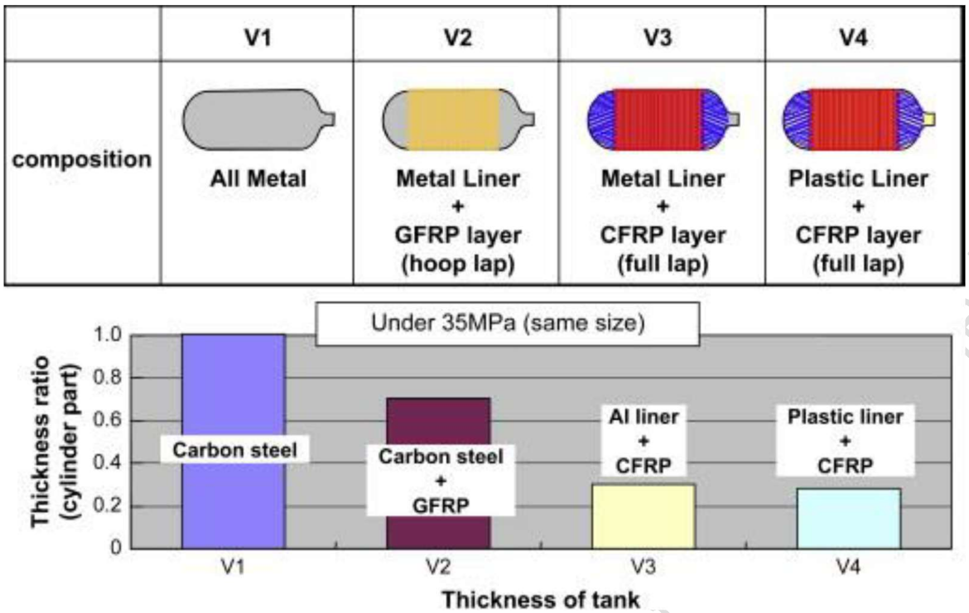

Fig. 3.17: Four Types of Hydrogen Cylinders

The internal layers and materials used in all four types.

A detailed view of a Type IV high-pressure tank, typically made from carbon fiber composites, with parts like the plastic liner, fiber wrap, and protective layers.

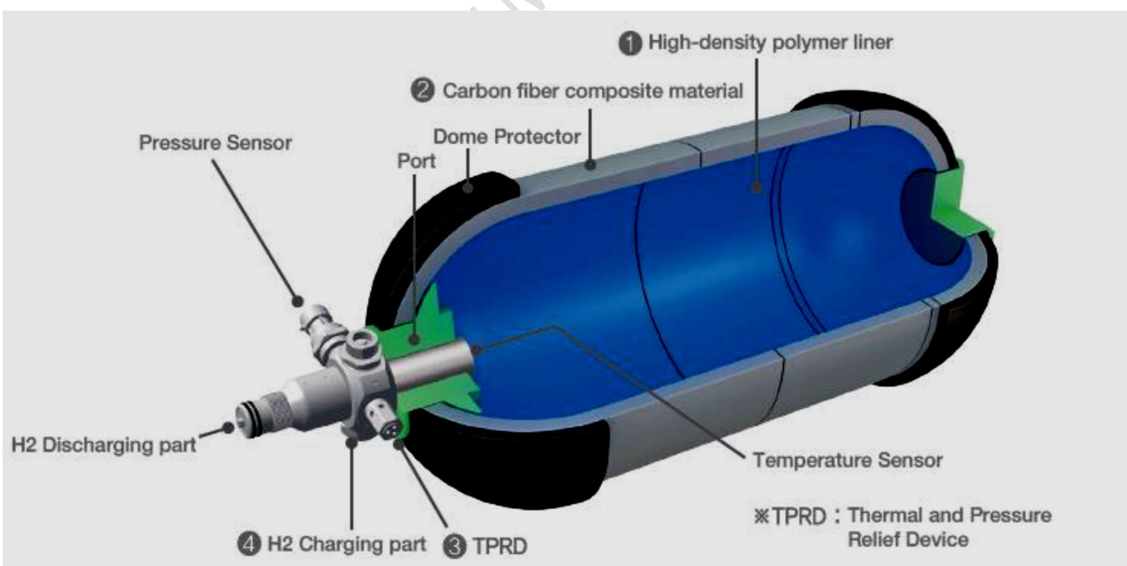

Fig. 3.18: High-Pressure Hydrogen Storage Cylinder

These materials help ensure safety, strength, and longevity even under high pressures.

Standards for Cylinder and Valve Materials

To ensure hydrogen cylinders are safe and reliable, they must meet international and national standards. Some important standards include:

Standard	Title
ISO 11114-1: 2020	Compatibility of metallic materials with hydrogen gas
ISO 11114-2: 2013	Compatibility of non-metallic materials with hydrogen gas
ISO 11114-4: 2017	Test methods to select hydrogen-embrittlement-resistant steels
Gas Cylinders Rules, 2016 Indian legal regulations (as amended from time to time)	

These standards help choose the right materials and construction methods for cylinders and valves to avoid issues like hydrogen embrittlement, leaks, and mechanical failure.

Check Your Progress

1. Multiple Choice Questions:

1. Which type of hydrogen cylinder is ideal for modern hydrogen vehicles due to its lightweight and durability?
   A. Type I
   B. Type II
   C. Type III
   D. Type IV

2. Which hydrogen cylinder type has a metal liner and is fully wrapped with composite fiber?
   A. Type I
   B. Type II
   C. Type III
   D. Type IV

3. What is the main disadvantage of Type I hydrogen cylinders?
   A. Too heavy for vehicle use
   B. Poor burst strength
   C. Hydrogen leakage
   D. Plastic liner degradation

4. Which ISO standard focuses on testing methods for hydrogen-embrittlement-resistant steels?
   A. ISO 9001
   B. ISO 11114-1

C. ISO 11114-2
D. ISO 11114-4

2. **Fill in the Blanks:**
   1. **Type III** hydrogen cylinders have a metal liner and full composite fiber wrapping, making them suitable for vehicular use.
   2. The Gas Cylinders Rules, **2016** govern the safety and usage of gas cylinders in India.
   3. Type IV cylinders are made using a plastic liner and **carbon fiber composite** and offer over 5 wt% hydrogen storage.
   4. Type I cylinders are very strong but heavy and can store hydrogen at pressures up to **20 MPa.**

3. **Short Answer Questions**
   1. Why are Type IV hydrogen cylinders preferred for modern hydrogen vehicles?
   2. What is the major limitation of Type II hydrogen cylinders?
   3. What safety features are ensured by the standards ISO 11114-1 and ISO 11114-2?
   4. What type of hydrogen cylinder is commonly used in industrial settings and why?

4. **Long Answer Questions:**
   1. Compare and contrast the four types of hydrogen cylinders in terms of construction, features, and suitability.
   2. Explain the importance of using proper materials and following standards in hydrogen cylinder construction.

Season 5: Depressurisation Methods of Hydrogen Storage System

Depressurisation of Hydrogen

Depressurising hydrogen is a more sensitive and risky process compared to other gases. Normally, when gases are released from high-pressure storage, they exit at a very high speed, which can cause the outlet nozzle to become hot. However, in the case of hydrogen, the situation is different. During hydrogen depressurisation, it is important to control the temperature of the outlet nozzle, as it may cool down quickly and become brittle. To prevent this and ensure safety, water is often sprayed on the hydrogen cylinder or tank during the depressurisation process to manage the nozzle temperature.

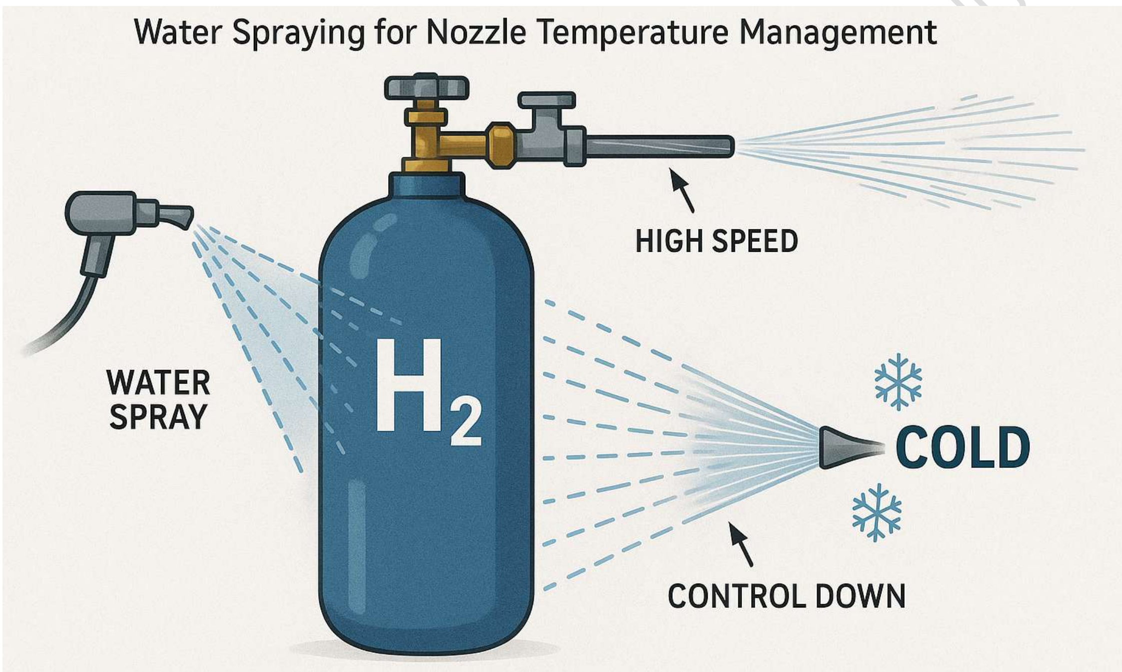

Fig. 3.19: Hydrogen Depressurisation

Depressurisation During Maintenance

Before any maintenance work is done on a hydrogen system, it is essential to bring the hydrogen pressure down to a safe level. This step is guided by standard procedures and not just visual checks or guesswork. In simple piping systems, this process is usually straightforward. However, in the case of larger tanks or vessels, proper analysis is required to ensure that all hydrogen has been safely removed.

The system should be designed in such a way that test points are available to confirm there is no remaining hydrogen inside the equipment. Maintenance should only begin after confirming this, and there should be written instructions or guidelines to follow for safe depressurisation.

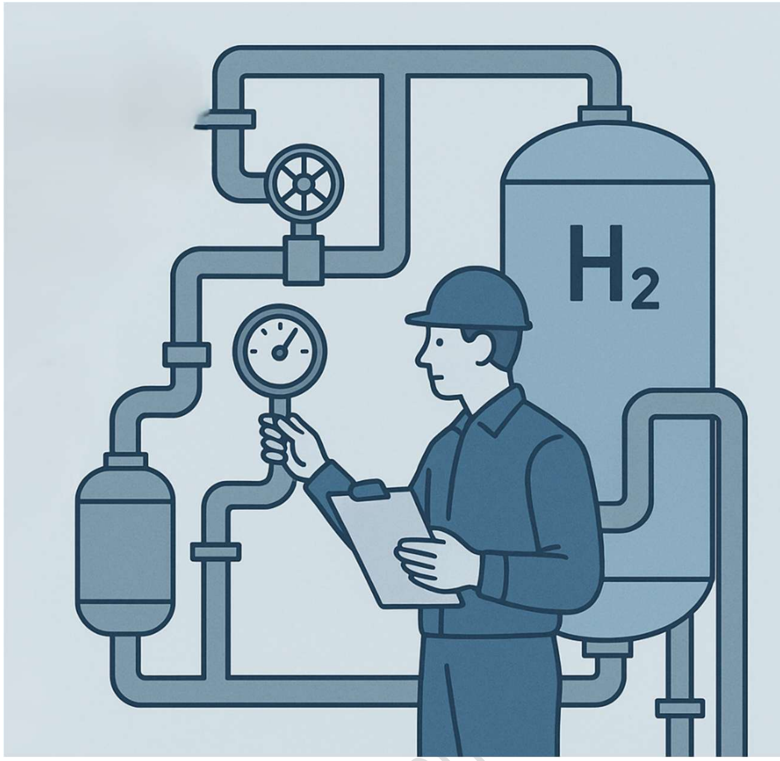

Fig. 3.20: Safe depressurisation

In the natural gas industry, reducing pressure is sometimes done by slightly loosening a pipe fitting. But doing the same in a hydrogen system is dangerous. Hydrogen can form an explosive mixture with air, and because it has a very low ignition energy, even small sparks or friction from tools or even body heat from the person working can ignite it. Therefore, to reduce these risks, hydrogen must be depressurised in a controlled area, away from people. It is also safer to release the gas in an upward direction so that it disperses quickly into the air.

Preparing a Hydrogen System for Maintenance

Before performing any maintenance work on a hydrogen system, it is essential to follow a set of safety procedures to ensure that the equipment is safe to handle. The steps involved are as follows:

- Stop or isolate the process flow – First, the flow of hydrogen through the system must be stopped or redirected to ensure the equipment is isolated.
- Depressurise the system – Release the hydrogen gas safely by venting it to a secure location designed for this purpose.
- Purge the system – Use an established purging procedure to remove any remaining hydrogen gas.

- Test for hydrogen – Ensure that no hydrogen is left in the equipment by conducting proper tests.
- Declare the system fit for maintenance – After confirming that the equipment is safe and free from hydrogen, it can be marked ready for maintenance work.

To supply the purge gas, it is recommended to use an inert gas like nitrogen. However, it is very important to vent the inert gas safely, usually outdoors, to prevent the creation of an oxygen-deficient environment which can be hazardous. To protect the inert gas system from possible hydrogen contamination, the purge system should be kept at a higher pressure than the hydrogen system, and check valves must be used to prevent gas backflow.

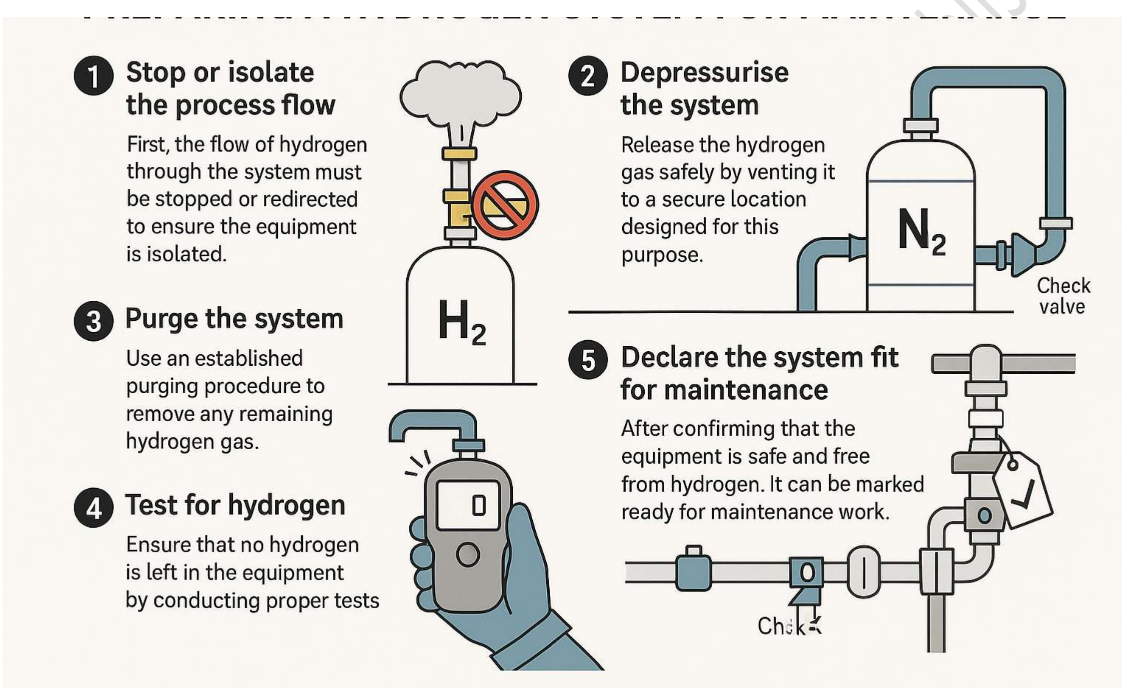

Fig. 3.21: Preparing a Hydrogen System for Maintenance

Bringing the Hydrogen System Back Online

Once the maintenance work is complete, reintroducing hydrogen into the system must also be done carefully. First, check that the entire system has been properly purged and that there is no air left inside. It is essential to reduce the oxygen concentration to below 1% before allowing hydrogen to flow again. Systems should be designed with proper test points to allow sampling and analysis before resuming operations.

In some specific cases, small pipes (less than 2 inches in diameter) may be purged with hydrogen directly. However, this should only be done with proper precautions:

- The hydrogen must be vented to a safe location, such as an elevated area outdoors.

- The piping must be strong enough to handle any sudden combustion (called deflagration) that may occur in case of ignition.

Accident Case Study: Hydrogen Fire Caused by Improper Purging

In a thermal power plant, a large generator is cooled using hydrogen and is powered by a steam turbine. During scheduled maintenance, it is necessary to remove the hydrogen from the cooling system to prevent any risk of fire or explosion. This is usually done by first purging the system with carbon dioxide (CO_2). To confirm that hydrogen has been fully removed, a densitometer is used to measure the gas concentration. Once 100% CO_2 is detected, air is introduced to make the system safe for maintenance work.

In one particular incident, the purging process was followed as usual. The densitometer showed 100% CO_2 concentration at the top of the generator, so the team proceeded to purge the system with air. After this, a pipe in the cooling loop was cut open to install new instruments. When the pipe was cut, pressurised gas was released. The workers assumed the gas was either CO_2 or air and continued their task. Unfortunately, some hydrogen was still trapped in the pipe and cooling loop. During welding, an electric arc caused a flame to appear at the pipe opening. This flame travelled back into the generator and led to a minor explosion inside the generator's casing.

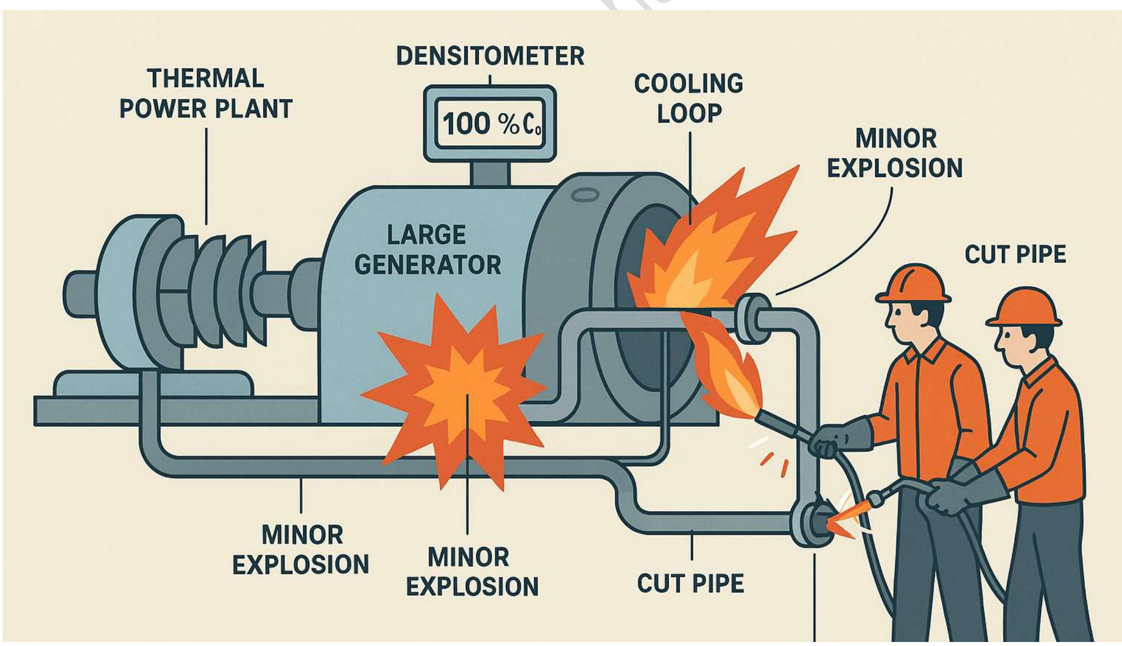

Fig. 3.22: Hydrogen Fire Caused by Improper Purging

Key Learnings from the Incident

The following are the key takeaways from this accident:

- Complete removal of hydrogen is challenging – Especially in large and complex systems, hydrogen may remain in confined areas and may not be evenly purged.
- Mixing and dilution of hydrogen with other gases can be uneven. This is particularly true in enclosed or partially enclosed spaces.
- Reliable gas concentration testing is essential – Before performing high-risk tasks like welding, gas levels must be tested at several points, not just one.
- Direct hydrogen measurement is more reliable – Trusting only the densitometer's CO_2 reading may not provide an accurate picture of hydrogen presence.
- Multiple analysis points are necessary – Gas analysis should be done not only at the top of the equipment but also at the exact location where work will be carried out.

Important Safety Reminder

Depressurisation of hydrogen does not only happen through controlled release from storage tanks or cylinders. It can also occur through accidental leaks in high-pressure pipelines, valves, pressure gauges, or safety valves. These components must be closely monitored. For added safety, water spray systems should be installed at such critical points to manage temperature and reduce fire hazards in case of leakage.

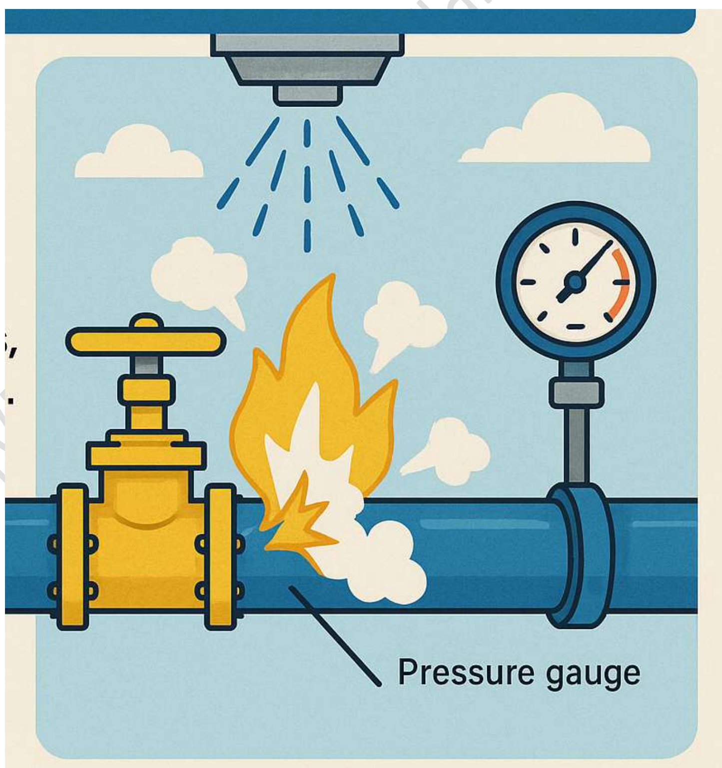

Fig. 3.24: Water Spray System to reduce fire hazards

Check Your Progress

A. Multiple Choice Questions:

1. Why is water often sprayed on a hydrogen cylinder during depressurisation?
   A. To clean the surface
   B. To prevent the gas from escaping
   C. To stop hydrogen from reacting with oxygen
   D. To manage nozzle temperature and prevent brittleness

2. Which gas is recommended for purging hydrogen systems before maintenance?
   A. Oxygen
   B. Carbon dioxide
   C. Nitrogen
   D. Argon

3. What is a critical mistake that led to a hydrogen fire in the thermal power plant case study?
   A. Welding without wearing safety gear
   B. Assuming hydrogen was fully removed based on a single CO_2 reading
   C. Using air instead of nitrogen for purging
   D. Using a faulty pressure gauge

4. What is the minimum oxygen concentration required before reintroducing hydrogen into the system?
   A. Below 21%
   B. Below 10%
   C. Below 5%
   D. Below 1%

B. Fill in the Blanks:

1. During **depressurisation**, hydrogen can cause the nozzle to become brittle due to rapid cooling.
2. In a hydrogen system, **test points** are necessary to confirm the absence of hydrogen before maintenance.
3. **Purge gas systems** should operate at a higher pressure than the hydrogen system to avoid backflow.
4. **Deflagration** is the term used for a sudden combustion that may occur in purged pipes.

C. Short Answer Questions:

1. Why is depressurisation of hydrogen more sensitive than that of other gases?
2. What should be done before starting any maintenance work on a hydrogen system?
3. Why must purge gases be vented safely outdoors?
4. What key lesson does the thermal power plant fire teach us?

D. Long Answer Questions:

1. Explain the procedure for safely depressurising a hydrogen system before maintenance.
2. Describe the safety measures taken when bringing a hydrogen system back online after maintenance

Session 6: Precautions and Safety Guidelines for Hydrogen Storage

Precautions for Safe Hydrogen Storage

By following these precautions, the risks associated with hydrogen storage can be minimised, ensuring a safer working environment.

1. Ventilation & Leak Prevention
   a. Ensure the storage area has proper ventilation, especially near the ceiling, as hydrogen is lighter than air.
   b. Install exhaust systems at roof level to quickly disperse leaked hydrogen.

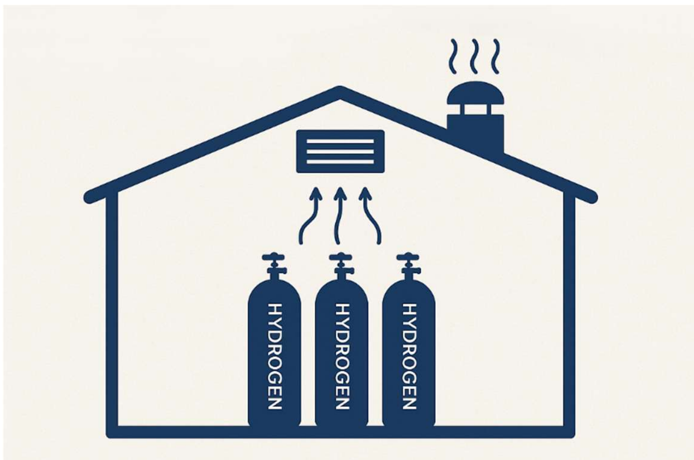

Fig. 3.25: Proper Ventilation

2. Leak Detection & Monitoring
   a. Regularly inspect valves, pipelines, and connections for leaks.
   b. Continuously monitor hydrogen concentration (in ppm or percentage) to detect leaks early.
   c. Periodically reduce pressure in storage tanks to identify small leaks.

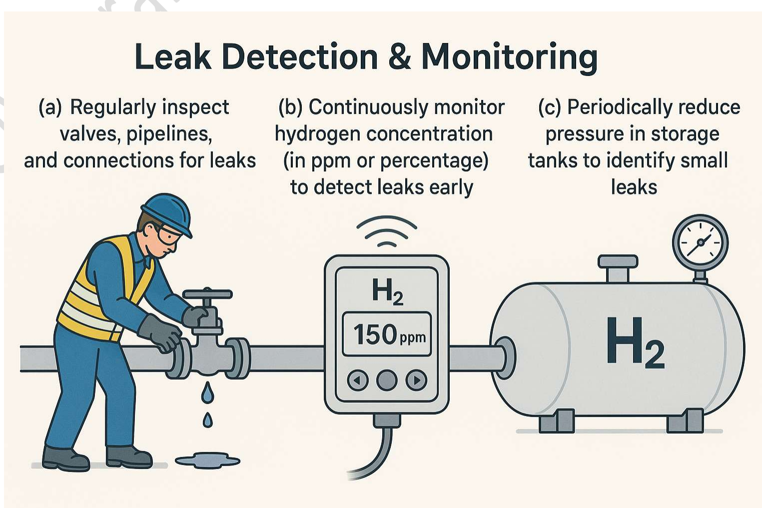

Fig. 3.26: Leak Detection and Monitoring

3. Safety Valves & Fire Protection
    a. Regularly test and monitor safety valves to ensure proper functioning.
    b. Install water spray systems and firefighting equipment near storage areas.

Fig. 3.27: Safety Valves & Fire Protection

4. Access & Personnel Safety
    a. Only trained and authorised personnel wearing proper safety gear should enter hydrogen storage areas.
    b. Mark emergency escape routes and ensure they remain unobstructed.

Fig. 3.28: Access & Personnel Safety

5. Storage Location & Hazard Prevention
    a. Keep hydrogen storage systems at a safe distance from other equipment or buildings.
    b. Prohibit spark-producing activities (smoking, welding, open flames) in and around the storage area.

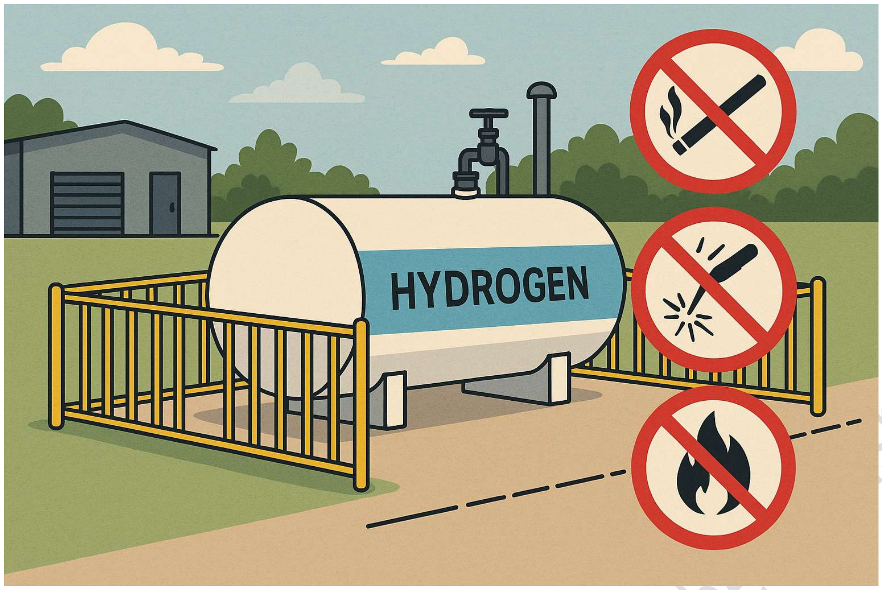

Fig. 3.29: Storage Location & Hazard Prevention

6. Handling & Cylinder Safety
    a. Avoid sudden opening of hydrogen cylinder valves ("cracking"), as hydrogen can self-ignite.
    b. Always store hydrogen cylinders upright to prevent damage or falls.

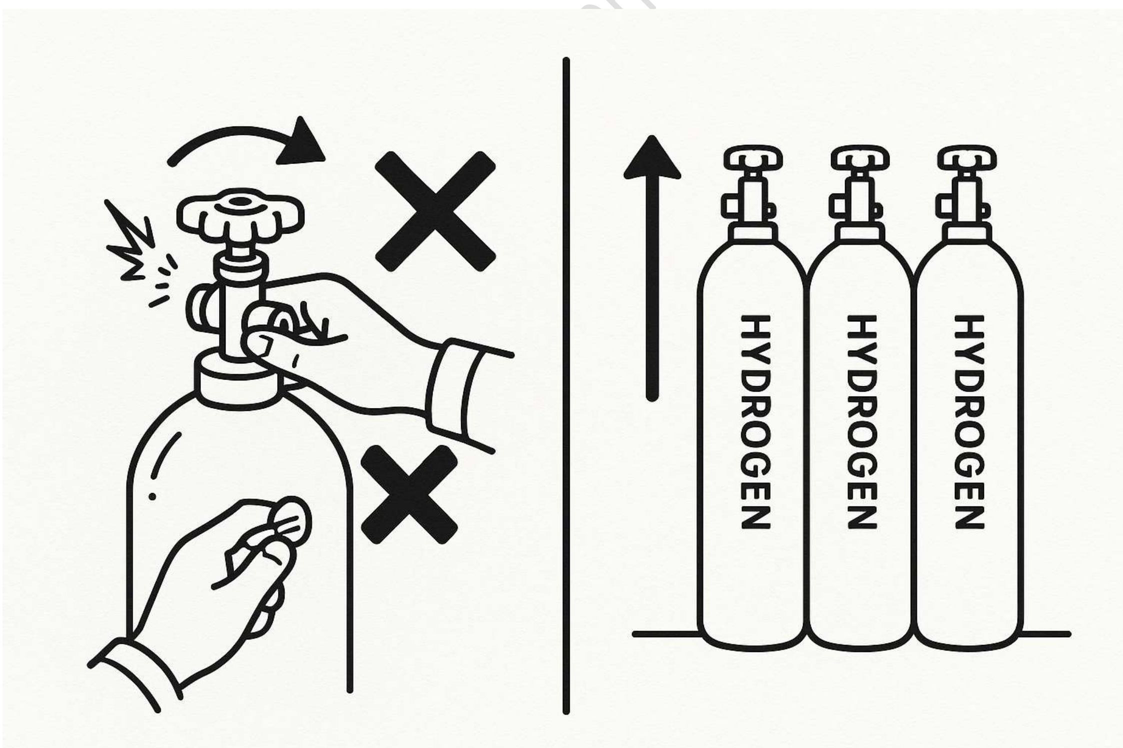

Fig. 3.30: Handling & Cylinder Safety

7. Maintenance & Inspections

a. Conduct regular inspections, testing, and maintenance of all safety valves and storage equipment.

Fig. 3.31: Maintenance & Inspections

Safety Norms for Hydrogen Handling and Use

Hydrogen has been used for more than a century, especially in industries such as chemicals, fertilisers, and oil refineries, mainly when produced from fossil fuels. However, with the growing concerns about climate change, green hydrogen (produced using renewable energy) is now being seen as a clean and sustainable alternative for the future.

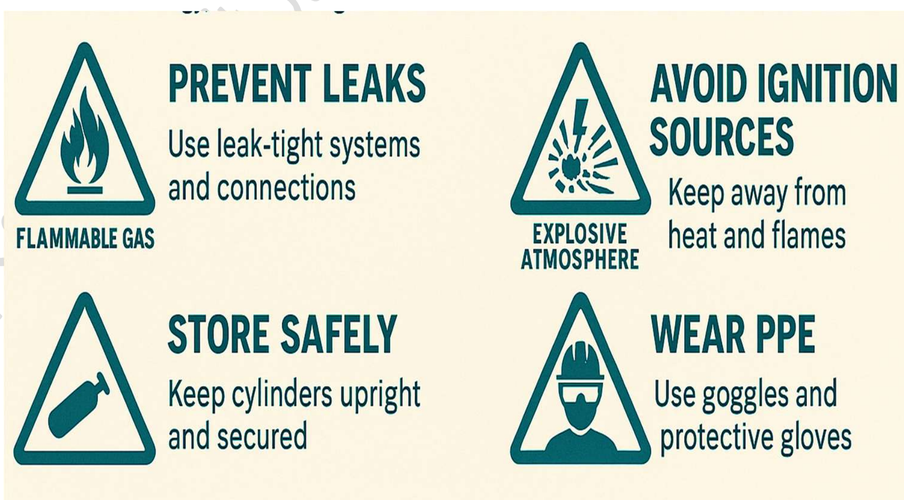

Fig. 3.32: Safety Norms for Hydrogen Handling and Use

To support the safe and efficient development of the hydrogen ecosystem, a well-defined regulatory framework is essential. This includes the establishment of safety codes, quality guidelines, and performance standards. These rules must match the needs of the industry and accommodate new and emerging technologies. In India, it is important to modernise and simplify existing approval procedures, making them faster and easier, especially to encourage innovation and support the 'Ease of Doing Business' initiative. Indian regulations should also align with internationally accepted standards and best practices to ensure global compatibility and consistency.

Indian Standard

Hydrogen Code of Safety (IS: 15201; 2002)

This national standard outlines the safety practices for handling hydrogen, focusing on its key hazards, mainly flammability and explosiveness. Several safety precautions must be followed, especially when working with compressed hydrogen gas:

- **Storage and Handling of Cylinders:** Hydrogen gas cylinders must always be stored upright, firmly secured, and kept away from direct sunlight and heat sources. They should be placed away from oxidising gases. Never roll, drop, or lift cylinders by their protective valve caps, as this can cause damage or leakage.
- **Use of Proper Equipment:** Regulators and fittings used with hydrogen cylinders must be designed specifically for hydrogen use. When transporting or moving the cylinders, ensure the protective valve caps are properly in place.
- **Avoid Dangerous Practices**: Hydrogen cylinder valves should not be cracked open for cleaning purposes, as hydrogen can ignite on its own under such conditions.
- **Leak Detection and Ventilation:** Regular checks should be done to identify potential hydrogen leaks. Good ventilation is necessary to prevent the buildup of leaked gas. Installing gas leak detection alarms in the working area is highly recommended.
- **Eliminate Ignition Sources:** While working with compressed hydrogen, all possible sources of ignition (such as sparks, flames, or static electricity) must be strictly avoided.

Personnel working with hydrogen systems must be properly trained to handle any safety situation. They should:

- Know the emergency contacts and reporting procedures.
- Be able to initiate emergency evacuations, if required.
- Understand when and how to shut off the hydrogen supply safely.
- Be trained in how to handle small hydrogen fires. In some cases, hydrogen fires may extinguish on their own, but if handled improperly, they could reignite. Water fire extinguishers should only be used by trained personnel.

Safety Measures to be Followed at Hydrogen Compression and Storage System

Hydrogen is classified as a hazardous material due to its high flammability and the potential for explosive reactions. Therefore, it is essential to follow strict safety measures when handling hydrogen, as well as when working near areas where hydrogen is stored or used. As a technician, being aware of hydrogen safety protocols is crucial, especially in detecting hydrogen leaks, which may not always be visible or easily noticeable.

Fig. 3.33: Hydrogen Safety Protocols

Hydrogen Leak Detection Methods

There are several reliable methods used to detect hydrogen leaks. These include:

1. Bubble Testing
2. Catalytic Detectors
3. Optical Detectors

These methods help identify leaks early, preventing accidents and ensuring the safe operation of hydrogen systems.

1. Bubble Testing

Bubble testing is a cost-effective and simple method for detecting hydrogen leaks. In this test, a soap and water solution is applied to parts of the hydrogen system, such as pipes, valves, and hoses. The system is then pressurised. If bubbles form at any spot, it indicates a leak at that location. Alternatively, the equipment can be submerged in water, and any escaping bubbles will point to the leak. This method, while simple, has limited sensitivity but can be quite effective for routine checks. Hydrogen's lightness causes the bubbles to move upward quickly, making it easier to detect the leak visually.

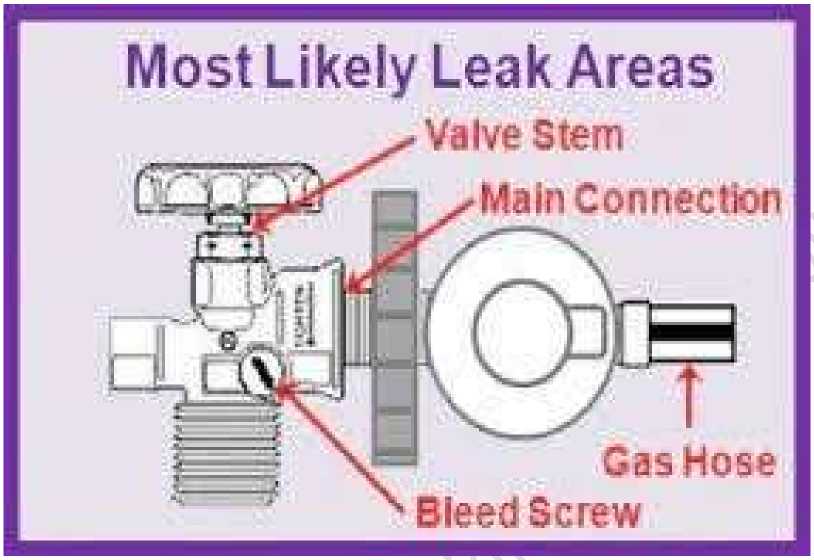

Fig. 3.34: Likely hydrogen leak points

2. Catalytic Detector

A catalytic detector is used to identify flammable gases such as hydrogen by detecting the heat generated during oxidation. It consists of two platinum wire-wound resistors: one active bead coated with a catalyst and one reference bead left untreated. When hydrogen (mixed with air) comes in contact with the catalytic bead, it burns slightly and releases heat, which changes the electrical resistance. This difference in resistance between the two beads indicates the presence of hydrogen. These detectors are widely used and can also be integrated with remote sensing thermometers for accurate readings.

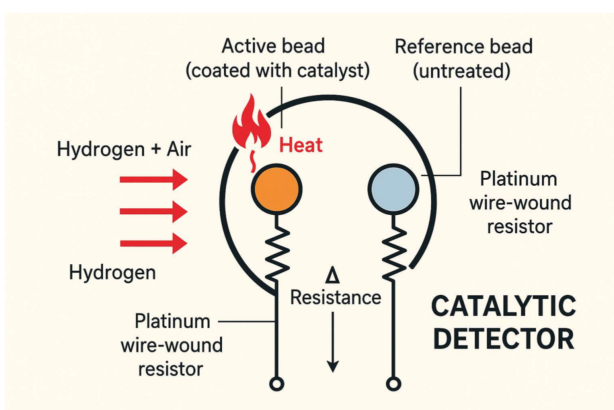

Fig. 3.35: *Catalytic Detectors*

3. Optical Detector (UV/IR Flame Detector)

An optical detector detects the ultraviolet (UV) radiation produced by hydrogen flames, which are often invisible to the naked eye. These detectors use UV-sensitive vacuum tubes that trigger an electrical response when UV photons hit the cathode, producing a photoelectron. This helps detect even small hydrogen flames quickly and accurately. Optical detectors are especially useful in confined or isolated spaces where false alarms are less likely. In addition, thermal vision cameras or remote sensing thermometers can also be used for flame detection over a large area. These cameras show high-temperature zones using colour coding, making it easier to identify danger points.

Fig. 3.36: ***UV/IR Flame Detectors***

Control System Integration

In a hydrogen plant, detecting a fire is only one part of safety. If flammable materials are still being introduced into a hazardous area after a fire is detected, it can lead to serious damage. To prevent such disasters, it is vital that the plant's control system and safety system work together efficiently. The safety system must communicate the status of all detectors and sensors to the control system in real-time. This ensures that both operators and safety personnel are immediately alerted, allowing them to take fast and accurate decisions to control the situation.

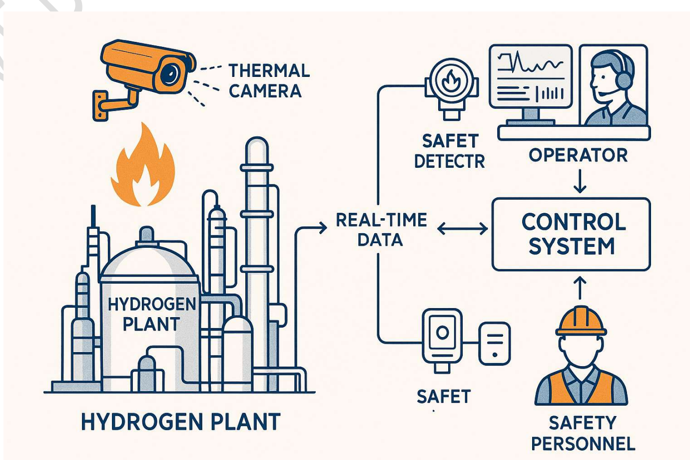

Fig. 3.37: Control System to Prevent Disaster in Hydrogen Plant

Additionally, there's potential in considering the use of a few thermal cameras to watch closely over risky areas. This could help in keeping an eye on things without needing too many people to go into those dangerous spots.

Use of Firefighting Systems for Hydrogen Fires

Hydrogen fires require special handling due to the gas's high flammability and unique burning characteristics. The most reliable method to manage a hydrogen fire is to allow it to burn in a controlled manner while safely cutting off the hydrogen supply. This should be done using remote operations from a safe location. Technicians must locate and close the block or isolation valves near the source of hydrogen. At the same time, water sprays can be used to cool surrounding equipment, extinguish any secondary fires, and prevent the fire from spreading to nearby areas.

Another effective firefighting method is the use of ***heptafluoropropane*** gas. This chemical can be introduced into the area affected by the hydrogen fire in concentrations ranging from 13% to 30% by volume in air. Maintaining this concentration helps to suffocate the fire and bring it under control until it is fully extinguished.

Hydrogen is rated Level 4 on the flammability scale (as per NFPA 704), which is the highest level, indicating extreme flammability. This is because hydrogen can ignite with just a 4% concentration in air, making it far more sensitive to ignition than many other gases. The presence of oxygen and the simple chemical reaction involved make hydrogen fires very dangerous if not managed properly.

Therefore, it is important for all personnel to be trained in hydrogen firefighting techniques and to ensure that fire suppression systems and emergency protocols are always in place and functional. Safety must be the top priority when working with or around hydrogen. The following figure represents the sign for the Hydrogen work zone.

Flame-Resistant Clothing (FRC)

In the event of a fire or explosion, regular clothing made from everyday fabrics can catch fire easily and may continue to burn. Some materials can even melt onto the skin, causing severe burns and long-lasting injuries. Often, the damage caused by burning clothes can be more dangerous than the fire itself.

To reduce such risks, Flame-Resistant Clothing (FRC) is used. This special type of clothing is designed to protect individuals who work in hazardous environments, such as those involving hydrogen, flammable gases, or high heat. FRC does not easily catch fire, and if it does, it is designed to self-extinguish once the source of heat or flame is removed. This significantly reduces the chances of serious burns caused by both the initial fire and the residual heat.

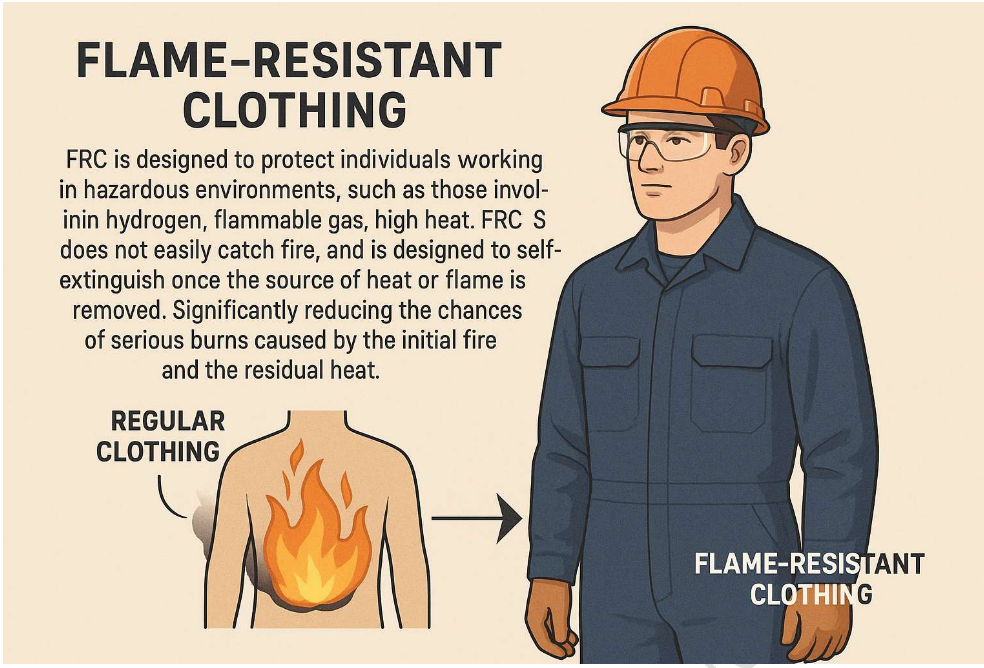

Fig. 3.37: Flame Resistant Clothing

FRC is made from materials that can withstand high temperatures, giving the wearer extra time to react and escape safely. However, it is important to understand that flame-resistant does not mean fireproof. All flame-resistant clothing can still burn if it is exposed to fire or intense heat for a prolonged period.

Therefore, while FRC is an important part of personal protective equipment (PPE), it must be used along with other safety measures and precautions to ensure maximum protection in high-risk environments.

Fig. 3.38: ***Signs for Hydrogen Work Zone***

Safety – Do's and Don'ts

Following are the safety Do's and Don'ts that needs to be take care while working with or around Hydrogen:

DO's

1. Provide hydrogen shutoff(s) for isolation
   a. Locate automatic fail-closed shutoff valves at critical points in the system (such as storage exit, entry to buildings, inlets to test cells etc.) to put the system in a safe state when a failure occurs
   b. Consider redundant or backup controls
   c. Install manual valves for maintenance and emergencies
2. Prevent cross-contamination
   a. Prevent back-flow to other gas systems with check valves, pressure differential etc.
3. Size the storage appropriately for the service
   a. Avoid excess number of deliveries/change-outs, if too small
   b. Avoid unnecessary risk of a large release from an oversized system

- Mock exercise including firefighting system to be periodically done.
- Use of safety appliances and PPE (personal protection equipment).
- Use of spark free special tools.
- Restricted entry in the hydrogen plant/storage area.
- Any outsider called for some special purpose then he should be well informed of safety/ hazard and must wear PPE and must be accompanied by responsible plant personal
- Monitoring of the firefighting equipment and other safety measures at specified locations.
- Vehicles for hydrogen transportation needs to be allowed under strict supervision.

DON'T

- No sparking of any type or smoking or mobile phone, etc.
- No other clothing/footwear other than specified.
- Petrol/ diesel vehicles are prohibited inside the hydrogen plant premises except

Check Your Progress

A. Multiple Choice Questions (MCQs)

1. Why should hydrogen storage areas have roof-level exhaust systems?
   A. To cool down the storage tanks
   B. To protect the roof from corrosion
   C. To disperse leaked hydrogen effectively
   D. To reduce noise

2. Which standard is India's national code for hydrogen safety?
   A. ISO 11114
   B. IS 15201:2002
   C. NFPA 70
   D. IEC 61511

3. Which detector is most suitable for identifying invisible hydrogen flames?
   A. Optical (UV/IR) detector
   B. Catalytic detector
   C. Thermal sensor
   D. Densitometer

4. What is the flammability rating of hydrogen on the NFPA 704 scale?
   A. 1
   B. 2
   C. 3
   D. 4

5. Which of the following gases is commonly used for purging hydrogen systems?
   A. Helium
   B. Carbon monoxide
   C. Nitrogen
   D. Oxygen

B. Fill in the Blanks

1. Hydrogen should always be stored in **upright** cylinders to avoid tipping or damage.
2. Hydrogen can **self-ignite** if the cylinder valve is suddenly opened, a process known as cracking.
3. Flame-Resistant Clothing (FRC) is designed to **self-extinguish** once the heat source is removed.
4. Check valves help prevent **backflow** in hydrogen piping systems.

C. Short Answer Questions

1. What precautions must be taken while entering a hydrogen storage area?
2. What is the function of a catalytic hydrogen detector?
3. Why is hydrogen considered highly dangerous even in small concentrations?
4. How should firefighting be managed during a hydrogen fire?

D. Long Answer Questions

1. Explain the different types of hydrogen leak detection systems.
2. Discuss key safety norms and precautions for hydrogen handling and storage.

UNIT 4: COMMISSIONING CHECKLIST

Module Overview

This module teaches you how to set up a green hydrogen generation system step by step. It includes how to install, test, and validate parts like electrolysers, compressors, drying units, and safety systems. You will learn to follow checklists from equipment manufacturers, perform pre-commissioning tests for pressure, purity, and leaks, and ensure you meet regulatory standards. You will also learn how to assess key inputs, outputs, and performance metrics to make sure the system runs efficiently and safely. This module is important for anyone involved in setting up and running green hydrogen plants.

Learning Outcomes

After completing this module, the student will be able to:

1. Describe the use of checklists for commissioning hydrogen systems as per OEM guidelines.
2. Explain the installation, testing, and commissioning checklist for green hydrogen systems.
3. Discuss key inputs, outputs, and performance metrics for hydrogen generation.
4. Identify pre-commissioning tests and downstream checks like purity, pressure, leakage, and compressor performance.
5. Explain trial runs and commissioning processes as per statutory and regulatory norms.

Module Structure

Session 1: Checklists for Commissioning
Session 2: Installation, Testing and Commissioning Checklist
Session 3: Inputs, Outputs and Key Performance Metrics for Hydrogen Generation
Session 4: Pre-commissioning Tests

Session 1: Checklists for Commissioning

Before a green hydrogen plant starts full operations, it must complete commissioning. This process makes sure everything functions as intended. To do this, engineers and technicians use checklists. These checklists help them verify each step systematically, ensuring safety, efficiency, and performance. Overall, we need to review the plant to confirm it is working as specified and check its guaranteed parameters and lifespan.

Plant Life Cycle

The life cycle of a green hydrogen plant has four main parts, as shown in the figure.:

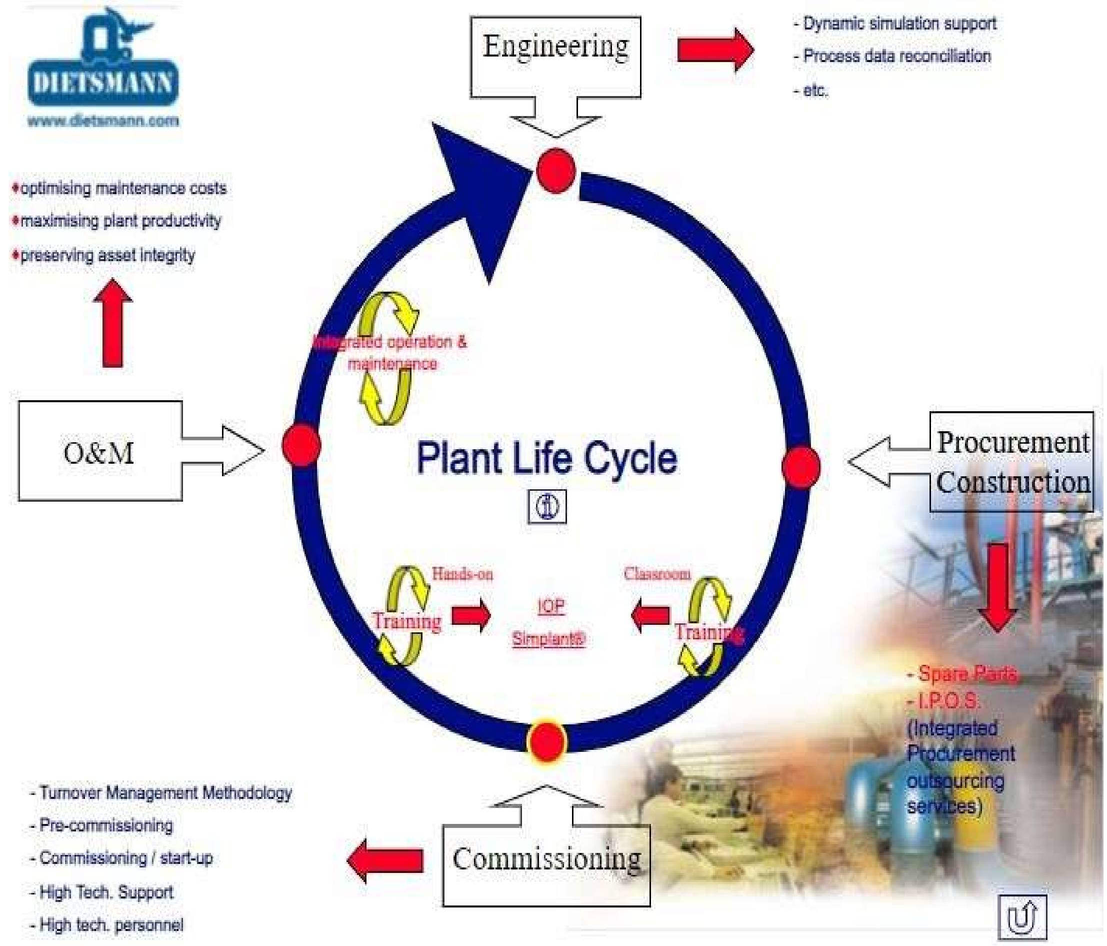

Fig.4.1: Commissioning approach

- Engineering: Design, drawings, installation/O&M manuals
- Procurement and construction: Procurement of materials and components, plants, systems etc.
- Commissioning: Pre-commissioning, commissioning, Performance guarantee (PG), trial runs, repairs required, if any, to be done and PG test will have to be repeated successfully to ensure the appropriate repair and then handing over.
- O&M: Operation of the plant to maximize the production/revenues, maintenance includes servicing, repair, replacement, storage of spares and consumables.

Checklist

A checklist is a list of tasks that need to be completed for each step of assembling or conditioning units, such as compressors, dryers, water separation units, electric supply systems, special tools, and consumables. It helps to remember what you need to check, find out, or take somewhere, ensuring that you don't forget anything.

You should prepare separate checklists for pre-commissioning, commissioning, testing, trial runs, and handing over the plant for each activity.

Fig.4.2: Plant Checklist

Throughout the lifetime of a hydrogen system, checklists are essential to ensure that personnel, transfer and storage, and inspection requirements are met safely. Key features of the checklist include:

- Listing specific equipment used in the system or facility.
- Including items like valve positions (open or closed) during transfer operations and what personal protective equipment (PPE) personnel are wearing.
- Confirming that leak detection and fire alarm systems are working and maintenance records are up to date.
- Ensuring that safety-related operations are completed and that parameters are within safe limits.
- Documenting quantities of materials used in the system.

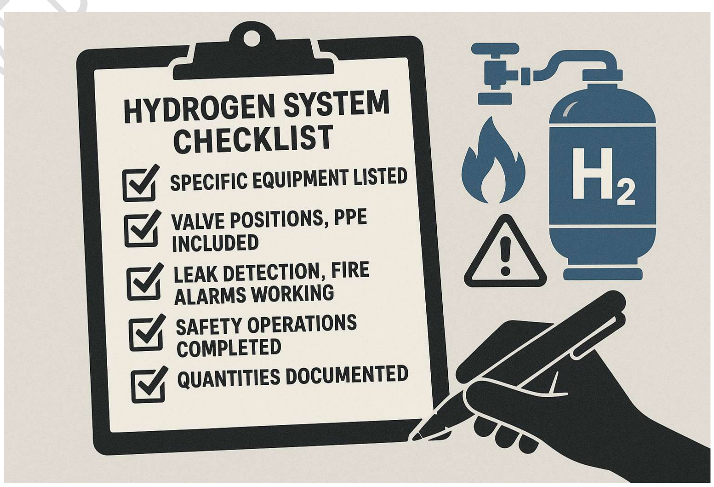

Fig.4.3: Hydrogen System Checklist

Commissioning

Commissioning is the process of planning, documenting, scheduling, testing, adjusting, verifying, and training to ensure a facility operates as a fully functional system according to the customer's requirements.

Commissioning Checklist:

A commissioning checklist helps confirm the safety and performance of new or modified systems in a facility. Use this comprehensive checklist to efficiently validate HVAC, pumping, piping, and lighting systems.

The steps in the commissioning process are shown in **Figure**. Follow these steps according to the recommendations of the Original Equipment Manufacturer (OEM) to keep the warranty or guarantee valid.

Fig. 4.4: Steps of a commissioning process

Indicative Checklist:

The table provides a quality plan checklist for a green hydrogen production plant.

HYDROGEN GENERATION PLANT-TESTS													
Tests/Check Items / Components	Material Test	WPS/PQR/Welder	DPT/MPI	Ultrasonic test	RT	Pneumatic test	Hydraulic / Water Fill tests	Assembly / fit up	Dimension	Functional/ operational tests	Performance tests	Other tests	Remarks
H2 PLANT													
A.COMPRESSOR								Y		Y	Y		
1) Casing	Y3												
2) Crank shaft/connectingrod	Y3		Y	Y					Y				
3) Piston/Diaphragm			Y3							Y			
B. DRYING PLANT							Y						
1.)Raw materialidentification	Y3		Y		Y^2								
C. HYDROGENGENERATOR							Y			Y	Y		
D. CELL MODULE							Y			Y	Y		
E. GAS HOLDER	Y3						Y						

1.Fillet welds/nozzles welds and knuckle portion of dished ends and all butt welds.

2. 100% butt welds and 100% for Tee joints and dished ends welds.

3. One per heat /HT batch.

Notes.
1.Quantum of checks shall be 100% unless otherwise specified.

Fig. 4.5: Hydrogen Generation Plant Indicative Tests list

Check Your Progress

A. Fill in the Blanks

1. Commissioning ensures that the plant functions as per the design and performance **standards.**

2. A **checklist** is used to keep track of tasks during commissioning and testing.

3. The operation and maintenance phase includes servicing, repairs, and spare part

management.

4. The **performance guarantee** (PG) test confirms that the plant meets output and safety expectations.

5. Leak detection and fire alarm systems must be confirmed to be working during **commissioning**.

B. Multiple Choice Questions (MCQs)

1. Which of the following is NOT part of the plant lifecycle?
   a) Engineering
   b) Procurement & Construction
   c) Shutdown Planning
   d) Commissioning

2. Why are checklists used during the commissioning process?
   a) To train engineers
   b) To track expenses
   c) To document government approvals
   d) To ensure all necessary checks and procedures are completed

3. What should be checked in a commissioning checklist related to personnel?
   a) Their names
   b) Their clothing brand
   c) Proper use of personal protective equipment (PPE)
   d) Number of workers

4. When is a performance guarantee (PG) test performed?
   a) Before handing over the plant
   b) During procurement
   c) After designing the plant
   d) During O&M phase

5. What is the final step of the commissioning process?
   a) Equipment purchase
   b) Handover
   c) Engineering

d) Plant shutdown

C. Short Answer Questions

1. What is the purpose of commissioning a hydrogen plant?
2. What does a commissioning checklist usually include?
3. Why must OEM recommendations be followed during commissioning?
4. What is included in the Operation & Maintenance phase of the plant lifecycle?

D. Long Answer Questions

1. Explain the four main phases of the green hydrogen plant life cycle.
2. Describe the importance and contents of a commissioning checklist.
3. What happens if proper commissioning is not done?
4. How do checklists contribute to safety in hydrogen plants?

Session 2: Installation, Testing, and Commissioning Checklist

As mentioned for the overall plant, the checklist for this section is agreed upon in writing by both the customer and the supplier based on specific documents in the purchase agreement. It is common to include all correspondence from the tender document to the plant handover in the checklist. The checklist will be updated as the project progresses. The approved checklist and any updates will be issued with the date noted.

Installation:

The customer and supplier have agreed in writing on a checklist for this aspect, referencing specific documents in the purchase agreement. It is common to include all correspondence from the tender document to the plant handover when preparing the draft checklist. This checklist is updated as the project progresses. The approved checklist and any updates will be issued with the date clearly stated. Installation activities for each piece of equipment include:

- Approval of drawings at each stage
- Stage inspections
- Approval for foundation correctness
- Installation checks for various equipment
- Final clearance to proceed

ITEM	APPROVED	DATE
Approval of drawings at each stage		
Stage inspections		
Approval for foundation correctness		
Installation checks for various equipment		
Final clearance to proceed		

Fig. 4.6: Installation activities

Testing:

Testing involves checking individual equipment and the conditioning unit, followed by testing after complete assembly. Approval is obtained after each test.

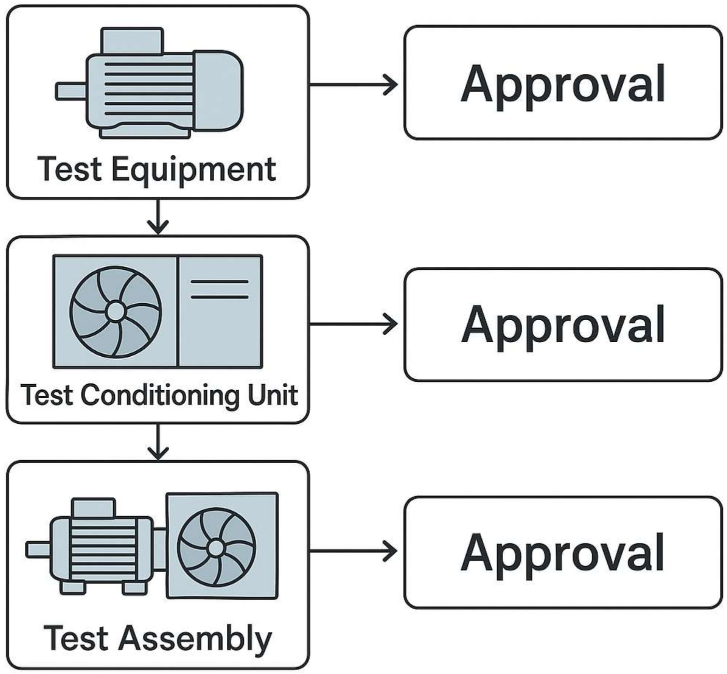

Fig. 4.7: Testing and Approval of Individual Equipment

Commissioning:

After testing each piece of equipment and the conditioning unit, commissioning occurs to verify proper operation. Both parties will record clearances after each commissioning stage. Any necessary repairs, modifications, or replacements will be made for successful pre-commissioning. During pre-commissioning, verify the parameters of each equipment and conditioning unit for compliance. The same steps will apply during the overall commissioning of the plant.

Checklist:

Compile checklist activities in a logical order under various sub-headings. The checklist consists of two parts:

- Part A: for equipment and conditioning units
- Part B: for installation, testing, and commissioning

Sample checklist for Compressor

COMPRESSOR CHECKLIST

Part-A:

☐	Equipment:	Check that items are received as per order.
☐	Drawings and Materials:	Check receipt of materials as per Bill of materials and drawings

Part-B:

☐	Installation:	Check foundation, check assembly as per assembly drawing
☐	Commissioning:	Check connections as per electrical drawings, both power and control circuits, protection devices of motor etc. Limit switches of valves connections, check operation of safety devices by operating them manually Only control supply to be made on power supply off

Fig. 4.8: Compressor Checklist

Testing: After successful commissioning, power supply to be made on to start compressor motor and connected operation, check current at no load, full load, temperature, vibrations etc.

Check Your Progress

A. Multiple Choice Questions (MCQs):

1. What is commonly included in the checklist prepared between the customer and supplier?
   A) Only equipment drawings
   B) Final inspection reports only
   C) Correspondence from the tender to plant handover
   D) Invoices and payment records

2. Which of the following is not part of installation activities for equipment?
   A) Final clearance to proceed
   B) Testing at full load
   C) Stage inspections
   D) Approval of foundation correctness

3. During commissioning, what is the primary objective?
   A) Designing the layout
   B) Verifying proper operation of all equipment
   C) Preparing financial statements
   D) Packaging the equipment

4. What does Part A of the sample checklist for the compressor focus on?
   A) Equipment and conditioning units
   B) Commissioning
   C) Testing
   D) Control circuits

5. When should power supply be turned on during compressor testing?
   A) Before installation
   B) After successful commissioning
   C) During transportation
   D) Before foundation checks

B. Fill in the Blanks:

1. The checklist is agreed upon in ***writing*** by both the customer and the supplier.
2. Installation activities include **approval of drawings** and *stage inspections*.
3. **Testing** involves checking both individual equipment and the conditioning unit.
4. The checklist is compiled in a **logical order** under various sub-headings.
5. During commissioning, parameters are verified for **compliance.**

C. Short Answer Type Questions

1. What are the key stages included in installation activities?
2. What does testing include in the checklist process?
3. What are the two parts of the checklist mentioned in the document?
4. Why is it important to issue updates of the checklist with the date?

D. Long Answer Type Questions:

1. Explain the significance of a checklist in the installation and commissioning of a hydrogen plant.
2. Describe the installation procedure of the equipment as outlined in the checklist.
3. Discuss the process and importance of testing and commissioning.
4. What is included in the sample checklist for the compressor, and why is it important?

Session 3: Inputs, Outputs and Key Performance Metrics for Hydrogen Generation

Hydrogen generation, especially through electrolysis, needs specific materials and systems to work properly. The main inputs include raw water, which is first treated to become demineralised (DM) or ultra-pure water so that it doesn't damage the equipment or affect the hydrogen quality. An electrolyte is also prepared, depending on the type of electrolyser being used. The entire system runs on a proper electric power supply, which gives the energy needed for splitting water into hydrogen and oxygen. Additionally, safety appliances like sensors, pressure valves, and shut-off systems are used to protect both the equipment and the operators.

1. Inputs

1. Raw Water: This is the initial source of water that requires treatment to make it suitable for various applications.
2. Demineralised (DM) Water or Ultra-Pure Water: This type of water has had its mineral ions removed, making it ideal for sensitive applications where purity is critical.
3. Electrolyte Preparation: This involves mixing specific chemicals to create solutions that conduct electricity, essential for various industrial and laboratory processes.
4. Electric Power Supply System: A reliable power source is crucial for operating electrical equipment and processes involved in water treatment and electrolyte preparation.
5. Safety Appliances: These are essential tools and equipment designed to ensure the safety of personnel and operations during the handling of raw and processed water.

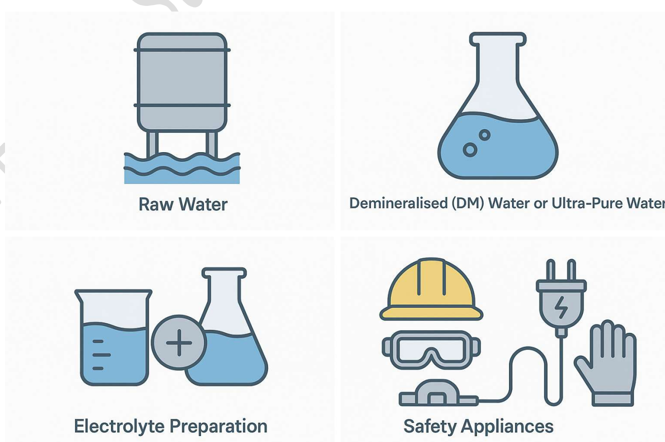

Fig. 4.9: Inputs for Hydrogen Generation

2. Outputs:

The key outputs include hydrogen gas produced from the electrolyser. This hydrogen often contains traces of moisture and oxygen, so it is further processed to improve its quality by removing water and oxygen. The gas is then sent through a drying unit and a compression system to make it suitable for storage or use. Besides gas outputs, the quality of electric power output, such as voltage and frequency, and the DC supply from the rectifier, are also monitored to ensure smooth operation of the hydrogen generation system.

- Hydrogen from the electrolyser
- Hydrogen quality after removing water
- Oxygen removal
- Drying
- Compression
- Electric supply output quality (voltage, frequency)
- DC supply quality from the rectifier

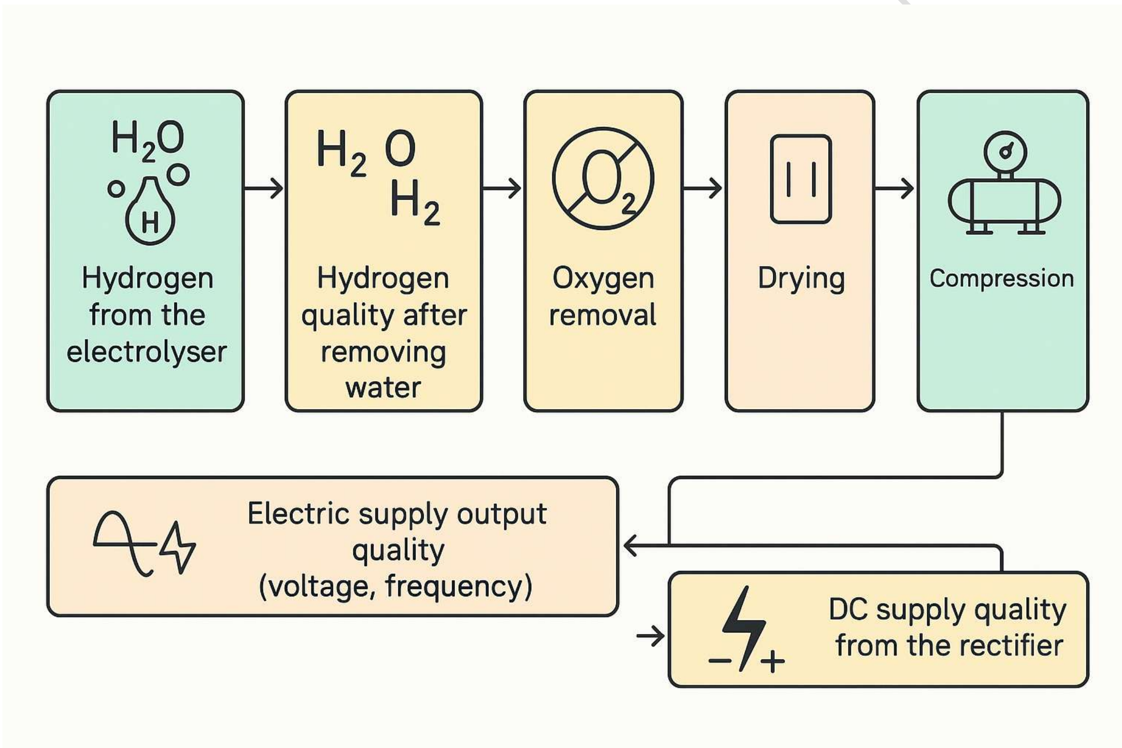

Fig. 4.10: Outputs for Hydrogen Generation

Key Performance Metrics

To ensure the hydrogen generation system is running efficiently and safely, several key performance metrics need to be regularly monitored and analysed.

A) Production of Hydrogen per Hour with Specified Purity

These metric checks how much hydrogen is being produced each hour and whether it meets the required purity level. It involves monitoring the hydrogen production rate, hydrogen purity, electricity consumption, and water consumption. If there are any deviations from the expected or contractual parameters, corrective actions should be taken according to the Operation & Maintenance (O&M) manual provided by the equipment supplier.

B) Performance Metrics of Feed Water: DM Water and Ultrapure Water

The quality of the water used in hydrogen production is crucial. Important parameters include the pH value and the resistivity or conductivity of the DM (Demineralised) or ultrapure water. These measurements help ensure the water is suitable for electrolysis. If the values are outside the acceptable range, appropriate corrective measures must be followed as per the supplier's O&M manual.

C) Hydrogen and Electrical Supply Performance Metrics

To maintain the efficiency and safety of a hydrogen generation system, it's important to monitor the performance of both the hydrogen output and the electric power supply. These parameters ensure that the system works as expected and delivers high-quality hydrogen consistently.

Hydrogen Performance Metrics

These include the following checks:

- Removal of water from hydrogen to avoid moisture in the final product.
- Removal of oxygen, CO_2, and other impurities to ensure safety and quality.
- The level of dryness of the hydrogen to make it suitable for storage or further use.
- Level of purity of the compressed (pressurised) hydrogen, which must meet industry or application-specific standards.

Analysis: The actual performance of these parameters (i to iv) should be regularly compared with the contractual values or agreed standards. If there are any differences or deviations, the necessary corrective actions should be followed as per the supplier's Operation & Maintenance (O&M) manual.

• *Performance Metrics of Electric Supply*

This includes both AC and DC supply performance:

- AC Power Supply: High voltage (HV) and low voltage (LV) levels, frequency, and total kVA capacity must be checked regularly.
- DC Power Supply: Check the DC voltage output from the rectifier, the presence of ripples in DC voltage, and the stability of voltage regulation.

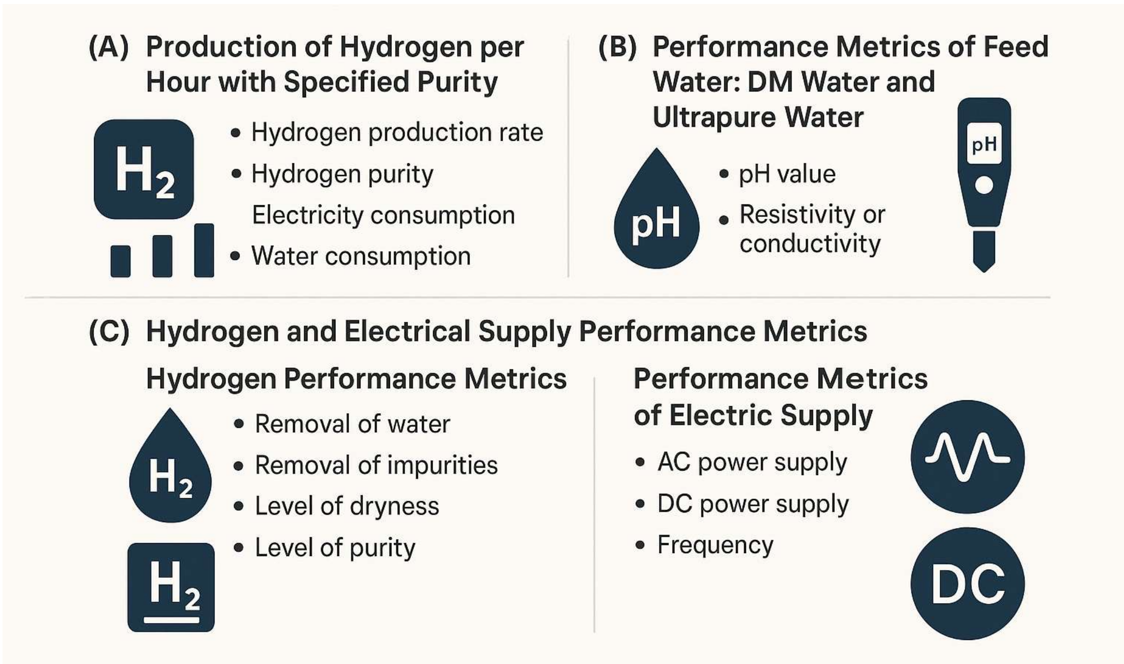

Fig. 4.11: Performance Metrics Need to be Regularly Monitored and Analysed.

Analysis: These actual measurements must also be compared with the values mentioned in the contract or technical specifications. If any parameter falls outside the allowed range, prompt corrective steps must be taken as per the supplier's O&M manual.

Check Your Progress

A. Multiple Choice Questions (MCQs)

1. **Which of the following is not an input required for hydrogen generation by electrolysis?**
   A) Cooling gas
   B) Electric power supply
   C) Raw water
   D) Electrolyte

2. **What is used to ensure safety in the hydrogen generation system?**

A) Air filters
B) Safety appliances like sensors and shut-off systems
C) Gasoline fuel
D) Fire crackers

3. **Why is DM or ultrapure water used in electrolysis?**
A) To reduce cost
B) To increase the pressure
C) To prevent damage to the equipment and ensure hydrogen quality
D) To cool the electrolyser

4. **What does the performance metric "Hydrogen production per hour with specified purity" monitor?**
A) Rate of compression
B) Voltage regulation
C) Heat dissipation
D) Hydrogen output and purity

B. Fill in the Blanks

1. ___________ water is treated to become DM or ultrapure water before being used in electrolysis. **Answer:** Raw

2. The gas produced from the electrolyser is ___________ to improve quality and remove moisture. **Answer:** dried

3. ___________ and oxygen must be removed from hydrogen before compression or storage. **Answer:** Water (moisture)

4. AC supply performance includes checking ___________, frequency, and kVA capacity. **Answer:** voltage levels

5. The DC supply performance is assessed by checking voltage, ripple content, and voltage ___________. **Answer:** regulation

C. Short Answer Type Questions

1. Why is ultrapure or DM water used in hydrogen generation?

2. List any two key inputs in a hydrogen generation system.

3. What is the purpose of drying hydrogen after electrolysis?

4. What parameters are monitored in the DC supply performance?

D. Long Answer Type Questions

1. Explain the main inputs required for a hydrogen generation system using electrolysis.
2. Describe the outputs of the hydrogen generation process and the steps taken to enhance hydrogen quality.
3. What are the key performance metrics used to assess hydrogen generation efficiency?
4. How is the performance of the electrical supply monitored in a hydrogen generation system?

Session 4: Pre-Commissioning Tests

We conduct several important tests to ensure the hydrogen production system operates safely and efficiently. These tests follow the guidelines in the supplier's manuals:

1. **Hydrogen Purity Test:** This checks the purity of the produced hydrogen, which is important for its use in other applications.
2. **Leakage Test:** This verifies that the system has no gas leaks.
3. **Compressor Assembly Operational and Performance Test:** This assesses how well the compressor assembly functions and performs, ensuring it meets specified standards.
4. **Drying Plant Hydraulic Test:** This observes the hydraulic systems to ensure they can handle operational pressures without failing.
5. **Hydrogen Generator & Cell Module – Hydraulic Tests:** This tests the hydrogen generator and cell modules for reliability and design accuracy.
6. **Safety Test:** This checks that all safety measures and protocols in the hydrogen production facility are effective.
7. **Trial Run:** After commissioning, this trial tests the system under almost full operational conditions to find any problems before starting full-scale operations.

Before we begin the pre-commissioning tests, we complete several checks to ensure everything is ready:

- **Water Quality Checks:** We thoroughly inspect the raw water's cleanliness and the quality of demineralised (DM) or ultra-pure water to confirm they are suitable for use.

- **Electricity Supply Checks:** We review the HVAC input supply, transformer, low voltage alternating current (LVAC) supply, rectifier performance, and the stability of the DC power supply, including voltage fluctuations and auto-tripping features.

- **Electrolyser Performance Checks**: We monitor each stack's performance, including the series of stacks, current drawn, power consumption, and the volume of hydrogen produced.

These pre-commissioning tests are used for checking that each conditioning unit functions properly.

Hydrogen Purity Test

For the Hydrogen Purity Test, we use a portable analyser that measures the hydrogen gas purity. It does this by assessing how well hydrogen conducts heat. We take separate readings for temperature and humidity and make corrections using a microcontroller. The analyser is calibrated in a laboratory to ensure accuracy.

Fig. 4.12: Portable hydrogen purity analyser

Hydrogen Leakage Tests

For the hydrogen leakage tests, we close the inlet and outlet valves and pressurise the system with nitrogen. Then, we introduce a small amount of hydrogen. This helps us find leaks at joints, valves, and safety mechanisms. We typically use a mixed gas with 5% hydrogen and 95% nitrogen as the tracer gas. A semiconductor hydrogen detection sensor measures any leaks by monitoring changes in electric current.

Fig. 4.13: Hydrogen leakage detector

Compressor Assembly Operational and Performance Tests

During the Compressor Assembly Operational and Performance Tests, we evaluate key factors such as pressure levels, vibrations, and noise levels. We also check that safety valves and alarm devices work correctly when needed.

These detailed tests ensure that every part of the hydrogen production system meets high operational standards, leading to safe and efficient production.

Drying Plant Hydraulic Test

Hydrogen dryers are important for removing moisture from hydrogen gas. This step is necessary to ensure the purity and reliability of hydrogen for various industrial uses. Moisture can cause problems like corrosion, reduced catalyst activity, and equipment failures. Therefore, getting rid of moisture is essential for both efficiency and product quality.

One common type of hydrogen dryer is the pressure swing adsorption (PSA) dryer. This dryer uses special materials, often zeolites, to trap moisture from the hydrogen gas. As the gas flows through the dryer filled with the adsorbent, the moisture gets captured, leaving a stream of dry hydrogen gas. To improve its dryness, this gas passes through a second vessel with a different adsorbent material, which captures any remaining moisture, enhancing hydrogen purity.

Another method for drying hydrogen gas is the membrane dryer. This technology uses a membrane that allows hydrogen gas to pass through while keeping moisture trapped. The captured moisture is vented away, creating a continuous flow of dry hydrogen gas for industrial applications.

The drying process usually happens under controlled pressure, ranging from 10 to 30 bars. To ensure the system's safety and integrity, hydraulic pressure tests are performed. During these tests, all outlets except the inlet are sealed. Then water is introduced under pressure, about twice the normal operating pressure. The pressure is then monitored for six hours to check for drops. Additionally, all valves are inspected carefully to make sure there are no leaks. A steady pressure reading indicates a successful test, confirming that the system is leak-proof.

Fig. 4.14: Hydrogen drying plant

In hydrogen production, hydraulic testing is also very important. Green hydrogen is produced by splitting water into hydrogen and oxygen through a process called electrolysis. This happens in an electrolyser with two separate compartments, one for the cathode and one for the anode, separated by a membrane to keep the gases from mixing. To stay safe and efficient, the pressure in the oxygen side is kept lower than on the hydrogen side. This pressure difference is maintained with proper pressure and safety devices, as well as secure pipes and valves. Hydraulic pressure tests ensure that the seals between the compartments are intact to prevent problems.

Always remember that safety is very important in hydrogen production systems. Safety tests check the automatic valves that respond to critical issues like high pressure, high temperature, lack of electric or water supply, excessive hydrogen leakage, valve malfunctions, and the ability to perform a manual emergency shut-down from a safe distance.

Starting a green hydrogen production plant involves several important steps beyond just construction. The process includes organised stages from initial setup to the official handover of the facility. These stages, illustrated in the **Figure,** show the key milestones that lead to the project's successful completion.

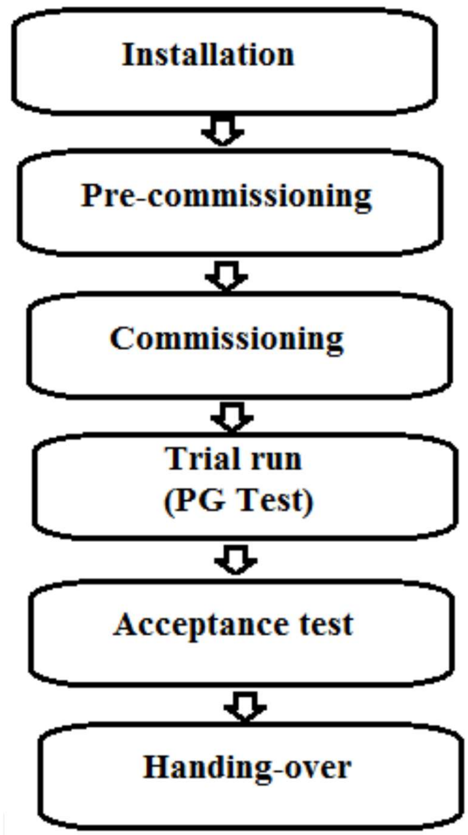

Fig. 4.15: Organised Setup for Project Completion

Pre-commissioning

The Pre-Commissioning phase involves important initial efforts to test and confirm that each unit, system, and sub-system in a specific area works correctly and meets design requirements. Every component goes through thorough checks and tests to ensure it is ready for the next commissioning phase.

Trial Run

Once the hydrogen production plant is commissioned, a trial run begins right away. This phase tests the plant's operation, requiring it to run smoothly without interruptions for at least 72 hours. During this trial, all components of the plant must function, and the system must actively produce hydrogen.

During the trial run, we check various contract requirements, including the expected hydrogen production rate per hour, electricity use (separated for the electrolysis and conditioning systems), and water consumption. These checks are essential for accepting the plant.

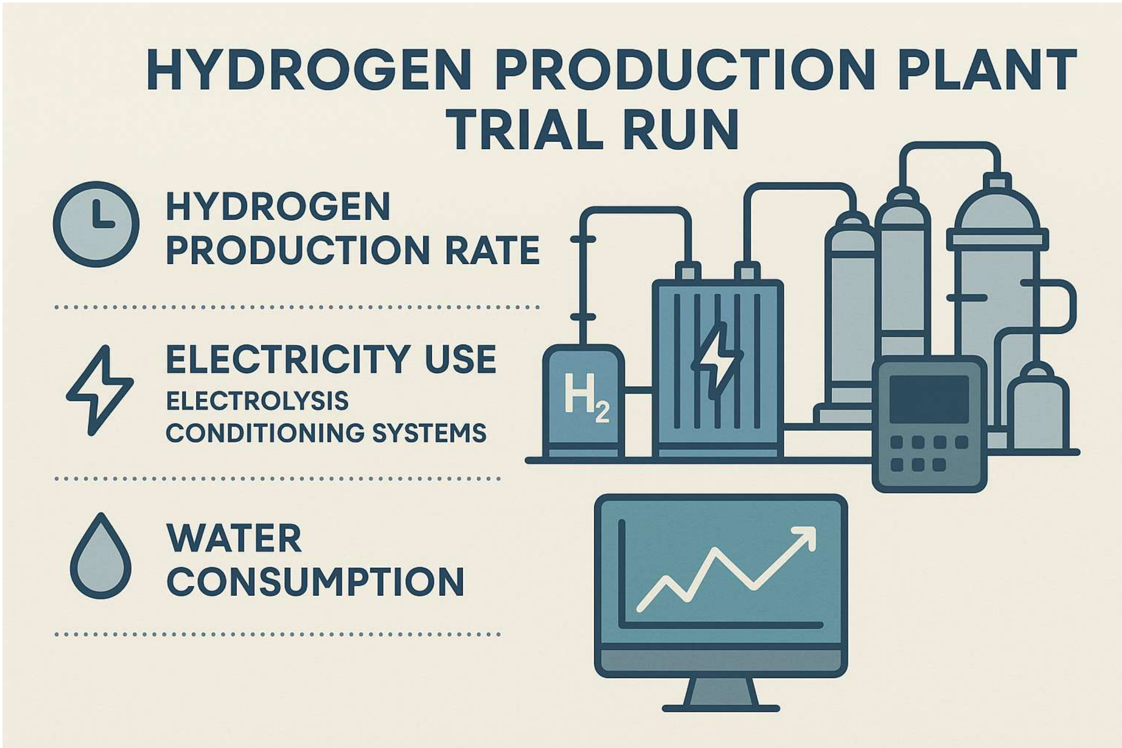

Fig. 4.16: Hydrogen Production Plant Trail Run

Applicable Standards

Final Acceptance Test

The Final Acceptance Test occurs after completing the Performance Guarantee (PG) test for the Green Hydrogen Plant. This test happens under real operating conditions, ensuring the plant runs without issues for 30 days, and is known as the "Final Acceptance Test."

We will accept the Green Hydrogen Plant only if it passes these strict tests. The following criteria apply:

1. The equipment must meet the required ratings and performance standards specified.
2. The guaranteed performance numbers must be precise, with no tolerances. All possible measurement errors should be included in these figures.
3. All guarantees must be proven during the PG test.
4. If the equipment or system does not meet the guaranteed performance during the PG test, we will require necessary adjustments or replacements. The corrected performance must then be revalidated in the next PG test.

Noise Management

All plant equipment and systems must operate continuously without exceeding the specified noise limits at all output levels.

To measure noise levels, we will use trusted international standards and methods. A calibrated sound level meter, compliant with IEC 651, BS 5969, or IS 9779, will be used.

We will record sound pressure levels at a distance of 1.0 meter horizontally from the closest equipment surface, and at an elevation of 1.5 meters off the floor.

We need to capture an average of six measurements around each piece of equipment and consider additional points based on relevant standards and equipment size. Measurements will be taken using a slow response on the A-weighting scale. The average of these A-weighted sound pressure levels, in decibels referenced to 0.0002 micro bar, must not exceed the guaranteed value. We will calculate corrections for background noise according to applicable standards, gathering all necessary data during the testing process.

Hydrogen Production Plant Overview: This document describes the key requirements and specifications for the Hydrogen Production Plant. It focuses on the tests and operational checks needed for effective commissioning.

Key Performance Demonstrations:

- Hydrogen Gas Compressors: We will demonstrate the capacity and discharge pressure of the hydrogen gas compressors at their rated duty point on-site to ensure they meet performance standards.
- Electrolyser and Rectifier: We will showcase the operational efficiency of the electrolyser and rectifier, including their capacity and power consumption, through thorough on-site testing.
- Stream Parallel Operations: It is crucial to demonstrate the parallel operation of two independent hydrogen generation streams to confirm system reliability.
- Hydrogen Quality Standards: We need to verify on-site that the purity and moisture level of the produced hydrogen meet the necessary quality standards for downstream applications.
- Hydrogen Generation Capacity: The capacity of the hydrogen production plant must be demonstrated for each stream, showing effective output and operational readiness.
- Operational Noise and Vibration Monitoring: On-site checks will measure the noise and vibration levels from the hydrogen gas compressors to ensure they meet acceptable standards.

Scope of Supply and Technical Specifications:

- The supplier must provide detailed technical information, construction features, and design parameters as specified. No deviations from these guidelines will be accepted.
- A Quality Plan (QP) outlining test procedures aligned with the specifications must be submitted for approval. All inspections and tests will be formally witnessed to validate test certificates and inspection records.
- All materials used must be equal to or better than those specified, with any alternative materials needing approval for their suitability.
- The supplier must provide any required commissioning spares and arrange for special tools and equipment needed for installation and testing.

Performance Guarantee Testing Parameters:

1. The performance guarantee (PG) tests will validate the capacity and discharge pressure of hydrogen gas compressors at their rated duty points.
2. We will test the electrolyser and rectifier for operational capacity, overall power consumption, and the effective parallel operation of both streams.
3. We will assess hydrogen purity levels, moisture content, and generation capacity for all operational streams.
4. We will check vibration and noise levels from the compressors to confirm they meet industry standards.

Testing Conditions:

1. The performance guarantee test will last at least 72 continuous hours to evaluate sustained operational performance.
2. The PG tests will follow an approved test procedure, which we will finalize together within an agreed time after the award notification.
3. The supplier will provide all necessary materials, equipment, and manpower for the PG tests, regardless of specification.
4. If any equipment fails to meet guaranteed performance metrics, the supplier must fix or replace it. We will conduct follow-up PG tests to confirm that repairs meet the guaranteed specifications.
5. This approach ensures that the Hydrogen Production Plant runs efficiently and reliably, meeting high performance and safety standards.to the highest standards of performance and safety.

Check Your Progress

A. Multiple Choice Questions (MCQs)

Q1. Which test confirms that the hydrogen production system has no gas leaks?
A) Purity Test
B) Hydraulic Test
C) Leakage Test
D) Trial Run
Answer: C) Leakage Test

Q2. During the Drying Plant Hydraulic Test, the system is pressurized to approximately:
A) 0.5 × operating pressure
B) 1 × operating pressure
C) 3× operating pressure
D) 2 × operating pressure
Answer: C) 2 × operating pressure

B. Fill in the Blanks

1. The ________ Test uses a portable analyser to measure how well hydrogen conducts heat. Answer: Hydrogen Purity
2. For leakage testing, a tracer gas mixture of 5% hydrogen and 95% ________ is used. Answer: nitrogen

3. Before pre-commissioning, _________ quality and _________ supply checks must be completed. Answer: water; electricity
4. The Trial Run must run uninterrupted for at least _________ hours to verify plant readiness. Answer: 72
5. Final Acceptance Test requires the plant to operate under real conditions for _________ days. Answer: 30

C. Short-Answer Questions

1. Name two checks performed before starting the pre-commissioning tests.
2. What safety functions are verified during the Safety Test?

D. Long-Answer Questions

1. Explain the purpose and procedure of the Compressor Assembly Operational and Performance Test.
2. Describe how the Drying Plant Hydraulic Test is carried out and why it is critical for hydrogen purity.

MODULE 5 PERFORM HEALTH AND SAFETY MEASURES FOR INSTALLING AND OPERATING GREEN HYDROGEN SYSTEMS

Module Overview

Safety is the backbone of every successful green hydrogen project. In this module, we will will explore the *real-world* safety rules, tools, and best practices used to protect people, equipment, and the environment in hydrogen plants.

From understanding how to respond in emergencies to learning how detectors, safety gear, and fire protection systems work, this module is packed with practical knowledge that every future hydrogen professional needs. Through examples, scenarios, and visual learning aids, you will become confident in managing risks at the workplace.

This is not just about reading ruleset's about developing the right mindset, learning how to act quickly and responsibly, and ensuring zero harm in hydrogen system operations. Let's make safety a habit, not just a requirement!

Learning Outcomes

After completing this module, students will be able to:

1. Identify and apply occupational health and safety standards related to hydrogen production systems.
2. Recognise potential hazards such as gas leaks, explosions, or equipment failures, and know how to respond during emergencies.
3. Use safety detectors, tools, and Personal Protective Equipment (PPE) to ensure a safe work environment.
4. Interpret safety labels and Material Safety Data Sheets (MSDS) for handling hazardous materials safely.
5. Maintain safe conditions like ideal temperature, humidity, and storage requirements for hydrogen and chemicals.
6. Implement workplace safety procedures, including first aid, fire protection, housekeeping, and compliance with statutory regulations.

Module Structure

Session 1: Occupational Health & Safety Standards and Regulations

Session 2: Emergency Situations in a Hydrogen System

Session 3: Detectors and Safety Tools

Session 4: Maintain Ideal Temperature and Humidity

Session 6: Storage Monitoring and Personal Safety

Session 7: Hazards Associated with Hydrogen Production System

Session 8: Work Safety Procedures and Instructions

Session 1: Occupational Health & Safety Standards and Regulations

Hydrogen is a fuel that is becoming more and more popular because it is clean and powerful. It doesn't produce harmful smoke or gases when used, which makes it good for the environment. But even though it is a great fuel, it can also be dangerous if not handled properly. That's why we call it a "high-hazard" material.

When we say "high-hazard," we mean that hydrogen needs special care while producing, storing, and using it. If not used safely, it can lead to fire, explosions, or health issues. Just like we take care while using gas stoves or driving vehicles, we must also follow safety steps with hydrogen.

This unit will help you learn how to stay safe while working with hydrogen. You will understand what makes hydrogen risky, how to handle it properly, and what safety systems are used to prevent accidents.

What Makes a Fuel Dangerous?

For any fire to start, three things must come together:

1. **Ignition Source** – like a spark, flame, or high heat
2. **Oxidant** – usually oxygen from the air
3. **Fuel** – such as hydrogen

Explanation: If we can prevent even one of these three from being present, we can stop a fire from happening. That is why all hydrogen systems are designed to avoid these three elements from coming together.

Fig. 5.1: Hydrogen Fire Triangle

Favourable Properties of Hydrogen

1. **Hydrogen is non-toxic**: Hydrogen does not contain any poisonous substances that can harm the human body. If a small amount of hydrogen is inhaled in an open or well-ventilated area, it will not cause poisoning or sickness. Unlike toxic gases like carbon monoxide, hydrogen doesn't enter the bloodstream and interfere with the body's functioning. However, even though it's non-toxic, it can still be dangerous in enclosed spaces where it might reduce the amount of oxygen available to breathe. So, while hydrogen itself isn't poisonous, it still needs to be used with caution.

2. **It is lighter than air**: Hydrogen is the lightest element in the universe, which means it is even lighter than the air around us. Because of this, if hydrogen leaks from a container or system, it doesn't stay close to the ground. Instead, it quickly rises upward and spreads into the open sky. This natural behaviour helps prevent dangerous situations. In open and well-ventilated areas, the leaked hydrogen moves away before it can gather in large amounts or reach an ignition source. That's why having good airflow and open space is important when working with hydrogen; it allows the gas to escape harmlessly, reducing the risk of fires or explosions.

Risks with Hydrogen

1. **Wide flammable range**: Hydrogen can burn in small or large amounts when mixed with air, making it more dangerous than many other fuels.

2. **Low ignition energy**: Hydrogen needs very little energy to catch fire. Even a tiny spark can ignite it.

Fig. 5.2: Risk with Hydrogen

Important Safety Measures

1. **Ventilation and Leak Detection**: Good airflow helps hydrogen escape safely if it leaks. Leak detectors alert us early to prevent accidents.
2. **Invisible Flame Detection**: Hydrogen burns with a flame that is hard to see. Special flame detectors and thermal cameras are used to detect hydrogen fires.
3. **Safe Distance**: The hydrogen production area should be far from other machines and industries to avoid interaction and risks.
4. **Quick Access to Help**: The plant should be located in an area where emergency teams can reach quickly if needed.

Embrittlement

Hydrogen can weaken some metals by forming small cracks. This is called embrittlement. Choosing the right materials is essential for building safe hydrogen systems.

Testing Hydrogen Systems

1. **Tank Leak Tests:** Check if hydrogen tanks have any holes or leaks.
2. **Garage Leak Simulations**: See how hydrogen behaves in a closed space like a garage.
3. **Drop Tests**: Check how strong the tank is by dropping it from a height.

These tests ensure that hydrogen systems are safe to use and handle.

Fig. 5.3: Testing Hydrogen Systems

Training for Safety

People working with hydrogen must be trained properly. Training teaches them:

- How to handle hydrogen safely
- What to do during emergencies
- How to use tools and machines safely

Fig. 5.4: Training for Safety

Occupational Health – Worker Safety

Occupational health focuses on keeping workers safe, healthy, and well-informed about their work environment. In India, where a large number of people are employed in industries, manufacturing, transportation, and service sectors, maintaining good occupational health is very important. Many workers operate in hot, crowded, or poorly ventilated environments, where the risks from gases like hydrogen can be higher. Occupational health in the Indian context also includes spreading awareness among workers who may have limited formal education, especially in rural and semi-urban areas. Government programmes like ESIC (Employees' State Insurance Corporation) and various safety acts help ensure health and safety at workplaces. Strong occupational health practices help reduce accidents, save lives, and create a better working atmosphere for India's workforce.

Fig. 5.5: Occupational health

It includes the following important points that support better occupational health and safety in workplaces across India:

1. **Reducing Accidents**: By identifying risks and hazards early like leaks, poor ventilation, or unsafe equipment we can prevent injuries or mishaps. For example, if workers are trained to detect hydrogen leaks quickly, accidents can be avoided.

2. **Better Productivity**: When workers are healthy and safe, they take fewer leaves, feel more energetic, and perform their tasks efficiently. In India, especially in

sectors like automobile workshops and small manufacturing units, better health practices directly improve productivity.

3. **Happy Work Environment**: A safe workplace leads to less stress. When workers feel confident that their well-being is being looked after, they are happier and more motivated. This is important in both urban factories and rural skill development centres.

4. **Awareness Training**: Workers are made aware of potential dangers and the right ways to handle equipment and materials like hydrogen. In India, where many workers may not have formal technical education, such training sessions, often held in regional languages, are critical to ensuring safety for all.

Fig. 5.6: Occupational health and Safety in India

Health Effects of Hydrogen

1. **Asphyxiation**
   Hydrogen can replace oxygen in a room. Breathing in such air can make someone dizzy, faint, or worse. Always keep the area well-ventilated.

2. **Cold Burns or Frostbite**: Liquid hydrogen is extremely cold. If it touches the skin, it can cause cold burns. Proper safety gear must be worn.

🚨 EMERGENCY SAFETY INSTRUCTIONS FOR HYDROGEN LAB 🚨

Please read and follow the safety tips below. Your alertness can prevent accidents!
Never enter the hydrogen area alone. Always work in pairs or under supervision.
✅ Make sure there is proper ventilation. Use exhaust fans and keep vents open at all times.
✅ Emergency oxygen cylinders must be accessible and located nearby.
✅ In case of a suspected hydrogen leak, DO NOT use mobile phones or create sparks.
✅ Use only flame detectors or thermal cameras to detect invisible hydrogen flames.
✅ Always wear protective gear – gloves, goggles, lab coats.
✅ Know the emergency exit routes and location of fire extinguishers.
✅ Report any unusual smell, sound, or pressure changes immediately to the lab in-charge.
Stay Alert – Stay Safe!
(This notice must be displayed at all entry points of the hydrogen lab.)

Fig. 5.7: Displayed Notice regarding Safety in Hydrogen Plant

OSHA – Workplace Safety

OSHA stands for Occupational Safety and Health Administration. It is an organisation that helps make workplaces safer for all workers. In simple words, OSHA is like a safety guard for people at work.

Fig. 5.8: Occupational Safety and Health Administration

Workplaces can include places like factories, repair workshops, power plants, or even small garages. There are many tools, machines, wires, gases, and fuels being used some of which can be dangerous if not handled carefully.

To prevent accidents, OSHA makes safety rules that every employer (company or factory owner) must follow. These rules include using protective gear, installing safety equipment, training workers, keeping first aid ready, and more.

In India, these types of rules are supported by organisations like the Directorate General of Factory Advice Service and Labour Institutes (DGFASLI) and the Ministry of Labour. By following OSHA, type safety guidelines, companies can protect their workers from accidents, injuries, and illness at work. stands for Occupational Safety and Health Administration. It makes rules to:

- Keep workers safe
- Prevent workplace accidents

- Check that employers follow safety practices

Fig. 5.9: Scope of OSHA activities

ISO – Global Safety Standards

ISO stands for International Organisation for Standardisation. It provides safety rules for companies across the world.

1. **ISO 45001** – Helps keep workplaces safe and healthy.
2. **ISO 18001** – Provides guidance for health and safety management.

First Aid Facilities

A first-aid dispensary should be located near the plant's exit gate. This helps medical help arrive quickly and move injured workers for treatment.

Check Your Progress

1. Multiple Choice Questions

1. What makes hydrogen a high-hazard material?
   A. It can cause fire or explosions if not handled properly
   B. It is expensive
   C. It is toxic
   D. It is heavy and sinks to the ground

2. What is the role of ventilation in hydrogen safety?
   A. It makes the room cooler

B. It helps hydrogen escape if leaked
C. It helps in detecting smoke
D. It removes toxic fumes

3. Why is hydrogen flame dangerous?
   A. It produces colorful smoke
   B. It burns with a visible red flame
   C. It is invisible and hard to detect
   D. It does not generate any heat

4. What does OSHA stand for?
   A. Operational System for Hazard Avoidance

   B. Occupational Safety and Health Administration

   C. Office of Safety and Hazard Assessment

   D. Organisation for Safe Hydrogen Access

5. What is embrittlement in hydrogen systems?
   A. Cracking of metals due to hydrogen exposure

   B. Melting of metal at high temperature

   C. Hardening of surfaces

   D. Rusting due to moisture

2. Fill in the Blanks

1. Hydrogen is considered a _________ fuel because it requires special handling. → **Answer: high-hazard**
2. The three components of the fire triangle are ignition source, oxidant, and _________. → **Answer: fuel**
3. Hydrogen is _________ than air, which allows it to rise and disperse quickly when leaked. → **Answer: lighter**
4. _________ burns or frostbite can occur if liquid hydrogen touches the skin. → **Answer: Cold**

5. _________ is an international safety standard that ensures workplace health and safety. → **Answer: ISO 45001**

3. **Short Answer Questions**
   1. What are two major risks associated with hydrogen?
   2. Why is it important to use protective gear while handling hydrogen?
   3. What is the role of ISO 45001 in occupational health and safety?
   4. How does proper training help in hydrogen safety?

4. **Very Long Answer Questions**
   1. Explain the fire triangle in the context of hydrogen safety and how its components can be controlled to prevent accidents.
   2. Discuss the occupational health importance in hydrogen-related workplaces, especially in the Indian context.
   3. Describe the safety measures taken in hydrogen labs and plants to avoid accidents.
   4. Explain embrittlement and testing methods used to ensure hydrogen system safety.

Activity
1. Students form pairs. One acts as a lab worker handling hydrogen, and the other is a safety supervisor. Practice emergency responses and safety checks. 2. Create a poster that includes key hydrogen lab safety tips (based on the displayed lab notice). Include symbols, color coding, and emergency contact info. 3. Students create a chart or 3D model explaining the fire triangle using real-life examples of ignition, oxidant, and fuel.

Session 2: Emergency Situations in a Hydrogen System

Hydrogen gas is an exciting energy source, but it comes with some risks because it's usually stored and transported at very high pressures. This means there's a real chance of leaks and even explosions if things go wrong. While it's rare for someone to breathe in hydrogen unless they are stuck in a small, closed space, burns or injuries from explosions are possible. If a fire does start, it can often be put out quickly by shutting off the hydrogen supply using special remote valves at the start of the pipeline. If there's nothing else nearby that can catch fire, regular firefighting equipment can usually handle it. In bigger emergencies, it's smart to call for outside help. For threats like sabotage, security cameras and even drones are used to keep an eye on things. Natural disasters like lightning, earthquakes, or floods also need special safety measures to protect hydrogen systems.

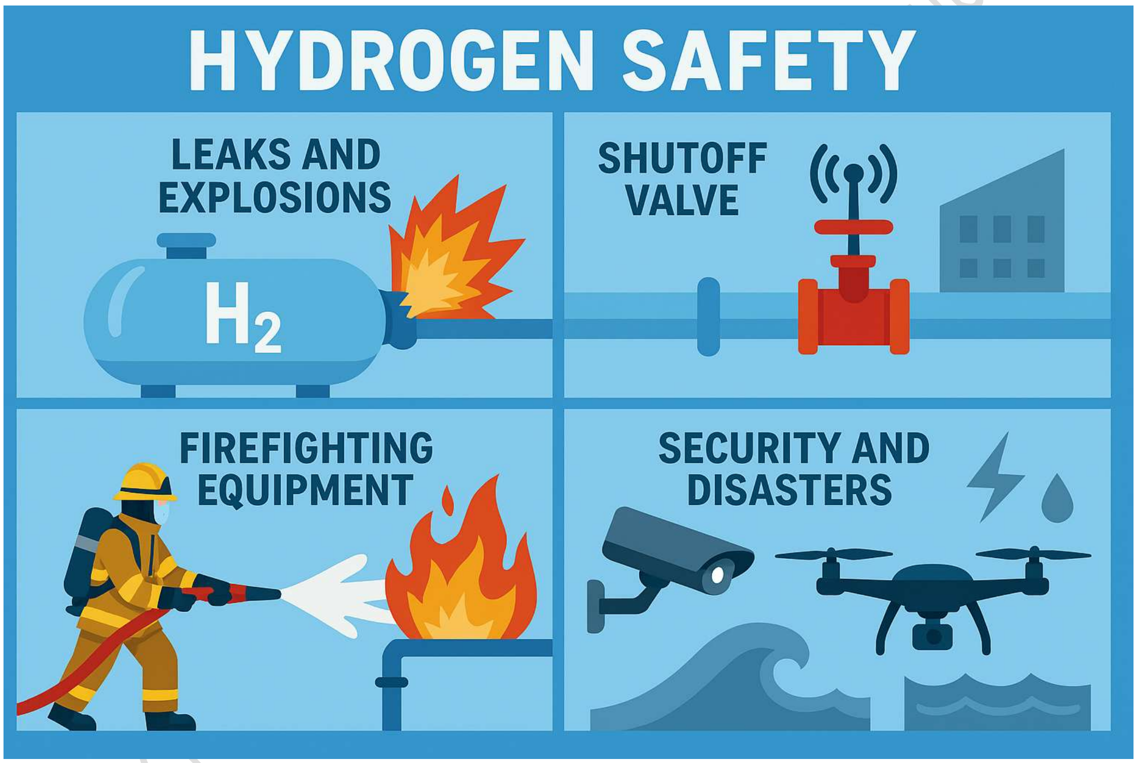

Fig 5.10: Hydrogen Safety

Flammability and Explosion Risks

Hydrogen is much more flammable than most other fuels. It can catch fire when its concentration in air is between 4% and 75%, and between 4% and 94% in pure oxygen. That's a huge range! So, it's super important to make sure hydrogen doesn't mix with air or oxygen in closed spaces. Hydrogen can also form explosive mixtures with oxygen in the air, especially between 18% and 59% concentration. Explosions can happen if there's a leak in a hydrogen plant or storage area, or even from intentional attacks. For large amounts of hydrogen, storing it underground is often much safer.

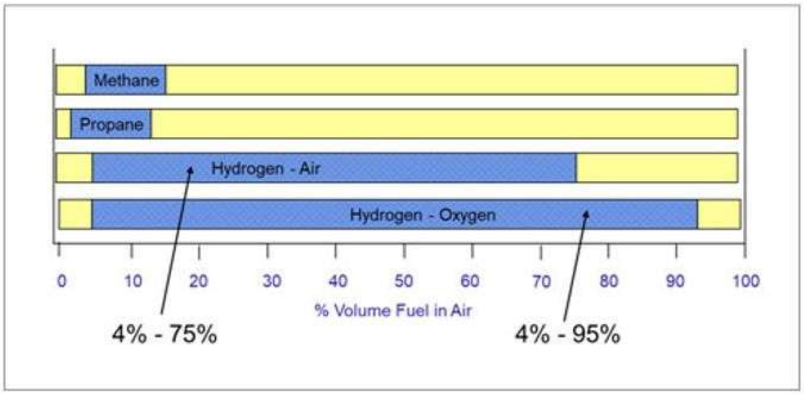

Fig 5.11: Hydrogen flammability range

Low Ignition Energy

Hydrogen needs very little energy to ignite much less than other fuels. This means that even a small spark or static electricity could set it off, making pipelines and storage tanks especially vulnerable to explosions.

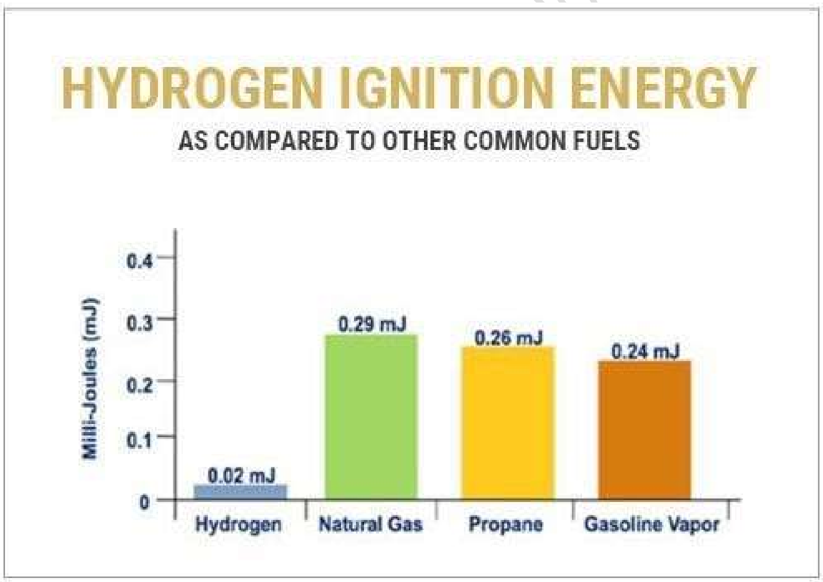

Fig 5.12: Hydrogen ignition energy

Natural Calamities

Natural disasters like earthquakes, floods, or wildfires can cause major damage to hydrogen plants. The amount of damage depends on how much hydrogen is stored and how quickly it's produced. To reduce risks, plants are often built with safe distances around them or protective walls.

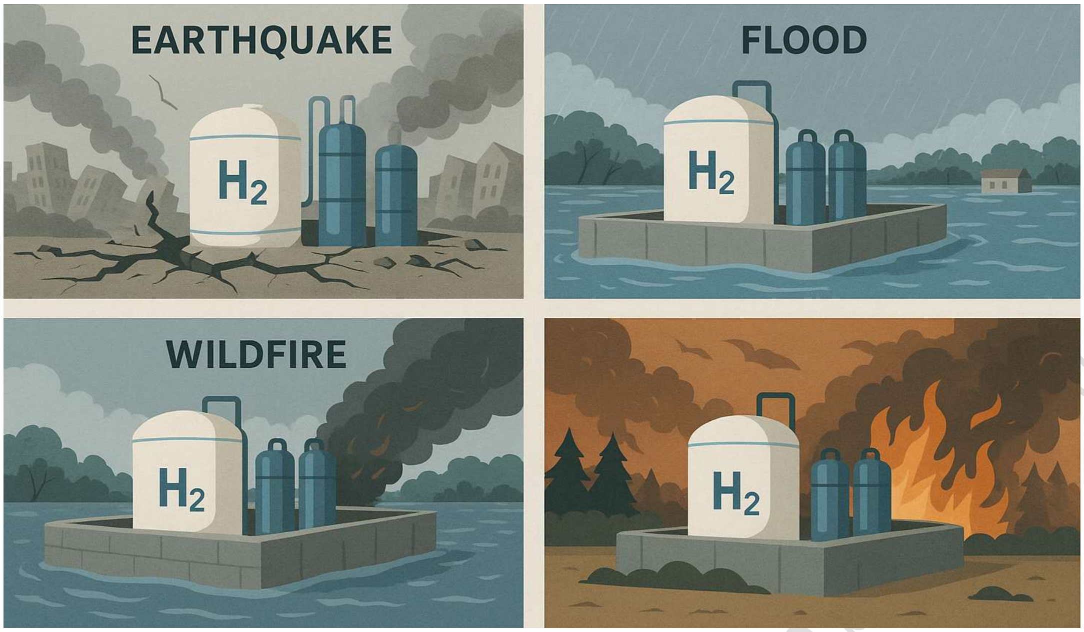

Fig 5.13: Natural Calamities

Check Your Progress

A. Multiple Choice Questions

1. Why is hydrogen stored at very high pressure considered risky?
   A. It creates loud noises
   B. It increases its weight
   C. It changes color under pressure
   D. It can lead to leaks or explosions if mishandled

2. What is the flammable range of hydrogen in the air?
   A. 1% to 30%
   B. 4% to 75%
   C. 10% to 80%
   D. 5% to 50%

3. What is the best way to stop a hydrogen fire in an early stage?
   A. Throw water on it

   B. Use a regular fire extinguisher

C. Shut off the hydrogen supply using remote valves

D. Cover it with sand

4. What is one reason hydrogen systems are often monitored with drones and cameras?
   A. To check weather conditions

   B. To monitor for sabotage or intentional damage

   C. To increase pressure

   D. To transport hydrogen

B. Fill in the Blanks

1. Hydrogen is _________ flammable than most other fuels. → **Answer: more**
2. Hydrogen can ignite with very low _________ energy. → **Answer: ignition**
3. Hydrogen can form explosive mixtures with _________. → **Answer: oxygen**
4. In natural disasters, hydrogen plants may be protected using _________ walls or safe distances. → **Answer: protective**
5. In large hydrogen fires, emergency responders should be _________ from outside. → **Answer: called**

C. Short Answer Questions

1. Why is hydrogen stored under high pressure considered a safety concern?
2. How does hydrogen's flammability range make it more dangerous?
3. What role do remote shut-off valves play in emergencies?
4. Name two natural disasters that can threaten hydrogen facilities.

D. Very Long Answer Questions

1. Explain the flammability and explosion risks associated with hydrogen and the precautions that should be taken to reduce those risks.
2. Describe how low ignition energy increases the danger in hydrogen systems and what safety steps should be taken.

3. How do natural calamities pose a threat to hydrogen facilities and what strategies are used to reduce damage?
4. What safety technologies and methods are used to respond to hydrogen emergencies, including sabotage or accidents?

Activity

1. Students create a chart showing hydrogen's flammable and explosive range compared to other gases like LPG or methane.
2. Conduct a role-play emergency. Assign roles such as safety officer, operator, and first responder. Practice shutting off the hydrogen and evacuating.
3. Design an infographic on "Hydrogen Emergency Do's and Don'ts" with visuals and bullet points.

Session 3: Detectors and Safety Tools

Hydrogen Leak Detection

Hydrogen leaks can be tricky; they might happen with or without a visible flame, and sometimes the leak is so small it's almost impossible to notice. To find tiny leaks, air samples are taken from the highest points in the plant and checked with gas detectors. In places like oil refineries, special detectors are always on the lookout for leaks. These detectors are so sensitive that they can spot hydrogen at just 0.2% concentration, which is very safe. Workers also use portable hydrogen detectors for extra safety.

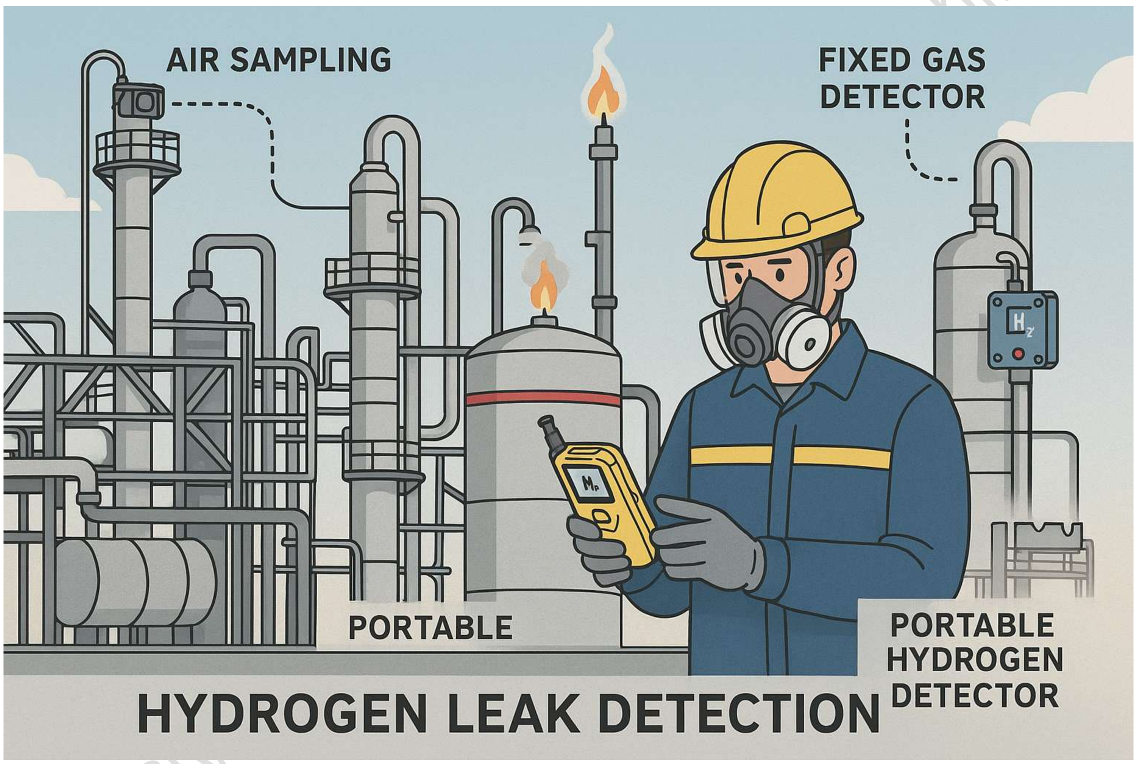

Fig 5.14: Hydrogen Leak Detection

Methods of

- **Hydrostatic Test:** The equipment is filled with water or oil and pressurized much higher than normal to check for leaks or permanent changes in shape.

- **Burst Test:** The vessel is filled with gas and tested at double the normal pressure to see if it can handle extreme conditions.

- **Helium Leak Test:** Helium is used because it can find even the tiniest leaks and doesn't react with anything. This method can detect leaks as small as 0.1 parts per million.

- **Vacuum Test:** A vacuum is created inside the equipment, or helium is injected and the whole thing is placed in a vacuum chamber. This can combine both burst and leak tests.

- **Hydrogen Sensor Test:** A safe, non-flammable mix of 5% hydrogen and 95% nitrogen is used. Special sensors "sniff out" leaks, and an audio signal gets louder as the detector gets closer to the leak. This method is cheaper than using helium, but not quite as sensitive.

- **Chemo-Chromic Detectors:** These are materials that change color when they come into contact with hydrogen, making it easy to spot leaks. Sometimes, these indicators are even built into special tapes that can be wrapped around pipes.

By using these safety tools and methods, hydrogen can be used safely and effectively in many industries, even as its use continues to grow.

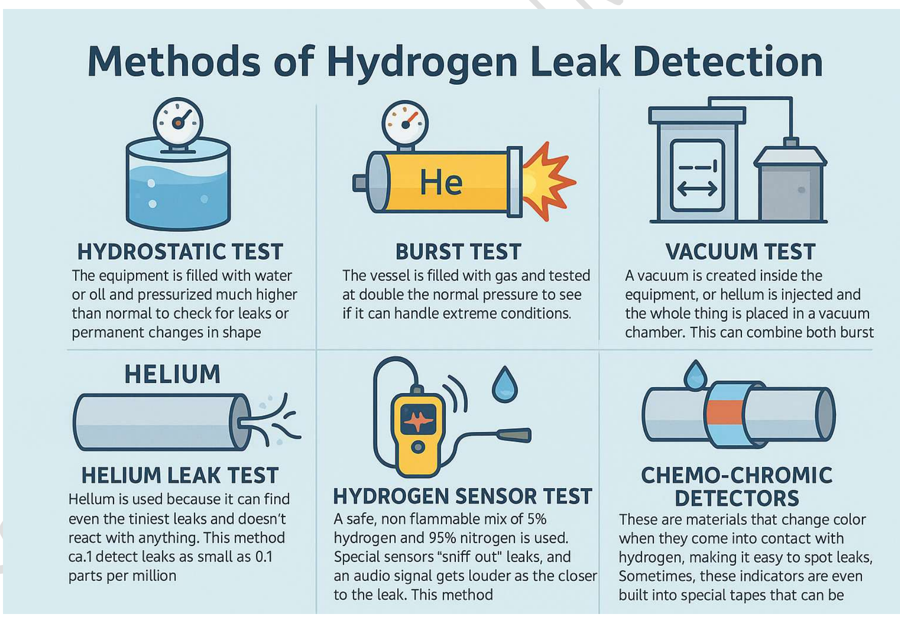

Fig 5.15: Methods of Hydrogen Leak Detection

Controls and Protection in Hydrogen Systems

Keeping Hydrogen Plants Safe

Safety in a hydrogen production plant is super important because of the risks involved with hydrogen gas. To make sure everyone stays safe, modern plants use smart control systems that work together with hydrogen and fire detectors. Here's how these systems help protect people and equipment:

What Happens When a Leak or Fire is Detected?

If a hydrogen leak or fire is detected, the control system jumps into action automatically. Here's what it does:

1. **Shuts off and isolates hydrogen sources** – This stops more hydrogen from escaping.
2. **Shuts down or deactivates equipment** – Machines are turned off or put into a safe mode to prevent accidents.
3. **Activates alarms** – Loud sounds and flashing lights warn everyone nearby about the danger.
4. **Boosts ventilation** – The system increases airflow to help clear out any leaked hydrogen.
5. **Manual Reset Required** – The system won't restart on its own; someone must check everything and reset it manually.
6. **Remote Notification** – Facility managers and emergency responders may get alerts, so help can arrive quickly if needed.

Fig 5.16: Control System after a Hydrogen Leak or Fire is Detected

Equipment/Alarms	Instrument Air	Dispenser	Compressor Control Panel	Compressor	Compressor Diaphragm	H2 Storage	Hydrogen System Entry way	25 ft away from H2 System	Hydrogen Fill	Hydrogen Equipment Enclosure	Equipment Shutdown Scenario	Site Shutdown Scenario
E-Stop		●	●	●			●	●				●
Heat Detection		●		●		●				●		●
Flame Detection		●		●	●	●				●		●
Leak Detection		●		●	●	●						●
Hose Break		●							●		●	
Mechanical Ventilation										●	●	
High Pressure				●							●	
Low Pressure	●			●							●	
High Temperature		●		●							●	
Low Temperature		●		●							●	
Mechanical Relief Device	●	●		●		●			●		N/A	N/A

Fig 5.17: Indicative shutdown control actions

Warning and Alarm Systems

Plants have special warning systems to spot any abnormal conditions or equipment failures early. Alarms use both sounds and lights, with different signals for different emergencies. Regular practice drills help workers know what to do when an alarm goes off. Emergency signals are shown in all operational areas, so everyone knows what's happening.

Fig 5.18: Warning and Alarm Systems

Material Safety

Chemical Labels

Chemicals, including hydrogen, are labelled using the Globally Harmonised System (GHS). This is an international system created by the United Nations to make sure everyone understands the hazards of chemicals. GHS labels use:

- Signal words (like "Danger" or "Warning")
- Pictograms (safety symbols)
- Hazard statements (what could go wrong)
- Precautionary statements (how to stay safe)

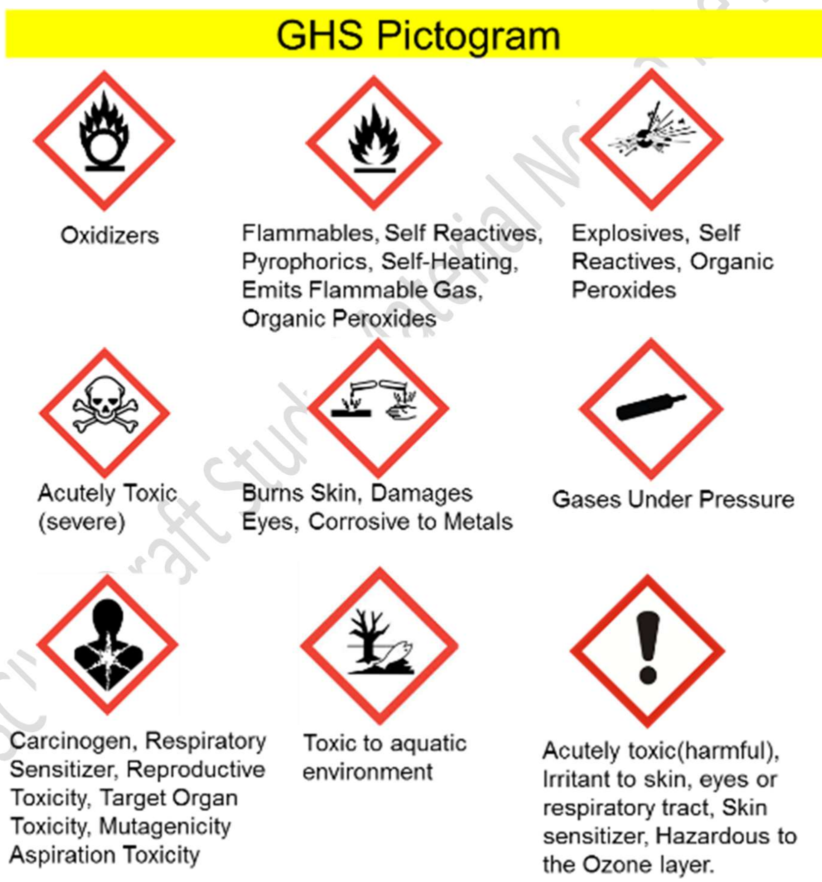

Fig 5.19: GHS safety symbols

Fig 5.20: Symbols indicating the nature of chemicals

It's important that labels are easy to understand and, where needed, shown in local languages. Special labels might also be used for different industries, like food or electronics, to warn workers about specific risks.

Using MSDS for Safe Handling

Material Safety Data Sheets (MSDS) are information sheets provided by chemical suppliers. They tell you about the hazards of a chemical and how to handle it safely. Here's what you need to remember when working with hydrogen:

1. Always read the MSDS and label before using hydrogen. If you're unsure, ask questions!
2. Release hydrogen only in well-ventilated areas.
3. Wear protective gear like goggles and face shields when working with pressurised gases.

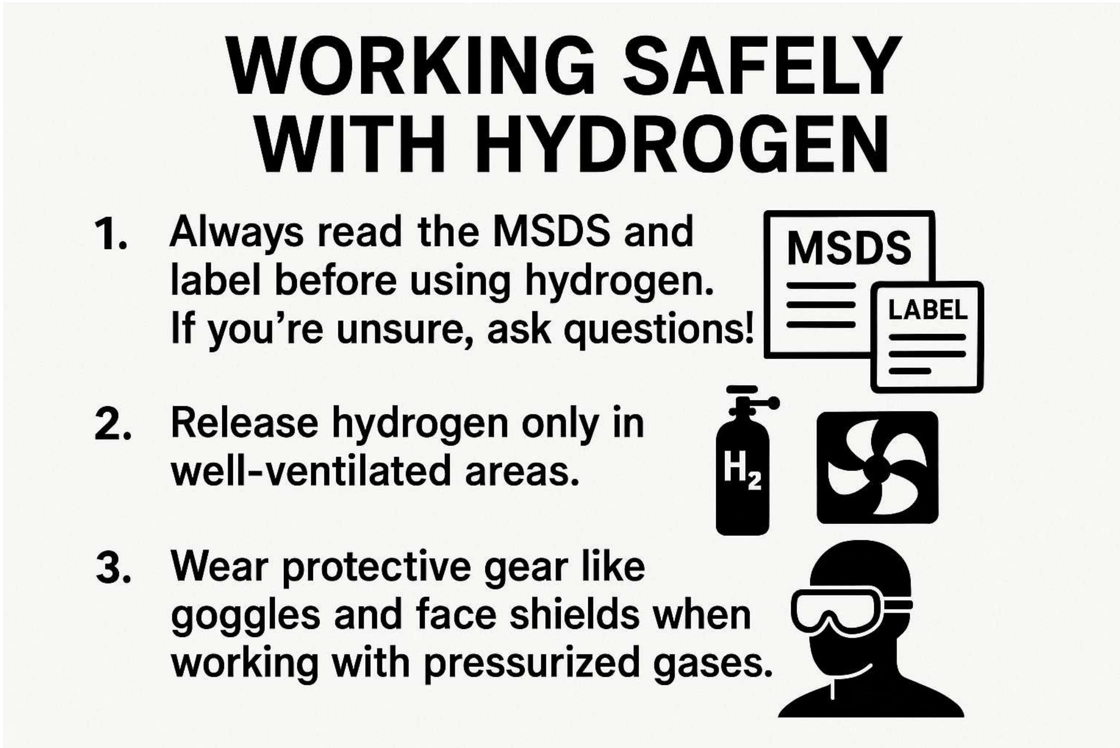

Fig 5.21: Working Safely with Hydrogen

Handling Gas Cylinders Safely

- Inspect cylinders and valves for damage. If you hear a hissing sound or smell gas, don't open the valve.
- Use the right regulator and equipment for the cylinder. Don't force connections or use homemade adaptors.
- Secure cylinders upright with a wall or rack, and keep the cap on until ready to use.
- Close valves when not in use.
- Never use lubricants or tape on valves or fittings.
- Keep cylinders clean and away from oil, grease, or dirt.
- Move cylinders carefully with a hand truck never roll or drop them.
- Avoid direct skin contact with escaping gas.

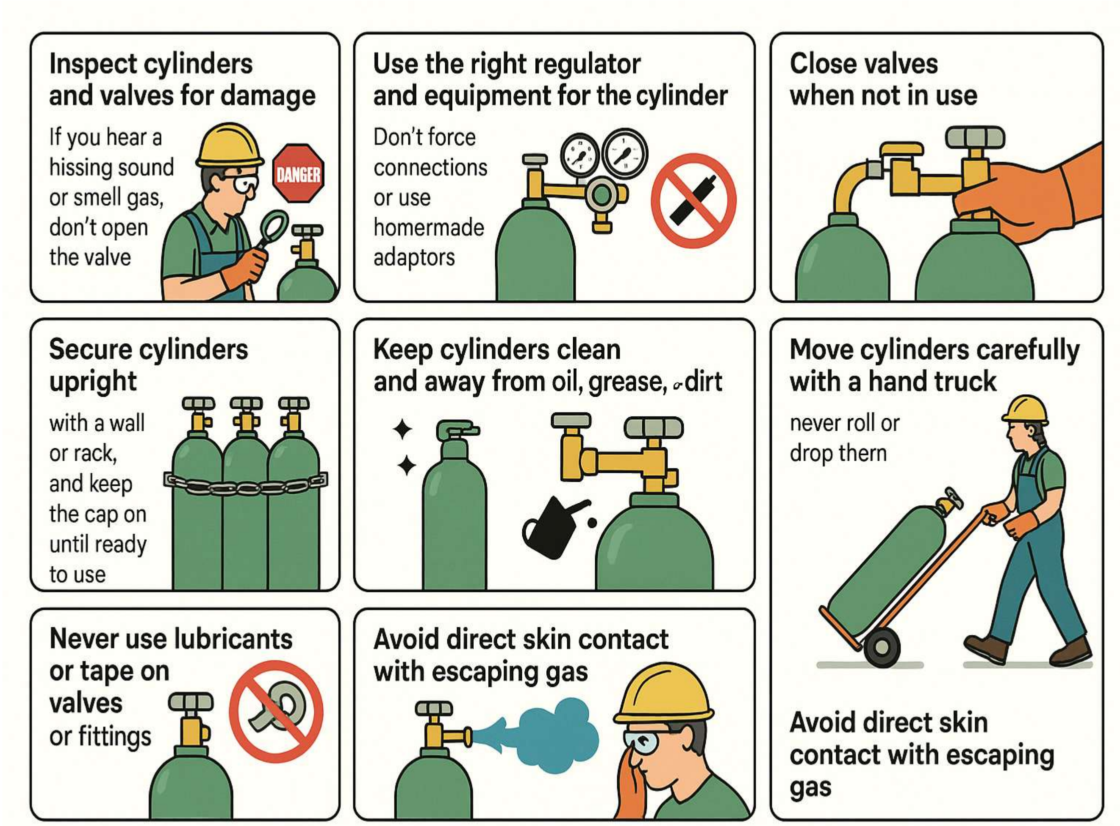

Fig. 5.21: Handling Gas Cylinders Safely

Why All This Matters

By following these safety controls and using proper labels and data sheets, hydrogen plants can prevent accidents and keep everyone safe. Remember, safety isn't just about rules it's about making sure everyone gets home safely at the end of the day!

Check Your Progress

A. Multiple Choice Questions

1. What is the minimum hydrogen concentration that some advanced gas detectors can detect?
   A. 2%
   B. 1%
   C. 0.5%
   D. 0.2%

2. Which gas is commonly used in leak detection for its non-reactive and sensitive properties?

A. Oxygen
B. Nitrogen
C. Helium
D. Methane

3. What is the purpose of chemo-chromic detectors in hydrogen safety?
   A. Measure pressure
   B. Change colour upon hydrogen exposure
   C. Cool the cylinders
   D. Create a vacuum

4. What happens when a hydrogen leak or fire is detected in a plant?
   A. The system increases pressure
   B. Manual operations continue
   C. The control system isolates the leak, shuts equipment, and triggers alarms
   D. Nothing changes

5. What is the main role of GHS labels on chemicals like hydrogen?
   A. To decorate cylinders
   B. To help workers understand chemical hazards
   C. To increase shelf life
   D. To reduce pressure

B. Fill in the Blanks

1. Hydrogen sensors often use a mixture of _________ hydrogen and _________ nitrogen. → **Answer: 5%, 95%**
2. The _________ Test uses helium to detect extremely small leaks. → **Answer: Helium Leak**
3. Warning systems in hydrogen plants use both _________ and lights to alert workers. → **Answer: sounds**
4. _________ stands for Material Safety Data Sheet. → **Answer: MSDS**
5. Cylinders must always be kept _________ using a wall bracket or rack. → **Answer: upright**

C. Short Answer Questions

1. What is the main advantage of using helium in leak detection tests?
2. What is the function of a control system when a hydrogen leak or fire is detected?
3. Why are MSDS important in handling hydrogen?
4. How should gas cylinders be transported safely?

D. Very Long Answer Questions

1. Describe at least four methods used to detect hydrogen leaks and explain the benefits of each.
2. Explain the sequence of actions a hydrogen plant's control system takes during a leak or fire emergency.
3. What is GHS labelling and why is it essential for hydrogen safety in industrial environments?
4. List the do's and don'ts of handling pressurised gas cylinders, especially hydrogen, and explain why they are critical.

Activity

1. Students create a visual or working model showing different types of hydrogen leak detection methods (e.g., color-changing tapes, sensors).
2. One student acts as the control system; others simulate responses to leak/fire alarms. Practice how workers react: evacuate, shut valves, or report.
3. Students design their own GHS-compliant label for a hydrogen container using signal words, hazard pictograms, and precautionary statements.

Session 4: Maintain Ideal Temperature and Humidity Level

How Temperature and Humidity Affect Hydrogen Purity

Normal room temperatures are safe and can be checked with simple thermometers. Humidity levels can also be acceptable if there is good ventilation.

A hydrogen purity analyser measures how pure the hydrogen gas is. The purity depends on temperature and humidity. Hydrogen purity measuring tools adjust for temperature and humidity effects. So, we measure these factors and make corrections to get accurate hydrogen purity readings.

Temperature and Its Effects

Higher temperatures improve the performance and efficiency of PEM fuel cells while also keeping the necessary humidity levels.

Humidity and Its Effects

Humidity refers to how much water vapour is in the air. More water vapour means higher humidity, and less means lower humidity. We often talk about humidity as relative humidity, which shows how much water vapour is in the air compared to the maximum it can hold at that temperature.

Effects on Steel

At a normal relative humidity of around 40% and 25 °C, the hydrogen concentration in steel is 0.4 parts per million (ppm). When the relative humidity increases, the hydrogen concentration in the steel gradually rises and stabilises at about 0.8 ppm.

Effects on Fuel Cells

Fuel cell performance drops significantly when relative humidity falls. For instance, at a current density of 0.34 A/cm^2, cell voltages are as follows:

- 0.675 V at 100% inlet RH
- 0.642 V at 70% RH
- 0.556 V at 50% RH
- 0.414 V at 35% RH
- 0.358 V at 25% RH

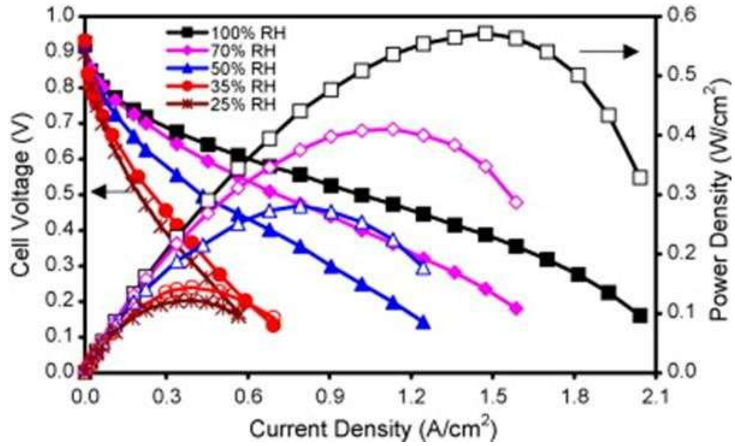

Fig. 5.22: Effect of relative humidity on fuel cell voltage

Monitoring Temperature and Humidity

It is important to keep track of temperature and humidity near hydrogen handling equipment to ensure safe conditions. Use a remote device to check the temperature and standard tools to measure humidity. Limit temperature increases for specific items, like compressors and electrical connections. High humidity can cause water to condense on metal surfaces, leading to rust and corrosion. To combat humidity issues, clean regularly, use hot air to dry surfaces, and maintain daily housekeeping. If any equipment is too hot, investigate and take action immediately.

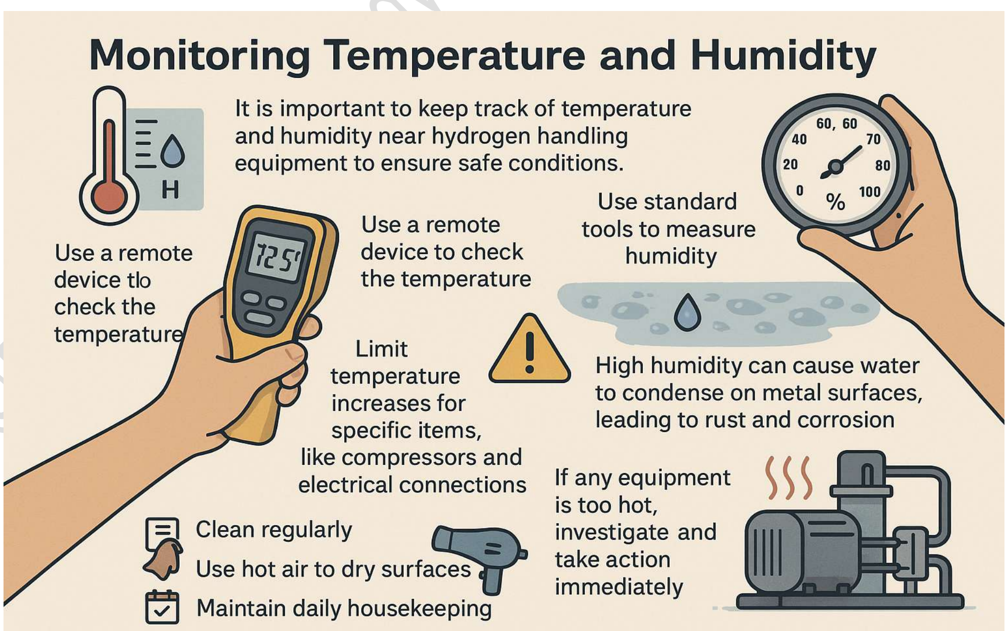

Fig. 5.23: Monitoring Temperature and Humidity

Check Your Progress

A. Multiple Choice Questions

1. What tool is used to measure the purity of hydrogen gas?
   A. Pressure gauge
   B. Thermometer
   C. Humidifier
   D. Hydrogen purity analyser

2. At which humidity level does steel reach about 0.8 ppm hydrogen concentration?
   A. When humidity increases and stabilises

   B. When the temperature is 0°C

   C. 25%

   D. 50%

3. What happens to fuel cell voltage as relative humidity decreases?
   A. Voltage decreases

   B. Voltage remains constant

   C. Voltage increases

   D. Voltage first increases then decreases

4. What is the main effect of high humidity on metal surfaces?
   A. Strengthening

   B. Corrosion and rust

   C. Cooling

   D. Insulation

→ Answer: B

5. Which of the following is a safe way to manage high humidity near hydrogen equipment?

A. Add more water vapour

B. Use lubricants on metal

C. Use hot air to dry surfaces

D. Paint everything black

B. Fill in the Blanks

1. Hydrogen purity can be affected by both ________ and ________. → Answer: temperature, humidity
2. At 25°C and 40% relative humidity, hydrogen concentration in steel is ________ ppm. → Answer: 0.4
3. When relative humidity drops to 25%, fuel cell voltage falls to ________ V. → Answer: 0.358
4. Low relative humidity causes ________ in fuel cell performance. → Answer: a drop
5. To measure temperature remotely, a ________ device can be used. → Answer: remote

C. Short Answer Questions

1. Why is it important to monitor temperature and humidity near hydrogen systems?
2. What does relative humidity represent?
3. How does low humidity affect PEM fuel cells?
4. What are two methods used to manage high humidity in hydrogen plants?

D. Very Long Answer Questions

1. Explain how temperature and humidity affect hydrogen purity and how the system corrects for these effects.
2. Describe the impact of relative humidity on steel and why it's important to maintain an ideal range.
3. Analyse how varying relative humidity levels impact PEM fuel cell performance, concerning cell voltage values.
4. List and explain the preventive measures to control temperature and humidity around hydrogen-handling equipment.

Activity

1. Students create a line graph showing how fuel cell voltage decreases with lower relative humidity based on the data from the session.
2. Design an ideal working space layout for hydrogen equipment, including temperature and humidity monitoring zones and safety tips.
3. Use real or dummy thermometers and hygrometers to record daily values in different classroom areas and interpret them.

Session 5: Storage Monitoring and Personal Safety

1. Smart Monitoring

Large hydrogen storage areas need constant attention, and staff should be alerted when action is needed. Keep the hydrogen storage room clean, well-ventilated, and at low humidity. Make sure it has fire protection and emergency exits.

Fig. 5.24: Smart Hydrogen Monitoring System

The room should be far from the main plant, electrical systems, and water supplies. Key features for safety include:

- A working ventilation system with alarms to alert staff.
- A bubble leakage detection device.
- A gas detector is placed high where hydrogen tends to gather.
- A device to measure humidity.
- A temperature measuring device.
- CCTV for surveillance.
- Restricted access, allowing only those wearing proper safety gear and personal protective equipment (PPE).
- Strict rules against smoking and using spark-producing tools. Ideally, electrical switchboards should be in safer, separate rooms.

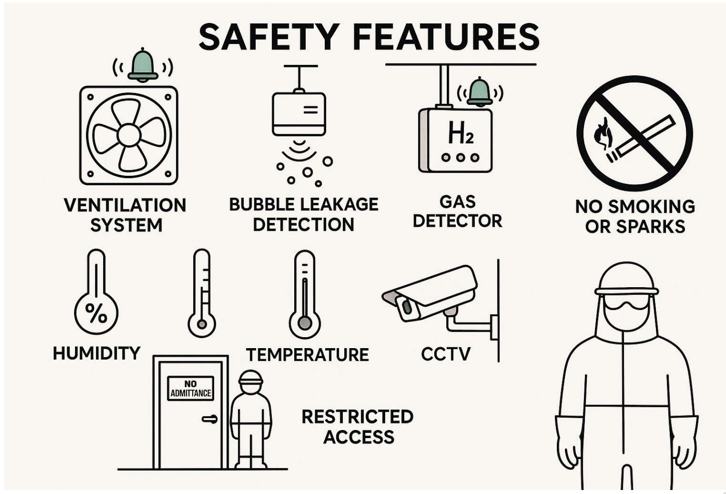

Fig. 5.25: Safety Features

You can improve monitoring by using a thermal camera to scan and check the temperatures of specific equipment or conditioning units. This can also be done remotely.

2. Health Monitoring

- Hydrogen gas is dangerous. Even when following safety guidelines, accidents can happen due to human mistakes, faulty equipment, or unexpected events. Because of this, knowing how to give first aid is important and required by law.
- Employees must shower every day after work. Eating, drinking, or storing food near hydrogen handling areas is not allowed.

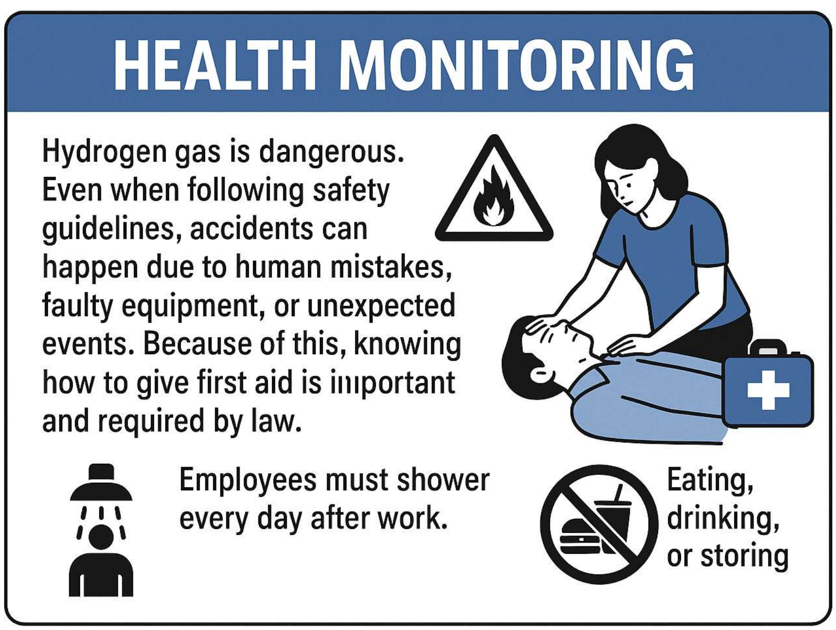

Fig. 5.26: Health Monitoring

3. Physical Examination

- Before assigning jobs that involve hydrogen, workers should have a health check to ensure they are fit for the job.
- Workers must also have a medical check every year, as required by laws like the Factories Act and State Factories Rules.

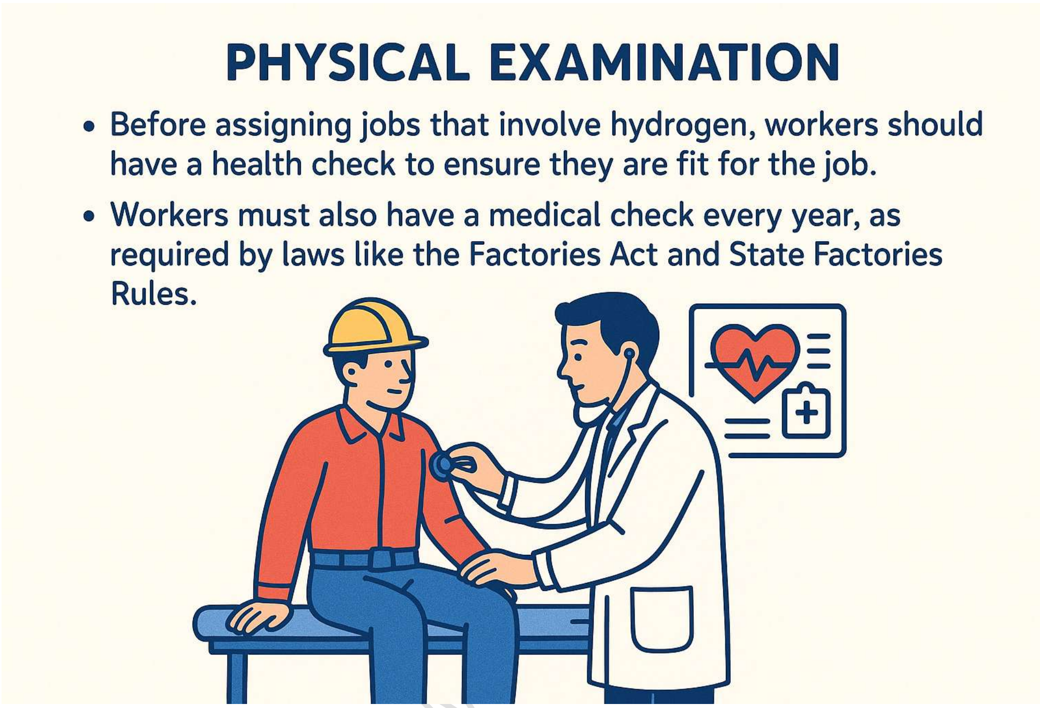

Fig. 5.27: Physical Examination

4. ***First Aid and Medical Treatment***

If someone is exposed to hydrogen, give first aid right away, no matter how serious it seems. Always send the injured person to a doctor, even for minor injuries. Provide the doctor with a clear account of what happened.

First Aid Treatment

Breathing too much hydrogen gas can cause suffocation. If this happens, move the person out of the dangerous area. If they are not breathing, start rescue breathing. If their heart has stopped, begin CPR (Cardiopulmonary Resuscitation). If you have medical oxygen and trained people available, give oxygen to the person. Do not give them anything to drink if they are unconscious. If they are conscious, have them sit or lie down quietly.

Skin Contact with Liquid Hydrogen

- To treat frostbite, soak the affected area in lukewarm water. Get medical help right away.

- If frostbite affects the eyes, seek medical help immediately.

An appropriate first aid kit should include hydrogen peroxide, antiseptic, saline solution, an emergency blanket, and triangular bandages.

Fig. 5.28: First Aid Kit

5. ***Non-Respiratory Equipment:***

Personal protective equipment (PPE) should include items that protect you from splashes, such as safety goggles and face shields for working with liquids. Employees should also wear safety helmets and boots or high-top shoes. In cold environments where there is a risk of exposure to freezing conditions, wear special clothing to protect your body. Establish safety standards and codes to handle these situations.

Keep contact numbers for hospitals, doctors, and ambulance services easily accessible, especially if a plant ambulance is not available or if several people need help. Oxygen cylinders and masks should also be part of your gear.

Personal Protective Equipment

Hydrogen is highly flammable, and leaks can cause serious fire hazards. Unlike petrol or diesel, which stay low to the ground, hydrogen quickly rises, making it less likely to catch fire. However, it ignites more easily than petrol or diesel. A small spark from static electricity can trigger a hydrogen explosion. Additionally, a hydrogen flame is hard to see and can burn out quickly. Because of these risks, wearing personal protective equipment (PPE) is essential in areas with hydrogen. Recommended PPE items include:

1. Loose-fitting gloves
2. Steel-toed shoes
3. Hard hat
4. Ear protection

5. Cotton or Nomex-3 overalls worn outside of boots
6. Eye protection
7. Long sleeves (do not roll them up while working)

The PPE items for hazardous areas are shown in Figure

Fig. 5.29: Items in personal protective equipment

A person working in a hazardous plant wearing PPE is shown in the Figure.

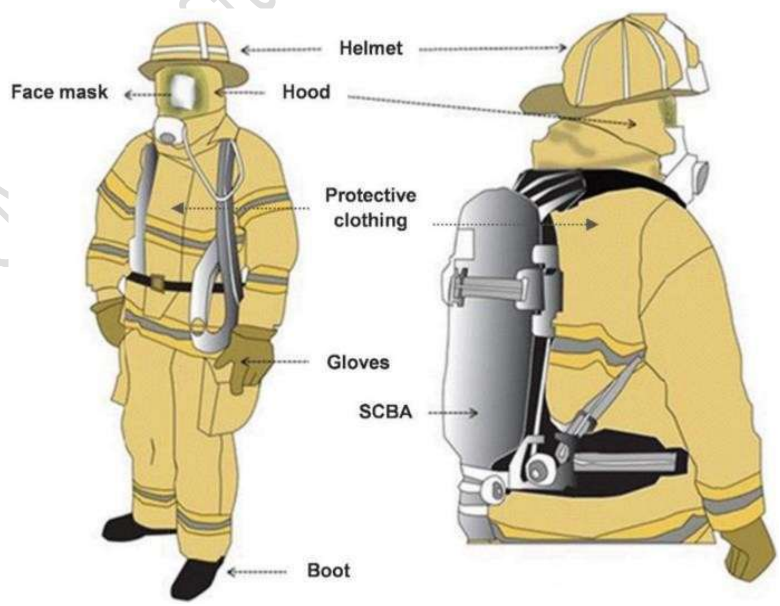

Fig. 5.30: PPE

Note:

Personal protective equipment (PPE) is not enough on its own. Safe working conditions, proper ventilation, and responsible behaviour from all workers are essential. PPE only protects the person wearing it, so unprotected workers can still face dangers.

Check Your Progress

A. Multiple Choice Questions

1. Where should hydrogen gas detectors be installed in a storage area?
   A. Near the floor
   B. At eye level
   C. Near the hydrogen cylinders
   D. High up, where hydrogen tends to gather

2. What is the correct action if someone is exposed to excessive hydrogen gas and stops breathing?
   A. Give them water
   B. Start CPR
   C. Call security
   D. Make them sit quietly

3. Which of the following is not part of the recommended PPE for hydrogen handling?
   A. Cotton overalls
   B. Safety goggles
   C. Plastic sandals
   D. Steel-toed boots

4. Why should electrical switchboards be located outside hydrogen storage rooms?
   A. To prevent spark hazards
   B. To reduce wiring costs
   C. To allow easier access
   D. For decoration

5. What does a bubble leak detector do?
    A. Measures pressure
    B. Measures gas purity
    C. Detects temperature
    D. Identifies gas leaks through bubbling reaction

B. Fill in the Blanks

1. Hydrogen flames are hard to _________ and can burn out quickly.
   → Answer: see
2. PPE should include long sleeves that are _________ while working.
   → Answer: not rolled up
3. High humidity in storage areas can increase the risk of _________ and corrosion.
   → Answer: rust
4. A thermal _________ can be used to monitor equipment temperature remotely.
   → Answer: camera
5. Emergency numbers for hospitals and ambulance services should be _________ available.
   → Answer: easily

C. Short Answer Questions

1. Why is it important to keep the hydrogen storage room far from electrical systems and water supplies?
2. What steps should be taken if a person has frostbite from contact with liquid hydrogen?
3. Why is daily showering recommended for workers handling hydrogen?
4. What are two key devices used in smart hydrogen monitoring systems?

D. Very Long Answer Questions

5. List and explain the essential safety features of a smart hydrogen storage monitoring system.
6. Explain how PPE helps prevent hydrogen-related injuries and list its main components.

7. Describe the correct steps to be taken when a person has inhaled too much hydrogen gas.
8. Why is regular health monitoring important for hydrogen plant workers, and what does it include?

Activity

1. Bring in or display images of PPE gear. Students must label and match each item to its purpose in hydrogen safety.
2. Design a safety poster highlighting rules for entering a hydrogen storage area (e.g., “No sparks,” “Wear full PPE,” “Gas detection active”).
3. Create a list and diagram of a proper first aid box for hydrogen handling areas. Present its items and explain their use.

Session 6: Hazards Associated with Hydrogen Production Systems

When working with hydrogen production equipment, it is important to know the hazards involved. These hazards include the risk of explosions, leaks, and high-pressure systems. To ensure a safe working environment, follow safety measures and maintain your equipment properly. Understanding the specific hazards of the equipment and using best practices can greatly improve safety during hydrogen production.

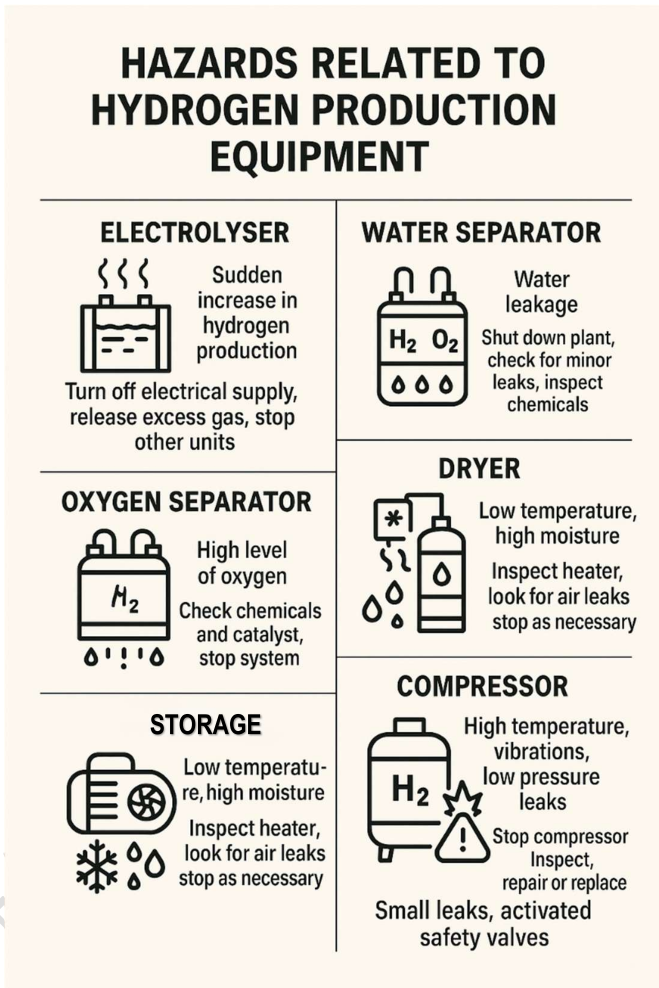

Fig. 5.31: Hazards related to hydrogen production equipment

Here are the hazards related to hydrogen production equipment:

1. **Electrolyser:** A sudden increase in hydrogen production can happen. If this occurs and it causes pressure problems or mixes oxygen with hydrogen, turn off the electrical supply. Release any excess gas right away and stop other processing units.
2. **Water Separator:** Water may leak, leading to a high-water content in the hydrogen output. Shut down the plant to check, replace, or fix any problems if minor leaks are found. Also, inspect the chemicals involved.

3. **Oxygen Separator:** A high level of oxygen mixed with hydrogen requires checking the chemicals and the catalyst. Stop the system to repair or replace it as needed.
4. **Dryer:** Low temperatures and high moisture levels in the hydrogen can occur. Inspect the heater's power supply and look for air leaks in the dryer. Stop, repair, or replace as necessary.
5. **Compressor:** Check for high temperatures, vibrations, low pressure, and leaks. If the compressor is faulty, stop it and conduct a thorough inspection. Repair or replace if a spare is available. If safety valves activate, shut down the entire plant, ensure forced ventilation, and evacuate personnel.
6. **Storage:** Small leaks or activated safety valves require actions similar to the compressor procedures.

Make sure all personnel are alerted and that firefighting and medical services are prepared for action. Regular practice drills are important.

Spillage and Leakage Hazards

In hydrogen production facilities, it is important to manage spills and leaks carefully. These risks can come from different processes and equipment, creating safety issues. We need to identify where leaks might happen, such as in storage tanks, pipelines, and valves, to keep operations safe and protect workers. Setting up strong monitoring systems and following good maintenance and emergency response practices can reduce these risks, helping to safeguard the environment and public health.

Spills/Leaks:

Regularly inspect equipment, containers, and vessels that handle hydrogen to find or prevent leaks:

- In case of a spill or leak, only trained and protected workers should stay in the area, while others should leave.
- Every organisation working with hydrogen must have a trained emergency response team ready 24/7 to manage spills or leaks.
- Take steps to quickly disperse harmful vapours if spills or leaks occur.
- For major spills or equipment failures, evacuate the affected areas. Unprotected workers must not return until it is deemed safe.
- Workers entering the area to test or repair damaged equipment need appropriate respiratory protection since high hydrogen levels might be present.
- If it's safe, stop the gas flow or shut off the leak.
- If a leaking cylinder cannot be fixed in place, move it to a safe outdoor space and repair the leak, or let it empty.
- For both gas and liquid spills, eliminate all ignition sources.

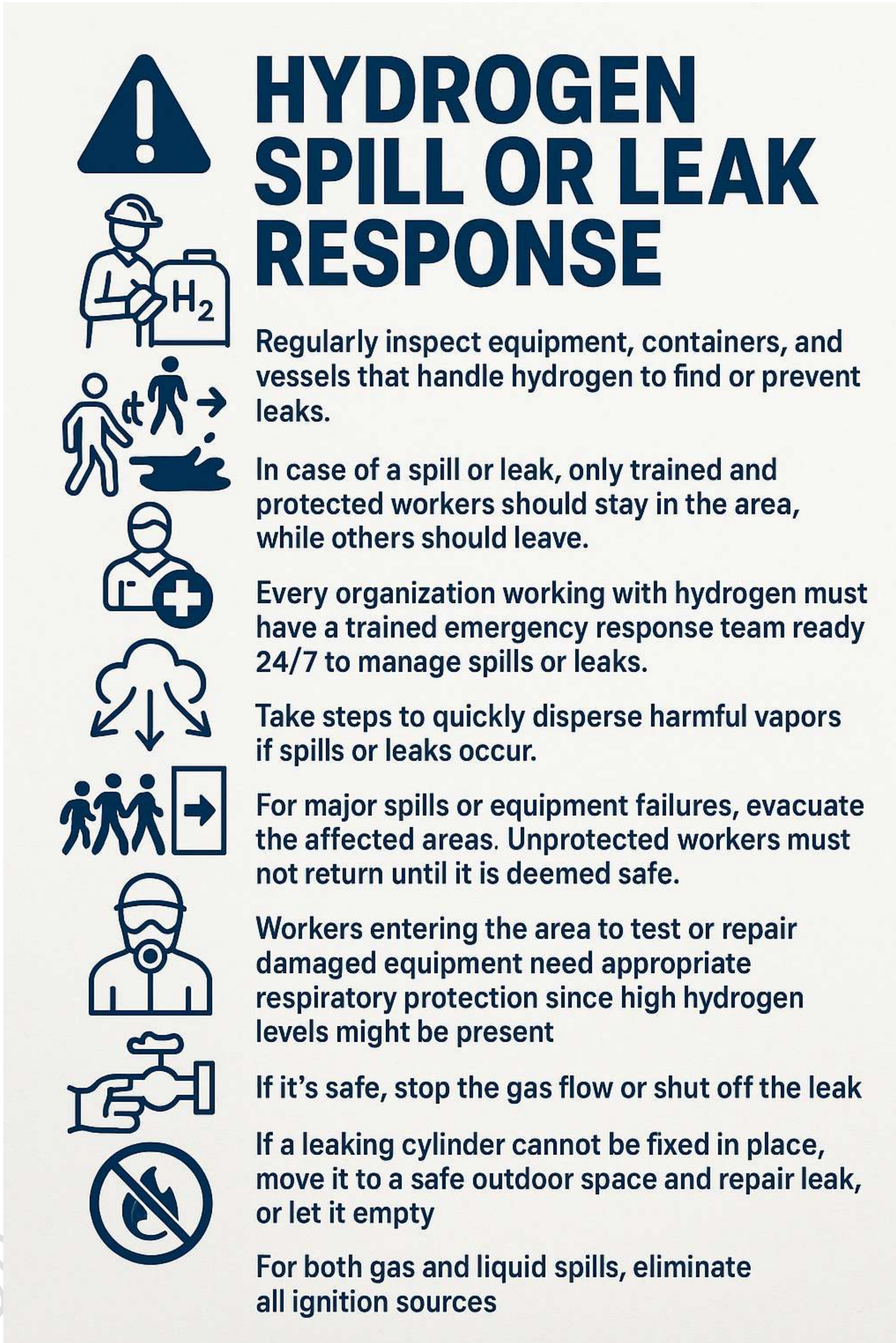

Fig. 5.32: Hydrogen Spill or leakage

Evacuation:

If a release occurs that cannot be controlled, all unprotected personnel must evacuate the contaminated area. Consider evacuating nearby areas as a precaution against the spread of the release or the risk of explosion or fire.

Check Your Progress

A. Multiple Choice Questions

1. What is the first step if a sudden increase in hydrogen production causes pressure problems in the electrolyser?
   A. Turn off the electrical supply
   B. Increase the power supply
   C. Replace the catalyst
   D. Restart the plant
2. If the compressor activates its safety valves, what should be done?
   A. Lower the pressure
   B. Open more valves
   C. Increase compressor speed
   D. Shut down the entire plant and evacuate personnel
3. What issue can arise from a faulty dryer in a hydrogen system?
   A. Low temperature and high moisture
   B. Increased hydrogen pressure
   C. High oxygen levels
   D. Corrosion of pipelines
4. What should you do if a leaking cylinder cannot be fixed in place?
   A. Leave it in the same area
   B. Throw it in water
   C. Move it to a safe outdoor area
   D. Increase temperature to reduce pressure
5. Who should remain in the area during a hydrogen leak or spill?
   A. All supervisors
   B. Only trained and protected workers
   C. Any available staff
   D. Medical personnel

B. Fill in the Blanks

1. A _________ separates hydrogen from oxygen in the production process. → Answer: Oxygen separator
2. To check for leaks or equipment damage in a hydrogen facility, conduct regular _________. → Answer: inspections
3. In the case of a hydrogen leak, _________ all ignition sources to prevent fires. → Answer: eliminate

4. _________ drills help prepare staff for emergencies in hydrogen production systems. → Answer: Practice
5. If the moisture content in hydrogen is high, check the _________ and air leaks. → Answer: heater's power supply

C. Short Answer Questions

1. What are the safety steps to be followed if the water separator shows signs of leakage?
2. What risks are involved with a faulty compressor in hydrogen systems?
3. What personal protection is required when entering an area with high hydrogen levels?
4. What actions must be taken if a hydrogen spill or leak cannot be controlled?

D. Very Long Answer Questions

1. Explain the possible hazards of each component in a hydrogen production system and the appropriate safety responses.
2. Describe the complete procedure for responding to a hydrogen spill or leak.
3. Why are compressor-related hazards critical in hydrogen production, and what measures should be taken during an emergency?
4. Discuss the importance of trained emergency response teams in hydrogen facilities and what their role includes.

Activity

1. Draw and label a layout of a hydrogen production unit, marking where leaks and failures might occur (electrolyser, storage, compressor, etc.).
2. In a classroom setting, simulate a hydrogen leak. Assign roles (emergency team, observer, maintenance staff), perform actions like evacuation and gas shutoff.
3. Make a poster titled "What To Do During a Hydrogen Leak" covering steps for containment, evacuation, and equipment handling.

Session 7: Work Safety Procedures and Instructions

Currently, hydrogen is mainly used in large industries like fertilizer plants, oil refineries, and steel factories. These industries follow their own safety rules to protect people and equipment. But now, hydrogen will also be used in everyday areas like public and private transport, small electricity systems (microgrids), and even for cooking. This means regular people will start using hydrogen. So, it has become very important to update safety rules, laws, and standards to make sure hydrogen is used safely by everyone.

Training

Everyone who works with hydrogen systems, whether for daily operation, maintenance, or during emergencies, must receive proper training for their specific job.

The training should include all important topics and possible dangers that workers may face. Along with general training, each person must also learn the tasks related to their specific role. From time to time, refresher training should be given to keep knowledge updated. Older or experienced workers should also get re-training to stay current with safety practices.

Every worker must know where the gas and fire alarm systems are located and how to use them properly. They should also know how to use sprinklers, fire monitors, and other firefighting tools. In addition, they must be familiar with the locations of safety showers, eye wash stations, and first aid kits.

Storage, Handling, and Labelling

Before hydrogen is transported, it must be stored, handled, and labelled properly. These steps are very important to ensure safety.

Storage

Hydrogen should be stored away from heat, flames, sparks, and oxygen. No smoking or open flames are allowed near hydrogen storage areas.

- Metal containers used for transferring or storing hydrogen must be properly grounded to avoid static electricity.
- These containers should have self-closing valves, pressure and vacuum seals, and flame arrestors.
- Only non-sparking tools should be used when opening or closing hydrogen containers.
- Explosion-proof electrical equipment must be used wherever hydrogen is stored or handled.

- Storage areas must have safety features like automatic/manual shutdown systems, sprinklers, gas and heat sensors, fire alarms, extinguishing systems, and explosion vents.
- Buildings should have good ventilation, especially near the ceiling, since hydrogen rises quickly.

Indoor Storage

- Do not damage or overheat tanks and cylinders.
- Vents and safety valves must lead to a safe outdoor location and include flame arrestors to prevent fire.

Outdoor Storage

- Outdoor hydrogen tanks must be kept at least 15 meters away from buildings unless next to a blank wall.
- They must be far from flammable liquids and should have a fire protection system.
- Cylinders should be kept away from direct sunlight and placed under a shed.

Bulk Storage (Non-Refrigerated)

- Hydrogen is lighter than air and rises quickly when leaked.
- It must be stored in sealed containers, either under normal pressure or high pressure.
- The storage area must have fire hydrants and sprinklers.
- Storage tanks must meet standard safety designs and include relief valves and vent pipes with flame arrestors.
- A drain should be added at the bottom of the vent pipe.
- Any gas released from relief valves must not enter work areas or come near fire sources.

Handling

People who handle hydrogen must wear safety gear like:

- Approved respirators
- Chemical-resistant gloves
- Safety goggles
- Protective clothing

Smoking or using fire near hydrogen is strictly not allowed. Always follow safe operating procedures while working with hydrogen.

Handling of Cylinders

🔽 You may include a labelled image here: Fig.

Handling cylinders

- Before filling a cylinder, check its test certificate. Only tested and approved cylinders should be used.
- Cylinders must be hydraulically tested before filling with hydrogen.
- Never drop, bump, drag, or slide cylinders. Always keep them upright.
- Don't use tools like ropes, slings, or hooks that can create sparks or static.
- Use a proper trolley or forklift to move cylinders safely.
- When using a crane, use a secure platform or cradle.
- Use racks or chains to hold cylinders in place when using them.
- Never place cylinders where they can become part of an electrical circuit.
- Do not remove the protective cap unless you're ready to use the cylinder.
- Only use standard hydrogen valves, and always check for gas leaks.
- Hydrogen cylinders should be painted red without any band to identify them.
- Never use cylinders (full or empty) as rollers to move objects.
- Do not change or damage markings or test dates on cylinders.

- When a cylinder is empty:
    - Close the valve
    - Insert the valve plug
    - Replace the protective cap
    - Tag it as 'EMPTY'
    - Store it separately from filled cylinders

Labelling

1. Any container or vessel that holds hydrogen must have a clear label or stencil to show that it contains hydrogen.
2. The label must follow official safety rules and regulations.
3. Each hydrogen cylinder should be marked with:
    - "FLAMMABLE GAS"
    - "CLASS 2" (This shows it is a flammable gas according to safety classification)

🔽 You may include an image here: Fig. - Label on compressed hydrogen vessel

Pre-departure Checks for Trucks Carrying Hydrogen Cylinders

Before and after loading hydrogen cylinders onto a truck, the driver must inspect the vehicle to make sure everything is safe and in good working condition.

Some important parts to check:

- Lights
- Tyres
- Suspension system
- Brakes

The driver should also keep a logbook to note important safety details during the journey, such as cylinder pressure.

The following items must be present on the vehicle:

1. Fire extinguishers – either Dry Chemical Powder (DCP) or Carbon Dioxide (CO_2) type.
2. An emergency kit for any accidental situation during transport.
3. A Transport Emergency (TREM) card – This provides emergency instructions.
4. An instruction manual with safety and handling guidelines.

Transportation of Hydrogen

When hydrogen is transported, it is very important to follow safety rules.

All vehicles used to carry hydrogen must display proper safety labels.

- A Class 2 label (which means flammable gas) must be clearly shown on the transport vehicle.

Labels and Markings for Transportation

While transporting hydrogen, several safety labels and markings must be used on the vehicle, containers, and pipelines. This help ensure proper handling and quick identification in case of an emergency. The important labels include:

- **Product Identification** – Name of the gas (Hydrogen)
- **Product Hazard Warning** – Warnings like "Flammable Gas"
- **Safety Venting Decals** – Labels to indicate safe gas release points
- **Flammable Gas Warning** – Clear "FLAMMABLE" label
- **No Smoking** – Strictly no smoking signs
- **No Open Flames** – No fire or sparks near hydrogen
- **Personal Protection** – Use of gloves, goggles, safety gear, etc.
- **Pipeline Labelling** – Pipes should be marked for gas flow direction and content
- **Authorized Personnel Only** – Only trained people should handle
- **Pressure Vessel Identification** – Tanks must show pressure rating and ID
- **Emergency Information** – Contact numbers and instructions
- **Valve and Component Identification** – Label all valves and parts clearly
- **Periodic Safety Inspection** – Regular checks and testing of information
- **Vent Stack Purge Identification** – Labels showing where gas is safely released
- **Static Grounding** – Signs showing grounding points to prevent sparks

Precautions During Transportation

When transporting hydrogen gas, strict safety rules must be followed to prevent accidents:

- No smoking in the driver's cabin or near the truck.

- Keep all flames, sparks, and ignition sources away from the vehicle.
- The driver must follow the specified route and speed limit.
- Do not park near residential areas or leave the truck unattended.
- Do not overtake other moving vehicles. Drive carefully and follow all road rules and traffic signals.

Repairs are not allowed during transport, especially those involving welding or gas cutting. If any repair is urgently needed, only trained personnel from the maintenance department, sent by the supplier, should do it.

The driver must check the hydrogen cylinder mounting and setup regularly, and report any problem immediately.

In Case of Emergency (e.g. Leak, Fire, Accident)

- Follow the emergency steps given in the transport instruction manual.
- Immediately contact the:
  - Manufacturer/Supplier
  - Police
  - RTO (Regional Transport Office)
  - Fire brigade
  - Local authorities

Activity

Demonstration at Hydrogen Production Site

Objective: Learn and demonstrate how to stay safe and avoid accidents while working at a hydrogen plant.

Hands-on Activity:

- Work alongside plant personnel during their shift.
- Observe their safety-related activities.
- Take notes about:

- What safety gear they wear (like helmets, gloves, goggles)
- What precautions they take (like checking valves, using gas detectors)

- Discuss with them why these safety steps are important.

Tips for Students:

- Carefully read the plant's safety rules.
- Follow instructions given by plant staff.
- Ask questions to understand the reasons behind every safety step.
- Practice correct use of Personal Protective Equipment (PPE).

Check Your Progress

A. Multiple Choice Questions

1. How far should outdoor hydrogen storage tanks be from buildings (unless near a blank wall)?

A. 5 meters
B. 10 meters
C. 15 meters
D. 25 meters

2. What should hydrogen cylinders be painted to indicate their contents?

A. Blue with a yellow stripe
B. White with green band
C. Yellow with red cap
D. Red without any band

3. What is **not** allowed when transporting hydrogen cylinders?

A. Stopping near residential zones
B. Fire extinguisher on board
C. Using a TREM card
D. Safety instruction manual

4. What label should be used to indicate the gas is flammable during transport?

A. Class 4
B. Class 2 – Flammable Gas
C. Class 1 – Explosives
D. Toxic Gas

B. **Fill in the Blanks**

1. Hydrogen storage areas should always be well-ventilated, especially near the _________. → **Answer: ceiling**
2. Only _________ tools should be used to open or close hydrogen containers. → **Answer: non-sparking**
3. Before transporting hydrogen cylinders, the truck driver must inspect lights, tyres, and the _________ system. → **Answer: braking/suspension**
4. Hydrogen cylinders should be marked with the warning "____________." → **Answer: FLAMMABLE GAS**

C. **Short Answer Questions**

1. What are the key components of safe hydrogen storage?

2. What should be checked before filling a hydrogen cylinder?

3. Why is labelling important in hydrogen transportation?

4. What are the emergency steps if a leak or fire occurs during hydrogen transport?

D. **Very Long Answer Questions**

1. Explain the key precautions for indoor, outdoor, and bulk hydrogen storage.
2. Describe the correct handling procedures for hydrogen cylinders.
3. What safety rules should a truck driver follow while transporting hydrogen cylinders?

4. Why is training important in hydrogen safety, and what should it include?

Activity

Objective:
To observe real-world hydrogen safety practices and understand safety tools, precautions, and PPE use.

Activity Steps:

1. Shadow a plant worker for a short time.
2. Observe and record:
    a. Safety gear worn
    b. Equipment checks
    c. Valve inspection procedures
    d. Gas detector usage
    e. Emergency readiness (alarms, showers, first aid)
3. Interview the worker about:
    a. Importance of each safety step
    b. Past incidents and learnings
4. Present your findings in a classroom presentation or report.

Expected Outcome:

Students will gain practical insight into workplace hydrogen safety and understand the importance of strict procedures and personal responsibility.

Answer Key

Module 1: Installation of Water Feed System

Session 1: Input Water System for Electrolyser

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. Purified
2. A	2. Ultrapure
3. B	3. Demineralisation
4. C	4. Semi permeable
5. D	5. 7

Session 2: Various Parameters Essential for Water as Feedstock

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. Resistivity
2. B	2. Potassium Hydroxide (KOH)
3. D	3. Deposits
4. B	4. pH, Conductivity
5. A	

Session 3: Understanding the Piping System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	1. Non- return
2. B	2. Underground
3. C	3. Motorized
4. C	4. Conductivity
5. A	

Module 2 Hydrogen Conditioning and Compression

Session 1: Conditioning/Purification of Green Hydrogen

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. hydrogen conditioning.
2. B	2. De oxo
3. A	3. Electrolysis
4. B	4. Dryer System
5. A	

Session 2: Hydrogen Conditioning System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	
2. C	1. Scrubber
3. B	2. Oxygen
4. A	3. Moisture

Multiple Choice Questions (MCQs)	Fill in the Blanks
5. A	4. Compressor
	5. Balance of Plant (BoP)

Session 3: Compression Process and Installation of Compression System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	1. lower calorific value
2. C	2. about 11 cubic meters
3. A	3. Volume decreases
4. A	4. Hydrogen Gas
5. B	5. Lubricated parts.

Session 4: Material Safety Data Sheet (MSDS)

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. Safety Information
2. B	2. Storage
3. C	3. Skin irritation
4. C	4. Risk
5. C	5. Safety regulations

Session 5: Selection of Compression System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. A	1. 100 to 900 bars
2. B	2. Dry
3. C	3. Suction valve
4. A	4. Pressure relief valve
5. D	5. 2

Module 3 Storage Unit

Session 1: Hydrogen Storage

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	1. lowest energy
2. B	2. Liquefaction, Regasification.
3. C	3. Embrittlement
4. C	4. Pipelines

Session 2: Setting Up a Hydrogen Storage System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. B	1. Cryogenic
2. C	2. Cylinders
3. A	3. leak detectors

4. D	4. cascade filling 5. flame-proof

Session 3: Architecture of Piping and Storage Layout

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	5. higher elevations
2. D	6. personnel
3. B	7. minimum
4. B	8. ventilation

Session 4: Type of Cylinders and their Setting Up Method

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	1. Type III
2. C	2. 2016
3. A	3. carbon fiber composite
4. D	4. 20 MPa.

Session 5: Depressurisation Methods of Hydrogen Storage System

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. D	1. Depressurisation
2. C	2. test points
3. B	3. Purge gas systems
4. D	4. Deflagration

Session 6: Precautions and Safety Guidelines for Hydrogen Storage

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. upright
2. B	2. self-ignite
3. A	3. self-extinguish
4. D	4. backflow
5. C	

Unit 4: Commissioning Checklist

Session 1: Checklists for Commissioning

Multiple Choice Questions (MCQs)	Fill in the Blanks
5. C	10. Standards
6. D	11. checklist
7. C	12. management
8. A	13. Performance guarantee
9. B	14. Commissioning

Session 2: Installation, Testing and Commissioning Checklist

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. writing
2. B	2. approval of drawings
3. B	3. Testing
4. A	4. logical order
5. B	5. compliance.

Session 3: Inputs, Outputs and Key Performance Metrics for Hydrogen Generation

Multiple Choice Questions (MCQs)	Fill in the Blanks
6. A	1. Raw
7. B	2. Dried
8. C	3. Water (Moisture)
9. D	4. Voltage levels
	5. regulation

Session 4: Pre-commissioning Tests

Multiple Choice Questions (MCQs)	Fill in the Blanks
1. C	1. Hydrogen Purity
2. D	2. Nitrogen
	3. water; electricity
	4. 72
	5. 30

Module 5: Perform Health and Safety Measures for Installing and Operating Green Hydrogen Systems

Session 1: Occupational Health & Safety Standards and Regulations

Multiple Choice Questions	Fill in the blanks
1. A	1. High Hazard
2. D	2. Fuel
3. C	3. Lighter
4. B	4. Cold
5. A	5. ISO 45001

Session 2: Emergency Situations in a Hydrogen System

Multiple Choice Questions	Fill in the blanks
1. D	1. More
2. B	2. Ignition
3. C	3. Oxygen
4. B	4. Protective
	5. Called

Session 3: Detectors and Safety Tools

Multiple Choice Questions	Fill in the blanks
1. D	1. 5%, 95%
2. C	2. Helium Leak
3. B	3. Sounds
4. C	4. MSDS
5. B	5. Uprigh

Session 4: Maintain Ideal Temperature and Humidity Level

Multiple Choice Questions	Fill in the blanks
1. D	1. Temperature, humidity
2. A	2. 0.4
3. A	3. 0.358
4. B	4. A drop
5. C	5. Remote

Session 5: Storage Monitoring and Personal Safety

Multiple Choice Questions	Fill in the blanks
1. D	1. See
2. B	2. Not rolled up
3. C	3. Rust
4. A	4. Camera
5. D	5. easily

Session 6: Hazards Associated with Hydrogen Production Systems

Multiple Choice Questions	Fill in the blanks
1. A	1. Oxygen Separator
2. D	2. Inspections
3. A	3. Eliminate
4. C	4. Practice
5. B	5. Heaters power supply

Session 7: Work Safety Procedures and Instructions

Multiple Choice Questions	Fill in the blanks
1. C	1. Ceiling
2. D	2. Non sparking
3. A	3. Braking/ suspension
4. B	*4. FLAMMABLE GAS*

GLOSSARY

TERM	DEFINITION
Absorber	A device used to remove impurities or unwanted gases from hydrogen.
Alkaline Electrolyser	A type of electrolyser using alkaline solutions to split water into hydrogen and oxygen.
Anaerobic	A process occurring in the absence of oxygen.
Anode	The positively charged electrode in an electrolyser where oxygen is generated.
Battery Storage	Energy storage system that stores excess renewable energy for later use.
Biogas	A type of renewable gas produced from organic matter.
Bop (Balance Of Plant)	All supporting components and systems required for a hydrogen plant to operate.
Boiler Feedwater	Water used for generating steam in plant processes.
Breaker Panel	An electrical panel containing circuit breakers for safety and distribution.
Brittle Fracture	Sudden failure of material due to hydrogen embrittlement or cold conditions.
Buffer Tank	A tank used to store excess hydrogen or water temporarily to manage flow fluctuations.
Calibration	The process of adjusting instruments to ensure accurate measurements.
Carbon Footprint	The total greenhouse gas emissions caused by an individual or system.
Catalyst	A substance that increases the rate of a chemical reaction without being consumed.
Cathode	The negatively charged electrode in an electrolyzer where hydrogen is generated.
Charge Controller	A device that regulates the voltage and current from solar panels to batteries.
Check Valve	A valve that allows flow in one direction only to prevent backflow.
Chiller	A system used to reduce the temperature of plant components or water.
Circuit Breaker	An automatic device for stopping the flow of electricity in case of overload.
Cloud Monitoring	Using digital systems to monitor hydrogen plant performance remotely.
Commissioning	The process of testing and starting up a hydrogen plant for operation.

Compression	The process of increasing the pressure of hydrogen gas for storage or transport.
Compressor	A device that increases the pressure of hydrogen gas for storage or distribution.
Condensate	Liquid formed when steam or gas cools and condenses.
Conductivity	A measure of a material's ability to conduct electricity or heat.
Control Panel	The system used to monitor and manage plant operations.
Corrosion Inhibitor	A chemical substance that prevents or reduces corrosion in systems.
Cryogenic Storage	A method of storing gases at extremely low temperatures.
Cut-Off Valve	A valve used to stop the flow of gas or liquid completely.
Cutting Torch	A tool used to cut metals using high-temperature flames, often in maintenance tasks.
Deaerator	A device used to remove dissolved gases like oxygen from water.
Deionized Water	Water that has had its ions removed, used in electrolyzers for hydrogen production.
Density	Mass per unit volume of a substance, important in gas measurement.
Dielectric Strength	The maximum electric field a material can withstand without breakdown.
Diffuser	A device that evenly distributes fluid flow and reduces velocity.
Distribution Pipeline	Pipes used to transport hydrogen gas to various points of use.
Drain Valve	A valve used to remove water or liquid from a system.
Dryer	A system used to remove moisture from gases or air in the hydrogen plant.
Dynamic Pressure	The pressure of a fluid in motion, part of total pressure measurements.
Efficiency	The ratio of useful energy output to the total energy input.
Electrochemical Reaction	A reaction that involves the transfer of electrons, as in electrolysis or fuel cells.
Electrode	A conductor that passes electric current into a non-metallic medium.
Electrolysis	The process of splitting water into hydrogen and oxygen using electricity.
Electrolyte	A conductive solution used in electrolysis to enable ion flow.
Emergency Shutdown System	A safety mechanism to immediately stop plant operations in emergencies.

Emission Control	Techniques used to reduce harmful emissions from plant operations.
Energy Audit	An assessment of energy use and efficiency in plant operations.
Evaporator	A device used to convert liquid into vapor by heating.
Expansion Tank	A tank that accommodates the expansion of fluids as they heat up.
Flame Arrestor	A device that prevents flames from traveling back into a gas line.
Flow Control Valve	A valve that regulates the flow rate of fluids or gases.
Flow Meter	An instrument used to measure the flow rate of gas or liquid.
Fossil Fuels	Natural fuels such as coal, oil, or gas, which release carbon emissions.
Frequency Converter	A device used to change the frequency of electric power supplied to equipment.
Fuel Cell	A device that converts hydrogen into electricity through an electrochemical reaction.
Gas Analyzer	A tool used to measure the concentration of gases in a mixture.
Gas Cylinder Bank	A collection of high-pressure cylinders used for storing hydrogen gas.
Gasket	A sealing material placed between two surfaces to prevent leakage.
Green Hydrogen	Hydrogen produced using renewable energy sources like solar or wind.
Grid Integration	Connecting a hydrogen plant to the power grid for energy supply or export.
Grounding	The process of connecting electrical systems to the earth for safety.
Hazardous Area	A location where explosive or flammable gases, vapors, or dusts may be present.
Heat Exchanger	A device that transfers heat from one medium to another.
High-Pressure System	A system designed to operate with gases or liquids at high pressure.
Hydraulic Pump	A pump that moves liquids or gases using mechanical energy.
Hydrogen Blending	Mixing hydrogen with natural gas for pipeline distribution.
Hydrogen Economy	A vision of using hydrogen as a key energy carrier for a low-carbon future.
Hydrogen Purity	The level of contaminants or impurities in hydrogen gas.

Hydrogen Storage	Methods and technologies used to store hydrogen gas safely.
Ignition Source	Any object or process capable of starting a fire or explosion.
Insulation	Material used to reduce heat loss or protect against electric shock.
Inverter	A device that converts direct current (DC) to alternating current (AC).
Isolation Valve	A valve used to isolate a part of the system for maintenance.
Joule-Thomson Effect	Temperature change of a gas when expanded or compressed without heat exchange.
Leak Detector	A safety device used to identify hydrogen leaks.
Lubricant	A substance used to reduce friction between moving parts.
Msds	Material Safety Data Sheet containing safety information for chemicals.
Magnetic Flow	
Magnetic Sensor	
Manifold	A pipe or chamber with multiple outlets for distributing fluids or gases.
Membrane	A selective barrier that separates hydrogen from other gases in an electrolyzer.
Nozzle	A device that controls the direction or flow of fluid or gas.
Portable Hydrogen Purity Analyer	
PSA (Pressure Swing Adsorption)	A method for purifying hydrogen using pressure changes.
Pipe Fittings	Connectors used to join sections of piping in the plant.
Piping Layout	The design arrangement of pipes in a plant system.
Plant Layout	The physical arrangement of components within the hydrogen plant.
Pressure Gauge	A device for measuring gas pressure in the plant systems.
Pressure Relief Device/ Valve	A safety device that prevents system overpressure by releasing gas or liquid.
Purifier	Equipment used to remove impurities from hydrogen gas.
Rectifier	An electrical device that converts AC to DC power for electrolysis.
Relief Valve	A valve that opens to release pressure when it exceeds safe limits.
Renewable Energy	Energy derived from natural sources that are replenished, such as wind or solar.

Renewable Hydrogen	Hydrogen produced using energy from renewable sources like wind or solar.
Reservoir Tank	A large tank used for storing liquids or gases.
Resistor	An electrical component that resists current flow, producing heat.
Rotary Compressor	A type of compressor that uses rotating parts to pressurize gas.
Safety Valve	A valve that automatically releases pressure to prevent accidents.
Sensor	A device that detects physical properties such as temperature, pressure, or flow.
Solar Panel	A device that converts sunlight into electricity, used for powering plants.
Solenoid Valve	An electromechanically operated valve used for fluid or gas control.
Spill Containment	Measures and equipment used to manage accidental spills or leaks.
Stack	The group of cells in an electrolyzer that produces hydrogen.
Storage Cylinder	A pressure-resistant container for storing hydrogen gas.
Surge Tank/ Tank	A tank that absorbs sudden pressure changes in pipelines.
Turbine	A device that converts fluid or gas flow into mechanical energy.
Ultrasonic Leak Detector	A device that detects leaks using ultrasonic sound waves.
Vaporiser	A device that converts liquid hydrogen into gas for use.
Vent Stack	A structure for safely venting gases to the atmosphere.
Water Purification	The process of removing impurities from water before use in electrolysis.
Welding	The junction formed when two metals are fused together.
Yield	The amount of hydrogen produced relative to input resources.