Renewable-Energy-Module-5-Important-Topics-PYQs

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Important Topics

1. Working and construction of small hydro power plant

What is a Small Hydropower Plant?

A small hydropower plant is a system that generates electricity by using the flow of water, typically from streams or rivers. These plants have a capacity below **10 MW**, making them suitable for local and remote areas.

Classification of Small Hydropower Plants

1. **Micro Plants**: Up to 100 kW.
2. **Mini Plants**: Between 100 kW and 1 MW.
3. **Small Plants**: Between 1 MW and 10 MW.

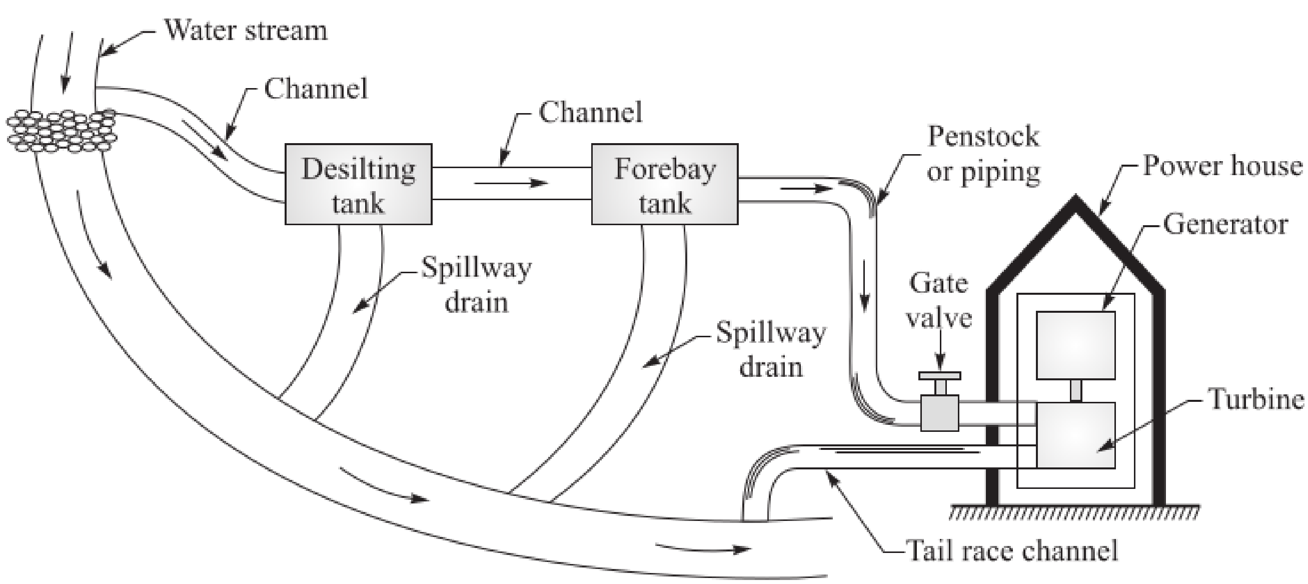


Figure 15.3 A typical layout of a micro hydro power plant.

Components of a Small Hydropower Plant

1. **Diversion Structure**:
   - A small dam or trench diverts water from a stream into the plant.
   - Ensures consistent water supply throughout the year.
   - Protects against flood damage.
2. **Desilting Tank**:
   - Removes debris like sand and pebbles from the water.
   - Protects the turbine from wear and tear.
3. **Water Channel**:

- Carries water from the diversion structure to the storage area.
- Made to minimize water and energy loss.

4. **Forebay Tank**:
    - Acts as a mini-reservoir to hold water temporarily.
    - Maintains steady water flow to the turbine.
    - Includes an overflow system to release excess water.
5. **Penstock**:
    - A pipeline that delivers water from the forebay tank to the turbine.
    - Water flows down this pipe, gaining speed and energy due to gravity.
6. **Powerhouse**:
    - Contains the turbine and generator.
    - The turbine spins when water flows through it, converting water energy into mechanical energy.
    - The generator converts mechanical energy into electricity.
7. **Tailrace Channel**:
    - Discharges water from the turbine back into the stream.

How Does It Work?

1. Water is diverted from a river or stream using a small dam or trench.
2. The water passes through a desilting tank to remove debris.
3. It flows through a channel into the forebay tank, where it is stored temporarily.
4. From the forebay tank, water travels through the penstock, gaining energy.
5. The turbine in the powerhouse spins due to the water flow, generating electricity.
6. The used water exits through the tailrace channel and rejoins the stream.

Merits of Small Hydropower Plants

- **Eco-Friendly**: No pollution or greenhouse gas emissions.
- **Renewable**: Uses water, which is a sustainable resource.
- **Cost-Effective**: Low operating costs and minimal skilled labor required.
- **Local Impact**: Ideal for remote areas; eliminates long-distance electricity transmission losses.
- **Quick Installation**: Construction can take as little as 6–24 months.
- **No Displacement**: Unlike large dams, these plants don’t require relocating communities.

Demerits of Small Hydropower Plants

- **High Costs**: Initial installation and generation costs can be expensive.
- **Seasonal Variations**: Depend on stream flow, which changes with seasons.
- **Remote Locations**: Higher managerial and maintenance costs due to isolated locations.
- **Damage Risks**: Susceptible to floods or extreme weather.

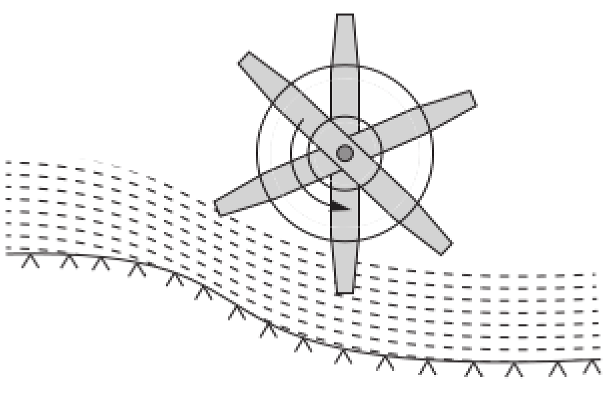
Example of Technology: Bulb Turbine

- A **bulb turbine** is enclosed in a shell-like structure and can work efficiently in shallow streams with low water heads (1–95 m).
- Suitable for generating power ranging from **5 kW to 50 MW**.

2. Types of turbines

Turbines are devices used to convert the energy of water into mechanical energy, which is then converted into electrical energy by a generator. They operate on two primary principles: **impulse** and **reaction**.

1. Water Wheel

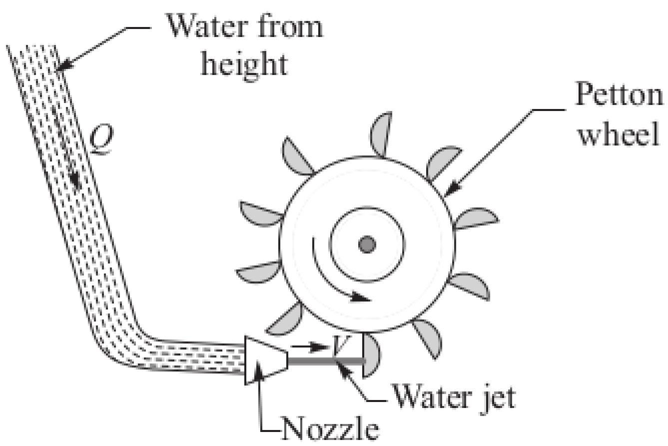


(a)

- **Working Principle**: This is the oldest type of turbine. It uses the kinetic energy of flowing water or potential energy from water stored at a height to rotate a wheel with paddles or blades.
- **Features**:
  - Operates at low speeds.

- Suited for low-head and high-flow applications.
- Mostly used in historic or traditional setups.

2. Impulse Turbine

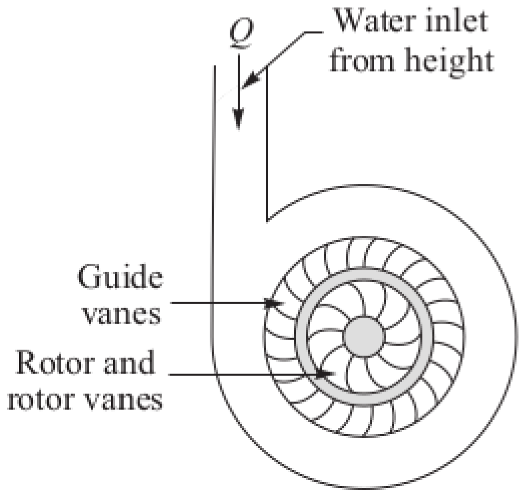


(b)

- **Working Principle**: Converts the entire potential energy (head) of water into kinetic energy using a nozzle. A high-speed jet of water strikes the blades (buckets) of the turbine, causing it to spin.
- **Example**: **Pelton Wheel**
  - **Design**: Equipped with spoon-shaped buckets mounted on a wheel.
  - **Applications**: Best suited for **high-head and low-flow** sites.
  - **Key Feature**: Water jet works in open-air conditions, and there is no pressure change in the turbine.

3. Reaction Turbine

- **Working Principle**: The water's potential energy is partially converted into kinetic energy within the turbine. Water flows through the turbine blades, and both pressure and velocity changes drive the rotation.
- **Types**:
  - **Francis Turbine**:



(c)

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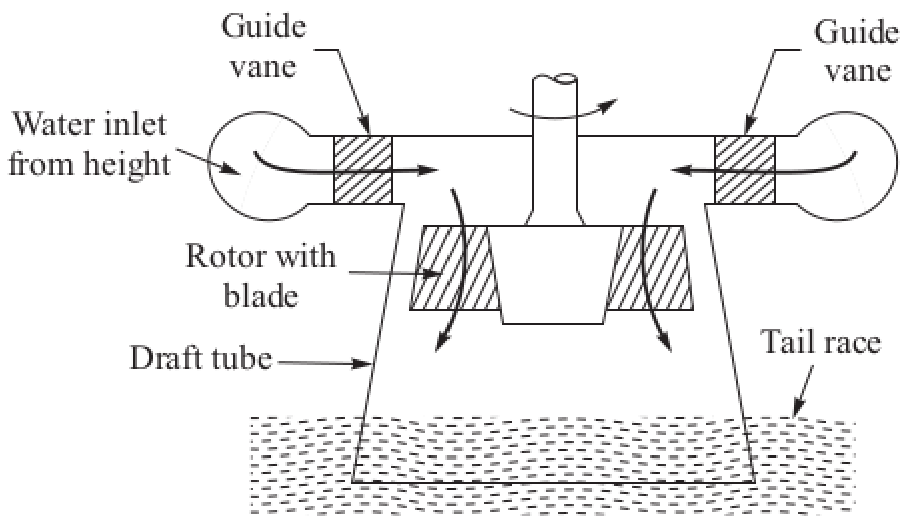
    - **Design**: Features fixed guide vanes and curved rotor blades.
    - **Applications**: Suitable for **medium-head and medium-flow** sites.
    - **Key Feature**: Water flows radially inward and exits axially.
- **Kaplan Turbine**:



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    - **Design**: Propeller-like blades that can adjust their angle to varying water flows.
    - **Applications**: Ideal for **low-head and high-flow** sites.
    - **Key Feature**: Highly efficient for fluctuating water conditions.

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3. Hydrogen production

Hydrogen is a clean and versatile energy carrier, and there are several ways to produce it. Let's break them down into simple methods:

1. Electrolysis of Water

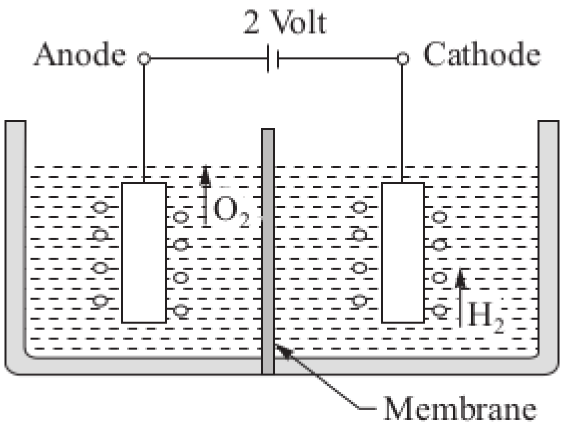

Figure 8.1 Electrolysis of water.

- **How It Works**: Electricity is used to split water into hydrogen and oxygen.
- **Setup**:
  - Two electrodes (metal plates) are placed in water with an electrolyte (like KOH solution).
  - When current flows, hydrogen forms at the **cathode** (negative electrode) and oxygen forms at the **anode** (positive electrode).
- **Key Points**:
  - Simple method but requires electricity.
  - Clean if renewable electricity (like solar or wind) is used.
- **Reaction**:

$$4\ H_2O + 4\bar{e} \rightarrow 2H_2 \uparrow + 4OH \ \text{(cathode)}$$

$$4\ OH^- \rightarrow O_2 \uparrow + 2H_2O + 4\bar{e} \ \text{(anode)}$$

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2. Thermochemical Method (Steam Reforming)

- **How It Works**: Steam reacts with natural gas (methane) at high temperatures (around 900°C) to produce hydrogen and carbon dioxide.
- **Steps**:
  - Methane reacts with steam to form hydrogen and carbon dioxide.

  - Carbon dioxide is removed later.
- **Key Points**:
  - Most widely used commercial method.
  - Cost-effective but not completely eco-friendly due to CO_2 emissions.
- **Reaction**:

$$CH_4 + 2H_2O = CO_2 + H_2$$
$$CO + H_2O = CO_2 + H_2$$

3. Thermolysis of Water

- **How It Works**: Water is split into hydrogen and oxygen using heat energy.
- **Key Points**:
  - Requires very high temperatures (~2500°C).
  - At lower temperatures (~850°C), the process is done in stages using chemical materials to assist the reaction.
  - Similar to electrolysis but uses heat instead of electricity.

4. Biophotolysis

- **How It Works**: Certain plants and algae use sunlight to split water and produce hydrogen.
- **Key Points**:
  - Uses natural processes and sunlight, making it eco-friendly.
  - Low-cost method but still under research for large-scale use.
- **Why It's Called Biophotolysis**:
  - "Bio" = biological organisms like algae.
  - "Photolysis" = splitting water using light (photons).

4. Hydrogen Storage

1. Methods of Hydrogen Storage:

- **Gaseous Form:**

- Stored in **steel tanks or cylinders** at **high pressures (350–750 atm)**.
- Suitable for small amounts; large amounts are stored **underground**.
- Hydrogen gas is lightweight but requires **3.6 times more volume than natural gas**.

- **Liquid Form:**
  - Stored at extremely low temperatures (below **-253°C**) in **cryogenic tanks**.
  - Requires less space than gas but is expensive due to cooling requirements.
- **Metallic Hydrides:**
  - Hydrogen forms compounds (hydrides) with metals like **lanthanum nickel** or **magnesium nickel**.
  - Heating these hydrides releases hydrogen.
  - Heavy but useful for stationary applications; unsuitable for vehicles due to weight.
- **Chemical Hydrides:**
  - Hydrogen is stored in chemical compounds like **ammonia borane**.
  - Safer and more space-efficient than metallic hydrides.

2. Advances in Hydrogen Storage:

- **Nanocomposites:** Magnesium nanoparticles in polymer matrices store and release hydrogen at moderate temperatures.
- **Aluminium Hydride:** Cost-effective, high-capacity material for rechargeable storage.
- **New Crystal Structures:** Materials like lithium amide combined with lightweight hydrides enhance storage.
- **Nanomaterials:** Carbon or silicon nanotubes and sponge-like materials improve storage capacity.

3. Hydrogen for Vehicles and Air Transport:

- **Fuel Cells:** Use hydrogen to generate electricity for vehicles.
- **Nanotube Storage:** Carbon and silicon nanotubes act as miniature hydrogen tanks.
- **Ammonia Borane:** High hydrogen capacity enables vehicles to cover long distances.
- **Air Transport:** Liquid hydrogen is used with **super-insulated cryogenic tanks**.

**4. Cost Considerations:*

The cost of hydrogen storage includes:

- Compression to high pressure.
- Cryogenic cooling for liquid hydrogen.
- Specialized containers and safety systems.
- Transportation expenses.

5. Transporting Hydrogen:

- Delivered via **gas cylinders**, **tankers**, or **pipelines**.
- **Short distances:** High-pressure cylinders.
- **Long distances:** Cryogenic liquid in super-insulated tanks.

6. Safety Issues:

Hydrogen is flammable and hard to detect due to its invisible flame. Safety precautions:

- **Leak Detection:** Add odorants to hydrogen.
- **Spark Prevention:** Automatic disconnection of batteries during accidents.
- **Fire Systems:** Install fire alarms and extinguishers.

Applications of Hydrogen:

1. **Electricity Generation:** Fuel cells.
2. **Aviation Fuel:** High energy density.
3. **Cooking:** Replacement for LPG.
4. **Vehicle Fuel:** Cleaner emissions.
5. **Steam Generators:** Produces pure water.
6. **Industrial Use:** Cooling large motors, making ammonia, and hydrogenation of oils.
7. **Energy Storage:** Intermediate for energy storage and transport.

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5. Fuel cell working principle

A **fuel cell** is a device that produces electricity directly from a chemical reaction. It's like a battery, but instead of storing energy, it continuously generates electricity as long as fuel (like hydrogen) and an oxidant (like oxygen) are supplied.

Working Principle of a Hydrogen-Oxygen Fuel Cell:

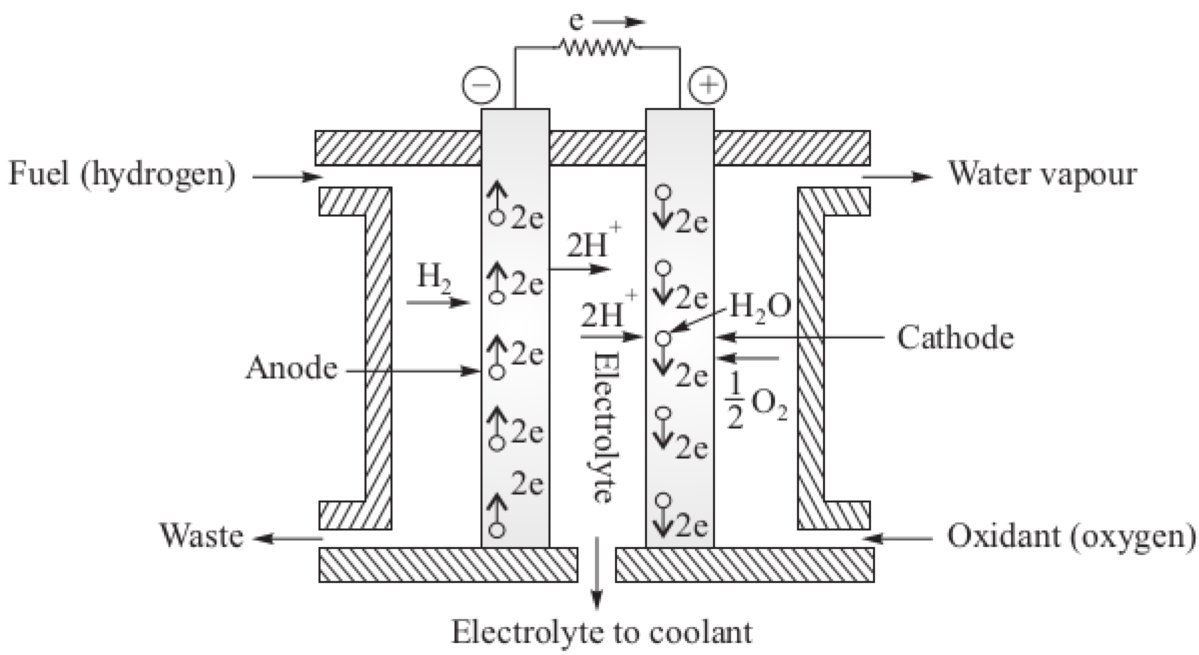

Figure 7.1 A hydrogen–oxygen or phosphoric acid and fuel cell.

1. **Components**:
   - **Anode (Positive side)**: Where hydrogen enters.
   - **Cathode (Negative side)**: Where oxygen enters.
   - **Electrolyte**: A medium that allows certain ions (charged particles) to pass while keeping hydrogen and oxygen gases separate.
2. **How It Works**:
   - **At the Anode (Oxidation)**:
     Hydrogen gas (H2) is split into protons (H+) and electrons (e−).
     The electrons flow through an external circuit, creating electricity.
   - **At the Cathode (Reduction)**:
     Oxygen (O2) reacts with the incoming electrons and protons to form water (H2O).
   - **In the Electrolyte**:
     The electrolyte allows only the protons (H+) to pass through, forcing the electrons to go through the external circuit, which powers devices.
3. **End Products**:
   - Electricity (used for power).
   - Water (as waste).
   - Heat (can also be used).

Previous Year Questions

1. What are fuel cells? List out the applications of fuel cells.

A fuel cell is a device that converts the chemical energy of a fuel (like hydrogen) and an oxidant (like oxygen) directly into electrical energy through an electrochemical reaction, without combustion. It operates continuously as long as fuel and oxidant are supplied, producing electricity, water, and heat as by-products.

Applications of a Fuel Cell

1. **Power Plants**:
   - Used for load leveling by storing energy as hydrogen and oxygen during low demand and converting it back to electricity during high demand.
2. **High-Efficiency Power Generation**:
   - Converts synthetic gas (hydrogen + carbon monoxide) into electricity with high efficiency (up to 70%).
3. **Distributed Power Generation**:
   - Reduces transmission and distribution costs by operating near load centers.
4. **Remote Areas**:
   - Ideal for providing electricity in inaccessible or remote locations.
5. **Transportation**:
   - Powers electric vehicles, spacecraft, and submarines due to their clean and efficient operation.
6. **Emergency Power**:
   - Provides reliable power for critical infrastructure like hospitals during outages.
7. **Battery Replacement**:
   - Serves as an alternative to conventional batteries in various applications.

2. What are the risks for the hydrogen energy storage?

1. **Leakage Risks**:

  - Hydrogen leaks quickly due to its small molecular size, spreading three times faster than natural gas.
  - Leaked hydrogen can form a flammable mixture in the air, posing fire or explosion risks.
2. **High Flammability**:
  - Hydrogen ignites easily with minimal heat or a weak spark.
  - The flammability risk is four times higher than natural gas.
3. **Invisible Flames**:
  - Hydrogen flames are not visible, making detection of fires challenging.
4. **Cold Burns from Liquid Hydrogen**:
  - Handling liquid hydrogen can cause cold burns.
  - Air must be completely removed from storage cylinders to prevent the formation of an inflammable hydrogen-air mixture.
5. **Vehicle-Related Risks**:
  - Hydrogen fuel tanks in vehicles are a potential explosion hazard, especially during parking, collisions, or leaks in the fuel line.

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3. Discuss the different methods used for the storage of hydrogen.

1. Gaseous Hydrogen Storage

- **Process**: Hydrogen is compressed and stored in strong steel tanks or cylinders at high pressures (350–750 atm).
- **Features**:
  - Suitable for small-scale storage.
  - Large amounts are stored in underground facilities.
- **Advantages**:
  - Simple and widely used.
- **Challenges**:
  - Requires significant volume due to low density.

2. Liquid Hydrogen Storage

- **Process**: Hydrogen is cooled to cryogenic temperatures (below -253°C or 20 K) to form a liquid and stored in insulated tanks.
- **Features**:
  - Reduces storage space.
  - Requires continuous low-temperature maintenance.
- **Advantages**:
  - Higher energy density.
  - Useful for transportation.
- **Challenges**:
  - High cost due to refrigeration.
  - Risk of evaporation (boil-off).

3. Metallic Hydride Storage

- **Process**: Hydrogen reacts with certain metals (e.g., lanthanum-nickel, iron-titanium, magnesium-nickel) to form metal hydrides, releasing hydrogen gas when heated.
- **Features**:
  - Pressure of released gas depends on temperature.
- **Advantages**:
  - Safe and compact.
  - Constant pressure at a given temperature.
- **Challenges**:
  - Heavyweight metal alloys make it unsuitable for vehicles.
  - Expensive materials.

4. Chemical Hydride Storage

- **Process**: Hydrogen is stored in chemical compounds that release hydrogen in the presence of an alkaline solution.
- **Features**:
  - Safer and more efficient than metallic hydrides.
- **Advantages**:
  - Higher volumetric efficiency.
  - Suitable for large-scale storage.

4. How does the polarisation effect in a fuel cell affect the conversion efficiency?

- In a fuel cell, **polarization** refers to the difference between the theoretical (or ideal) voltage and the actual voltage output.
- This occurs due to various losses at the electrodes, which are primarily a result of different forms of polarization.
- Polarization affects the **conversion efficiency** of a fuel cell by reducing the amount of usable electrical power it generates, which directly lowers its overall efficiency.

The main types of polarization that contribute to these losses are:

1. Chemical Polarization

- **Cause**: This occurs due to the rate at which ions are discharged at the electrodes and the ability of the electrode material to facilitate this process.
- **Impact on Efficiency**: If the discharge of ions is slower than expected or inefficient, it leads to a drop in voltage output, reducing the cell's efficiency.

2. Concentration Polarization

- **Cause**: This happens when the concentration of reactants at the electrode surface decreases during current flow, especially when the fuel or oxidant is consumed faster than it is replenished.
- **Impact on Efficiency**: As the concentration of reactants at the electrode falls, the fuel cell's ability to generate power is hindered, leading to a further loss of potential, and hence, reduced efficiency.

3. Resistance Polarization

- **Cause**: Resistance polarization is caused by the internal resistance of the electrolyte. As ions move through the electrolyte, resistance increases, and some energy is lost in the form of heat.
- **Impact on Efficiency**: Increased internal resistance results in a voltage drop, leading to lower overall efficiency, as more energy is wasted in overcoming resistance.

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5. What are the benefits of using hydrogen as a fuel?

1. **Environmentally Friendly**:
    - Hydrogen combustion produces **only water vapor** as a byproduct, which means it does not emit pollutants
2. **Renewable Energy Potential**:
    - Hydrogen can be generated from **renewable sources** such as solar, wind, and hydropower through processes like **electrolysis**
3. **High Energy Density**:
4. **Ease of Transportation**:
    - Hydrogen is relatively **easy to transport** by rail, road, or pipelines over long distances.
5. **Flexibility in Applications**:
    - Hydrogen can be used in a wide variety of applications, including:
        - **Fuel cells** for electricity generation (e.g., in cars, buildings, and industries)
        - **Combustion engines** for powering vehicles and machinery
        - **Spacecraft and rockets** for propulsion
        - **Power plants** for generating electricity
    - This versatility makes it a key player in a wide range of industries and applications.
6. **Storage of Excess Energy**:
    - Hydrogen can be produced using **excess energy** from renewable sources (e.g., solar or wind) during times of high availability and stored for later use.
7. **Safety and Efficiency**:
    - Hydrogen has a **faster flame speed** and **lower ignition temperature** compared to many other fuels, making it more efficient to burn. It also requires less heat to start combustion, which can enhance the performance of engines or fuel cells.

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6. What are the properties of hydrogen? Why it is considered as a secondary energy source?

Properties of Hydrogen

1. **Light Gas**: Hydrogen is a very light gas, one-fourth the density of air and one-ninth that of natural gas.
2. **Low Boiling Point**: It liquefies at a very low temperature (-253°C).

3. **High Energy Density (by mass)**: Hydrogen has more energy per kilogram (120 MJ/kg) than gasoline (44 MJ/kg).
4. **Fast Burning**: It burns faster than natural gas.
5. **Easy to Ignite**: Hydrogen requires less heat to start burning compared to natural gas.
6. **Pollution-Free**: When burned, it produces only water vapor, no harmful emissions.

Why Hydrogen is a Secondary Energy Source

1. **Needs Primary Energy to Produce**: Hydrogen is made from other energy sources like fossil fuels or renewable energy (e.g., solar, wind, nuclear).
2. **Energy Carrier**: It stores and transports energy, similar to electricity.
3. **Storage and Transport**: It can be stored and transported long distances, making it useful when energy is produced in one place but needed in another.
4. **Flexible Energy**: Hydrogen can be used to generate electricity (fuel cells) or heat (combustion).*

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7. Describe the construction and working of an alkaline fuel cell. List two application

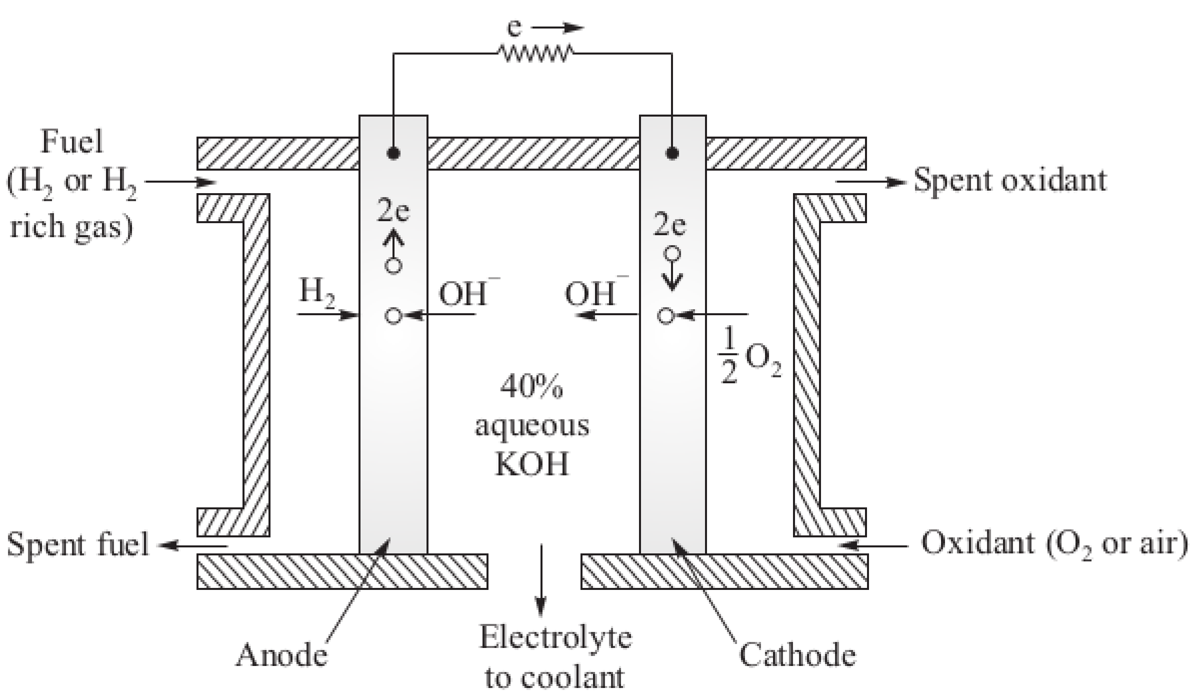

Figure 7.8 Alkaline fuel cell.

Construction of an Alkaline Fuel Cell:

1. **Fuel**: Hydrogen (H_2) or hydrogen-rich gas.
2. **Oxidant**: Oxygen (O_2) or air.
3. **Electrodes**: Porous nickel electrodes are used for both anode and cathode.
4. **Electrolyte**: A 40% aqueous solution of potassium hydroxide (KOH).
5. **Output Voltage**: 1.23 V at 90°C.

Working Principle:

- **Anode (Hydrogen Side)**: Hydrogen gas (H_2) is introduced at the anode, where it is oxidized. This results in the release of electrons and the formation of hydroxide ions (OH^-):
  - The electrons flow through the external circuit to the cathode, generating electricity.
- **Cathode (Oxygen Side)**: Oxygen (O_2) or air is introduced at the cathode. Here, oxygen molecules combine with water (H_2O) and electrons to form hydroxide ions (OH^-):
  - The hydroxide ions (OH^-) move through the electrolyte (40% KOH solution) to the anode, where they react with hydrogen to form water (H_2O), completing the circuit.

Applications of Alkaline Fuel Cells:

1. **Spacecraft Power**: Alkaline fuel cells are used in space missions, such as those by NASA, for powering spacecraft and satellites, due to their high efficiency and reliability.
2. **Backup Power Systems**: AFCs are used in backup power applications where clean and reliable electricity is required, such as in remote telecommunications or emergency systems.

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8. Draw a neat schematic of a Hydrogen-Oxygen fuel cell, write down the chemical reactions involved and explain the working.

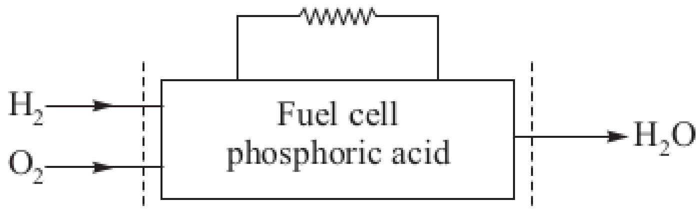

Figure 7.2 A hydrogen–oxygen or phosphoric acid fuel cell.

Chemical Reactions Involved:

1. **At the Anode (Hydrogen Side):**
   - Hydrogen gas (H_2) is supplied to the anode, where it is oxidized to produce protons (H^+) and electrons (e^-):
   - $H_2 \rightarrow 2H^+ + 2e^-$
   - This oxidation process liberates electrons, which flow through the external circuit to the cathode, generating electrical power.
2. **At the Cathode (Oxygen Side):**
   - Oxygen gas (O_2) is supplied to the cathode, where it reacts with protons (H^+) and electrons (e^-) to form water (H_2O):
   - $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$
   - This reaction results in the production of water as the only by-product of the fuel cell.

Working of a Hydrogen-Oxygen Fuel Cell:

1. **Hydrogen Supply**: Hydrogen gas (H_2) is fed into the anode side of the fuel cell.
2. **Anode Reaction**: At the anode, the hydrogen molecules (H_2) are split into protons (H^+) and electrons (e^-). The electrons flow through an external circuit, producing electrical power.
3. **Electrolyte**: The electrolyte, which is phosphoric acid (H_3PO_4), conducts the protons (H^+) from the anode to the cathode, allowing the flow of positive charges.
4. **Cathode Reaction**: At the cathode, oxygen (O_2) is introduced and reacts with the protons (H^+) and electrons (e^-) to form water (H_2O).
5. **Output**: The overall output of the reaction is water (H_2O), and electrical energy is produced from the flow of electrons through the external circuit.