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INTERNAL ASSESSMENT TEST – II

Sub:	Non-conventional Energy Resources							Code:	BME755D
Date:	1/12/2025	Duration:	90 mins	Max Marks:	50	Sem:	VII	Branch:	ECE

Answer any 5 full questions.

		Marks	CO	RBT
1	Write a detailed note on thermochemical methods of hydrogen production. Explain at least one thermochemical cycle with reactions and process flow.	[10]	CO3	L1
2	With neat schematic diagrams, explain the types of geothermal power stations: (a) Dry steam plants (b) Flash steam plants	[10]	CO5	L2
3	What are the problems associated with biogas production? Explain the applications of biogas in domestic, agricultural, and industrial sectors.	[10]	CO5	L1

4	Define the coefficient of performance (Cp) of a windmill rotor. Explain Betz limit and factors affecting Cp in practical wind turbines.	[10]	CO3	L1
5	Explain the working of double-basin tidal system.	[10]	CO5	L1
6	With a neat and labeled diagram, explain the Rankine cycle.	[10]	CO5	L3
7	Write short note on collector efficiency and collector heat removal factor.	[10]	CO2	L3

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1.Write a detailed note on thermochemical methods of hydrogen production. Explain at least one thermochemical cycle with reactions and process flow.

Thermo-Chemical Hydrogen Production:

Thermochemical hydrogen production *is a process that uses* ***high-temperature heat sources*** *to* ***drive chemical reactions*** *that* ***split water*** *(H_2O) into* ***hydrogen*** *(H_2) and* ***oxygen*** *(O_2) without* ***direct electricity*** *consumption. Unlike conventional electrolysis, which requires significant electrical input, thermochemical cycles leverage sequential chemical reactions where reactants are regenerated, making the process more energy-efficient. These cycles typically operate at* ***temperatures ranging*** *from* ***500°C*** *to over* ***1000°C*** *and are powered by nuclear reactors, concentrated solar power (CSP) systems, or industrial waste heat. The primary advantage of thermochemical cycles is their potential for high efficiency (40–50%), making them a promising alternative for large-scale, low-carbon hydrogen production.*

1. Sulfur-Iodine (S-I) Cycle

One of the most well-researched thermochemical cycles is the Sulfur-Iodine (S-I) cycle, developed by General Atomics and considered for integration with high-temperature nuclear reactors and solar thermal systems. The S-I cycle consists of three main chemical reactions that take place in a closed-loop process, where sulfur and iodine act as catalysts while water is the only net reactant.

Step 1: Sulfuric Acid Decomposition

Sulfuric acid is thermally decomposed at high temperatures (~850°C) to produce sulfur dioxide, oxygen, and water:

$$H_2SO_4 \rightarrow SO_2 + H_2O + \frac{1}{2}O_2$$

Step 2: Bunsen Reaction *(Hydrogen Iodide and Sulfuric Acid Formation)*

Sulfur dioxide, iodine, and water react to form hydrogen iodide (HI) and sulfuric acid:

$$I_2 + SO_2 + 2H_2O \rightarrow 2HI + H_2SO_4$$

This reaction occurs at around 120°C. The sulfuric acid is recycled back into step 1.

Step 3: Hydrogen Iodide Decomposition

At temperatures around 450°C, hydrogen iodide decomposes to regenerate iodine and release hydrogen gas:

$$2HI \rightarrow I_2 + H_2$$

Since all intermediates are continuously regenerated, the overall net reaction of the S-I cycle is simply water splitting:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2$$

The S-I cycle has a theoretical efficiency of ~50% and eliminates the need for electrical input, making it suitable for high-temperature nuclear or solar-driven hydrogen production.

2. Hybrid Sulfur (HyS) Cycle

The Hybrid Sulfur (HyS) cycle, also known as the Westinghouse cycle, is a two-step process that integrates a high-temperature thermal reaction with an electrochemical step to minimize electrical energy requirements.

Step 1: Thermal Decomposition of Sulfuric Acid

At high temperatures (~850°C), sulfuric acid decomposes into sulfur dioxide, oxygen, and water:

$$H_2SO_4 \rightarrow SO_2 + H_2O + \tfrac{1}{2}O_2$$

Step 2: Electrochemical Reduction of Sulfur Dioxide

Instead of relying on high temperatures to split hydrogen iodide (as in the S-I cycle), the HyS cycle uses an electrochemical step at around 80°C:

$$SO_2 + 2H_2O \rightarrow H_2 + H_2SO_4$$

This step requires a much lower voltage (~0.17V) compared to conventional electrolysis (1.23V), significantly reducing electricity consumption.

The overall reaction remains the same as direct water splitting:

$$H_2O \rightarrow H_2 + \frac{1}{2}O_2$$

The HyS cycle is particularly attractive because it avoids solid-phase reactions and operates at lower temperatures compared to other thermochemical cycles.

3. Metal Oxide Cycles

Several metal oxide-based thermochemical cycles have been proposed, utilizing the redox properties of metal oxides to split water. Among them, the Zinc/Zinc Oxide (Zn/ZnO) cycle and Iron/Iron Oxide (Fe/FeO) cycle are widely studied.

Zinc/Zinc Oxide (Zn/ZnO) Cycle

This cycle involves two main steps:

1. ***Thermal Reduction of Zinc Oxide:***
   At very high temperatures (~2000°C), zinc oxide is reduced to zinc metal and oxygen gas:

$$ZnO \rightarrow Zn + \frac{1}{2}O_2$$

2. ***Hydrolysis Reaction:***

   The produced zinc metal reacts with water at a lower temperature (~400°C) to generate hydrogen and reform zinc oxide:

$$Zn + H_2O \rightarrow ZnO + H_2$$

Since zinc oxide is regenerated, the overall reaction again reduces to water splitting:

$$H_2O \rightarrow H + \frac{1}{2}O_2$$

This cycle is particularly promising for solar-driven thermochemical hydrogen production, as it efficiently captures and utilizes concentrated solar energy.

2. With neat schematic diagrams, explain the types of geothermal power stations:

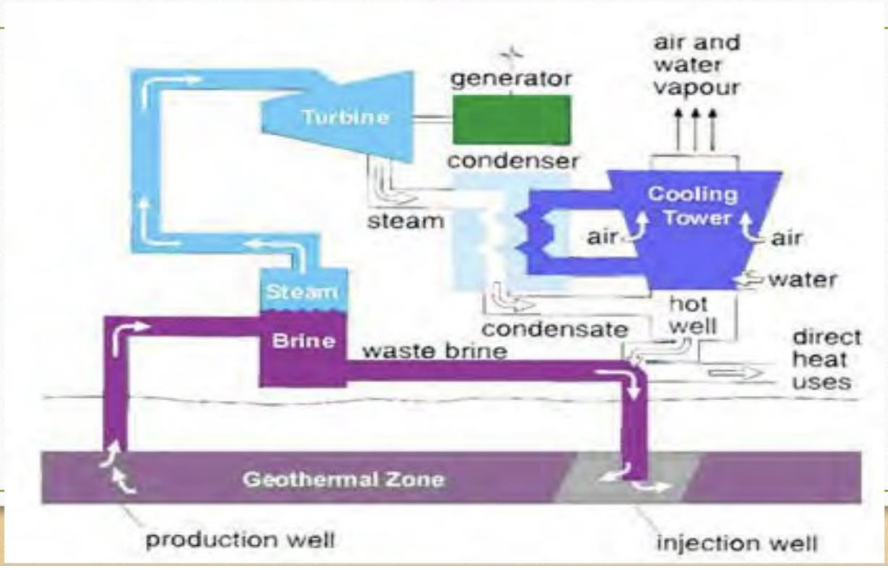
(a) Dry steam plants
(b) Flash steam plants

Dry Steam Power Plant:

- Operating over 100 years
- Steam produced directly from the reservoir runs the turbines that power the generator
- Dry steam systems are simple
- Requires steam condensate injection piping and minimal steam cleaning devices
- Requires Rock catcher to remove large solids and Centrifugal separator to remove condensate and small solid particulates

2.Flash Geothermal Power Plant

use hot water above 182°C (360°F) from geothermal reservoirs.



3.What are the problems associated with biogas production? Explain the applications of biogas in domestic, agricultural, and industrial sectors.

Problems Associated with Biogas Production

1. **Feedstock Quality Issues**
   – Irregular supply of dung/crop waste reduces gas output.
   – High lignin content (e.g., dry straw) decomposes slowly.

2. **Operational Problems**
   – Poor mixing leads to scum formation and lower gas yield.
   – Temperature fluctuations (especially in winter) slow down digestion.
   – Overloading the digester causes acidification and gas drop.

3. **Technical & Maintenance Issues**
   – Gas leakage from low-quality digesters.
   – Corrosion in pipelines due to H_2 S content.
   – Blockages caused by slurry solids.

4. **Environmental & Social Challenges**
   – Requires water; scarcity affects rural units.
   – Odour problems if slurry handling is improper.
   – Initial installation cost is high for rural households.

5. **Skill & Management Issues**
   – Lack of trained manpower for monitoring pH, temperature, and maintenance.
   – Poor awareness leads to improper usage and abandonment of plants.

Applications of Biogas

1. Domestic Applications

- **Cooking:** Clean fuel replacing firewood, kerosene, LPG.
- **Lighting:** Biogas lamps for rural households.
- **Water Heating:** For bathing and household cleaning.
- **Biogas-based generators:** Small generators to run fans, lights, and small appliances.

2. Agricultural Applications

- **Pumping Irrigation Water:** Biogas engines can run water pumps.
- **Operating Farm Machinery:** Chaff cutters, threshers, small power tillers.

- **Heating for Dairy/Poultry Farms:** Maintaining warm conditions for calves, chicks.
- **Organic Fertilizer (Slurry):** Digested slurry improves soil fertility and reduces chemical fertilizer use.

3. Industrial Applications

- **Process Heating:** Used in food processing, textile, leather, and chemical industries.
- **Electricity Generation:** Biogas-based power plants (using gas engines or microturbines).
- **Combined Heat and Power (CHP):** Industries use biogas for both electricity and steam.
- **Waste Management:** Treatment of organic industrial waste (slaughterhouses, sugar mills, breweries).
- **Vehicle Fuel (Bio-CNG):** Upgraded biogas used in buses, autos, and industrial transport fleets.

4. Define the coefficient of performance (Cp) of a windmill rotor. Explain Betz limit and factors affecting Cp in practical wind turbines.

Coefficient of Performance (Cp) of a Windmill Rotor

The **coefficient of performance (Cp)** is defined as:

Cp = (Power extracted by the rotor) / (Total available wind power in the swept area)

It represents the **fraction of the kinetic energy** in the wind that the turbine can convert into useful mechanical power.
Its value ranges from **0 to 1**, but in practice it is **much less due to several losses**.

Betz Limit

The **Betz limit** (also called **Betz Law**) states that:

- A wind turbine **cannot extract more than 59.3% (Cp = 0.593)** of the kinetic energy from the wind.
- This is because the wind must **retain some velocity** after passing through the rotor; otherwise, air would not continue to flow through it.
- Betz derived this using **momentum theory** considering an ideal rotor with no mechanical or aerodynamic losses.

Thus, **maximum theoretical Cp = 0.593**.

Factors Affecting Cp in Practical Wind Turbines

In real turbines, Cp is always **lower** (typically 0.35–0.48). Key reasons:

1. Blade Aerodynamics

- Imperfect airfoil shape
- Angle of attack deviations
- Drag losses and flow separation
- Tip losses causing reduced lift near blade ends

2. Number of Blades

- Too many blades → high drag, low speed
- Too few blades → insufficient torque
- 2–3 blades are optimal for high Cp

3. Tip Speed Ratio (TSR)

- Cp depends strongly on **λ = (blade tip speed)/(wind speed)**

- Each turbine has an **optimal TSR** for maximum Cp.
- Too low TSR → stall
- Too high TSR → excessive drag

4. Mechanical and Electrical Losses

- Gearbox friction
- Generator inefficiency
- Bearing losses
- Misalignment and structural vibration

5. Wind Conditions

- Turbulence and gustiness reduce effective energy capture.
- Wind shear and tower shadow cause periodic power fluctuations.

6. Blade Pitch Control

- Incorrect pitch setting leads to underperformance.
- Active pitch control improves Cp but adds complexity.

7. Wake Effects

- Turbines placed close together experience reduced wind speed due to wakes, lowering Cp.

5.Explain the working of double-basin tidal system.

Double Basin System

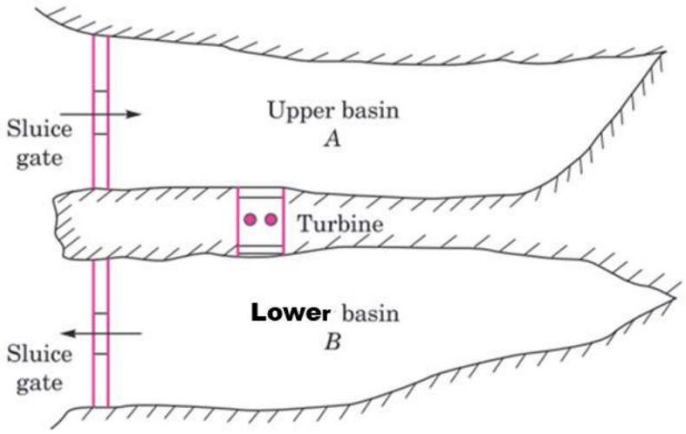
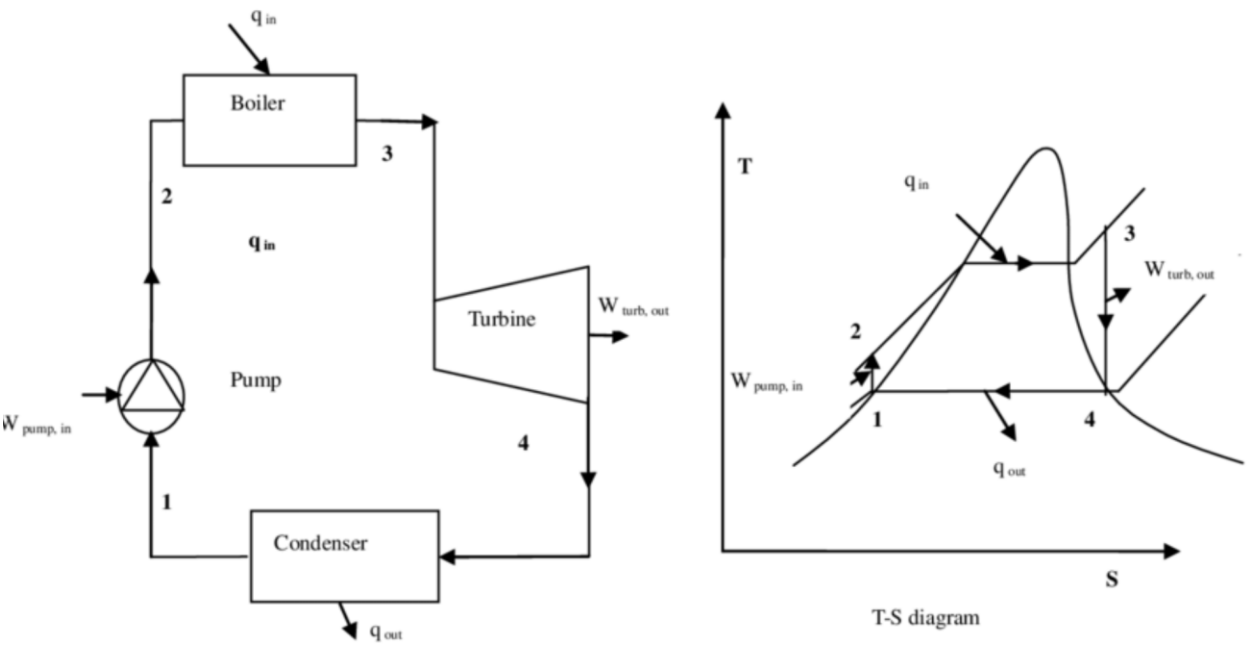


Fig. Double Basin System

- This system has two basins at different levels and a dam is provided in between these basins as shown in Figure. Inlet and outlet sluice gates are provided in the dam.
- The water level in upper basin is maintained above the level of water in the lower basin.
- The upper basin is filled with water during high tide and lower basin is emptied during the low tide. Therefore, a permanent head is created between the upper and lower basins.
- When sufficient head is developed, the turbines of the power plant are started. The water flows down from upper basin to the turbine which discharges into the lower basin . Thus the electrical power is generated.
- When the water level in upper basin is maximum during high tide the inlet sluice is closed and the level of water in lower basin keeps on rising due to discharge of water by the turbine.
- When the rising level in lower basin becomes equal to the level of the falling tide, the outlet sluices are opened.
- When the tide reaches its lower most level, the outlet gates are closed.
- After some time, the tide rises. When its level becomes equal to low level of the upper basin, the inlet gates are opened.
- Consequently, the level of water in upper basin starts rising. Thus, the cycle is repeated.

6.With a neat and labelled diagram, explain the Rankine cycle.



The **Rankine cycle** is the fundamental thermodynamic cycle used in **steam power plants** for converting **heat energy → mechanical work → electricity**.
It consists of **four main processes** involving water/steam as the working fluid.

1. Process 1–2: Pumping (Isentropic Compression)

- The **feedwater pump** raises the pressure of saturated liquid from the condenser pressure to the boiler pressure.
- As water is incompressible, the pump work is very small.
- **No phase change** occurs; temperature increases slightly.

2. Process 2–3: Heat Addition in Boiler (Isobaric Heating)

- High-pressure water enters the **boiler**, where heat is supplied at constant pressure.
- The fluid turns into **dry saturated steam** or **superheated steam**.
- This steam stores large amounts of thermal energy.

3. Process 3–4: Expansion in Turbine (Isentropic Expansion)

- Steam expands through the **steam turbine**, producing **mechanical work** (used to drive the generator).
- Pressure and temperature drop as the steam expands.
- This is the main power-producing stage.

4. Process 4–1: Condensation in Condenser (Isobaric Heat Rejection)

- Low-pressure steam enters the **condenser**, where it releases heat to cooling water and becomes **saturated liquid**.
- Condensation occurs at nearly constant pressure and temperature.
- The cycle closes as this liquid returns to the pump.

7.Write short note on collector efficiency and collector heat removal factor.

Collector Efficiency (ηc)

Collector efficiency is the measure of how effectively a solar collector converts **incident solar radiation** into **useful thermal energy**. It is defined as:

$$\eta_c = \frac{\text{Useful heat gained by the fluid}}{\text{Solar radiation incident on the collector area}}$$

Key Points

- Depends on **absorber plate properties**, **transmittance of the glass cover**, and **thermal losses** to surroundings.
- Efficiency decreases as the **temperature difference** between the absorber plate and ambient air increases.
- Typically expressed as:

$$\eta_c = \eta_0 - a_1 \left(\frac{T_p - T_a}{I}\right) - a_2 \left(\frac{T_p - T_a}{I}\right)^2$$

where
η_0 = optical efficiency,
a_1 , a_2 = heat-loss coefficients,
T□ = plate temperature,
T_a = ambient temperature,
I = solar irradiance.

Collector Heat Removal Factor (FR)

The **heat removal factor (FR)** indicates how effectively the collector fluid removes heat from the absorbe plate. It represents the **ratio of actual useful heat gain** to the **maximum possible heat gain** if the entire absorber plate were at inlet fluid temperature.

$$F_R = \frac{\text{Actual useful heat gain}}{\text{Maximum possible useful heat gain}}$$

Key Points

- Accounts for **temperature distribution** across the collector plate.
- Always **less than 1** because the absorber plate temperature is higher than the inlet fluid temperature
- Higher FR means better heat transfer between plate and fluid (good design, higher mass flow rate).
- Used in the useful heat gain equation:

$$Q_u = F_R A_c \left[S - U_L (T_{in} - T_a) \right]$$

where
A□ = collector area,
S = absorbed solar radiation,
U_L = overall heat loss coefficient,
T_in = inlet fluid temperature.