Module-3

Performance Analysis of Liquid Flat Plate Collectors

❖ Introduction

- Liquid flat plate collectors absorb solar energy using a dark absorber plate, with a liquid (like water) flowing through tubes to collect the heat. A transparent cover reduces heat loss. The heated liquid is used for applications like water or space heating.

➢ **Performance Highlights:**

- **Efficiency:** 40–70%, depending on sunlight, insulation, and temperature difference.
- **Heat Losses:** Reduced by insulation and glazing.
- **Affected by:** Solar radiation, ambient temperature, and flow rate.
- **Applications:** Water heating, space heating, and industrial use.

❖ Collector Geometry

- The geometry of a liquid flat plate collector is designed to maximize solar energy absorption and heat transfer to the circulating liquid. It typically consists of a flat, rectangular absorber plate made of metal with high thermal conductivity attached to the parallel tubes or channels through which the heat transfer liquid flows.
- The plate and tubes are enclosed within an insulated casing with a **transparent glass cover** on top to allow sunlight in and reduce heat loss. The size, shape, and arrangement of the absorber plate and tubes are optimized to provide maximum surface area for heat absorption while ensuring efficient fluid flow and minimal thermal losses.

❖ Selective Surfaces

- Selective surfaces are special coatings applied on the absorber plate of a liquid flat plate solar collector that are designed to absorb maximum solar radiation while minimizing heat loss.
- These surfaces have high absorptivity for solar short-wave radiation, which helps capture more sunlight efficiently.
- They also possess low emissivity for long-wave thermal radiation, which reduces heat loss by radiation from the absorber surface.
- This selective behaviour helps in improving the overall efficiency of the solar collector.
- Materials like black chrome, black nickel, and titanium oxide are commonly used as selective coatings.
- These surfaces are also thermally stable, durable, and resistant to corrosion, making them suitable for long-term use in solar thermal systems.

❖ Basic Energy- Balance Equation

- Energy balance is simply the relationship between energy input and energy output.
- In thermal systems, this is defined as: "A fundamental concept for thermal analysis of any thermal system is based on the conservation of energy, which can be analysed through energy balance calculation under steady state conditions.
- In steady state, the useful energy output of the collector is the difference between the absorbed solar radiation and the total thermal losses from the collector."

Useful energy = Absorbed solar energy - Thermal losses

- An energy balance on the absorber plate yields the following equation;

$$\boxed{q_u = A_p S - q_l}$$

- Where,
  - q_u = useful heat gain, i.e., the rate of heat transfer to the working fluid,
  - S = incident solar flux absorbed in the absorber plate,
  - A_p = area of the absorber plate,
  - q_l = rate at which heat is lost by convection and re-radiation from the top, and by conduction and convection from the bottom and sides.

❖ Transmissivity of the Cover System

- Transmissivity is a crucial optical property of the cover system in a liquid flat plate collector, as it determines how effectively solar radiation reaches the absorber to be converted into heat.
- Transmissivity of the cover system is the fraction of solar radiation incident on the cover that passes through it and reaches the absorber plate.
- It tells us how much sunlight can pass through the transparent or semi-transparent covers (like glass or plastic) placed above the absorber plate in a flat plate collector.
- It is denoted by the symbol τ (tau).
- Value of transmissivity ranges between 0 and 1:
  - $\tau = 1$ means 100% of sunlight passes through (ideal, but not realistic).
  - $\tau = 0$ means no sunlight passes through.
- A high transmissivity cover allows more solar energy to reach the absorber, improving collector performance.
- It depends on: Material and thickness of the cover, Angle of incidence of sunlight, Wavelength of solar radiation.

❖ Transmissivity – Absorptivity Product

- It is the product of transmissivity (τ) of the cover and absorptivity (α) of the absorber plate.
- Represents the effective solar energy absorbed by the collector after passing through the cover.
- A higher ($\tau \cdot \alpha$) value means more solar energy is absorbed, leading to better efficiency.
- Typical values range from 0.75 to 0.90 for good quality collectors.
- Depends on material properties of the cover (glass/plastic) and absorber (coating/metal).
- Angle of incidence affects the product — efficiency decreases at larger angles.
- Appears in the useful heat gain equation of the collector:

$$Q_u = A \cdot (\tau \cdot \alpha) \cdot G - \text{losses}$$

- Plays a crucial role in determining the optical efficiency of the collector.
- Dirt, dust, and aging can reduce τ or α, thereby lowering ($\tau \cdot \alpha$).
- It is a key parameter to optimize in sol
- ar collector design.

❖ Collector Heat Removal Factor (F_R)

- The collector heat removal factor (F_R) is a measure of how efficiently a solar collector transfers the absorbed solar heat to the working fluid.
- It is defined as the ratio of the actual useful heat gain to the maximum possible useful heat gain, assuming the entire collector surface is at the fluid inlet temperature.
- A higher F_R value means better performance, as more heat is being transferred from the absorber plate to the fluid.
- It depends on factors such as the fluid flow rate, thermal conductivity of materials, heat transfer coefficient, and the temperature difference between the fluid and the surroundings.
- The value of F_R is always less than or equal to 1, as some heat is always lost to the surroundings.
- $F_R = F' \cdot \dot{m} \cdot C_p / A_c \cdot U_L \quad [1 - \exp(-A_c \cdot U_L / \dot{m} \cdot C_p)]$
    - Where
    - F_R = Collector heat removal factor
    - F' = Collector efficiency factor
    - $\dot{m}$ = Mass flow rate of fluid (kg/s)
    - C_p = Specific heat of fluid (J/kg·K)
    - A_c = Collector area (m^2)
    - U_L = Overall heat loss coefficient ($W/m^2 \cdot K$)

❖ Collector Efficiency Factor (F′)

- The Collector Efficiency Factor (F′) shows how well the heat from the absorber plate is transferred to the fluid inside the tubes.
- It is the ratio of actual heat transfer to the maximum possible heat transfer if the entire absorber was at the same temperature as the fluid.
- The value of F′ is always less than 1 because of heat losses and resistance in materials.
- It depends on factors like the thermal conductivity of the absorber plate, spacing between tubes, and the heat transfer rate between the plate and the fluid.
- A higher F′ means better efficiency in moving heat from the plate to the fluid.
- $F' = \dot{m} \cdot C_p / A_c \cdot U_L \, (T_p - T_f / T_p - T_a)$
  - Where
  - F' = Collector Efficiency Factor (dimensionless)
  - $\dot{m}$ = Mass flow rate of fluid (kg/s)
  - C_p = Specific heat of fluid (J/kg·K)
  - A_c = Collector area (m²)
  - U_L = Overall heat loss coefficient (W/m²·K)
  - T_p = Absorber plate temperature (°C or K)
  - T_f = Fluid temperature (°C or K)
  - T_a = Ambient temperature (°C or K)

❖ Collector Flow Factor (F_f)

- The Collector Flow Factor (F_f) shows how effectively the heat transfer fluid flows through a solar collector.
- It is the ratio of actual heat removed by the fluid to the maximum possible heat that could be removed if the flow were ideal.
- It depends on the mass flow rate, specific heat of fluid, collector area, and heat loss coefficient.
- A higher flow factor (close to **1**) means the fluid flows uniformly, and the collector performs well.
- A lower value means poor flow distribution, which reduces the efficiency of the collector.
- It is important for ensuring efficient heat removal and designing high-performance solar collector.
- $F_f = T_{fi} - T_a / T_p - T_a$
  - Where
  - F_f = Collector Flow Factor (dimensionless)
  - T_{fi} = Inlet fluid temperature (°C or K)
  - T_p = Absorber plate temperature (°C or K)
  - T_a = Ambient temperature (°C or K)

❖ Effect of Various Parameters on the Collector Performance

1. Solar Radiation Intensity

- The amount of solar radiation directly affects how much heat is absorbed by the collector. Higher radiation levels result in more energy input and better thermal performance. On cloudy days or during early mornings and evenings, performance decreases due to lower solar input.

2. Collector Orientation and Tilt Angle

- The orientation and tilt of the collector must be optimized to face the sun directly for most of the day. In India, for example, collectors are usually tilted towards the south. A correct tilt angle ensures maximum solar energy is captured throughout the year.

3. Ambient Temperature

- Ambient temperature affects heat losses from the collector. When the ambient temperature is low, the temperature difference between the collector surface and the air is higher, which leads to greater heat losses, especially through convection and radiation.

4. Wind Speed

- Increased wind speed enhances convective heat loss from the collector surface to the surroundings. This can significantly lower the thermal efficiency, especially if the collector is poorly insulated or lacks protective covers.

5. Fluid Flow Rate

- The rate at which fluid flows through the collector is very important. Higher flow rates improve heat transfer between the absorber plate and fluid, reducing the average temperature of the collector and hence reducing thermal losses. However, very high flow rates may result in lower outlet temperatures.

6. Absorptivity and Emissivity of Absorber Surface

- A good absorber plate should have high absorptivity (to absorb more solar energy) and low emissivity (to minimize heat loss through radiation). Selective coatings are used to achieve this balance and improve efficiency.

7. Thermal Conductivity and Plate Material

- Materials with high thermal conductivity, like copper or aluminium, are preferred for absorber plates, as they quickly transfer heat to the fluid. Poor thermal conductivity can delay heat transfer and reduce efficiency.

8. Collector Insulation

- Good thermal insulation at the back and sides of the collector prevents heat from escaping into the environment. Better insulation reduces overall heat losses and maintains higher fluid temperatures.

9. Heat Loss Coefficient

- This represents the total heat loss from the collector. This means lower heat losses and better collector performance. It depends on insulation quality, wind speed, and surface temperature.

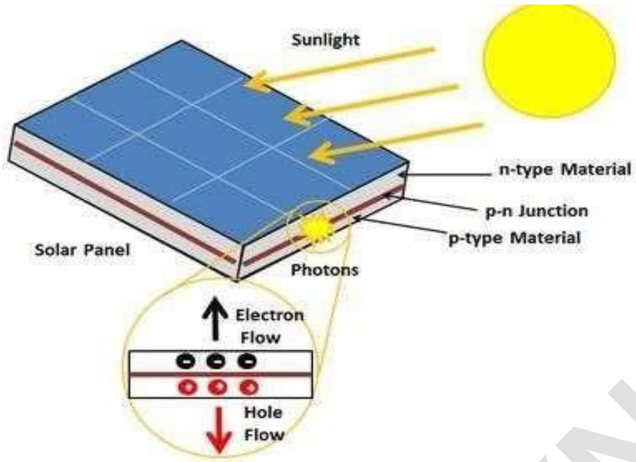
10. Cover Plate Transmittance (τ):

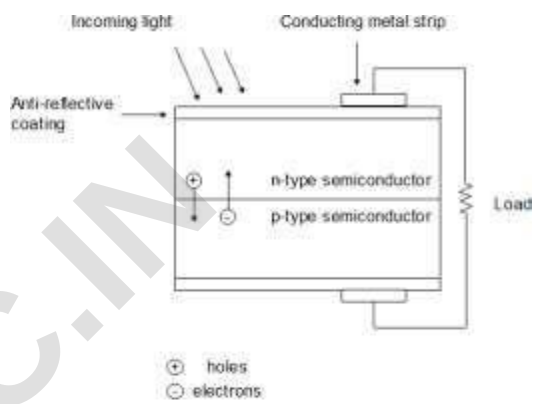
- The transparent cover plate (usually glass) should have high transmittance to allow more solar radiation to reach the absorber. Low-transmittance covers reduce the amount of usable solar energy.

Photovoltaic Conversion

- A photovoltaic cell is a type of PN junction diode which harnesses light energy into electricity. They generally work in a reverse bias condition. It is analogous to a solar cell since they belong to similar working principles but have distinct differences.

❖ Working Principle

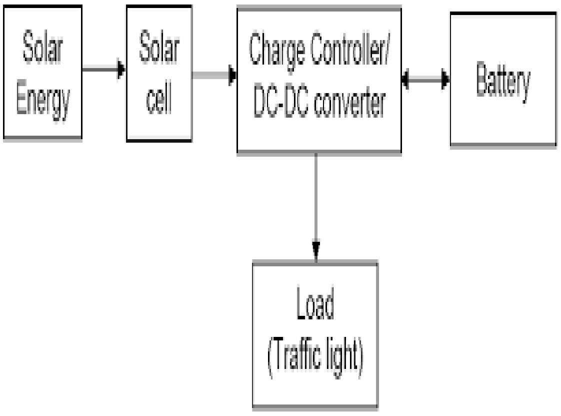




❖ Working Principle

- **Absorption of Sunlight**:
  The PV cell is made of semiconductor material (usually silicon). When sunlight (photons) falls on the cell, it gets absorbed by the semiconductor.
- **Generation of Electron-Hole Pairs**:
  The energy from the absorbed sunlight excites electrons, causing them to break free from their atoms, creating **electron-hole pairs**.
- **Separation of Charges**:
  An internal electric field at the **p-n junction** of the cell pushes the electrons towards the **n-side** and holes towards the **p-side**.
- **Flow of Electric Current**:
  When an external circuit is connected, electrons flow through the circuit from the n-side to the p-side, producing **direct current (DC) electricity.**
- **Power Generation**:
  This flow of electrons (electric current) can be used to power electrical devices or stored in batteries.

❖ Application of Solar Photovoltaic Cell in Traffic Light System



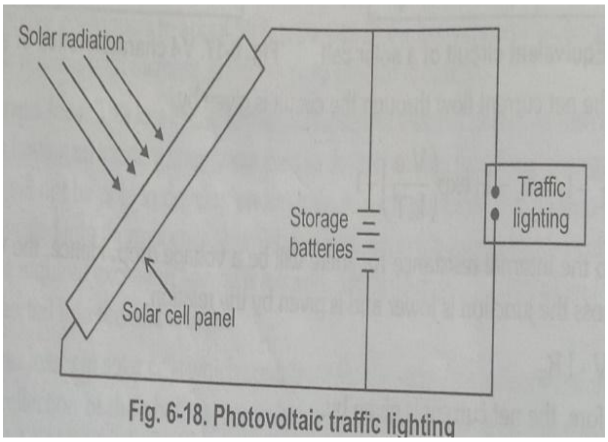


Fig: Block Diagram **Fig: Circuit Diagram**

- A solar-powered traffic light system uses solar panels to convert sunlight into electricity, which then powers the traffic signals and is stored in batteries for nighttime use. The system typically includes solar panels, a charge controller, a battery, and the traffic light mechanism.

❖ Construction

- **Solar Panels:** These are the photovoltaic (PV) cells that capture sunlight and convert it into direct current (DC) electricity.
- **Charge Controller:** This device manages the flow of electricity from the solar panels to the battery, preventing overcharging and ensuring optimal charging conditions.
- **Battery:** This stores the electrical energy generated by the solar panels for use when sunlight is unavailable, such as at night or during cloudy weather.
- **Traffic Light Mechanism:** This includes the LED lights, signal casings, and other components that display the traffic signals.

❖ Working

- Sunlight falls on the solar panels, generating electricity.
- The charge controller regulates the voltage and current, ensuring the battery is charged properly.
- The battery stores the electrical energy for later use by the traffic lights.
- The traffic light mechanism, powered by the battery, displays the appropriate signals (red, yellow, green).
- This system can be designed to operate automatically, adjusting light patterns based on traffic flow and other factors.
- Some systems include sensors to detect traffic and adjust signal timing accordingly.