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Anjugramam - Kanyakumari Main Road, Palkulam, Variyoor P.O. - 629 401, Kanyakumari District.

CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 2

SOLAR CONCENTRATING COLLECTORS AND PV TECHNOLOGY

Prepared by:

Mr.Arunpandian.N.

Assistant Professor

Department of Agricultural Engineering

Optically concentrating collectors are a category of solar thermal collectors that use optical elements such as mirrors or lenses to concentrate sunlight onto a smaller, high-efficiency receiver. These collectors aim to increase the intensity of sunlight to significantly higher levels than that of direct, diffuse, or ambient solar radiation, thereby achieving higher temperatures and improving the efficiency of the system. Concentrated solar power (CSP) systems typically utilize these types of collectors, as they are capable of generating high-temperature heat suitable for electricity generation and other industrial processes.

Working Principle of Optically Concentrating Collectors

The main principle behind optically concentrating collectors is to collect and focus sunlight onto a smaller surface area, increasing the intensity of the solar radiation that reaches the receiver. This concentrated radiation results in higher thermal energy, which can be used for various applications such as:

- **Electricity generation** in power plants.
- **Industrial heating** processes.
- **Water desalination.**
- **Agricultural drying.**

The collector consists of two main components:

1. **Optical concentrators** (e.g., mirrors or lenses) that direct the sunlight toward the receiver.
2. **Receiver** that absorbs the concentrated sunlight and transfers the energy to a working fluid (e.g., water, oil, or air), which then carries the heat for further use.

Types of Optically Concentrating Collectors

There are several types of optically concentrating collectors based on the way sunlight is concentrated and the design of the system. These are classified into two broad categories: **linearly concentrating** and **point concentrating** systems.

1. Linearly Concentrating Collectors

In these systems, sunlight is concentrated along a linear axis. These collectors are often used in large-scale solar power plants or industrial applications.

- **Parabolic Trough Collectors (PTC):**
 - **Design:** Parabolic trough collectors consist of long, parabolic-shaped mirrors that focus sunlight onto a receiver tube that runs along the focal line of the parabola. The receiver tube contains a heat transfer fluid (such as synthetic oil or molten salt) that is heated by the concentrated solar energy.

- **Working Principle:** As sunlight strikes the parabolic mirror, it is reflected and concentrated onto the receiver tube. The heat transfer fluid inside the tube absorbs the heat and carries it away to produce steam for power generation or provide thermal energy for industrial applications.
- **Applications:** Used primarily in large-scale CSP plants and industrial heating.
- **Linear Fresnel Reflector Collectors:**
 - **Design:** These collectors use multiple flat or slightly curved mirrors to focus sunlight onto a receiver tube placed above the mirrors. Unlike parabolic trough collectors, the mirrors are arranged in parallel rows.
 - **Working Principle:** The sunlight is concentrated along a linear receiver, and the heat transfer fluid is heated as it flows through the receiver. The system is simpler than parabolic troughs and uses smaller mirrors.
 - **Applications:** Suitable for medium-scale applications and commercial use.

2. Point Concentrating Collectors

These collectors focus sunlight onto a single point, which can reach very high temperatures. Point concentrating collectors are generally more efficient at converting solar radiation to thermal energy but are more complex and expensive to construct and maintain.

- **Parabolic Dish Collectors:**
 - **Design:** Parabolic dish collectors consist of a large, dish-shaped mirror that concentrates sunlight onto a receiver located at the focal point of the dish. The receiver typically contains a heat engine, such as a Stirling engine or a thermoelectric generator, that converts the heat into mechanical power or electricity.
 - **Working Principle:** The parabolic mirror reflects and focuses sunlight onto the receiver. The receiver collects the concentrated solar energy, which is transferred to a working fluid or used to drive a heat engine.
 - **Applications:** Used for small-scale power generation, providing electricity to remote locations or off-grid applications.
- **Central Receiver Systems (Heliostat Fields):**
 - **Design:** In central receiver systems, a field of mirrors (called heliostats) tracks the sun and reflects sunlight onto a central receiver located at the top of a tower. The receiver collects and absorbs the concentrated solar radiation.
 - **Working Principle:** The heliostats are adjustable to track the sun's movement throughout the day, continuously focusing the sunlight onto the receiver. The receiver absorbs the concentrated heat and transfers it to a heat transfer fluid (such as molten salt), which is then used for steam generation and electricity production.
 - **Applications:** Typically used in large-scale solar power plants (e.g., CSP plants), where the concentrated heat is used to generate electricity through turbines.

Reflectors in Optically Concentrating Collectors

Reflectors are essential components of concentrating solar collectors because they reflect and direct sunlight onto the receiver. The design of the reflector determines the collector's optical

efficiency and the amount of sunlight that can be concentrated. Reflectors can be categorized into two main types: **specular** and **diffuse** reflectors.

1. Specular Reflectors

Specular reflectors are designed to reflect sunlight in a single direction, typically toward the receiver. These reflectors have smooth, highly polished surfaces that minimize energy loss by ensuring a direct path for the reflected rays.

- **Materials:** Silver-coated glass, aluminum, or polished stainless steel are commonly used materials for specular reflectors. These materials have high reflectivity and low absorption, allowing them to concentrate more sunlight onto the receiver.
- **Advantages:** High efficiency and better control over the direction of sunlight, leading to more precise focusing.
- **Disadvantages:** These reflectors require precise fabrication and alignment to maintain high reflectivity and optimal performance.

2. Diffuse Reflectors

Diffuse reflectors scatter light in multiple directions, resulting in a less focused concentration of sunlight. These reflectors are generally used in systems where the focus on a single point or line is not critical.

- **Materials:** Diffuse reflectors often use materials like white or light-colored painted surfaces, which reflect light in multiple directions. They may also use diffusing coatings or materials with a rough surface that scatter the light.
- **Advantages:** Simpler construction and lower cost compared to specular reflectors.
- **Disadvantages:** Less efficient than specular reflectors, as the scattered light leads to a reduction in the intensity of the concentrated sunlight.

Key Factors Influencing Reflector Performance

1. **Reflectivity:** The ability of a reflector to reflect sunlight without significant losses. Higher reflectivity increases the overall efficiency of the collector.
2. **Surface Texture:** The smoothness and polishing of the reflector surface determine how effectively sunlight is reflected and concentrated. A smooth surface minimizes energy losses due to scattering.
3. **Durability:** Reflectors must withstand environmental conditions such as rain, dust, and UV radiation, which can degrade their performance over time. Protective coatings can help increase their lifespan.
4. **Tracking Mechanism:** In many concentrating collectors, the reflector is equipped with tracking mechanisms that adjust the angle of the mirrors to follow the sun's movement. This ensures the sunlight is always focused on the receiver.

Conclusion

Optically concentrating solar collectors play a pivotal role in harnessing solar energy for high-temperature applications such as electricity generation and industrial heating. The different types of concentrators—parabolic troughs, Fresnel reflectors, parabolic dishes, and central receiver systems—offer various solutions for large-scale or small-scale energy production. The performance of these systems heavily depends on the type of reflectors used, as well as the optical properties, tracking mechanisms, and materials involved. By efficiently concentrating sunlight, these systems can generate the high temperatures required for a wide range of industrial applications, contributing to the growing field of concentrated solar power.