International Journal of Interdisciplinary Innovative Research &Development (IJIIRD)
ISSN: 2456-236X
Vol. **08** Special Issue **01 | 2023**

Concentrated Solar Power Systems for Enhancing Power Generation in Summer Season

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ABSTRACT

Concentrated solar power (CSP) involves the concentration of solar radiation using mirrors or other optical elements to convert the sun's energy into thermal energy. This thermal energy is then used for heating, industrial purposes, or electricity generation through steam turbines. CSP plants often incorporate thermal storage units to provide energy during non-sunny periods. Effective CSP implementation requires high direct solar radiation (DNI), which is abundant in sun belt regions located between 15 and 40 degrees north and south of the equator. These regions include the Middle East, North Africa, South Africa, India, southwestern United States, Mexico, Chile, Peru, eastern China, Australia, southern Europe, and Turkey. The article focuses on various systems for generating electric power from concentrated solar energy and discusses different heat transfer fluids and thermal storage methods.

Keywords: Fresnel reflector (FR) system, Heat transfer fluids, Parabolic trough (PT) system, Solar dish (SD) system, Solar tower (ST) system, Thermal storage systems

INTRODUCTION

Concentrating Solar Power Plants

Concentrated solar power (CSP) can be generated using four methods:

1. Parabolic Trough (PT): This widely used technology employs parabolic mirrors to focus sunlight on a heat receiver. The receiver consists of stainless steel tubes coated with a special material for enhanced solar energy absorption. Synthetic oil or molten salt is used as a heat transfer medium, reaching temperatures of 300°C. Typical examples include a 70MW plant in the United States and a 50MW plant in Spain.

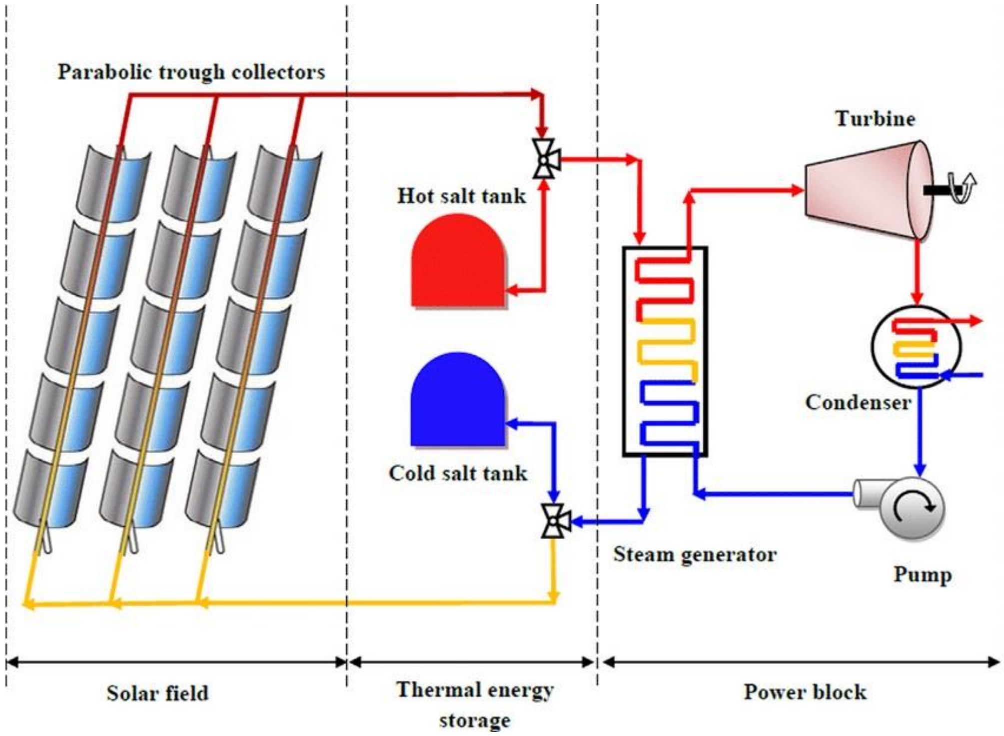

Fig. 1: Layout of Parabolic Trough CSP system

2. Fresnel Reflector (FR): Similar to PT plants, FR plants use ground plane mirrors to focus sunlight on a fixed receiver. The receiver, typically a water-filled tube, generates superheated steam that can be used to rotate a turbine. FR plants have lower efficiency than PT plants but are more cost-effective. An example is a 5MW plant in Australia.

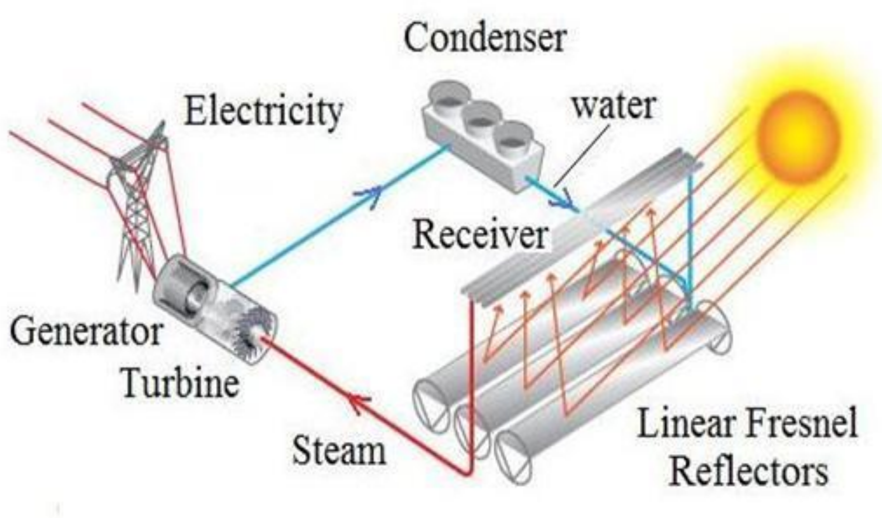

Fig. 2: Layout of Fresnel Reflector CSP system

3. Solar Tower (ST): ST plants use large mirrors called heliostats to track the sun and concentrate its rays on a central receiver mounted atop a tower. The higher concentration factor in ST plants results in higher heat generation compared to PT and FR plants. Molten salt is commonly used as the heat transfer medium. An 11MW plant in Spain serves as an example, with 624 heliostats and a receiver temperature of 290°C.

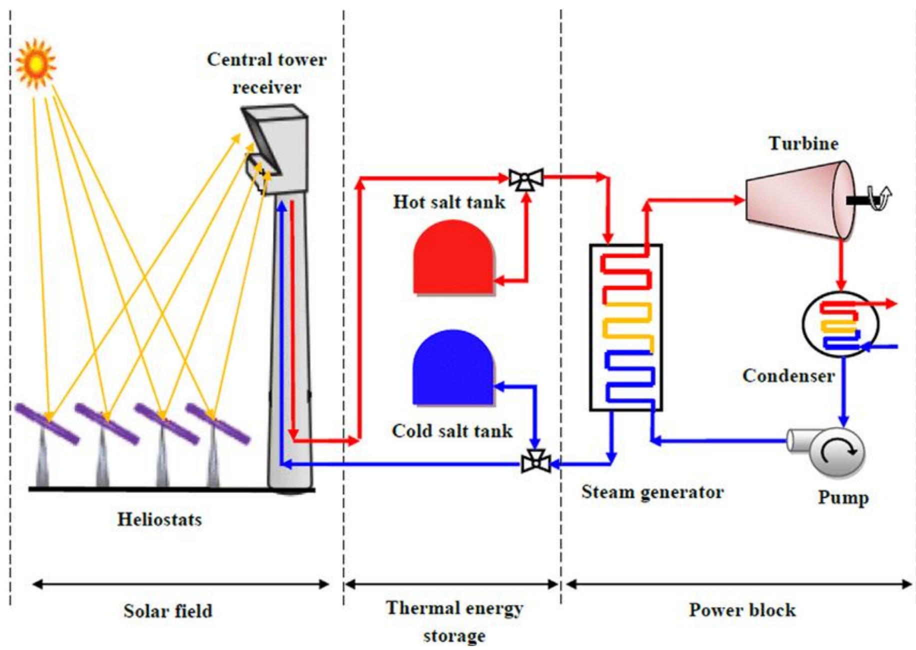

Fig. 3: Layout of Solar Tower CSP system

4. Solar Dish (SD): SD systems utilize an oval dish to reflect sunlight onto a receiver, which can be a Stirling engine or a small turbine integrated with a generator. SD systems have high efficiency due to their high concentration factor, but heat storage remains a challenge. Examples include a Dish in Australia with a power capacity ranging from 10-100 kW.

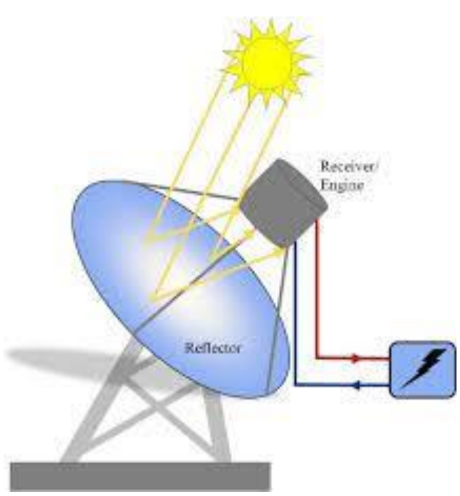

Fig. 4: Layout of Solar Dish CSP System (1) and The Big Dish (Australia) (2)

Heat Transfer Fluids

Different heat transfer fluids are used in CSP plants. Examples of these fluids include binary salts, triple salts, synthetic oil, liquid metals, water, gases, air, solids, and liquid glass.

Binary salts are a mixture of sodium nitrate and potassium nitrate, melting at a temperature of 290°C. Triple salts consist of a mixture of potassium nitrate, calcium, sodium nitrate, and potassium nitrate, melting at 131°C. While salts are stable at high temperatures up to 600°C, they can solidify at high temperatures, leading to pipe blockages. To address this issue, a heating system must be available during abnormal operating conditions.

Synthetic oil, or mineral oil, can withstand temperatures up to 400°C. However, it deteriorates over time, is expensive, flammable, and has a limited maximum temperature capacity.

Liquid metals such as sodium, lead, eutectic, and tin have a solidification temperature below zero degrees Celsius and a boiling point exceeding 1600°C. They can operate at low pressures, allowing for smaller tube thickness and lower viscosity.

Water is suitable for generating saturated steam at temperatures below 300°C and pressures below 45 bar. However, it requires expensive metal pipes due to its high pressure.

Gases like carbon dioxide, helium, and nitrogen can reach very high temperatures limited only by the materials used in the tubes and ducts. They have good heat transfer properties and lower rust compared to air. However, they have low density, requiring larger tanks and heat exchangers.

Air, although available everywhere, also has low density like gases.

Solids, such as ceramic particles with diameters of 200 μm to 600 μm combined with oil or gas, can reach temperatures of 900°C. Carbon nanoparticles with air are another example of solid heat transfer medium.

Liquid glass is chemically stable and resistant to high temperatures. However, it has high viscosity, making pumping difficult. It can reach temperatures below 450°C and is recommended for heat storage applications.

Thermal Storage Techniques

Thermal storage is used to increase the capacity factor and dispatchability factor of CSP plants. It offers a lower cost compared to batteries used in solar photovoltaic plants. Several thermal storage methods are employed:

1. Direct System with Two Tanks: This system uses the same fluid for heat transfer and thermal storage. The fluid is stored in two tanks, with the first tank at a high temperature and the second tank at a low temperature. The fluid passes from the low-temperature tank to the receiver, where it is heated by the sun's heat. Then, it goes to the high-temperature tank for storage. From the high-temperature tank, the fluid goes to a heat exchanger to generate steam for electricity production. Finally, the fluid leaves the heat exchanger at a low temperature and enters the second tank. Examples of plants using this system include those in California, where industrial oil or molten salt is used for heat transfer and storage.

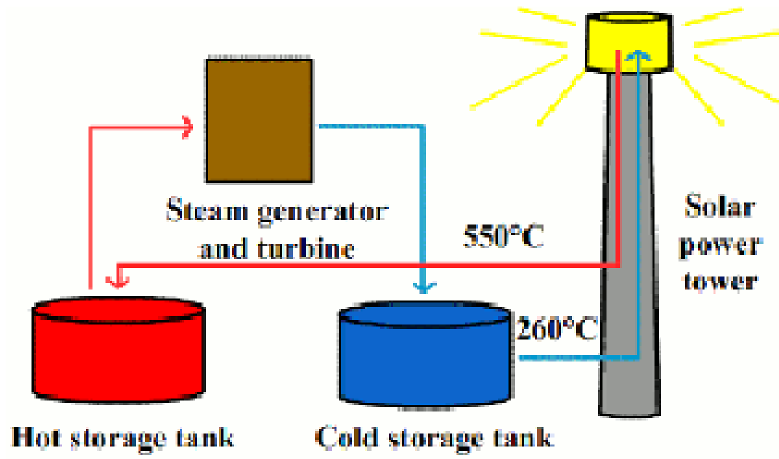

Fig. 5: Schematic of Direct thermal storage system with two tanks

2. Indirect System with Two Tanks: In this system, separate fluids are used for heat transfer and heat storage. The heat storage fluid passes through a heat exchanger, where it is heated by the high-temperature heat transfer fluid. The heat transfer fluid then leaves the heat exchanger at a low temperature and returns to the receiver for solar energy heating. The heat storage fluid, now heated, is passed through another heat exchanger to generate steam for driving a turbine. This system requires an additional heat exchanger, increasing costs. Examples of plants using this system include parabolic trough plants in Spain and the United States, which use organic oil for heat transfer and molten salt for heat storage.

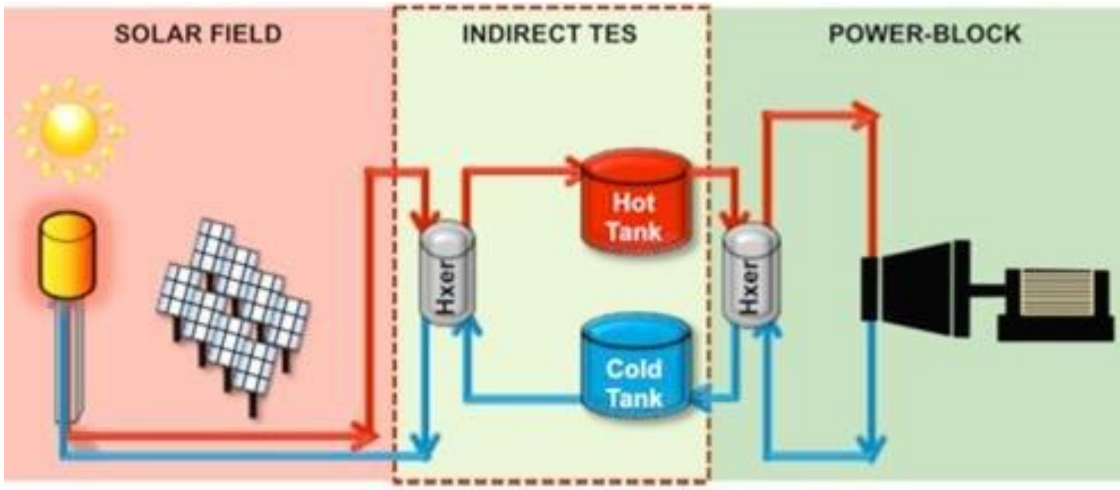

Fig 6. Layout of Indirect Thermal Storage with two tanks

3. One-Tank Thermocline System: The one-tank thermocline system utilizes a single tank containing a thermal medium consisting of a combination of solid material and fluid. Examples of such combinations include silica rocks with molten salts, graphite with molten salts, ceramics with molten salts, concrete with molten salts, and saturated water with saturated steam, with a layer of steam separating them. The principle of operation of this system relies on the formation of thermal layers within the fluid due to buoyancy. The portion of the fluid with a higher temperature rises to the top, while the portion with a lower temperature descends to the bottom. Between these two fluid layers, a layer of medium temperature known as the thermal line separates them. The low-temperature fluid flows from the bottom of the tank to the receiver, where it is heated by solar energy. It then moves from the receiver to the top of the tank, increasing the thermal energy, while the thermal line drops to the bottom. When the fluid flows in the opposite direction from the top of the tank to the heat exchanger to generate steam, and then to the tank, at a low temperature, the thermal line rises to the top. The use of a single tank reduces the cost of the system (Fig. 8).

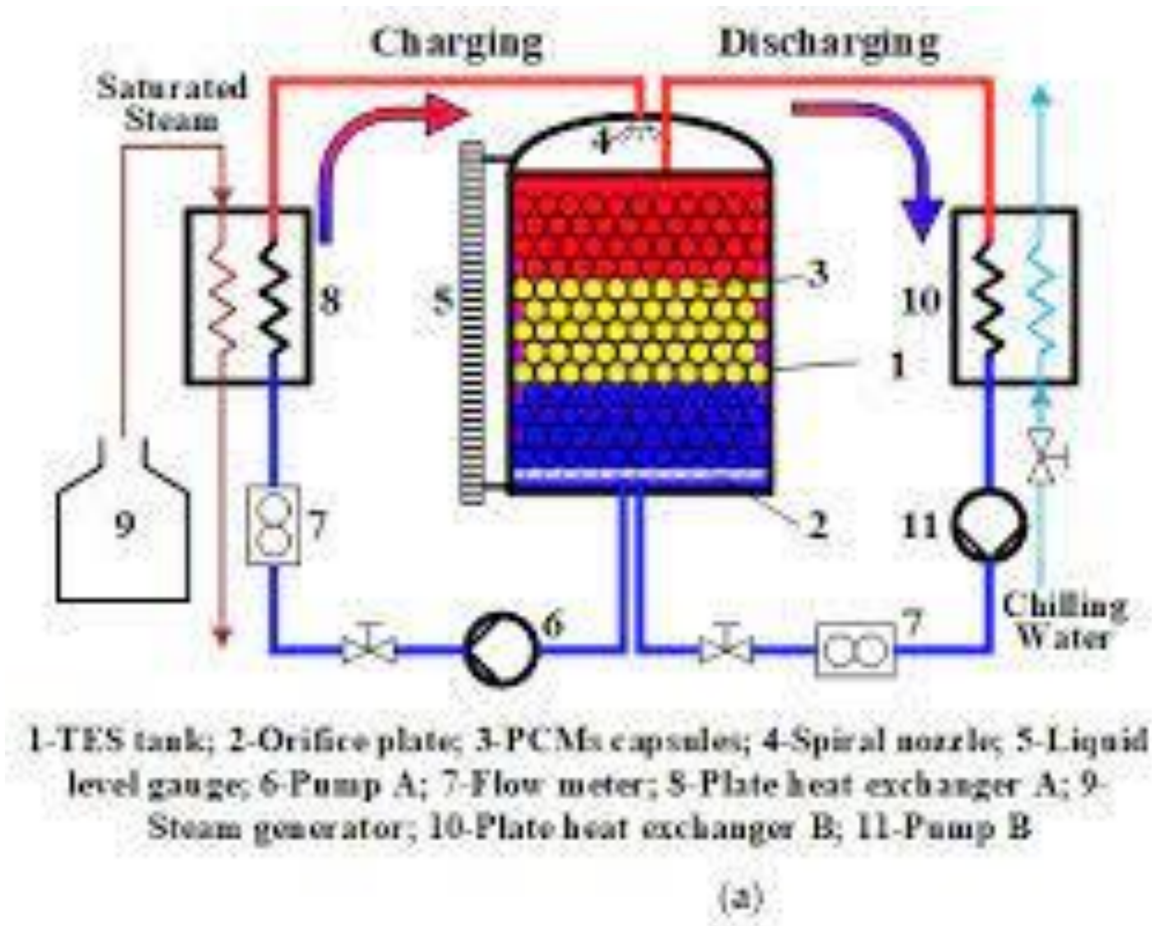

Fig. 7: Layout of One Tank Thermocline CSP system.

CONCLUSION

In India's hot summer, photovoltaic (PV) solar power is not a viable solution for the electricity demand due to its reduced efficiency at high temperatures and disproportionate cost compared to the generated electrical capacity. On the other hand, concentrated solar power (CSP) offers increased efficiency with rising temperatures, making it an excellent solution for meeting the increased electricity demand during the summer season. As India is one of the hottest regions globally, with abundant sunlight for 14 hours and vast desert areas, CSP becomes the ideal choice for renewable energy. It is expected that CSP will become the energy of the future by implementing main grids using various CSP plant techniques. Additionally, the installation of microgrids in homes and workplaces using the solar dish (SD) technique is also a possibility.

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