Advances in concentrated solar absorber designs

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Abstract. Concentrated solar power (CSP) with thermal storage (TES) can generate continuous power output. It can be used for various applications by overcoming the intermittent solar radiation. As heat losses occur in absorber because of heat flux, tracking, optical errors. Hence, improving efficiency arises. Reducing heat loss is vital. The absorbers are volumetric, cavity, tubular liquid, solid particle-type. The occurrence of heat flux on absorbers from heliostats. Performance affects because of clouds in transient conditions. The review focuses on advances in solar absorber designs. It concentrates on meeting sustainable development's energy and power requirements.

Keywords. Solar energy, thermal storage, parabolic dish, absorber, PCM.

1. Introduction

CSP performs a significant part in converting solar to electricity. Broadly used CSPs are parabolic trough collectors (PTCs), Fresnel lens collectors (LFR), central towers (CST), and parabolic dish collectors (PDC). The vital segment of solar plant is absorber. The fluid in absorber absorbs solar energy. This energy is utilized for power, process applications. The greatest exergy loss of about 40% occurs in heliostats hence lower ambient temperature is preferred [1]. Heat flux on central absorbers from decline heliostats and performance affects because of clouds in transient conditions.

The heat flux on central absorbers depends on heliostats. Performance affects because of transient clouds. Better energy and economic performance from CSP. Receiver temperature is about 900 to 1200 K [2]. Technologies to increase temperature of receiver were presented [3]. Strategy to gauge the occurrence of heat flux on central absorbers studied [4]. The performance affects because of cloud disturbances [5]. Heat transfer occurs in molten salt receiver in transient conditions [6]. Fig. 1 shows CSPs. Line absorber requires precise aligning. Point absorbers used in PDC.
A novel sun trailing technique to enhance concentration efficiency [7-9]. A novel hybrid solar receiver leads economic benefits [10]. An exceptional receiver model for CST [11,12], latest model of molten salt receiver for CST [13] are studied. Effect of incidence angles on cylindrical receivers of CST studied [14]. Heat losses occur in absorber because of heat flux, tracking, optical errors, etc., to improve efficiency arises. CSP can accomplish a concentration around 600 and temperatures of 800° C. A higher porosity improves the thermal and hydrodynamic performance of volumetric receiver [15]. The wind speed, extraction angle, and suction velocity on receiver effectiveness are analysed [16]. Their influences are discussed. Wind causes heat loss. Angle makes more absorptions. Fig. 2 shows major CSP technologies.

Concentration distribution of radiation over the receiver surface estimated and the output characteristics of concentrator for various model limits [17]. A thermal stress analysis of superheated water/steam in a solar cavity receiver below concentrated radiation, and the thermal stresses were calculated [18]. A modified cavity receiver with conical protrusions for solar dish and observed a performance improvement [19]. A new cylinder flux map based on HFLCAL model [20] and the recent developments and CSP challenges. A relative study on convection
loss of PDC cavity receivers at various positions using CFD [21]. Heat flux on CST from heliostats and performance affects because of clouds in transient state. Steady output materializes with TES. TES selection is vital.

A numerical approach to volume receiver using CFD [22]. Heat transfer model to capture volume absorber dynamics [23]. Heat flux on central absorbers from decline heliostats and performance affects because of clouds in transient conditions. Open volume receivers can provide heat using ambient air as working fluid over temperatures of 700°C. The dish concentrator with cubical and cylindrical cavity receivers performed using oil [24,25]. The cubical and cylindrical cavity receiver's average efficiency was acquired as 65.14% and 56.44%, respectively.

2. Concentrated Solar Power (CSP)
CSP is an immense power generation from renewables which is being utilized. By concentrating solar radiation onto a small area, higher temperatures of 400°C to 1000°C obtained. The thermal energy is transferred to electricity with steam or gas turbine. CSP includes solar field where the radiation is concentrated onto an absorber, a TES for store thermal energy, and power block to convert the heat to electricity. CSP includes power cycles like steam Rankine, organic Rankine, combined cycle. The occurrence of high heat flux on central absorbers from large mirrors. Optical performance affects because of clouds in transient conditions. PDC and ST plants focus the radiation on a point with higher concentration. They produce working temperatures. The central absorbers accomplish concentration of 600 and temperatures 800°C.

PDCs give concentration greater than 1000 with temperatures of 1600°C. Solar to electrical efficiency (SEE) is the ratio of total solar energy falling into the concentrator to electricity generated. The CSP efficiencies technologies are given in Table 1. The capacity factor (CF) of CSP is the ratio of actual energy generated in each period to the energy that could be generated if the plant operated continuously at the full output. CFs of CSP technologies are given in Table 2. As significant losses occur in absorber because of heat flux, tracking, optical errors. Various absorbers include a volumetric, cavity, tubular liquid. Heat flux on central absorbers from decline heliostats and performance affects because of clouds in transient conditions.

| Technology | SEE (%) |
|------------|---------|
| PTC        | 15      |
| CST        | 15 – 35 |
| LFR        | 8 – 10  |
| PDC        | 25 – 30 |

The irregular solar radiation controls the capacity and the reliability. It gets over by integrating TES with the CSP. Two TES technologies were commercially executed, which include the molten salt systems for the PTC and SPT. Steam accumulators for the direct steam generation (DSG) plants are used. A restriction of steam accumulator is the pressure drop during the release of steam. Build-in an encapsulated storage capsule is favorable in steam accumulators. High heat flux on central absorbers from affects during transient weather.
3. Solar absorbers

The absorber is a vital in CSP as it is subjected to high radiation flux, thermal stress, and temperature. The absorber design should be made so that the thermal losses, cost, etc., are minimum and the irradiance, absorptance, efficiency, etc., are maximum. The irregular solar radiation controls the capacity. Reliability of system and can get over by the integration of TES systems with the CSP. The commonly used method for transferring the heat from absorber is using heat transport fluid (HTF), namely water. PDC and ST plants focus the radiation at high concentration. The CSP performance depends upon absorber and the TES to a greater extent. The various solar absorbers used on CSP are the cavity, cylindrical, volumetric, tubular absorber, thin absorber, central absorber, particle absorber. The heat flux and tracking improve efficiency arises. The occurrence of heat flux on central absorbers from decline heliostats and performance affects because of clouds in transient conditions.

3.1. Cavity absorber

The cavity absorber is a photo-thermal conversion in solar plant. It heats working fluid containing by absorbing radiation. The cavity geometry has a significant outcome on overall heat flux. The irregular solar radiation deteriorates reliability. TES compensates the issues by integrating with CSP. The cavity absorber provides a lower flux density of solar radiations. It reduces temperature gradients and thermal stresses. The fins on cavity helping enhanced efficiency. Table 3 shows LFR receiver’s key aspect.

| Technology          | Capacity factor (%) |
|---------------------|---------------------|
| PTC without storage | 25                  |
| PTC with storage    | > 40                |
| SPT                 | around 25           |
| LFR                 | around 15           |
| PDC                 | 50                  |

Table 3. LFR cavity absorbers.

| Shape of cavity absorber | Summary             |
|--------------------------|---------------------|
| Cylindrical              | Low flux density    |
| Triangular               | Higher optical efficiency. |
| Trapezoidal              | Low efficiency      |
3.2. Volumetric absorber

The volumetric absorber consists of an effective area for solar absorption larger than that of radiation losses. The outlet fluid temperature should be higher than the temperature of absorber material on irradiated surface. This is referred to as the volumetric effect. It results in a minimization of absorber radiation losses. These absorbers can be operated at either atmospheric or elevated pressure. Sufficiently higher temperatures around 900°C can be achieved with energy storage [26,27]. The intermittent solar radiation control’s reliability of system got affected.

For linear concentrating systems, the operating conditions on tubular absorbers are dependent on chosen HTF, which determines the maximum temperature. PRC produce a linear focus on absorber tube along the parabola’s focal line. Trough systems using the thermal energy collection through the evacuated tube absorbers are currently the most widely used CSP. The integration of TES systems with the CSP is effective option. PDC focus the radiation at high concentration and losses occur.

3.3. Point-focus absorbers

The absorbers for the point focus concentrators such as dishes and central absorbers typically operate at much higher temperatures (500–800°C) and higher concentration (500–5000). In CST, the absorber is the heat exchanger where the concentrated solar radiation is intercepted and transformed into thermal energy and utilized in power cycles. The reflected beam radiation is concentrated onto a point focus absorber, and the CSP can reach an operating temperature of over 1000°C, like the tower systems. Fig. 3 shows the CSP schematics. Major CSP working mediums are provided (Table 4).

Table 4. CSP working mediums.

|                         | Sodium | Na–K | LBE  | Solar salt |
|-------------------------|--------|------|------|------------|
| **Melting point (°C)**  | 98     | −11  | 125  | 220        |
| **Boiling point (°C)**  | 890    | 785  | 1533 | 565        |
| **Thermal conductivity (W/m K)** | 119.3 | 26.2 | 13.7 | 0.53       |
| **Density (kg/m³)**     | 820    | 749  | 10,139 | 1804   |
| **Specific heat capacity (kJ/kg K)** | 1.256 | 0.937 | 0.143 | 1.52      |
| **Dynamic viscosity (Pa s)** | 0.000149 | 0.000176 | 0.00144 | 0.00169 |
| **Prandtl number**      | 0.0016 | 0.0063 | 0.015 | 4.85      |
The central absorbers have several advantages, like they typically achieve higher concentration of 300 to 1500. They are highly efficient, both in receiving and storing energy. They are converting it to electricity. They are larger in scale and the integration of TES systems with the CSP is essential to improved productivity. Falling particle receiver (FPR) enables higher working temperatures (>1000°C). FPR is inexpensive energy storage. It has higher receiver efficiencies for CSP technologies, thermochemical reactions, and process heat. It enables temperatures essentially higher than the conventional receivers employing molten nitrate salts. Heat flux on central absorbers from decline heliostats and performance affects because of clouds in transient conditions. CSP involve radiation at high concentration and radiation loss is higher. Novel materials must minimize losses.

4. Conclusions

The various receivers for CSP are presented. The review focused on advances in solar absorber designs. CSP mainly generates power economically. CSP is reliable with performance. The major conclusions follow:

- CSP with TES generate continuous power output. CSP used for various applications by overcoming the intermittent radiation.
- Benefit of CSP such as power tower systems and parabolic troughs is the TES in addition to different parts.
- The integration of TES with the CSP is efficient. Materials selection is vital for CSP components.
- FPR is inexpensive energy storage and medium.
- The energy storage increases the capacity factor. This is a significant standard in an electrical power distribution system.
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