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Recent developments in geometrical configurations of thermal energy storage for concentrating solar power plant

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ABSTRACT

Concentrating solar power plant coupling with thermal energy storage is a new and emerging technology in the renewable energy field. A multitude of research works focus on improving the performance of the power plant for getting the higher efficiency and lower cost. Due to the poor thermal conductivity of phase change materials and complex physical/chemical heat transfer process in the storage tank, geometrical configurations of the storage tank are vital for the system's performance, thus affect the large-scale application of concentrating solar power plant. This paper presents a review of geometrical configuration of thermal energy storage tank by summarizing a series of numerical, experimental and theoretical studies in the open literatures. A widespread discussion for thermal energy storage tank in future application has been proposed in the paper. The results can provide a good reference for designing, operating, and energy-saving of thermal energy storage system for concentrating solar power plants.

Contents

1. Introduction

With the growing global energy demand, the conventional fossil fuels are deficient and environmental unfriendly. Concentrating solar power (CSP) plant is a unique way among all renewable energy system, which includes solar energy, wind energy, biomass energy, geothermal energy, etc., however, some drawbacks of solar energy, i.e. variable and uncontinuous characteristics of solar radiation, mismatching of the supply and demand energy, have a critical limit for its development. A host of advancements has taken place in recent years and the aim is to make the system cost-effective and large-scale applications. Thermal energy storage (TES) plays a key role for CSP plant due to enable continuous or alternative operation for the entire period. During sunny days or off-peak periods, solar energy is stored in TES system, and the energy can be retrieved during the night, cloudy days, or on-off periods. Owing to outstanding role of TES system, many research and development (R&D) projects of institute, university, and company aim to improve and optimize the performance of TES system.

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Nomenclature

Acronyms

CSP	Concentrating solar power
R&D	Research and development
PCM	Phase change material
HTF	Thermal energy storage
TES	Thermal energy storage
O&M	Operation and maintenance
LHS	Latent heat storage

TES system often consists of three contributions: the storage medium, heat transfer fluid (HTF), and containment system. The factors for design and application of TES are vital as [1]: high efficiency and stability; low cost; and low environmental impact. Also, the methods of TES system can be classified as: sensible heat storage (SHS), latent heat storage (LHS), and thermochemical storage. There are some design criteria for TES system as following [1]: nominal temperature and specific enthalpy drop in the load (discharge and conversion side); maximum load; operational strategy; and integration in the plant.

In past four decades, there are widely researches on TES system of CSP plants. Some review articles have a summary in the open literatures, which focus as follows: TES technologies and systems [2], phase change material (PCM), design considerations and performance enhancement techniques [3], performance enhancement in latent heat thermal storage system [4], materials, heat transfer and phase change problem formulation for latent heat TES system [5], TES for residential application [6], TES using PCM capsules [7], latent heat TES using Computational Fluid Dynamics (CFD) [8], PCMs for high-temperature TES system[9], microencapsulation methods of PCMs [10], thermal stability of PCMs used in latent heat energy storage system [11], preparation, thermal properties and applications of shape-stabilized TES materials [12], mathematical modeling on latent heat TES [13], passive PCM latent heat TES systems towards buildings' energy efficiency [14], storage materials and thermal performance enhancement techniques for high temperature phase change thermal storage systems [15], thermal conductivity enhancement of PCMs [16], thermal conductivity enhancement of nanostructure-based colloidal suspensions [17], TES with PCMs and application [18], screening analysis of metal hydride based TES systems [19], state of the art on high temperature TES for the plant [20,21], seasonal TES [22,23], solar collectors and TES [24], thermochemical heat storage system [25,26]. The review of geometrical configurations of TES system, however, is limited in the previous works.

2. Effect of geometrical configurations on the system's performance

It is well known that the geometrical configurations of TES tank have a huge impact on the performance of the system, which includes heat transfer rate, charge and discharge time, the temperature distribution of the materials in the tank, quantity of TES materials, heat exchanger characteristics, system's operation and maintenance (O&M), and thermal-electric conversion efficiency of the system etc.

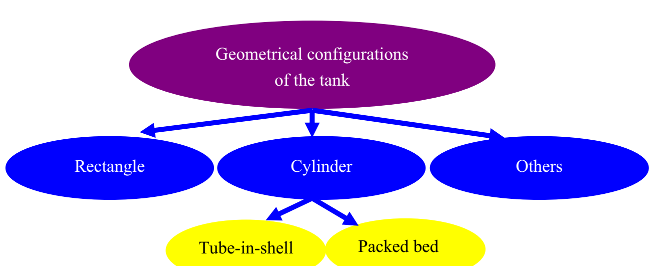

Fig. 1. Geometrical configurations of the tank.

Currently, main geometrical configurations of the storage tank include cylinder and rectangle shown in Fig. 1. In recent developments, other geometrical configurations of the storage tank, i.e., multi-materials/multi-tanks, helical tube, or vertical wavy enclosure, have also been designed and studied.

Fig. 2 shows two typical TES tanks in CSP plant with cylindrical and rectangular shapes. It can be seen from the figure that there is a heat transfer process between the HTF and storage materials. Also, it is very obvious that there are different heat transfer characteristics for different shapes. In order to obtain lower cost and higher efficiency of the power plant, the optimization of the geometrical configuration of TES tank is very necessary. Some enhancement techniques focus on as follows: changing the geometrical configuration, adding finned tube, adopting multiple PCMs during the heat transfer process etc.

There are an ocean of works to improve the system's performance, but the summary is a little limited. Therefore, the present review article focuses mainly on the recent developments in geometrical configurations of TES system for CSP plant. A widely discussion for the designing TES system in future application has been presented. It will provide a good reference for designing, operating, and energy-saving of solar thermal power plant.

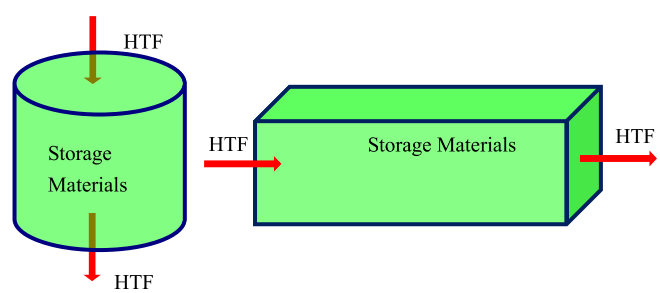

Fig. 2. Typical TES tanks with the cylindrical (left) and rectangular (right) shapes.

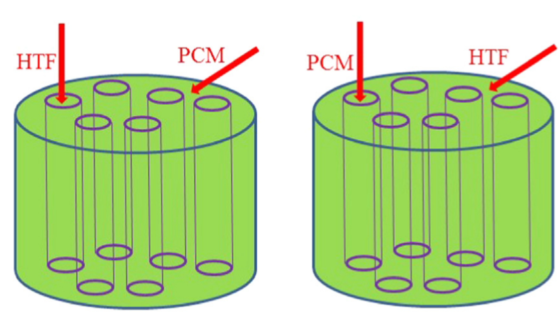

Fig. 3. Schematic diagram of tube-in-shell cylindrical storage tank.