

# Succinct Review on State-of-art Carbon-based Phase Change Material for Solar Thermal Storage Applications

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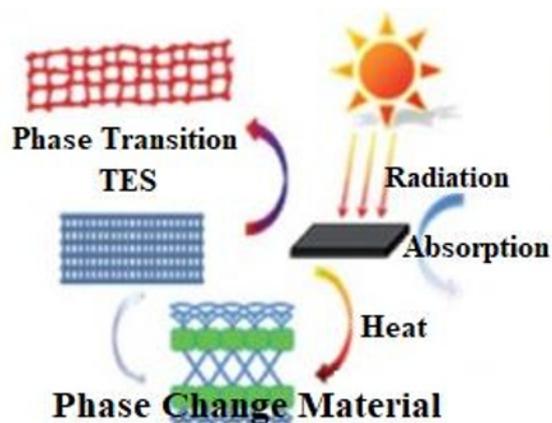
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**Abstract.** Radiation from the sun continually generates enormous solar energy reaching the atmosphere and then radiates back into the outer space over a while. The energy source is considered to be potential renewable thermal energies if effectively harnessed and stored. Thermal energy storage could be in either cold or heat form for later use for either cooling and heating purposes respectively; it can also be utilized for electricity production. The development of highly efficient and cost-effective heat storage materials has been an emerging school of thought for researches into smart methods of heat storage. The authors briefly review the state-of-art carbon-based composite phase change materials (PCM) that have been employed in applications that are related to thermal storage. Various types of recently developed carbon composites with improved thermal storage properties have been succinctly discussed. The technological implications of employing the identified materials in the thermal storage applications were also highlighted and discussed.

## 1 Background

The consumption of fossil fuels over the years to meet energy needs has led to an alarming increase in greenhouse gas emissions [1]. On the global scene, the need to explore renewable energies has become a top priority [2]. Thermal energy is one of the solar radiation's components of emanating from the sun, and it has an expanding field related to renewable energy technologies [3], [4]. According to NASA reports, the earth system (land surface, oceans, and atmosphere) absorbs and emits an average of about 340 watts of solar energy per square meter of space year-round [5], [6]. This indicates that a massive amount of solar energy enters the earth's crust every day and radiates back into the outer space untapped [7].

This short review presents solar thermal energy was presented as a sole prospective renewable heat source. Consequently, the intermittent nature of solar radiation, reflection, and irradiation have made thermal energy storage a requirement for saving the extra heat generated for use at the time and place of demand [8] [9]. Figure 1 illustrates the mechanism of solar-to-heat conversion involved in the concept of thermal energy storage (TES).



**Figure 1.** Mechanism of solar-to-heat conversion in a typical thermal energy storage system (TES) [10].

## 2 Concept of Thermal Energy Storage (TES)

TES technology conserves thermal energy either by cooling or heating a medium such that energy can be reserved and then later used for either heating or cooling purposes. In some other applications, the stored energy can be utilized to produce electricity [11]. Figure 2 shows the details of the classification of thermal energy.

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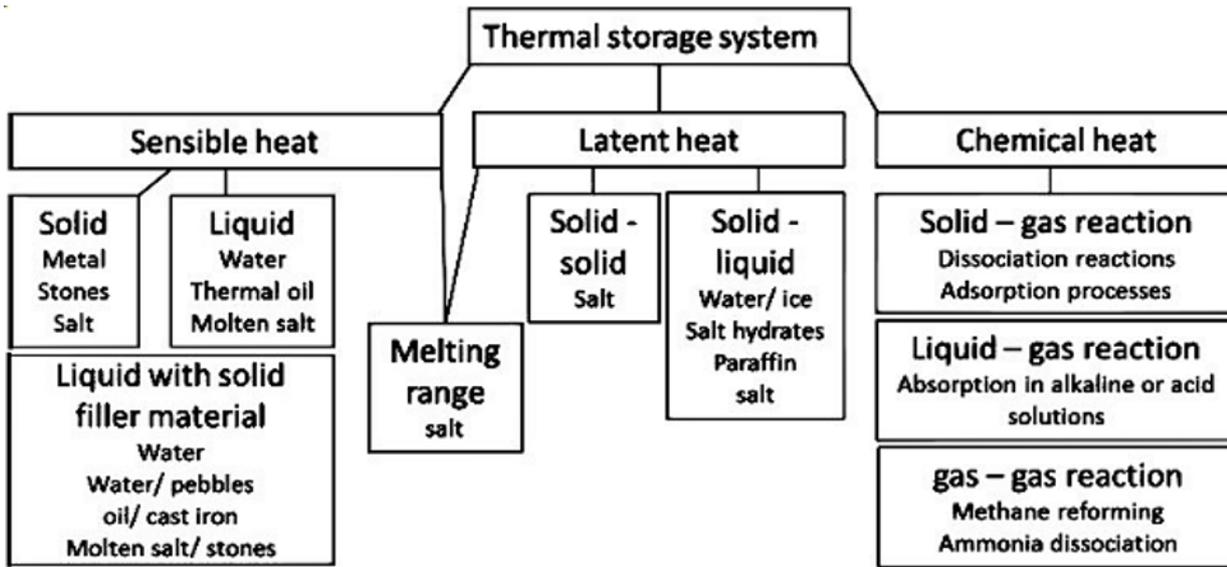


Figure. 2. TES Types [12]–[15].

### 2.1 Phase Change Materials for TES System

The transfer of heat energy experienced when a material transforms from either solid to liquid or vice-versa is referred to as Latent heat system (LHS) [16]. Materials that exhibit this LHS ability are referred to as Phase change materials (PCMs) [17]. PCM absorbs and releases heat at a constant rate unlike conventional heat storage materials [15]. A distinctive advantage of this PCM system is that it has a higher energy density than sensible thermal storage systems (SSM) [18].

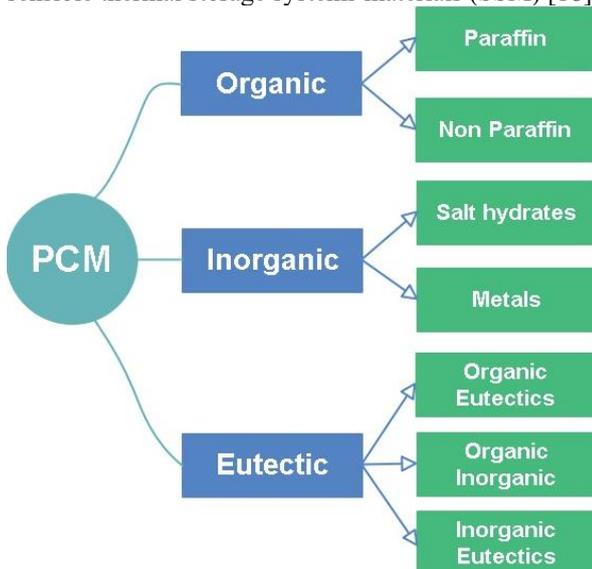


Figure. 3. Types of PCM for TES [19] [20]

The summary of the classifications of the PCM was shown in Figure 3. The materials for latent heat storage highlighted in the figure had been used for solar TES applications by several scientists [21], [22]. They are all essential materials for LHS-TES because they have been known to store up to between 5 and 14 times more heat per unit volume than SSMs such as water, masonry or rocks [23]. The determination of whether a PCM is suitable for each application is dependent on the range of

temperature such material can handle [24]. Many TES applications use PCM as they are found suitable for their versatile thermal performance [25]. Figure 4 illustrates a briefly illustrates the existing categories of the system based on the melting point that can help in choosing the PCM desirable for the application. However, some of the associated problems of the PCM are low thermal conductivity, flammability, phase separation, subcooling and thermal instability among others [27]. High fusion heat and a precise melting and solidification temperature are desirable properties in LHS materials, that is, PCMs [28].

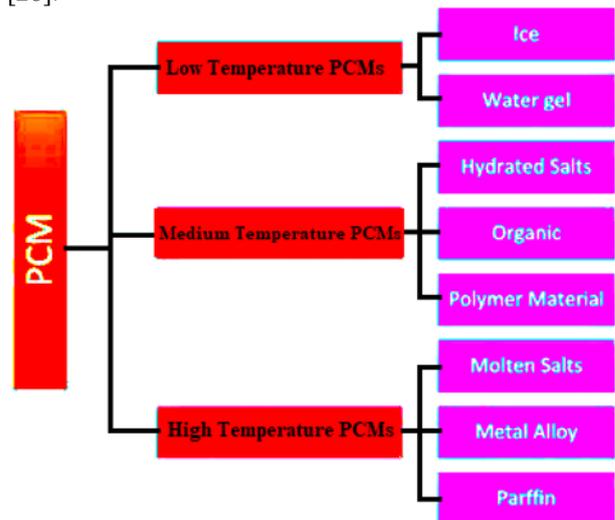
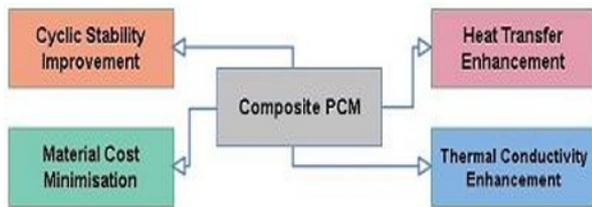


Figure. 4. Categories of PCM for TES based on the temperature handling range [26].

### 2.2 Composite Phase Change Materials (CPCM)

The major disadvantage of PCMs is their low thermal conductivity [29]. Various modifications have been attempted to improve the TES properties of the PCMs using high thermal conductivity materials-based composites [30]. Figure 5 depicts the different modes of quality that can be embedded in a developed PCM composite.

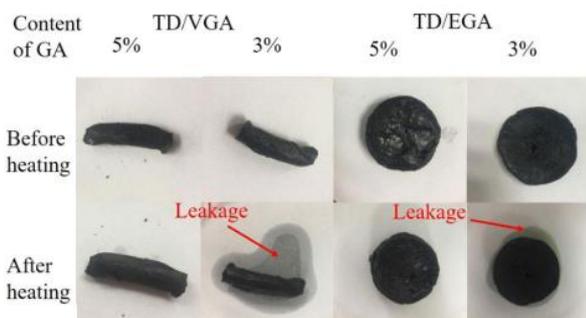


**Figure 5.** CPCM Enhancement for TES System [31]

There exist three major types of PCM composites [32] as listed below:

1. Metal foam CPCM: The PCM is being impregnated in a metal foam. The highly porous metal foam serves as a reinforcing frame, to give a high specific stiffness and strength, as well as an improved thermal conductivity. However, leaking of the PCM from the metal foam and corrosion of the metal components with time can be a problem [33] [34].

2. Form stable CPCM: A stable composite material is used to contain the PCM thus preventing any leakage thereof (as displayed in figure 6). The materials usually used include polymers, diatomite, silica, perlite and the likes of other ceramics. The main advantage of form stable CPCM is that they do not need to be enclosed in a capsule. However, the introduction of the stable counterpart can make the fusion enthalpy decrease significantly [35].



**Figure 6:** Images of TD/GA Form stable CPCM before and after the leakage tests [36].

3. Carbon-based CPCM: PCM combined with any carbon materials like expanded graphite (EG), carbon nanofibers, graphite, graphene, and their nanos. The resultant composite's properties are highly dependent on the carbon-based material type used, as well as the process of manufacturing [37]. Carbon-based CPCM holds the promise of high intrinsic thermal conductivities that can produce composites with high thermal conductivity [38]. This short review is to highlight state-of-art works on carbon-based CPCM for solar TES.

### 3 State-of-art Carbon-based CPCM

In a recent publication, Qi et al., (2017) obtained a new hierarchical 3D graphene foam (HGF) and filling the pores of graphene foam (GF) with hollow graphene strips [39]. HGF was developed into a paraffin wax (PW) composite. PW/HGF-CPCM has the thermal conductivity of 744% and 87% greater than that of the

pure PW and PW/GF-CPCM respectively. The PW/HGF-CPCM offers light thermal energy storage with conversion and storage efficiency, considerable potential for the application of TES and solar cells. In one of the latest researches involving carbon CPCM, a unique CPCM was prepared by Zhang, Wu, & Wang, (2018) using Aluminium potassium sulphate dodecahydrate (alum,  $KAl(SO_4)_2 \cdot 12H_2O$ ) as PCM and EG as nucleating agent and porous matrix for improving thermal conductivity [40]. Alum/EG-CPCM demonstrated excellent thermal reliability and chemical stability before and after 500 temperature cycling tests. The results showed that the new CPCM is a potential candidate for solar TES.

In another recent research, Zheng et al. (2019) improved upon the phase change of an industrial-grade disodium dodecahydrate hydrogen phosphate by the introduction of sodium sulphate decahydrate, sodium silicate, and graphite [41]. The results indicated that the thermal storage performance of the hydrated composite salt  $Na_2HPO_4 \cdot 12H_2O$ - $Na_2SO_4 \cdot 10H_2O$  at a ratio of 9.5:0.5 and a 6% of graphite and sodium silicate added at a ratio 7:5 are better than the standalone  $Na_2HPO_4 \cdot 12H_2O$  and  $Na_2SO_4 \cdot 10H_2O$  respectively. Subcooling in  $Na_2SO_4 \cdot 10H_2O$  alone is significantly reduced, and phase separation in  $Na_2HPO_4 \cdot 12H_2O$  is completely eliminated. This composite material may find its application limited due to the relatively low operating temperature of the material. Nevertheless, it will make an excellent solar TES material for building applications as established by [30].

More recently, Li et. al., (2019) used flake graphite-carbon nanofiber laced bentonite to stabilize stearic acid to get a form stable CPCM [42]. Carbon nanofibers was grown on a flake graphite surface using a chemical vapour deposition to improve the thermal conductivity, followed by a chemical bond with modified bentonite. Li et. al., (2019) also submitted that the improved composite has excellent chemical compatibility and high thermal stability at 180°C. The thermal conductivity of this CPCM is 10.50 times higher than that of a pure PCM, which allows a faster heat transfer efficiency and a good temperature response. The CPCM produced is a feasible candidate for solar TES applications because of its higher latent heat capacity and considerable thermal conductivity.

### 4 Conclusion

The application of carbon-based composite for the thermal application cannot be over-emphasized. Researches are continuing to improve TES using carbon-based PCM composite. Materials used to store thermal energy systems were reviewed, and a comparison between the properties of the different composites developed was presented with a keen interest in solar TES applications. It was noticed that the fundamental lack of solar salts is their low thermal conductivity. The use of salt compositions containing graphite was found particularly very promising. Carbon-based CPCM holds

the promise of high intrinsic thermal conductivities that can produce composites with high thermal conductivity. For this purpose, graphite composites have been proved to be ideal CPCM materials.

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