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Research Article

Analysis of energy and exergy of a thermal storage system using multiple phase change material

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ABSTRACT

A practical method for balancing supply and demand in renewable energy is cascade latent thermal storage. Thermal energy storage (TES) systems with phase change material (PCM) store energy at different temperature levels. This study aims to present the comparative energy and exergy efficiency analysis of single PCM and multiple-temperature PCM TES using different PCM in a temperature range of 100-200°C. The analysis is carried out in three configurations: 1) single PCM with Hydroquinone, 2) single PCM with Catechol, and 3) Multiple-temperature PCMs with Hydroquinone and Catechol. In the first and second configurations, heat transfer fluid, i.e. therminol-66, flows in their respective individual PCM tanks and analysis is carried out. In the third configuration, i.e. multi-temperature PCMs, heat transfer fluid (HTF) flows in descending order of respective melting point. Energy and exergy efficiency were analysed regarding temperature and time during the charging and discharging cycles. From the analysis, the overall exergy efficiency using Hydroquinone and Catechol as PCM in the TES system in cascading is 38.57%, which is relatively higher than the exergy values of the single PCM, which indicates that by providing multi-grade thermal energies, multiple PCMs can increase thermal performance while also expanding the thermal energy's application scope.

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INTRODUCTION

The International Energy Agency (IEA) predicts that global energy consumption will rise by more than one-third by 2035 compared to current energy requirements, resulting in a 20% increase in CO2 emissions. Because of the excessive use of fossil fuels in daily life, which has accelerated both their depletion and the acceleration of climate change brought on by global warming, it is now necessary to have access to environmentally friendly energy sources to meet the rising demand for clean energy [1,2]. In light of this, solar energy is a reliable substitute and clean energy source for mankind's global development. Since solar energy is a cheap, plentiful, and sustainable kind of renewable energy, it may be linked with many systems to manage energy usage and help the current civilisation break its dependence on fossil fuels. Integrating solar energy has made it possible to conduct

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various investigations using the energy and exergy methodologies [3–6]. Abinicks Raja et al. discuss several improvements to flat plate solar collectors (FPSCs) are discussed, such as phase change materials (PCMs) and nano-coatings (e.g., black nickel-cobalt) that optimise tilt angles and collector plate geometry. It draws attention to continuing research in optical enhancements and the integration of micro heat pipes and PCMs such as paraffin wax, tritriacontane, and erythritol to increase energy storage and prolong collector working hours. Enhancing the geometry of absorber pipes, particularly those with triangular cross-sections, has excellent potential to improve heat transfer efficiency. These developments aim to make FPSC more successful and encourage the broad use of renewable energy sources, providing a more affordable option than photovoltaics [7]. Ernest et al. described the environmental benefits of the double-effect solar still despite observable time delays in the temperature profiles of the solar components. The lower glazing temperature of the lower basin allowed it to produce distillate earlier in the day than the top basin. The upper basin, exposed to colder ambient temperatures, contributed significantly to the nocturnal output. The nocturnal yield, which benefits from better temperature differentials and sensible heat storage, comprised 55% of the freshwater production. The double-effect solar still is an economical and environmentally benign method of distilling fresh water from salt water, offering decentralised, emission-free freshwater production for 0.0508 $/L over a 10-year lifecycle, with a short payback period of 267 days [8].

Phase change material (PCM)--based Thermal Energy Storage System (TES) modelling is the most dependable and valuable solar energy storage method. Latent heat is the form of energy that the material stores during phase transition. Systems based on latent heat storage perform better and have a higher energy storage density than sensible heat systems [9,10]. Guruprasad et al. classify PCM for various thermal energy storage systems for solar applications [11]. The performance of the TES system is directly associated with the phase transition properties. Therefore, the selection of the PCM plays a significant role in determining the efficiency of the thermal storage system [12–14]. Sharma et al. reviewed thermal energy storage with phase change materials and applications, and they focused on the available thermal energy storage technology with PCMs in different applications. Various applications include water heating systems, solar cooking, space heating and other cooling applications [15–17]. Aldoss and Rahman stated that a multi-PCM thermal energy storage setup attains higher performance than a conventional single-PCM design in both charging and discharging cycles. This indicates that using a multi-PCM concept in TES design is necessarily superior in an absolute sense [18]. Xu and Zhao & Shamsi et al. experimented with the thermal performance of a cascaded thermal energy storage system on steady cases. A cylinder system was employed, and packed bed-type storage was used. The upper layer was filled with the PCM of the highest melting temperature, and the bottom PCM should have a relatively low melting temperature and high heat capacity [5,19]. Pankaj & Sanjay studied a mathematical model that assesses a thermal energy storage system (TESS) that uses two phase change materials (PCMs) in spherical capsules enclosed in a cylindrical shell: 70% paraffin and 30% beeswax. The TESS design, with a hexagonal tube for heat transfer fluid flow, demonstrated a remarkable 32% increase in heat transfer efficiency compared to circular tubes. The 70-30% paraffin-beeswax combination in the TESS had a 21.5% higher heat storage capacity than using either PCM alone. The TESS's estimated charging and discharging periods were roughly 2.6 and 3.2 hours, respectively, indicating a significant improvement in thermal performance [20]. Zohra et al. investigate improving thermal energy capture and retention; this study presents a revolutionary solar system design incorporating phase change material (PCM) into the heating process. In addition to absorbing solar radiation, the PCM inside the solar collector also conducts heat from the solar heater, storing energy through phase change for faster heating. With appropriate melting times and adequate energy storage, the enthalpic method modelling of the rectangular plate shape shows promising results. The system's performance is validated using ANSYS simulation, which agrees with previous research. By optimising the inclination angle of the system, melting acceleration and energy storage capacity are further increased, making it a more efficient option for quick energy accumulation than earlier designs [21].

Energy analysis is crucial in the study of process effectiveness. In contrast, exergy analysis is another essential tool for investigating the realistic behaviour of processes involving various energy losses and internal irreversibility. Sunil et al. performed an Energy and Exergy analysis of various typical solar energy applications. These energy and exergy analyses are always helpful in investigating the performance characteristics and economic viability for the sustainable development of technology [22–24]. Gong and Mujumdar investigated the relative merits of using 2,3,5 PCMs by performing an Exergetic analysis of energy storage using multiple PCMs. It was noted that an extension of energy charge followed by discharge is necessary for further understanding and optimisation [6]. Xu et al. developed a mathematical model for the overall exergy efficiency of the combined charging-discharging process of a 3 PCM system based on optimum melting temperature. They stated that increasing the inlet temperature of the TES system Heat Transfer Fluid can increase the maximum overall exergy efficiency [25]. A very similar type of Energy and Exergy analysis was performed by Li et al., employing two Phase Change Materials with Finite Time Thermodynamics. They concluded that the overall energetic efficiency could be improved by 19% to 50% using two PCMs compared to one PCM. Hence, multiple-temperature PCM has improved efficiency in a thermal energy storage system [26].

This study aims to derive the comparative analysis of energy and exergy efficiency of three different configurations with two novel PCMs, Hydroquinone and Catechol, in which therminol-66 heat transfer fluid. The PCMs selected for the three configurations are as follows: the first configuration is single-layered Hydroquinone PCM thermal energy storage, the second is single-layered Catechol PCM thermal energy storage, and the third configuration is multiple-temperature PCM thermal energy storage which is therminol-66 flows in the descending order of cascaded PCM tanks, i.e., initially flows into Hydroquinone PCM tank and followed into Catechol PCM tank. A comparative energy and exergy analysis is carried out between these three configurations for charging and discharging.

MATERIALS AND EXPERIMENTATION

The selection of materials while making thermal energy storage is crucial to determining the system's overall efficiency. Considering many properties, two new PCM materials, Hydroquinone and Catechol, were chosen for thermal storage tanks. These PCM materials are heated to their respective melting points by passing HTF, i.e. therminol-66, and the properties of PCMs and HTF are given in Table 1 [27,28] and Table 2 [29], respectively. It is the most suitable heat transfer fluid for high-temperature applications, and the operating temperature ranges from the lowest of 0oC to the highest temperature of 345oC. The selected phase change materials were melted and poured into spherical aluminium balls. Spherical encapsulation offers the highest surface area for heat transfer between HTF and PCM. These aluminium balls with PCM inside were cascaded vertically into three layers, with three balls each. This layered setup of PCM balls was kept inside the storage system tanks. HTF in tank 1 is heated using a heater and circulated to tanks 2 & 3. The PCMs were arranged in descending order according to their melting temperatures.

Table 1. Properties of PCMs

Properties	Hydroquinone	Catechol
Melting temperature (°C)	170	105
Density (kg/m^3)	1300	1340
Latent heat of fusion (kJ/Kg)	247	207
Specific heat capacity (kJ/Kg)	1.20	1.28

Table 2. Properties of HTF

Properties	Therminol-66
Oil density	1005
Specific heat capacity (kJ/kg K)	1.495
Oil thermal conductivity (W/mK)	0.12
Kinematic Viscosity (m^2/s)	29.64 x 10^{-6}
Usage range (°C)	0-345

Experimental Setup

A thermal storage system was developed to analyse energy and exergy, as shown in Figure 1. The TES system essentially consists of three tanks: heater tank, PCM 1 tank (Hydroquinone), and PCM 2 tank (Catechol) arranged in decreasing temperature of melting points, which are insulated with glass wool, an external gear pump to ensure the flow of Heat Transfer Fluid between the tanks, thermocouples fitted to each tank to take the temperature readings, a processing unit, and heater units to heat the HTF. The experiment was conducted in charging and discharging cycles by taking the corresponding temperature readings at pre-determined intervals (10 min) with three configurations: Hydroquinone PCM TES, Catechol PCM TES, and Cascaded PCM TES. The essential physics underlying the two configurations, such as cascaded PCM TES and single PCM TES, are HTF, i.e., in the case of a single PCM TES system, therminol-66 is heated using a heating coil or PTC. It flows into their tank, and heat is absorbed from HTF to PCM until their melting point; a Latent heat absorption causes a phase change, which is then recirculated within the system and released to HTF when energy is needed, usually at night. The heated HTF, however, first flows into the high-temperature PCM—the Hydroqunione PCM storage tank—where the energy is absorbed by its phase change. The same HTF then flows into the low-temperature PCM tank, where the remaining inert energy is transformed into useful energy by the phase change of catechol, and finally, the heated HTF flows into the heating tank. This is how a cascaded PCM TES system works. Therefore, cascade PCM TES has more useful energy than a single PCM TES system.

Solar energy is concentrated in the absorber tube because of the highly reflective stainless steel used in constructing the PTC's reflective surface with a 6m length and 9 m^2 surface area. A gear pump keeps the HTF circulating as it passes through the absorber tube and absorbs heat from concentrated sun energy. During the charging process, the heat transfer fluid is heated with the help of a heater or PTC, which is transferred to PCMs in tanks 2 and 3. The PCMs absorb the heat from HTF and change their phase upon reaching their respective melting temperature. During the phase change process, PCMs store the input thermal energy as latent heat. Thermocouples are arranged in each tank to take the temperature readings at regular intervals. The HTF is allowed to circulate between tanks 1, 2 and 3 to maintain the mass flow rate and to have a steady heat transfer rate. The charging process follows the discharging cycle. The heater is turned off, thus cutting off the heat input supply in tank 1. The temperature of the HTF gradually comes down. During this process, the heat energy stored by the PCM is liberated and returned to the HTF. The heat energy is released when changing its phase from liquid to solid. The discharging process is much slower than the charging process and is determined by the heat-storing capacity and latent heat of the PCM. During this process,

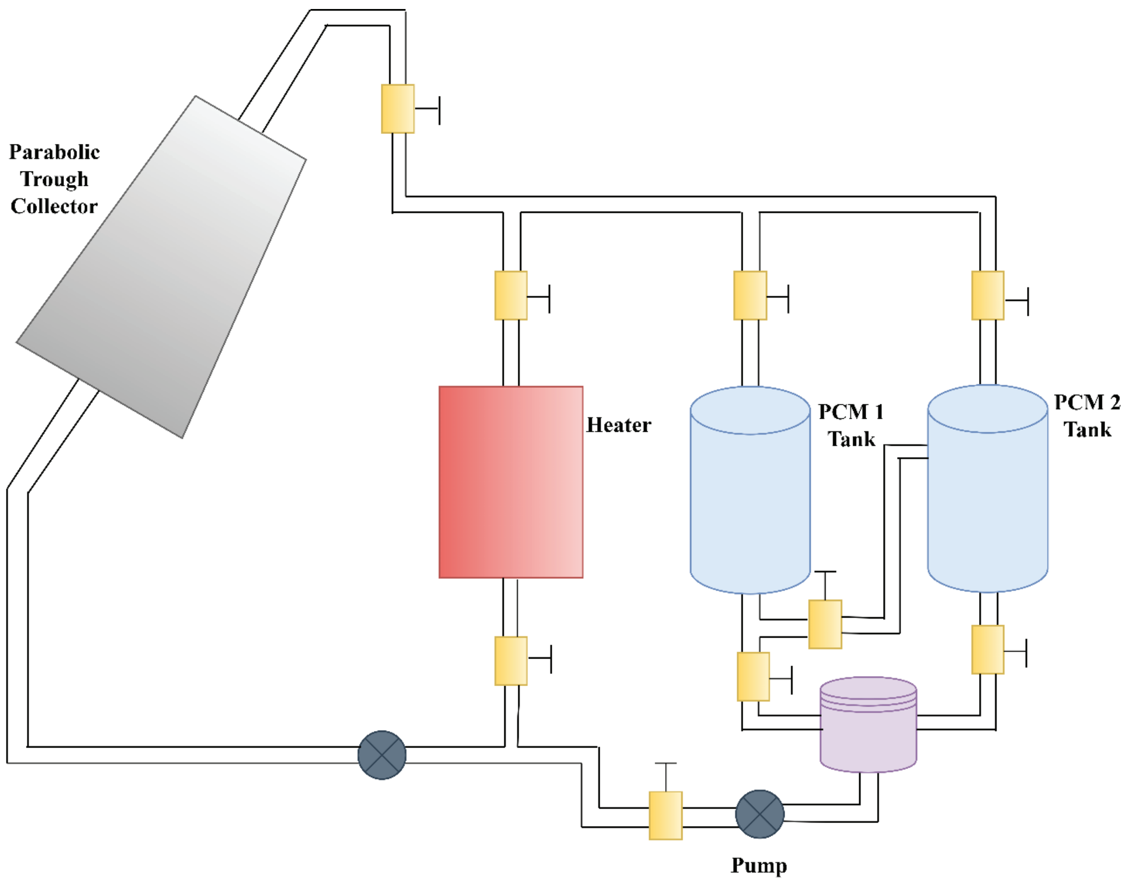

Figure 1. Experimental layout.

the gradual temperature drop in the HTF is noted down at regular intervals of time. These values are essential in mathematical calculations for energy and exergy analysis. The total time of discharging is more than the total time of charging due to the transfer of thermal energy back to the heat transfer fluid during the discharging cycle, which happens without any external source, unlike the charging process where the input heat energy is aided by two heater element arrangement in tank 1.

Exergy Analysis

The energy and exergy analyses are carried out using the first and second laws of thermodynamics. The analysis is carried out in two processes, charging and discharging, using the following equations [30,31]:

Energy received by PCM 1 from the HTF during charging

$$Q_{c.p1} = n\, m_{p1}\, C_{p.p1}(T_{m.p1} - T_{c.i.p1}) + n\, m_{p1}\, L_{p1} + n\, m_{p1}\, C_{p.p1}(T_{c.f.p1} - T_{m.p1}) \quad (1)$$

Energy received by PCM 2 from the HTF during charging

$$Q_{c.p2} = n\, m_{p2}\, C_{p.p2}(T_{m.p2} - T_{c.i.p2}) + n\, m_{p2}\, L_{p2} + n\, m_{p2}\, C_{p.p2}(T_{c.f.p2} - T_{m.p2}) \quad (2)$$

Where n =no. of balls, C_p =specific heat capacity, T_m = melting temperature, L =Latent heat of fusion, and m= mass

The releasing heat rate of HTF flowing through the PCM 1 tank is given by

$$\dot{Q}_{c.p1} = \dot{m} C_{p.a}\,(T_{c1} - T_{c2}) \quad (3)$$

Similarly, for the PCM 2 tank, the Heat rate of HTF is given by

$$\dot{Q}_{c.p2} = \dot{m} C_{p.a}\,(T_{c2} - T_{c3}) \quad (4)$$

The exergy rate processed by the HTF before contacting the PCMs is

$$\dot{E}_c = \dot{m}\, C_{p.a}\left[(T_{c1} - T_e) - T_e\left(ln\left(\frac{T_{c1}}{T_e}\right)\right)\right] \quad (5)$$

The exergy rate stored in PCM 1 and PCM 2 is given by Jegadheeswaean et al.

$$\dot{E}_{st.c} = \dot{E}_{st.c.p_1} + \dot{E}_{st.c.p_2} = \dot{m}\, C_{p.a}\,(T_{c1} - T_{c2})\left[1 - \frac{T_e}{T_{m.p1}}\right] + \dot{m}\, C_{p.a}\,(T_{c2} - T_{c3})\left[1 - \frac{T_e}{T_{m.p2}}\right] \quad (6)$$

Exergy efficiency for the charging process is given by:

$$\eta_{ex.c} = \frac{\dot{E}_{st.c}}{\dot{E}_c} = \frac{\dot{m}\, C_{p.a}\,(T_{c1}-T_{c2})\left[1-\frac{T_e}{T_{m.p1}}\right] + \dot{m}\, C_{p.a}\,(T_{c2}-T_{c3})\left[1-\frac{T_e}{T_{m.p2}}\right]}{\dot{m}\, C_{p.a}\left[(T_{c1}-T_e) - T_e\left(ln\left(\frac{T_{c1}}{T_e}\right)\right)\right]} \quad (7)$$

Energy received by PCM 1 from the HTF during discharging

$$Q_{d.p1} = n\, m_{p1}\, C_{p.p1}\left(T_{d.i.p1} - T_{m.p1}\right) + n\, m_{p1}\, L_{p1} + n\, m_{p1}\, C_{p.p1}\left(T_{m.p1} - T_{d.f.p1}\right) \quad (8)$$

Energy received by PCM 2 from the HTF during discharging

$$Q_{d.p2} = n\, m_{p2}\, C_{p.p2}\left(T_{d.i.p2} - T_{m.p2}\right) + n\, m_{p2}\, L_{p2} + n\, m_{p2}\, C_{p.p2}\left(T_{m.p2} - T_{d.f.p2}\right) \quad (9)$$

Where n =no. of balls, C_p =specific heat capacity, T_m = melting temperature, L =Latent heat of fusion, m= mass

The absorbing heat rate of HTF flowing through the PCM 1 tank is given by Gong and Mujumdar [6]

$$\dot{Q}_{d,p1} = \dot{m}\, C_{p.a}\,(T_{d2} - T_{d1}) \quad (10)$$

Similarly, for the PCM 2 tank, the absorbing Heat rate of HTF is given by

$$\dot{Q}_{d.p2} = \dot{m}\, C_{p.a}\,(T_{d2} - T_{d3}) \quad (11)$$

The exergy rate obtained by the TES system HTF flowing through the PCMs is

$$\dot{E}_d = \dot{m} C_{p.a}\left[(T_{d1} - T_e) - T_e\left(ln\left(\frac{T_{d1}}{T_e}\right)\right)\right] \quad (12)$$

The exergy rate stored in PCM 1 and PCM 2 is given by Jegadheeswaran et al. [31]

$$\dot{E}_{st.d} = \dot{E}_{st.d.p_1} + \dot{E}_{st.d.p_2} = \dot{m}\, C_{p.a}\,(T_{d2} - T_{d1})\left[1 - \frac{T_e}{T_{m.p1}}\right] + \dot{m}\, C_{p.a}\,(T_{d2} - T_{d3})\left[1 - \frac{T_e}{T_{m.p2}}\right] \quad (13)$$

Exergy efficiency for the discharging process is given by

$$\eta_{ex.d} = \frac{\dot{E}_d}{\dot{E}_{st.d}} = \frac{\dot{m} C_{p.a}\left[(T_{d1}-T_e) - T_e\left(ln\left(\frac{T_{d1}}{T_e}\right)\right)\right]}{\dot{m}\, C_{p.a}\,(T_{d2}-T_{d1})\left[1-\frac{T_e}{T_{m.p1}}\right] + \dot{m}\, C_{p.a}\,(T_{d2}-T_{d3})\left[1-\frac{T_e}{T_{m.p2}}\right]} \quad (14)$$

Overall Exergy Efficiency Analysis During Charging-Discharging

The overall exergy efficiency of the PCMs for a combined charging-discharging process is equal to the product of the exergy efficiencies of the charging and discharging processes [6,17].

$$\eta_{ex.overall} = \eta_{ex.c} \cdot \eta_{ex.d} \quad (15)$$

The above equations and overall exergy efficiency were used for the energy and exergy analysis. Many relationships and trends have been observed, and the results obtained are presented in the discussion below.

Uncertainty Analysis

Any work always involves some degree of uncertainty. The primary sources of these uncertainties include test techniques, ambient factors, calibration, sensors, and observations. Given the uncertainty, the desired test findings can be analysed for any work. “R” has a function of numerous self-regulating variables, such as the following, if a quantity is to be measured.

x1, x2, x3,...xn then R = R(x1, x2, x3,…xn) (16)

Let WR represent the measured quantity uncertainty and W1, W2, W3,... Wn represents the uncertainties of the independent variables. The measured quantity’s uncertainty is then provided by

$$WR = \sqrt{\left[\left(\frac{\partial R}{\partial x_1} W_1\right)^2 + \left(\frac{\partial R}{\partial x_2} W_2\right)^2 + \left(\frac{\partial R}{\partial x_3} W_3\right)^2 + \cdots\ldots\ldots + \left(\frac{\partial R}{\partial x_n} W_n\right)^2\right]} \quad (17)$$

The temperature readings in the absorber tube of the collector and the cascaded system are sensed using eleven K-type thermocouples. Each storage tank has three thermocouples positioned at the top, centre, and bottom. There are two thermocouples at the PTC inlet and outlet. The process heater further makes use of two additional thermocouples. The temperature is measured using a K-type thermocouple, which has an accuracy of 0.15°C and a resolution of 0.1°C on a digital temperature indicator. Within the computed temperature range, the instrumentation error is 0.59%. The HTF flow rate in the circuit is adjusted with a 1.95% error rate using a flow meter. A circulating pump with specifications of 0.5 HP, 28 A of current, and 2800 rev/min is utilised to circulate the HTF in closed circuits. There is a 1.56% error in immediate heat transmission and a 1.42% error in cumulative heat transfer.

RESULTS AND DISCUSSION

The exergy analysis is carried out on a charging and discharging cycle for 430 and 680 minutes at a regular interval. The analysis is carried out for single PCMs and cascaded PCM thermal energy storage systems. PCM 1 tank indicates hydroquinone, and PCM 2 tank indicates catechol, arranged in descending order of their melting temperatures.

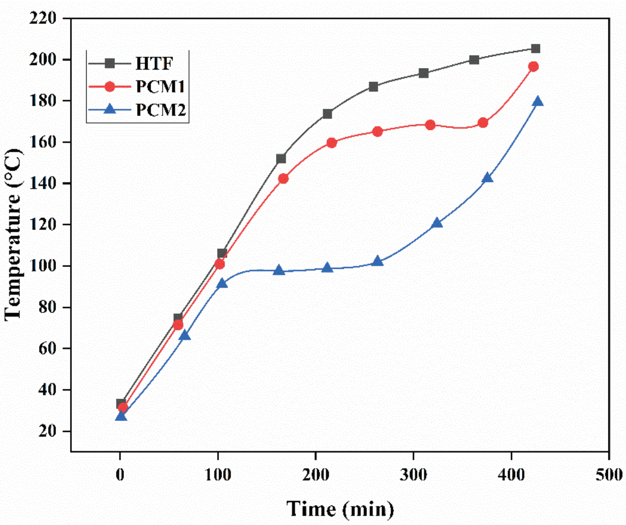

Figure 2. Temperature profile during charging.

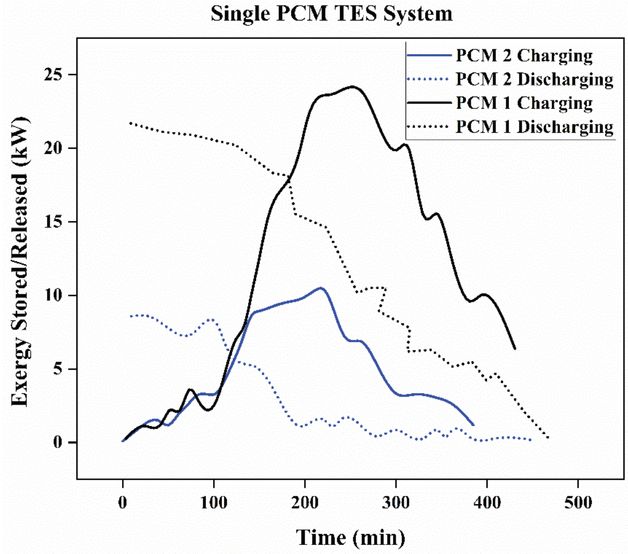

Figure 4. Exergy analysis of Single PCM TES system.

Figure 2 depicts therminol-66, hydroquinone, and catechol temperature profile during the charging process. In the first few minutes, the temperature increased slower due to the lesser sunshine, the profile increased linearly up to 100 mins, and the amount of energy stored still 100 mins is related to sensible heat storage. After 100 mins, the temperature therminol-66 reached 210°C due to the gradual rise of sunshine. In contrast, for PCMs, the point of fusion begins at 100 min, after latent heat energy was observed by the phase changing up to 200°C and 180°C for hydroquinone and catechol PCM, respectively and the same trend of sunshine is also studied by Beemkumar et al. (2018) and Antoni et al. (2013) [27,29].

Figure 3 explains the temperature profile for the discharging process. After attaining their respective maximum temperature concerning the strength of sunshine, they maintain the same temperature until the strength of sunshine gets reduced, and the point of reduction of sunshine is considered as the start of the discharging process and is carried out for 680 mins. The amount of heat sustained during the discharging process follows the trend of hydroquinone > therminol-66 > catechol. The heat was discharged faster in catechol and attained 25°C with maximum heat release during the discharge process. In contrast, hydroquinone attained 40°C by phase transition with less heat release than catechol PCM throughout the discharging process.

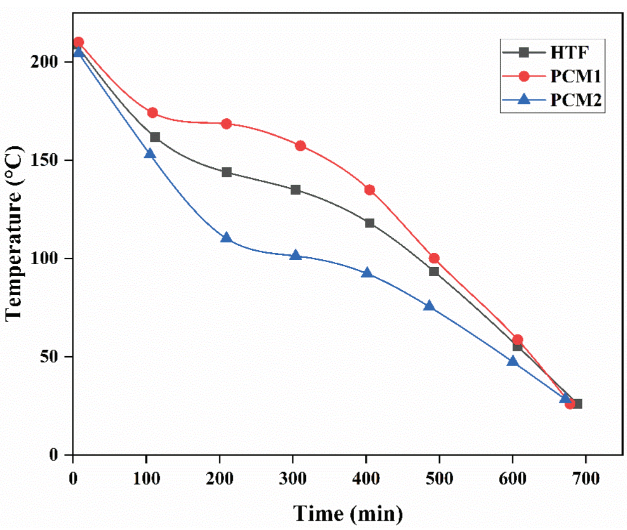

Figure 3. Temperature profile during discharging.

Figures 4 and 5 show the exergy stored and released for single PCM and cascaded PCM TES systems, respectively. From Figure 4, the amount of exergy stored for PCM 1 starts from zero and increases slowly till 100 mins. After that, the exergy sorted was increased gradually to its maximum of 24kW during the phase change, i.e., latent heat storage at 220 mins with linear fluctuations in energy due to the sunshine fluctuations. After that, the amount of energy stored remains the same for some time, from 220 to 300 minutes, and it reduces linearly with fluctuations. Similarly, in PCM 2, the maximum amount of exergy stored is 11kW at 210 mins, which is maintained for 50 mins and starts to decrease due to storage capacity and sunshine reduction. Exergy released is also analysed to measure the storage capacity of PCMs in a measure of time in which PCM 1 tends to have a higher capacity of exergy storage even at lesser sunshine and leads to a high-temperature application process than PCM 2. Figure 5 shows the exergy stored and release of the cascaded PCM thermal energy storage system. It is explicit that a cascaded PCM thermal energy storage system has maximum exergy stored with minimal release compared to a single PCM thermal storage system. The exergy stored profile gradually increased from 5kW to 25kW with the phase change at a time interval of 80-200 mins, and it maintains for 100 mins with the range of

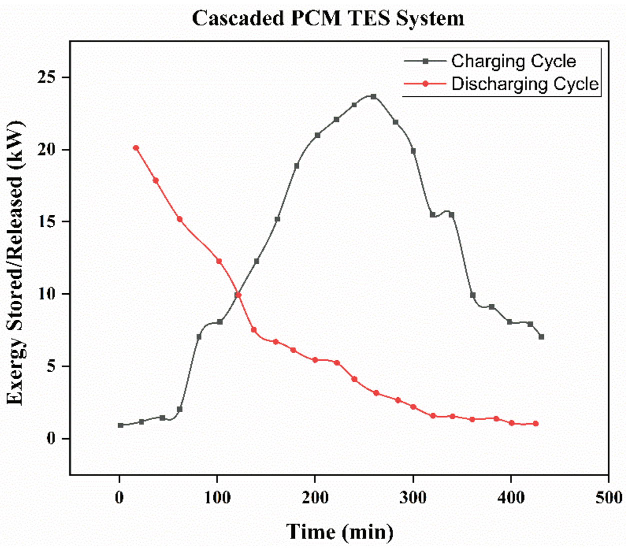

Figure 5. Exergy analysis of cascaded PCMs TES system.

25-22kW after it starts decreasing and still, it stores 8kW of exergy at the end of the cycle. Along with exergy stored, release is also measured, and it maintains a 3kW amount of exergy at the end of the cycle with linear release throughout the cycle from 20kW to 4Kw with minimal fluctuations, which shows that cascaded PCM thermal energy storage has better efficiency than the single PCM thermal energy storage system.

Figure 6 shows the overall exergy efficiency of the single and cascaded thermal energy storage system. These values were calculated using exergy efficiency values during charging and discharging. From Fig.6, it has been observed that the overall exergy efficiency values follow a decreasing trend from 170 minutes to 430 minutes for all three configurations of the thermal energy storage system. The

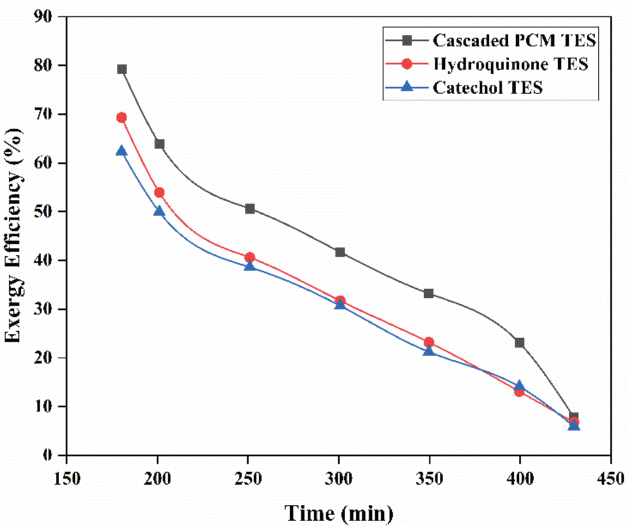

Figure 6. Overall exergy efficiency.

overall exergy values during the phase change process have been considered. It has been found that the average overall exergy efficiency of the cascaded thermal energy storage system is 38.57 % higher than the remaining two single PCM thermal energy storage systems.

CONCLUSION

The comparative exergy analysis of single PCM thermal energy storage and cascade thermal energy storage system was analysed. The analysis is carried out in February, and the maximum temperature attained is nearly 220°C. With the consideration of February month, the exergy analysis was conducted and concluded that cascaded PCM thermal energy storage system configuration is an effective method for balancing supply and demand in the use of renewable energy than the single PCM thermal energy storage system. During the charging and discharging process, PCM 1, i.e., hydroquinone, shows higher effectiveness than PCM 2, i.e., catechol. From the exergy analysis, a cascaded PCM thermal energy storage system shows 38.57 % higher efficiency than a single PCM thermal energy storage system. The exergy stored was higher in cascaded PCM TES with minimal fluctuations, i.e., 25kW for 100-minute durations at the maximum rate. It shows that by providing multi-grade thermal energies, multiple PCMs can increase thermal performance while also expanding the scope of application for thermal energy.

NOMENCLATURE

c	Charging
Cp	Constant pressure specific heat capacity (J $kg^{-1}K^{-1}$)
d	Discharging
η	Efficiency
e	Environment
ex	Exergy
$\dot{E}$	Exergy rate (W)
f	Final
1	Heater Tank
A	Heat Transfer Area (m^2)
h	Heat transfer coefficient (W m^{-2} K^{-1})
a	Heat Transfer Fluid
$\dot{Q}$	Heat Transfer Rate (W)
L	Latent Heat (kJ/kg)
i	Initial
m	Melting
m	Mass (kg)
$\dot{m}$	The mass flow rate of heat transfer fluid (kg s^{-1})
p1	PCM 1
p2	PCM 2
2	PCM 1 Tank
3	PCM 2 Tank
n	No of balls
N	Number of heat transfer unit
st	Stored

T Temperature (°C)
Q Thermal Energy (kJ)
t Time (min)

AUTHORSHIP CONTRIBUTIONS

Conceptualisation, Methodology, Supervision, Writing – Original draft Preparation: [Jayaprakash V, Ganesan S,], Formal Analysis and Investigation, Writing – Review and Editing, Experimentation, Resources: [Beemkumar Nagappan, Sunil Kumar M].

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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