Development of an acetanilide/benzoic acid eutectic phase change material based thermal energy storage unit for a passive water heating system

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Abstract. In the present work, two organic phase change materials (PCMs) are used to develop a new eutectic PCM for sharp melting point with high latent heat of fusion. Optimized eutectic can be suitable for a passive water heating system (PWHS). The binary eutectic PCMs consisting of different compositions of acetanilide and benzoic acid are prepared and optimized at a composition of 30:70 by weight percentage. Optimized samples are characterized by using differential scanning calorimetry (DSC), Fourier transform infrared spectrophotometry and field-emission scanning electron microscopy. The results of DSC showed that melting temperature and latent heat of the optimized eutectic PCM is found to be 75.56°C and 193.56 J g⁻¹. A negligible change in melting temperature and latent heat of fusion of the optimized eutectic based PCM after 100 accelerated heating and cooling cycles is observed. The prepared eutectic PCM is employed as a thermal energy storage (TES) system for PWHS. The experimental results of a eutectic PCM based TES system for the PWHS show that the use of eutectic helps in enhancing the maximum utility of solar energy during off-shine hours.

Keywords. Phase change material (PCM); eutectic; differential scanning calorimetry (DSC); thermal energy storage (TES); passive water heating system (PWHS).

1. Introduction

Solar thermal energy storage (STES) is very much essential to meet the gap between energy demand and supply because of the intermittent nature of solar radiation. Solar energy is exploited in a wide variety of technologies such as solar heating, photovoltaic [1], solar architecture, solar thermal energy [2], molten salt power plants and artificial photosynthesis. For researchers, solar thermal energy that utilizes the solar energy in the thermal energy storage (TES) systems is one of the most interesting areas of study. Solar thermal energy is a complementary technology, and materials are developed to be employed in solar TES devices and these can be used according to our necessity. For storing thermal energy, phase change materials (PCMs) are used due to their unique property of storing and releasing a large amount of latent heat during phase transition [2,3]. PCMs absorb and store thermal energy in day time and the stored thermal energy is released to the surrounding medium during night hours. Several researchers reported a large number of PCMs for latent heat storage applications [4–7]. The PCMs are mainly classified as organic PCMs, inorganic PCMs and eutectic PCMs with a variety of applications [8–10]. Specific attention is given to develop a new class of PCMs and for the improvement of thermal conductivity by using an encapsulation method

and shape stabilization procedures. The organic PCMs and their eutectic mixtures are superior to inorganic PCMs due to their high latent heat of fusion, less volume changes, non-toxic behaviour, good thermal and chemical stability and not having super cooling after repeated cycles [11–14]. A large number of research studies have been conducted in order to obtain potential PCMs with better thermo-physical properties for low and high temperature ranges that are suitable for TES applications. Shukla *et al* performed the thermal cycling test of organic and inorganic PCMs and reported that organic PCMs have been considered more suitable than inorganic PCMs for the purpose of accelerated thermal cycling test and hence for stability of thermo-physical properties [15].

Zuo *et al* experimentally observed that the binary system prepared by using caprylic acid and 1-dodecanol shows that the eutectic point with eutectic melting temperature is 6.52°C and latent heat of melting of eutectic is 171.06 J g⁻¹, corresponding to the mass fraction of 1-dodecanol is 30% [16]. After 120 cycles, the change in the melting temperature and latent heat of the eutectic mixture is in the acceptable level. Zeng *et al* investigated the thermo-physical properties of the lauric acid (LA)/1-tetradecanol binary system with an eutectic melting temperature of about 29°C for building applications [17]. Jebasingh investigated PCMs based on ternary eutectic by using capric acid (CA), myristic acid (MA) and

palmitic acid (PA) when doped with 10% of xG, an increase in 20.8% of thermal conductivity was observed [18]. Fauzi *et al* reported the differential scanning calorimetry (DSC) results that showed the lowest melting temperature occurs at a composition ratio of 7:3 wt% of MA/PA and they observed that addition of surfactants increased the thermal conductivity of the MA/PA eutectic mixture [19]. Bansal and Buddhi reported the analytical study of the latent heat storage system in a cylinder [20]. Tayeb developed a domestic hot water system using $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ as the PCM [21]. Jaykumar *et al* performed an experiment in a summer and winter season for heating and cooling of building space by using TES having a length and width of 1.5 and 0.5 m respectively [22]. Chaurasia reported a comparative study of energy storage systems based on latent heat and sensible heat for the solar heated hot water system during night [23]. Many researchers reported different PCMs and design of the storage unit for water heating applications [24–29]. Mazman *et al* conducted an experiment using a new PCM with a weight percentage of 80:20 prepared by using paraffin and stearic acid, paraffin and palmitic acid and MA and stearic acid with the graphite compound for a water heating system [30]. Marka *et al* explained the utilization of solar water heating systems (SWHSs) and solar grade materials [31] in the context of Indian climate and gave an account of the energy saved for every 100 litre SWH for domestic use estimated in the report of Ministry of New and Renewable Energy (MNRE's) in terms of costs. Xiangli *et al* concluded that if the parameter of H/D of the pool is about 0.6–1.5, the system will get better heat storage if it has following: 260 m² collector, 30 m³ tank and 500 m³ pool. The storing pump runs when the temperature of the outlet reaches 55°C [32].

Tang *et al* prepared shape-stabilized PCMs by using fatty acid eutectics/expanded graphite composites and used them for TES [33]. Narayanan *et al* experimentally investigated eutectic PCMs for (i) providing hot water using the fabricated SWHS and (ii) the solar rechargeable glove [34]. Shahbaz *et al* investigated eutectic based on choline chloride as a quaternary ammonium salt and calcium chloride hexahydrate for building applications with a latent heat range of 127.2–135.2 kJ Kg^{−1} and with a phase change temperature range of 20.65–23.05°C [35]. Fauzi *et al* prepared fatty acid eutectic mixtures by using MA/PA and myristic acid/palmitic acid/sodium stearate (MA/PA/SS). In this study, it is reported that MA/PA/SS has better thermo-physical properties than the MA/PA eutectic mixture after 1500 thermal cycles for its utilization in a latent heat TES [36]. Reddy *et al* developed a TES system using paraffin and stearic acid as PCMs and these PCMs are stored in a capsule of a diameter of 38 mm in the TES system. On the basis of experimentation it is reported that the charging time and recovery of storage energy are less affected by PCM materials used in the experiment. From the economical point of view, stearic acid can be utilized for the TES system [37]. Shape-stabilized composites by using PCMs were synthesized and analysed by different researchers [38]. Jie *et al* prepared a shape-stabilized composite using diatomite and MA with the addition of activated

carbon for building applications [39]. Yang *et al* designed and prepared carbon-based composite PCMs having a latent heat of the composite of 152.8 J g^{−1} [40]. Cabeza *et al* studied the different TES technologies with different PCMs for building applications. From 2003 to 2008 many reviews have been published in the order to understand the TES technologies, its design, the consumption of sustainable energy and its applications [41,42]. Pluss polymers have commercialized different PCMs in the temperature range of 30–300°C for various applications [43]. Kim *et al* studied the thermal and structural properties of shape-stabilized PCM composites, prepared by using octadecane (OD) and expanded graphite (WEPG) and reported that the OD/WEPG composite with 30% WEPG content showed better shape stability and thermal properties and it can be used in packaging materials [44].

Every day, India receives around 4 to 7 kWh m^{−2} solar radiation [45]. Recently, Marka *et al* reported that by the end of year 2022, about 20 million m² collector areas for the SWHS is planned to be achieved, which is almost 6-fold higher than the collector area of 3.5 million m² installed in 2010. Therefore accordingly if all SWHSs are considered to be installed in India, then for every 1000 people 3 m² of the collector area could be achieved [31]. There are eight zones in India. Out of them hot and dry and composite climate zones are preferred for the utilization of the PCM based SWHS for its use during summer and winter. These two zones have better impact on the practical use of the PCM based SWHS. The present experiment is conducted to study the impact of climatic conditions of various zones in India.

For any specific application, a tailor made PCM containing a suitable melting point is required. The aim of the present study is to introduce the new binary eutectic compositions prepared by using acetanilide and benzoic acid and their thermo-physical properties are investigated and optimized. To the best of the author's knowledge the analysis of the configuration of benzoic acid and acetanilide eutectic has not been reported earlier. Benzoic acid and acetanilide are used as PCMs because they have high latent heat of fusion per unit volume so that the required volume of the container to store a given amount of energy is less. Furthermore, they have good chemical stability, no degradation after repeated number of melting/freezing cycles and commercially available at low cost and can be used in the SWHS as TES materials. In the present work, the organic PCM mixture is optimized using acetanilide and benzoic acid with a mass ratio of 30:70 for sharp melting point with high latent heat of fusion even after hundred numbers of accelerated thermal cycles. Peak melting temperature and latent heat of fusion are determined by using DSC for non-cycled and cycled PCMs. Subsequently, optimized eutectic having a peak melting temperature of 75.6°C and a latent heat of fusion of 193.6 J g^{−1} is used in the TES unit for the passive water heating system (PWHS) and its performance is investigated.

Table 1. Thermo-properties of base PCMs.

Materials	Melting temperature (°C)	Latent heat of fusion (J g ⁻¹)
Acetanilide	112–115	211
Benzoic acid	121–124	194.8

Table 2. Eutectics of acetanilide and benzoic acid at different weight %.

PCM	Description	Weight percentage (wt%)	
	A _m B _n	Acetanilide	Benzoic acid
Eutectic mixture of acetanilide and benzoic acid	A ₁ B ₉	10	90
	A ₃ B ₇	30	70
	A ₅ B ₅	50	50
	A ₆ B ₄	60	40
	A ₇ B ₃	70	30
	A ₈ B ₂	80	20
	A ₉ B ₁	90	10

2. Experimental

2.1 Materials

Benzoic acid (99.0%) and acetanilide (99.0%) by Merck are used without any further purification. The thermo-physical properties of PCMs are shown in table 1.

2.2 Preparation of an eutectic mixture

In the present study, the melting–mixing method is used for the eutectic preparation by allowing the two organic PCMs: (a) benzoic acid and (b) acetanilide [46]. In a typical process, benzoic acid and acetanilide were weighed in the given proportion, mixed and melted together without using any supporting materials. In the laboratory, the melting point of eutectic mixtures was measured by using a Thiele tube setup and optimized for the required melting point using the acetanilide and benzoic acid composition with a mass ratio of 30:70.

The eutectic mixtures of benzoic acid and acetanilide at different mass ratios were prepared and are shown in table 2. DSC measurement was performed for the optimized sample at the desired melting point of eutectic mixtures using the Thiele tube setup. The thermo-physical properties are optimized using the acetanilide and benzoic acid composition with a mass ratio of 30:70.

2.3 Characterization techniques

2.3a Thermal analysis of PCMs before and after accelerated cycles: For accelerated thermal cycling testing, in the

first phase, heating and cooling experiments are performed for 100 cycles and the samples are analysed intermittently to understand the trends of the behaviour of the PCM and reported in this study and the results are found to be encouraging. Furthermore, the results of the higher number of thermal cycles are under process. The accelerated thermal cycle test was carried out to study the change in the peak melting temperature and latent heat of fusion of eutectic prepared by acetanilide/benzoic acid. For thermal analysis, the eutectic mixture was repetitively heated and cooled above its melting temperature and below its solidification temperature respectively for 100 cycles. The DSC analysis was performed for non-cycled and cycled optimized eutectic PCMs.

PCMs having different compositions are listed in table 2. Samples of 5–6 mg are heated from 5–50°C at a ramp rate of 10°C min⁻¹ and processed for DSC. The thermo-physical properties of pure PCMs and optimized eutectics before and after 100 accelerated thermal cycles are measured and reported.

2.3b Morphology of eutectic: The morphology of non-cycled and cycled PCM based eutectic was examined by using field emission scanning electron microscopy (FE-SEM), [Supra 55 Zeiss] with a wide operating voltage ranging from 0.02–30 kV.

2.3c Chemical stability of eutectic: Fourier transform infrared (FT-IR) spectral analysis [Tensor 27, Bruker with the MIR source, ZnSe beam splitter and DLaTGS detector] was performed to explore the possibility of a chemical reaction between benzoic acid and acetanilide for forming a stable PCM based eutectic. Infrared spectra of non-cycled

Figure 1. Schematic diagram of PWHS with thermal storage unit during (a) charging and (b) discharging.

and cycled PCM based eutectic were recorded in the range of $400\text{--}4000\text{ cm}^{-1}$ by using a KBr disc.

In the present work, the most essential part is to optimize the eutectic PCM at the mass ratio of 30:70 having a melting temperature of 75.6°C corresponds to an application suitable for the PWHS and the performance of the storage unit is evaluated.

2.4 Passive water heating system (PHWS)

2.4a PWHS description: In the present work, a binary eutectic based TES unit has been developed and its use in a domestic SWHS is exploited. The proposed design of the TES unit containing PWHS is shown in figure 1a and b. The present PWHS is a type of indirect passive system, which has the TES unit filled with prepared eutectic using an acetanilide and benzoic acid composition with a mass ratio of 30:70. The TES unit is made up of two concentric steel containers C1 and C2, the height and diameter of the outer steel container C1 are 0.04 and 0.165 m and those of the inner steel container C2 are 0.035 and 0.1 m.

2.4b Pure compound: High latent heat is required for the selection of any thermal storage material and this property is analysed by using DSC for the pure PCM. Both the DSC results of acetanilide and benzoic acid show that

Figure 2. DSC curve of (a) pure benzoic acid at heating rate: $10^\circ\text{C min}^{-1}$ and (b) pure acetanilide at a heating rate: $10^\circ\text{C min}^{-1}$.

latent heat is sufficiently high and can be used for the preparation of eutectic in the SWHS. The thermographs of pure acetanilide and benzoic acid are shown in figure 2(a) and (b), respectively. It is clear from the thermograph that only one endotherm is observed for benzoic acid and acetanilide at a scanning rate of $10^\circ\text{C min}^{-1}$. The onset, peak melting and end point temperatures of benzoic acid and acetanilide are 117.2 , 121.4 and 127.1°C and 113.0 , 114.6 and 120.4°C respectively with a latent heat of 211 J g^{-1} and 194.8 J g^{-1} respectively.

2.4c The acetanilide–benzoic acid based eutectic PCM: The eutectic mixtures with a series of mass ratios (acetanilide: benzoic acid = 0:100, 10:90, 30:70, 50:50, 60:40, 70:30, 80:20, 90:10 and 100:0) were prepared and thermal properties are measured by using DSC. A sample with a suitable proportion is optimized by comparing melting temperature. Figure 3 shows the solid–liquid phase diagram of different proportions of acetanilide and benzoic acid. In this figure the eutectic point was observed at 75.6°C . It depicts that the acetanilide/benzoic acid with a mass ratio of 30:70 has the lowest melting temperature.

Figure 4 shows the DSC heating curve of acetanilide/benzoic acid with a mass ratio of 30:70 as the eutectic PCM before and after accelerated thermal cycles. The onset, peak melting temperature and end point temperature of the optimized eutectic before the thermal cycle test are 70.2 , 75.6 and 90.0°C , respectively with the measured latent heat of melting is 193.56 J g^{-1} . The value of latent heat of optimized

Figure 3. Variation of melting temperature with the mass fraction of benzoic acid in eutectic mixture.

Figure 4. DSC curves of PCM based eutectic with composition containing mass ratios 30:70 of acetanilide and benzoic acid before and after 100 cycles at a heating rate $10^{\circ}\text{C min}^{-1}$.

eutectic is enough that can be helpful in storing large amounts of heat. The optimized eutectic temperature with high latent heat was found to be suitable as the TES material for SWHS applications. The onset, peak melting temperature and end point temperature of all endotherm are measured and listed in table 3.

2.4d The thermal stability of acetanilide/benzoic acid eutectic: After 100 thermal cycles, peak melting temperature and latent heat of melting of acetanilide and benzoic acid eutectic with a mass fraction of 30 and 70% respectively,

are determined by using DSC and are listed in table 4. From the experimental results it is observed that after 100 thermal cycles, the melting temperature of the eutectic mixture changed by 0.2°C and the latent heat of melting changed by -1.1 J g^{-1} respectively. Hence, from the above results it is clear that acetanilide/benzoic acid eutectic achieves a better thermal stability even after 100 accelerated thermal cycles using acetanilide and benzoic acid compositions with a molar ratio of 30:70. Figure 4 shows the DSC curve before and after 100 cycles of eutectic using acetanilide and benzoic acid compositions with a molar ratio of 30:70.

2.4e Surface morphological characterization of eutectic:

The use of any storage material in a TES system depends on the performance during charging and discharging of the PCM, i.e., the TES device should absorb and release heat energy at the same constant temperature called as melting temperature of the PCM. For the continuous use of the TES device, phase change temperature should contain thermo-physical properties consistent with time irrespective of the usage. Hence accelerated thermal cycle testing is necessary to understand the consistent phase change behaviour during charging and discharging. Hence accelerated thermal cycle testing is most important before finalizing the PCM for a given specific application. FE-SEM was performed to analyse the morphology of the prepared PCM based eutectic before and after 100 thermal cycles. Figure 5(a) and (b) represent the FE-SEM images of PCM based non-cycled eutectic using an acetanilide and benzoic acid composition with a mass ratio of 30:70 while figure 5(c) and (d) show PCM based eutectic after 100 thermal cycles.

From figure 5(c) and (d), it is observed that eutectics are identical in nature, showing a flake like layer structure with a milky colour. In particular, it represents the morphology of acetanilide/benzoic acid eutectic composition at different magnifications highlighting their three-dimensional network structure. The micrograph at higher magnification confirms the better distribution of acetanilide with benzoic acid after repeated thermal cycles as compared to uncycled eutectic. The surface morphology of eutectic is homogeneous in nature after 100 accelerated thermal cycle testing at a eutectic composition

Table 3. Melting temperatures of pure PCM and their various compositions.

Material	Melting temperature, $^{\circ}\text{C}$		
	Onset temperature	Peak temperature	End temperature
Benzoic acid	117.2	121.4	127.1
Acetanilide	113.0	114.6	120.4
A ₁ B ₉	106.2	112.0	119.2
A ₃ B ₇	70.2	75.6	90.0
A ₅ B ₅	72.4	76.2	98.6
A ₆ B ₄	73.6	76.8	95.4
A ₈ B ₂	83.2	100.2	111.6
A ₉ B ₁	95.8	107.2	116.2

Table 4. Thermo-graphic data of the acetanilide/benzoic acid eutectic after 100 cycles.

Number of cycles	Melting temperature, °C	Latent heat of fusion, J g ⁻¹
0	75.6	193.6
100	75.4	192.5

Figure 5. FE-SEM micrographs of eutectic mixture of acetanilide/benzoic acid at the mass ratio of 30:70 (a, b) for zero thermal cycles and (c, d) after 100 thermal cycles.

of 30:70. The FE-SEM results revealed that the eutectic PCM shows the stability in morphology after thermal cycling and acetanilide and benzoic acid are completely mixed.

2.4f FT-IR analysis of eutectics: Figure 6 shows the FT-IR spectra of a non-cycled eutectic mixture at the mass ratio of 30:70 of acetanilide/benzoic acid. The IR spectrum of eutectic mixture shows the characteristic peaks of both acetanilide and benzoic acid [47,48]. In figure 6, the peaks around 3297 and 3291 cm⁻¹ show the N–H and H–O stretching respectively. The peaks at 3193 and 3134 cm⁻¹ were observed due to the C–H stretching. The peak around 2802 cm⁻¹ shows the carbon hydrogen stretching. From the IR spectra, absorption can be observed at 1664, 1600, 1555, 1432, 1368 and 1322 cm⁻¹ out of which 1664 and 1600 cm⁻¹ belong to the stretching

vibrations of C=O and the peak at 1555 cm⁻¹ is related to the C=C stretching and the ring stretching. The peaks at 1432 and 1368 cm⁻¹ are due to the carbon hydrogen bond and C–COOH stretching. The peaks at 1322 and 1261 cm⁻¹ are assigned to the dimer and ring stretching respectively. The peak at 1178 cm⁻¹ is related to the OH bond and the CH bond. The peaks at 961 and 905 cm⁻¹ are assigned to the plane CH bond. The bands at 756 and 606 cm⁻¹ are assigned to the plane band. Finally, the peak at 534 cm⁻¹ is related to the C–H bond and the C=O bond.

The FT-IR spectrum of eutectic after 100 accelerated thermal cycles is also recorded and is shown in figure 6. The N–H stretching and carbon hydrogen stretching are found at 3291 and 2856 cm⁻¹ respectively. All the remaining peaks were found at the same frequency. Additional peaks were not observed in the IR spectra of eutectic after 100 accelerated

Figure 6. FT-IR spectra of non-cycled eutectic and after 100 thermal melting/solidification cycled.

thermal cycles. The FT-IR results before and after 100 accelerated thermal cycles were in the acceptable level.

Figure 6 displays the FT-IR spectra with both the characteristic peaks of benzoic acid and acetanilide. It is concluded from the FT-IR spectra of the optimized eutectic based PCM before and after accelerated thermal cycles that benzoic acid and acetanilide were mixed physically and chemically compatible.

2.4g Result on the TES based PWHs: In the present experimental study, the prepared eutectic PCM using the acetanilide and benzoic acid composition with a mass ratio of 30:70 was used in a PWHs. In order to analyse the performance of the optimized eutectic PCM unit, it is coupled to a SWHS. Experiments on the TES based PWHs were accomplished by the optimized eutectic PCM using acetanilide and benzoic acid compositions with a molar ratio of 30:70 in a setup as addressed in the experimental section and shown in figure 1a and b.

During charging period, the thermal energy is absorbed by the eutectic PCM and changes its phase from solid to liquid. The eutectic PCM stores the thermal energy in the form of latent heat energy and it melts at a constant phase change temperature. The graphical representation of the performance of the eutectic PCM and water in the PWHs during charging and discharging is shown in figure 7a and b. The temperature fluctuations of the eutectic PCM during charging is shown in figure 7a. It is observed that the temperature of the eutectic PCM increases moderately until it attains its eutectic melting temperature of 75.6°C and the complete phase change takes place in 35 min. When the charging process is completed, the PCM is completely melted and then the flow of hot water is stopped by closing the valve V_1 .

During discharging, cold water is circulated in the system by opening valve V_2 and during the process the PCM starts freezing. Figure 7b represents the temperature of hot water and the PCM independently during discharging. During this process, the temperature of the circulating water at the outlet

Figure 7. Temperature distribution of (a) PCM during charging and (b) PCM and hot water during discharging.

is reduced from 75.50 to 37°C in 38 min. The temperature of the PCM during discharging is continuously decreased as the cold water absorbs the energy from the charged PCM. To maximize the performance of the PWHs, the required flow rate should be lower in order to increase the outlet temperature. In our experiment a water flow rate of 0.0271 min^{-1} is maintained. Normally, a TES unit used in the PWHs requires a rate of charging that is faster than the rate of discharging of the TES material so that hot water will be available for a longer duration during discharging.

Similar results are observed in the present experiment. The use of this novel eutectic composite prepared by acetanilide and benzoic acid in the PWHs helps to reduce the charging duration and also it increases the discharging duration. In our experiment, the charging process took place in 35 min and the discharging process took place in 38 min. The discharging efficiency is observed to be 18.8% by neglecting overall heat transfer losses during experimentation. In terms of electrical tariff the amount of saving upon the use of 0.2 kg PCM is 0.11 INR for the utilization of thermal energy from the PCM during off sunshine hours.

3. Conclusion

In this paper, two novel organic PCM based eutectic mixtures of acetanilide and benzoic acid were prepared for the TES material in the PWHs. Samples were analysed by DSC,

FE-SEM and FT-IR in order to determine their thermal properties, surface morphology, and chemical stability respectively. The metastable state of eutectic was identified. The peak melting temperature and the onset melting temperature of the eutectic are measured as 75.6 and 70.2°C, respectively, corresponding to the optimized mass fraction of acetanilide and benzoic acid with weight percentages of 30 and 70%. The latent heat of eutectic mixture is 193.6 J g⁻¹ and found suitable for the TES medium used in the PWSH. After 100 accelerated thermal cycles, the change in the melting temperature and the latent heat of melting of eutectic were in the acceptable level. The FT-IR results show that there is no strong chemical interaction found between benzoic acid and acetanilide. The eutectic mixture is found to be chemically stable. It is also observed that the morphology of the optimized PCM based eutectic remains unchanged after 100 thermal cycles. Hence acetanilide/benzoic acid eutectic has a potential for its use as a suitable TES medium for the water heating storage system. The novel eutectic is employed as the TES unit in the PWSH. It was observed that the use of novel eutectic in the SWHS led to reduce the discharging rate and enhance the charging rate. The discharging efficiency is observed to be 18.8% by neglecting overall heat transfer losses during the experimentation. In terms of electrical tariff the amount of saving upon the use of 0.2 kg PCM is 0.11 INR for the utilization of thermal energy from the PCM during off sunshine hours.

In this way the overall efficiency of the PWSH is increased up to a great extent. Hence it can be concluded that acetanilide/benzoic acid eutectic composition has good stability for its use as a TES material for a water heating system.

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