International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 11, Issue 8 [August. 2022] PP: 156-166

Performance Analysis Of Cascaded Thermal Energy Storage System Using Different Pcms

V.PRADHEEP, V.NARESH,L.INDIRAKUMAR

Absrract

The sun emits energy at the rate of 3.8 × 10^{23}*kW*, out of which theearth intersects only 1.8×10^{14}*kW*(Kalogeria, 2014). The remaining energy isreflectedintheatmosphere.Whenconvertinginterceptedenergyatanefficiency of 10 %, 0.1 % of the energy received by the earth from the sunwouldbefourtimestheworldtotalpowergeneratingcapacity.Thisisequivalenttotheoutputofonehundredmillionm odernpowerstations(Hankins 2012). Solar energy can be harvested for different applications thatinclude power generation, space heating, water heating, cooking, drying etc.Though the efficiency of solar-based systems is low with a high initial cost,theirusagesareabruptlyincreasinginmanysectorsconsideringitsenvironmentalfriendliness andrenewablenature.
Currently,thecumulativeinstalledcapacityofsolargenerationacross the world is 629 GW and the top installers are China, USA and India,withagenerationcapacityof30,100*MW*,13,300*MW*and9,900*MW*(IEA2019),respectively.Theaboveplantsutili zephotovoltaic(PV)technology for power generation, but the cost, availability and disposal of PVpanel are the major raising concerns. In addition, low conversion efficiency,maintenanceunderextremeweatherconditions,numberofcontrolcomponentsforachievingtherequiredqua lityandsynchronizinginadecentralizedmodemaketheirusagemorecomplex.

Fortunately,Indiaisblessed with abundant solar radiation, receiving 4-7 kWh of solarradiationper m^2per day inmanyparts, with 300 sunnydays in a year.Asper the reportby the Central Electricity Authority ofIndia, the amount of solar energyreceived is equivalent to 5000 *trillion kWh* in a year, which is several foldshigherthanthetotalenergyconsumption ofIndia(848*billionkWh*).

The solar energy is effectively collected using a flat plate collectorandaconcentratingcollectorinasolarthermalsystem.Thefeasibilityofsolar thermal technologies is evaluated based on the availability of direct solarradiationandcountriesliketheUSAandSpaininstalledthelargestcapacityof solar thermal power plants. The main feature of a solar thermalsystem isitsadaptabilitytoenergymanagement,easeofhybridizationwithconvectional system and prolong useful life. Recently, significant growth hasbeenseeninSouthAfricaandMoroccoinsolarthermalbasedpowergeneration. As against the above mentioned advantages, one of the majorproblemsisthegapbetweensupplyanddemandduetotheintermittentavailabilityofsolarenergy.Thedevelopment ofsuitableenergystoragetechnology can be a promising solution for proper energy management andconservation, particularly in the medium temperature application like SolarWaterHeating (SWH)system.

Date of Submission: 18-08-2022 Date of Acceptance: 02-09-2022

INTRODUCTION

The solar energy is effectively collected using a flat plate collectorandaconcentratingcollectorinasolarthermalsystem.Thefeasibilityofsolar thermal technologies is evaluated based on the availability of direct solarradiationandcountriesliketheUSAandSpaininstalledthelargestcapacityof solar thermal power plants. The main feature of a solar thermalsystem isitsadaptabilitytoenergymanagement,easeofhybridizationwithconvectional system and prolong useful life. Recently, significant growth hasbeenseeninSouthAfricaandMoroccoinsolarthermalbasedpowergeneration. As against the above mentioned advantages, one of the majorproblemsisthegapbetweensupplyanddemandduetotheintermittentavailabilityofsolarenergy.Thedevelopment

ofsuitableenergystoragetechnology can be a promising solution for proper energy management andconservation, particularly in the medium temperature application like SolarWaterHeating (SWH)system.Thisisequivalenttotheoutputofonehundredmillionmodernpowerstations(Hankins 2012). Solar energy can be harvested for different applications thatinclude power generation, space heating, water heating, cooking, drying etc.Though the efficiency of solar-based systems is low with a high initial cost,theirusagesareabruptlyincreasinginmanysectorsconsideringitsenvironmentalfriendliness andrenewablenature.In addition, low conversion efficiency,maintenanceunderextremeweatherconditions,numberofcontrolcomponentsforachievingtherequiredqualityandsynchronizinginadecentralizedmodemaketheirusagemorecomplex.

1.1 SOLARWATERHEATINGSYSTEMS

Domesticwaterheatingsystemsareknownforbeingthesecondlargestend-useofenergy,accountingfor19%oftotalenergy,as in general, 30 - 40 % of the electricity tariff in afamily is devoted to producing hot water using electricity and natural gas(Fuentes *et al.* 2018). Thermal performance of SWH systems depends mainlyon the amount of solar energy transmitted, absorbed and conducted in thecollectors and also the thermal transport properties of Heat Transfer Fluid(HTF).Theeffectiveutilizationofsolarenergycanreducenearly70-90%of the energy cost incurred for water heating applications. The first ever SWHsystemwascommercializedandpatentedby(Kemp1891).The SWH systems are broadly classified into the active and passivesystem. The first one has circulating pumps and necessary controls and notseeninthelater.

1.2ActiveSWHSystem

These systems use one or more circulating pumps for increasing theheat transfer rate and active SWH system is of two types viz. direct andindirect system.In adirect circulationsystem,water iscirculatedbythe pumpfromstoragetocollectorsduringsunnyhours.Bythismethod,amajorproblem of freezing is encountered. As the circulating system enhances theenergy transfer, it can be widely used in the area, where the freezing does notoccurfrequently.Inanindirectsystem,workingfluidismixedwithantifreeze, circulated in a closed-loop by the pumps and the heat gained in thesolar collector is transferred to water in a heat exchanger. The commonly usedworking fluid in these systems are the aqueous solution of glycols and theschematicarrangement ofsuchasystemis illustratedinFigure1.2.

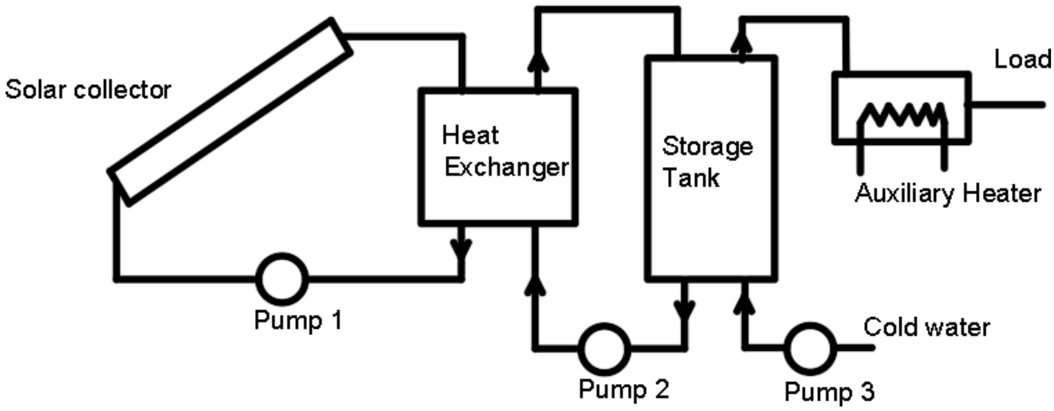


Figure1.2Flowdiagram ofanindirect SWHsystem

1.3 PassiveSWHSystem

Therearetwotypesofpassivesystems;IntegratedCollectorStorage Solar Water Heaters (ICSSWH) and thermosyphon system. ICSSWHsystem has a storage tank, which acts as a collector as well asa storagesystem. This system is very useful in places, where the probability of freezingHTF is minimum. It is capable of providing hot water during an evening atthe home. In the late 1900s, batch of SWH systems (ICSSWH) had beenreplaced by a thermosyphon system due to their pertinent heat loss problems.In this system, water flows when warm water rises as the cooler water sinksandessentiallythecollectormustbeplaced belowthe storagetank tocirculatewarm water into the tank.

The main drawback associated with the system isthat water with high hardness cannot be used without the presence of a watersoftener.TheschematicarrangementofsuchpassivesolarwaterheatingsystemisshowninFigure1.3.ThoughapassiveSWHsystemislessexpensive than an active system, they are not as efficient. Nevertheless, thepassivesystemcanbemorereliableandmaylastlonger.

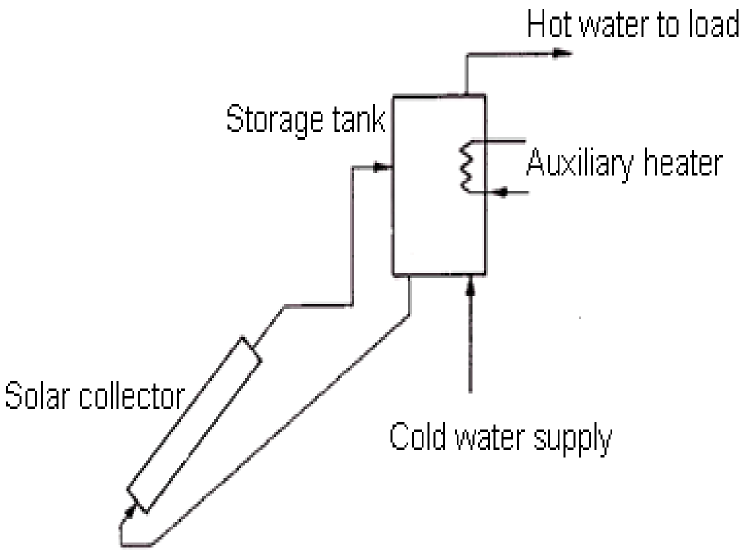


Figure1.3 Schematicarrangementofpassivesolarwaterheating system

1.4SOLARCOLLECTORS

Solar collectors transform solar radiation into heat and, in turn,transfer that heat to the working media like water, solar fluid or air. They arethe most important critical components of any solar system. Many technicalchallenges need to be addressed in the effective collection of solar energy.Considerableresearchworkshavebeencarriedoutanddevelopednewtechnologiesonharvestingsolarenergyfor attainingmaximumcollection.Thesolarcollectorsarebroadlyclassifiedinto

twomajorcategoriesviz.tracking and non-tracking solar collectors. The first accurate model of flatplatecollectorwasdevelopedbyHottel-Whillierinthe1950sandthiscollectorwerethemostwidelyusedfordomesticwaterheatingandsolarspacingcooling/heating. A temperature up to 75 ºC can be easily achieved, still thehigher temperature can be obtained using heat transfer fluids other than water.Both beam and diffuse solar radiation are collected in the non-concentratedcollectorlikeflatplatecollectors,andtheydonotrequiretrackingofthesunandalsoinvolvelowmaintenance. Dependingontheconstructionsandconfigurationof an absorber, there are several types of non-tracking collectors as shown inFigure1.4.Aconcentratingcollectorutilizesaparabolicshapereflectingsurfaceand concentrated, the incident solar rays to a focal line or point where theabsorber is placed. These collectors only interceptbeam radiation,capable ofachieving very high temperature due to the concentration of diffused solarradiationinasmallerarea(Kumaresan*etal.*2017).

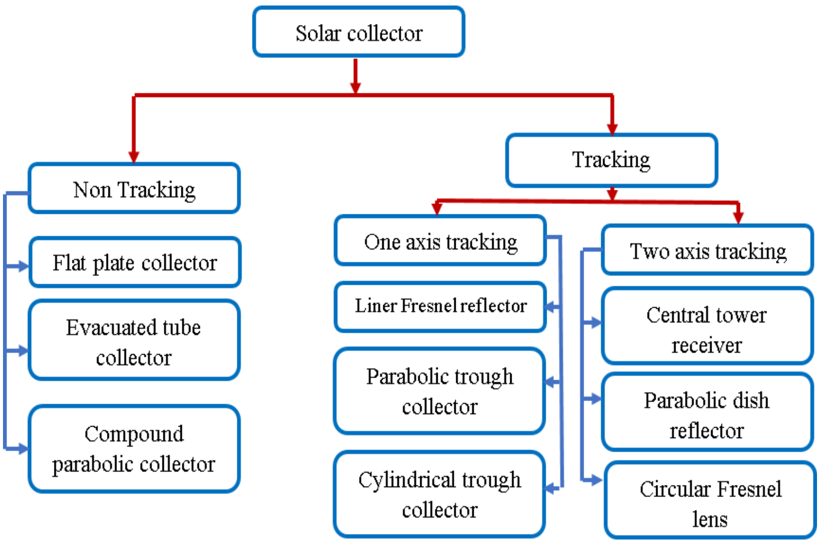


Figure1.4 Classificationofsolar collectors

Despitetheadvantagesofconcentratingcollectorslikehigherthermalefficiency,therequirementoflessmaterialandlow costperunitareaovertheconventionalflatplatecollector,therearecertaindisadvantagesasgivenbelow:

- Depending on the concentration ratio, only little diffuse solarradiationcanbecollected.
- The concentrating collectors cannot follow the daily motions ofthesunduetoitsapparentmovementacrossthesky.Thisnecessitates the requirement of complex tracking mechanisms,thatinvolvemoreexpensivecomponents.

Increasing attention has been seen on the development of stationarysolar collectors with a Compound Parabolic Concentrator (CPC). This type ofcollector operates over a wide range of operating temperature, capable ofcollectingbothdirectbeamradiationandpartofdiffuseradiation.Thecollected radiation is concentratedon the stationary absorber tubes (Orosz&Dickes2017).Byusingmultipleinternalreflections,anyradiationenteringtheaperture area of the collector is focused to the absorber surfaceby CPC,placed at the bottom of the collector. The CPCs are designed either symmetricand asymmetric and the main features of CPC are described in the followingsection.

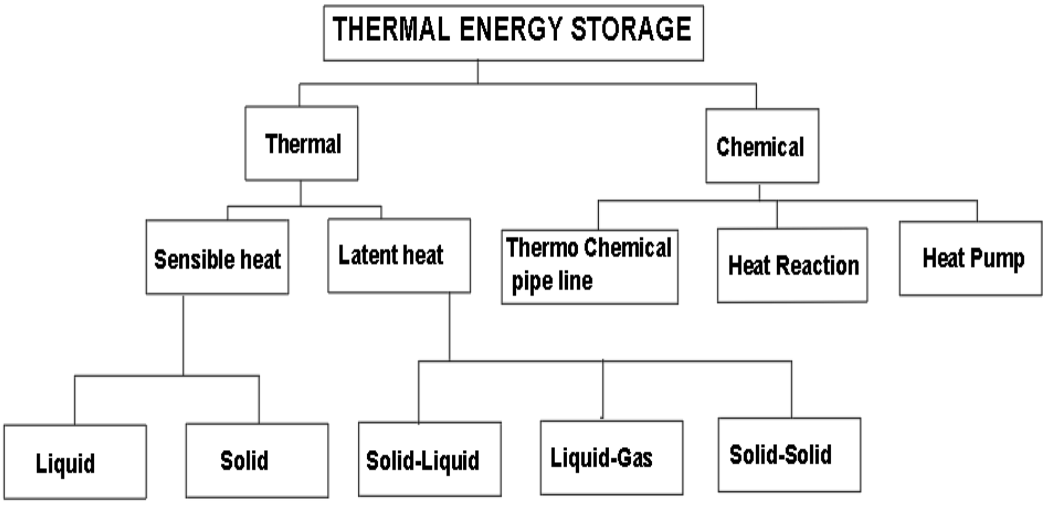
1.5 CompoundParabolicCollectors (CPCs)

Pioneeringworkwascarriedoutontheconceptofthethreetrackings concentrating static concentrator by Tabor in late 1950s. Studies byHinterberger&Winston(1966)exploredtheimportanceofnon-imagingconcentratorsinsolarthermalapplications.CPCcanacceptincomingradiationwithawiderangeofangle,focusingontheabsorberthroughmultiple internal reflections. A gap is maintained between the receiver andreflectorintheCPCtopreventlosses.Thegapshouldbesmallandanincrease in gap leads to a loss of thermal performance due toa reduction inthereflectedarea.Asthereisnoneedfortrackingcollectionofpartofdiffused radiation, the CPC solar collector is more effective than ParabolicTrough Collector (PTC) in attaining HTF temperature nearly up to 300 ° C(Karwa *et al.* 2015). Moreover, its capability of collecting diffuse radiationduring cloudy days is advantageous in areas where the percentage of diffusedradiation is high (Widyolar*et al.* 2018). Growing interest recently seen indomestic and industrial sector makes the CPC technologies more relevant forlow and medium temperature applications. The tubular absorber CPC is moresuitablefortheSWHsystem,yieldingrelativeahigherheatcollectionefficiency.

2.1 THERMALENERGYSTORAGESYSTEM

Thermal Energy Storage (TES) system is a technology that helpsstorage of thermal energy by heating or cooling in a storage medium so thatthe stored energy can be utilized at a later time. TES system is widely used inapplicationlikebuildingsanddifferentindustrialprocess,wherenearlyhalfof the energy consumption is in the form of thermal energy. Variations inenergy demand in these sectors are seen during the day and between the days.TES system can reduce the mismatch between energy supply and demand.Moreover, deployment of TES system reduces decarbonization of the electricgrid,heatdemandandcost.TheglobalmarketsizeofTESisprojectedtoUSD 8 billion for the year 2027, owing to the continuous shifting towardsrenewableenergysourceswhicharehighlyintermittentinnature(GlobalIndustry2020).ThebenefitsofTESintegrationwithrenewableenergysourcesincludeanincreaseintheshareofrenewablesinenergyneeds,becoming particularly important in the solar water heating application, whenthesunlightisnotavailable.

TES system is the most promising one, as the stored energy can bedirectly consumed in the form of hot or cold energy, minimizing the energylosses during conversion in different applications (Alptekin&Ezan 2020).Energy can be stored either in the form of sensible or latent heat; the LHTESsystempossessesahigherenergystoragedensity,capableofstoringorretrieving energy in a nearby isothermal condition (Suresh & Saini 2020).Inthe former case, a sensible heat storage system is relatively less expensive.However, its low energy density about 3-5 times lower than that of a latentheat storage system requires a larger volume. In addition to the above twotypes of TES system, a thermochemical storage system is also being used fordifferent applications in which energy is stored and released by the breakingmolecule bond in the chemical reaction. The major classification of a thermalstoragesystemispresented inFigure1.10.



(Source: Sharma*etal.*2009)

Figure2.1Classificationof TESsystems

2.2 LatentHeatStorageSystem

Latent Heat Thermal Energy Storage (LHTES) system works basedon the principle of storing or releasing heat when a storage material undergoesa phase change transition from solid to liquid or liquid-solid, which may alsobe accompanied by the sensible heat. The potential utility of a thermal storagesystemusingmaterialsundergoingsolid-gasandgas-liquidisruledout.Although using solid-solid phase change is free from the containment designproblem, the low latent heat of these materials makes them not suitable forTESapplication.Solid-liquidphasetransitionismoreattractiveduetonegligible volumechange.

Nowadays PCMs can be used in LHTES applications, storing theheat during solid-liquid phase change processes or vice versa and providing alarge heat capacity over a limited temperature range. When the temperature ofPCMsreachesthemeltingtemperature,PCMschangethephasefromsolid-liquid,absorbingtheheatasthereactionisendothermic.Similarly,when the temperature of PCMs reaches the below solidifying temperature,PCMschangetheirstatefromliquidtosolid,releasingthestoredenergy.

TheamountofenergystoredperunitmassduringthemeltingperiodisdeterminedfromEquation.
where,m- massof PCM(kg),c- specificheat ($Jkg^{-1}K^{-1}$),a_m-fractionmelted

2.3 PhaseChange Materials

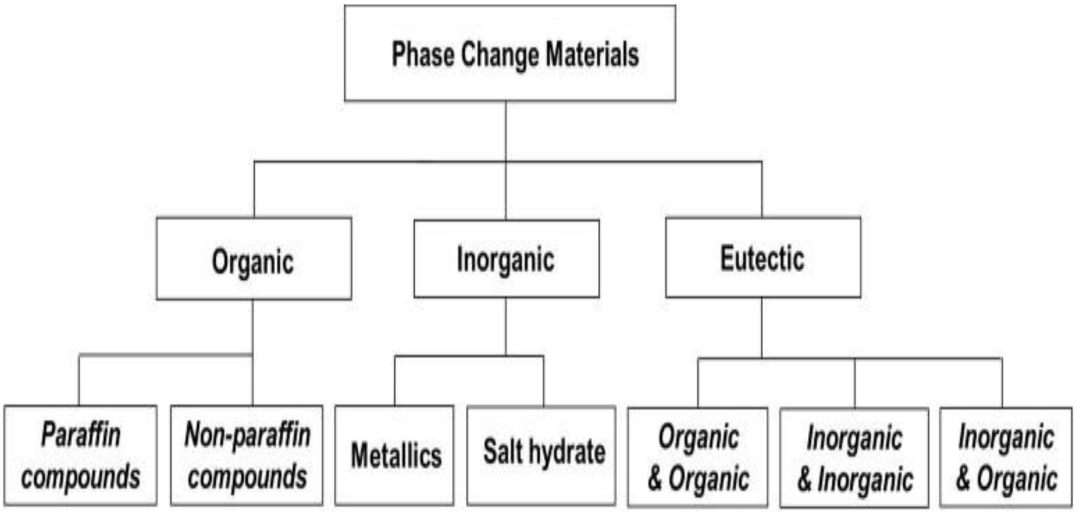
Phase Change Materials (PCMs) are substances that possess largelatent heat and a range of phase transition temperature. It is important tohighlightacrucialfeatureofthematchingofphasetransitiontemperaturerangeto take advantage of the latent heat involved in the solid-liquid phase changeprocess.ThePCMsaremainlygroupedintoorganic,inorganic,eutecticsmixtures as shown in Figure 1.11. Among these, paraffin received greaterattentionduetohigherstoragedensity,congruentmelting/solidificationoccurringwithoutanysubcooling,non-reactivetootherchemicalreagents,andtheyarewaterrepellent(Kumaresan*etal.*2012).Awidevarietyofnon-paraffin PCMs such as fatty acid, ester, alcohol and glycols are availableand their application in TES has been reported by (Sharma *et al.* 2009). Themajoradvantageousanddisadvantageousofeachcategoryof PCMsaresummarized in Table A1.2 as given in Appendix I. Numerous PCMs arecommerciallyavailableinthephasetransitiontemperaturerangingbetween30 °C to 600 °C and some of the commonly used PCMs in a solar thermalapplication is listed in Table A1.3 as given in Annexure I. They can be usedforseveralcyclesofheating/coolingmodewithoutthermaldegradation.PCMs with high latent heat can offer a nearly isothermal heat exchange with ahigher storage per unit volume. Despite various relative merits mentionedabove,thethermalperformanceofPCMsishinderedthroughincompletemelting and solidification. This leads to a lower energy storage density mainlyduetoitspoorthermalconductivity(Zhao*etal.*2018).Practically,theabove-mentioned drawbacks are different from each other that need to beaddressedforenhancingtheoverallperformance.

Various methods have been proposed in the past for enhancing thethermal performance ofLHTES system that include the dispersion of highthermalconductivityparticleinthePCMs(Pramothraj*etal.*2019;Chandrasekaran*etal.*2014;Kumaresan*etal.*2012

),employingextendedsurface (Elfeky*et al.* 2018; Seeniraj& Narasimhan 2008), metal foam/metalmatrix, implementing the cascaded arrangement of PCMs (Farid &Kanzawa1989; Farid *et al.* 1990), dispersion of PCMs into geometric stability structure(Ehid& Fleischer 2012),and the addition of nucleating reagent into PCM(Vikram*etal.*2019).Eachoftheabove-mentionedtechniquehasbeenstudied in recent years. But, there is no single technique found as superior forperformance augmentation of the LHTES system. The choice of a specifictechnique is left to the designer's concern on a case to case basis depending onthe scope of an application. Addition of extended surface and dispersion ofhigh conductive particles for a given system could contribute to enhancedenergystoragerate(powerdensity).However,employingcascadedPCMsand micro-encapsulation of PCMs enhance both energy storage and powerdensity(Narasimhan2019).

The following thermal physical properties of PCMs should be takeninto consideration in the designing of any LHTES system for any specificapplications.

- Thedesiredphasetransitiontemperature.
- Latentheat offusionperunitmassshouldbe high.
- Highthermalconductivityshouldbehighduringliquidandsolidphases.
- Theminimumchangeinvolumeanddensityduringthephasetransitiontime.
- Minimalsub-coolingatthetimeof freezing.



(Source: Sharma*etal.*2009)

Figure2.3ClassificationofPCMs

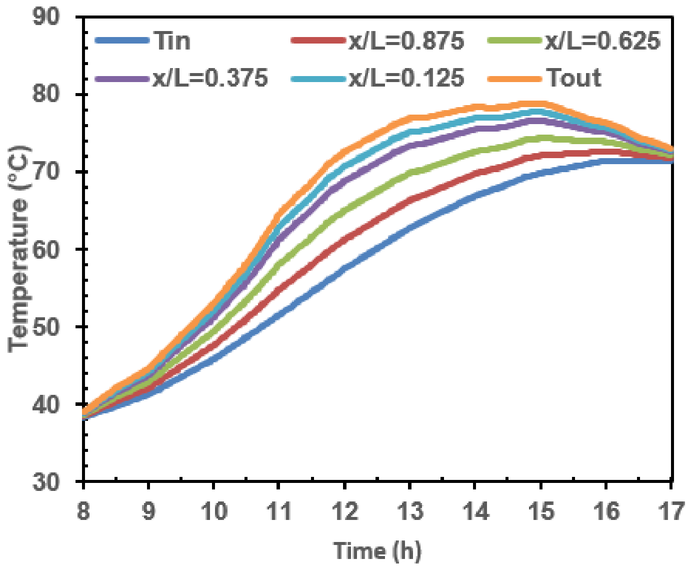
Inaddition,tothat,thePCMsshouldnothaveasignificantenvironmental impact during their life cycle. It should be remarked that thebehaviourofcommercialPCMsisdifferentfromtheidealPCMs.Theenthalpy curves of commercial PCMs are different from theidealone owingto the existence of subcooling and difference in thermal cycle stability. Thesecurve could be impacted bya commonphenomenonlikesubcooling, andcycle stability. The major problems in PCMs based TES system are phaseseparation and segregation. A reduction in phase change enthalpy of PCMsexhibitsphaseseparationafterrepeatedcycling.Considerableresearchworkis being carried out in thefieldof PCMsbased TES system and thehotstoragesystemshavebeendeployedinindustrialapplications.Thecomparison study between sensible heat and latent heat storage material forthe stored energy of4.18×10^6 kJ in terms of mass and volume of the materialcanbe seenfrom Appendix 1(Table 1.4).

TheimplementationoftheTESsystemwithsolarcollectorhasthefollowingadvantages:

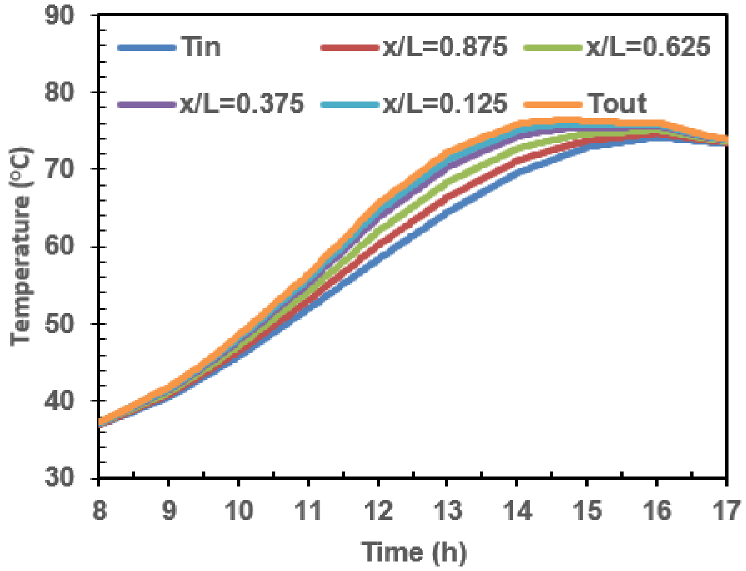
- The provision of a TES system can make a significant reductionin the consumption ofauxiliaryenergyinmost solar systemsanddramaticallyincreasethesocalledsolarfraction.
- Variations in solar irradiance can cause an instantaneous changeinenergygeneration(i.e.,powerorheat).Thesestrongvariations impact not only the availability of energy, but also theconsistency of the power grid, Coupling of the TES system intothe solar system can enhance the thermal inertia, reduces thefluctuationsand systemstability.
- Energy demand during peak hours cannot accord with the peaksolar radiation. TES system can enhance the dispatchability of asolar system by storing heat energy at the time of off-peak hoursand retrieve it at the time of peak hours demand. This results inmatching the energy generation and demand and also enhancesprofitabilityasthepeak-hourelectricitytariffsarehigher.

➢ Reductioninoverallheatlosscoefficient,resultinginenhancement of thermal efficiency and downsizing the SWHsystem.

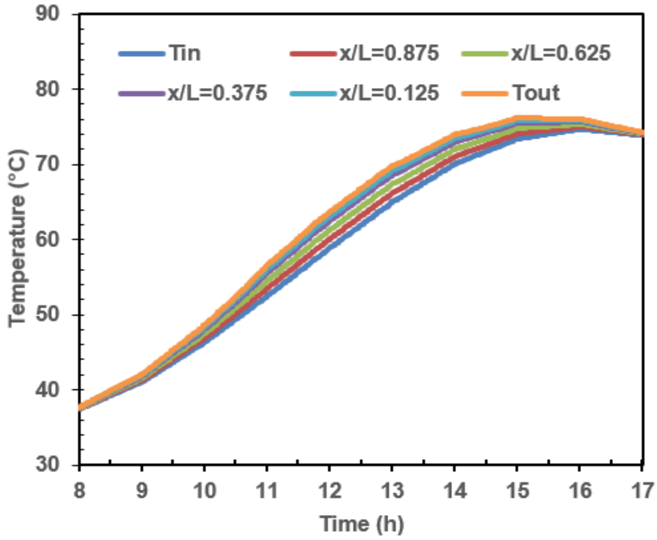
Results and discussion
3.1 Selection of PCMs
It is necessary to determine the degree of stratification along the flow direction of the HTF using a sensible heat storage medium to select the appropriate PCMs. The experiments were performed at different flow rates of 60 kg/h, 120 kg/h and 180 kg/h. Time-temperature (T-t) history of HTF at different locations inside the TES tank is presented in Fig 3 (a-c). As seen from the figure that the initial temperature of the HTF in the storage tank varies from 35-36 °C for all three different flow rates. The average rise in the temperature of the HTF in the TES tank is insignificant from 8.00 h-9.00 h, even though the temperature across collector is higher as shown in Fig 3 (a). The reason is that the high thermal inertia associated with the experimental components. After that, the HTF temperature in the storage tank progressively increased until 13.00 h and further increased is seen till15.00 h. After 15.00, average HTF temperature in the storage started to decline. The reason is energy collected by the solar collector is less compared losses taking place during the HTF flow through pipes and storage unit. The similar trend is observed in the HTF plot for the other two flow rates as depicted in Fig 3 (a-b). Hence from the graphs, it is observed that temperature profile of the HTF varies on two input parameters such as solar radiation and mass flow rate. Based on the experiments conducted on three different day with three different flow rates the maximum and minimum temperature of HTF at each zone are arrived.
The minimum temperature of HTF is taken as a reference temperature for the given zone to select the suitable PCMs to be placed in a particular zone. In order to achieve the complete charging process, the PCMs melting temperature in each zone is selected based on the minimum HTF temperature with driving potential of 7 °C for top zone (x/L=0.125), followed by 14 °C for next-two zone (x/L=0.375 and x/L=0.625), and 21 °C bottom zone (x/L=0.875), respectively. The reason for selecting PCMs linearly along the storage tank height is that once the top zone is filled with PCM, the part of the HTF temperature profile reduces their slope [21]. Further, it is also understood from the above experiments that the stratification effect predicts the range of PCMs can be placed in a particular location, whereas it cannot identify the right temperature meting point for the given condition. In the present studies, the experiments are conducted by placing six different PCMs as shown in Fig 2 and in which the selection of PCMs was done based on the degree of stratification temperature. The thermophysical properties of the selected PCMs for the present work is given in Table 4.



(a)



(b)



(c)

Fig.3.1 Temperature plot variation of HTF at different flowrate (a) 60 kg/h, (b)120 kg/h, (c)180 kg/h

3.2 MIX number

A simple way of showing the degree of stratification of a TES is by 2D plots. As the temperature profile does not give the information in the best way to characterize the stratification in a water storage tank, dimensionless numbers called MIX numbers is used which condense this information in a single parameter. Fig.8 shows the MIX number of HTF at a flow rate of 60 kg/h, 120 kg/h and 180 kg/h. A non-dimensionless time, which is instantaneous time by the total charging time, was utilized to depict the MIX number. The various mass flow rate shows very comparable MIX number plots during the charging process. At the start of charging process, the MIX number goes from higher value to lower value for a particular time period, followed by lower MIX number to higher MIX number, this indicates stratification and destratification effect in the storage tank. This is because the overall temperature gradient in the storage tank increases during the charging process for a certain period and after that overall temperature gradient started to degrade in a storage tank. Similar trend of the MIX number are seen with the mass flow rate of 120 kg/h and 180 kg/h in Fig.8. For the low mass flow tare of 60 kg/h, the MIX number was minimum as compared to the other flow rate, announcing that mass flow rate of 60 kg/h could maintain larger stratification effect for maximum duration compared to other two cases. Moreover, the MIX number during peak value for 60 kg/h, 120 kg/h and 180 kg/h are 0, 0.44 and 0.59. The result implies that, once the flow rate increases from 60 to 120 kg/h and 120 to 180 kg/h the stratification effect was reduced to 56 % and 34 % respectively. Thus, it is construed that storage tank attains better stratification for varying heat load at a lower flow rate compared to a higher flow rate.

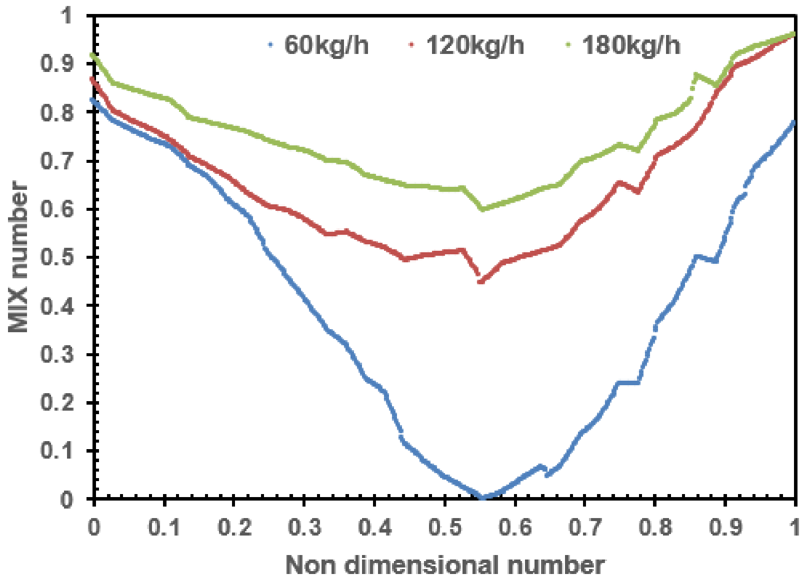


Fig.3.2 MIX number for various flowrates at varying heat load.

3.3 CUMULATIVE ENERGY

The cumulative energy retrieved by HTF during discharging process. It is seen that time require for retrieving 18817 kJ, 21008 kJ and 23564 kJ are 125 min, 96 min and 57 min for the mass flow rates 60 kg/h, 90 kg/h and 120 kg/h respectively. From the temperature point of view (Fig 12), it is observed that the higher the mass flow rate were, the faster PCMs is discharged. The temperature difference between the PCMs and HTF stay higher as the flow rate increases and also the losses associated with the outlet heat transfer rate also reduced considerably for higher mass flow rates. Due to this at higher flow rate the energy retrieving capacity of HTF for given stored energy is higher compared to other two flow rates.

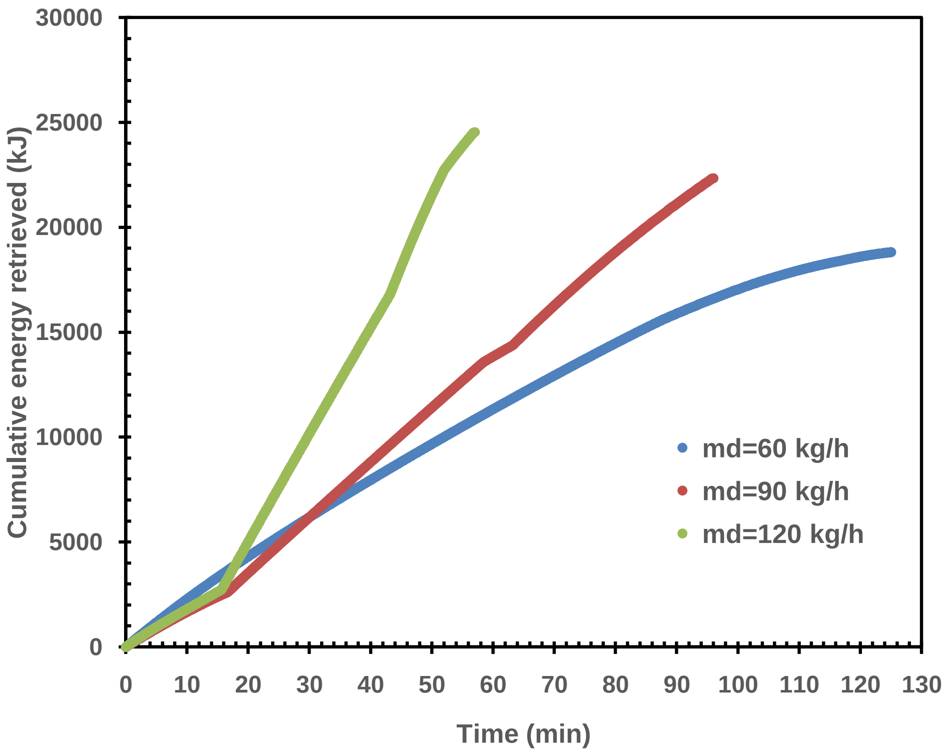
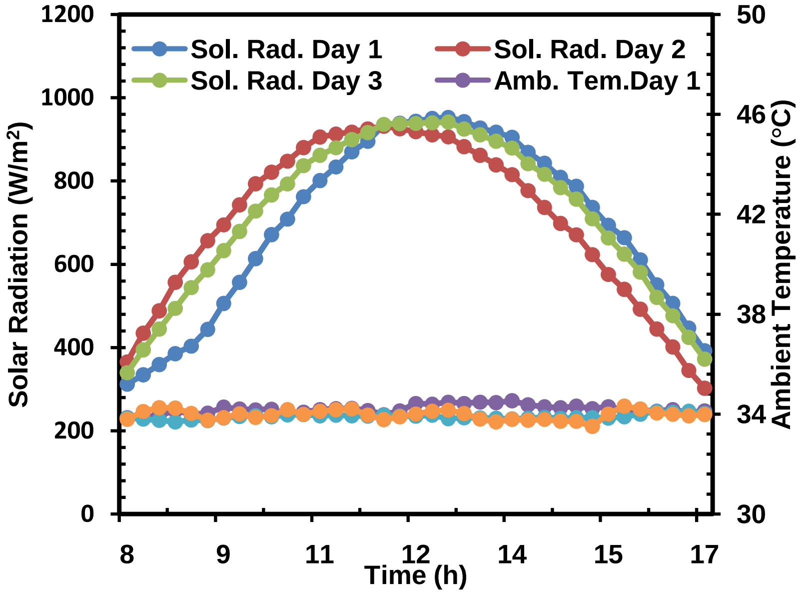


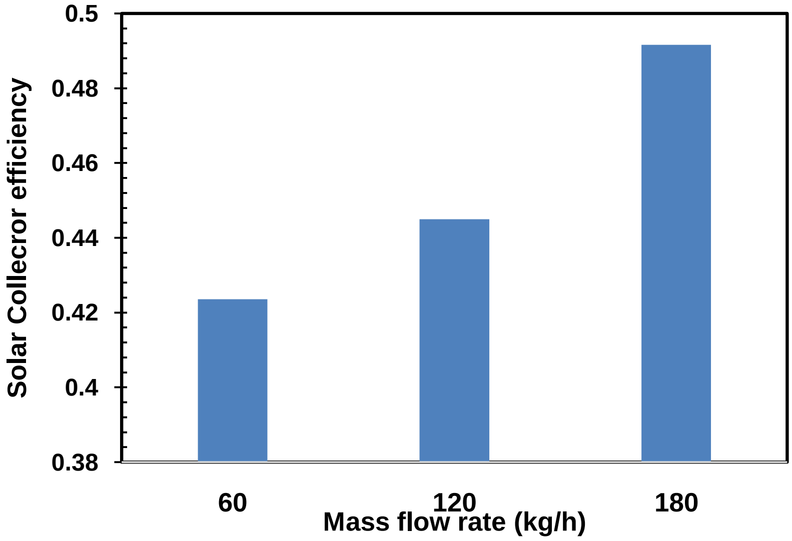
Fig.3.3 Cumulative energy retrieved by the HTF from the cascaded LHTES system

3.4 Efficiency of CPC solar collector

The solar radiation, mass flow rate and temperature difference between inlet and outlet is considered as an important key factor while calculating the system efficiency. Thus, the variations of collector efficiency along with ambient temperature and daylight hours for various mass flow rate are depicted in Fig. 12 and 13. It is observed from the plot that these three days of the solar irradiation and ambient temperature don't have sensible change to affect the final comparison results. As the flow rate increases the heat transfer coefficient between the HTF and solar collector absorber plate was increased. Due to the increase in heat transfer coefficient between absorber tube and HTF, the overall heat loss coefficient in the solar collector got reduced considerable. As a result, the energy gain by the HTF fluid got increased, due to which the thermal efficiency of solar collector increased by increase in flow rate with the percentage 42 %, 44 % and 49 % respectively.



Hourly variation of solar radiation and ambient temperature



Effect of solar collector efficiency for various flow rates

Conclusions

An experimental study of the performance evaluation of a CPC collector, integrated with a cascaded LHTES system is carried out. The performance study of the CPC collector and the cascaded LHTES system has been conducted during full sunny days. The temperature evolution of PCMs and HTF during charging and discharging processes are studied. The collector efficiency, energy stored and retrieved in the cascaded LHTES system and thermal stratification behavior are estimated and the major conclusion is drawn as given below:

➢ During charging process, it is noticed that the latent heat of the PCMs are completely utilized for the given time. These observations show that the PCMs arrangements made within the storage tank are in the right configuration for the given experimental condition.

- The simultaneous phase transition were seen for six PCMs in three different flow rates. It is due to the minimum temperature band gap between PCMs, surface convection and nearly uniform temperature driving potential between the PCMs and HTF throughout the storage tank.
- The cumulative energy stored at any instant of time increases with increase in flow rates for given inlet HTF temperature. It is due to higher energy content associated with the HTF for higher flow rates. The stratification behavior was studied using MIX number and the result revealed that stratification effect was influenced by the HTF flow rate, the incoming solar radiation to the aperture area and out let of HTF temperature from the solar collector.
- The solar collector started to increase their efficiency as the flow rate progress. The improvement is due to enhancement in the internal convective heat transfer rate as the HTF flow increases. The thermal efficiency of solar collector increases from 42 % to 49 % as the flow rate increases from 60 kg/h to 180 kg/h.
- In the present work discharging was conducted during night time after completion of charging process. It is inferred that the HTF attain a nearly an isothermal temperature once the latent of different PCMs in the storage tanks was capture simultaneously.

The above PCMs configuration integrated with solar collector is best suited to meet the domestic hot water demand for Indian climatic conditions.