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Stratification Performance Analysis of Thermal Energy Storage System Using Cylindrical Encapsulated PCM

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ABSTRACT

In the contemporary era, phase change material (PCM) is used in the solar water heaters to store the extra amount of heat energy available during the full sunshine hours. The primary purpose of this study is to examine the performance of PCM incorporated solar water heating system using the flat plate collector as a heat source. In this study, a cylindrical aluminum PCM tank acts as the thermal energy storage unit. Paraffin wax is used as the PCM. Water is used as heat transfer fluid (HTF) to transfer heat from the flat plate collector to the storage tank. The charging has been carried out on clear days without and with PCM under actual operating conditions. It shows that from the experiments, the PCM improves the performance on the system by bettering the charging energy efficiency and thermal efficiency of the Storage tank.

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1. INTRODUCTION

A Thermal energy storage tank with a phase change material (PCM) thermal storage tank is proposed with the view that traditional heat water storage tanks present several problems including large space requirements, significant heat loss and unstable system performance. An entire heating season (November–March) is selected as the research period based on numerical models of the PCM. In addition, taking a public building in Lhasa as the object, the heating conditions, contribution rate of solar energy, and overall energy-saving capability provided by the heating system are analyzed under different PCM storage tanks and different terminal forms. The results show that a thermal storage tank with a PCM tank provides a 34% increase in energy saving capability compared to an ordinary water tank heating system. It is suggested that the design selection parameters of the PCM storage tank should specify a daily heat storage capacity that satisfies 70~80% of the entire heating season. A floor radiant system with supply/return water temperatures of 40/35 provides the optimal operation and the largest energy saving capability. In 2011, theInternational Energy Agencysaid that "the development of affordable, inexhaustible and clean solar energy technologies will have huge longer-term benefits. It will increase countries' energy security through reliance on an indigenous, inexhaustible and mostly import-independent resource, enhancesustainability, reduce pollution, lower the costs of mitigatingglobal warming, and keepfossil fuelprices lower than otherwise. These advantages are global.

2. EXPERIENTAL SETUP

An experimental investigation was carried out to study the combined thermal energy storages like sensible TES and latent heat TES of phase change material.
Thermal storage tank is heat water storage in occupies space. Tank has manufacturing stainless steel. The tank is two position one outer tank and other inner tank.

There are two physical systems namely LHS system and SHS system considered in the present analysis. The LHS system considered for the analysis is a cylindrical storage system of height 1100 mm and diameter 500 mm. It consists of three zone.
PCM porous region and leaves through a lower fluid cold zone before it leaves the storage tank through the exit pipe. The middle PCM zone is of porosity. The second physical system considered is a SHS system. The SHS system consists of similar geometrical dimensions as that of an LHS system. However, the entire region of the storage tank is considered as a single fluid zone instead of three different zone considered in the LHS system.

The following are the assumptions made in the physical model. The storage tank is perfectly insulated. The flow of the HTF is laminar in the storage tank. The thermo physical properties of the HTF are assumed to be constant, except for the density. The porosity and the properties are isotropic in the porous region.

The latent heat of the PCM is assumed as high specific heat, in the narrow range of the phase change temperature, which is modelled from the digital scanning calorimetric analysis of the PCM. The other thermo physical properties of the PCM are assumed constant.

SPECIFICATION:

NAME	DIAMETER	LENGTH
OUTER TANK	700 mm	1200 mm
INNER TANK	500 mm	1000 mm
Tank thickness (each area) =100 mm		

Inlet pipe is top on the TES tank in ¾ inch heat fluid inlet from solar heater.
Outlet pipe is bottom on the TES tank is ¾ inch. The storages of the water required to moves in vary application.

TECHNICAL SPECIFICATION:

S.NO	DESCRIPTION	VALUE
1.	Melting temperature	65°C
2.	Thermal conductivity (solid)	0.1383 W/m°C
3.	Thermal conductivity (liquid)	0.1383 W/m°C
4.	Specific heat (solid)	2890 J/kg.K
5.	Specific heat (liquid)	2890 J/kg.K
6.	Density (solid)	947 kg/m3
7.	Density (liquid)	750 kg/m3
8.	Latent heat	190 J/kg

PROPERTIES:

Product range: density 12 kg/cubic m to 100 kg/cubic m and thickness 12mm to 100mm
Temperature range: glass wool is suitable for applications ranging from minus 195 degree Celsius to plus 230 degree Celsius. for special applications up to 450 degree. aluminum foil facing is suitable up to 120 degree Celsius.
Chemical stability: glass wool is chemically inert. application does not cause or accelerate corrosion. glass wool is rot proof and odorless.
Fire safety: glass wool is non-combustible in accordance with bs 476 incombustible, extremely low spread of flame, non-emission of dense smoke and toxic gases, on depletion of oxygen (high oxygen index 70%).
Biological: glass wool is inorganic. does not encourage growth of fungi and vermin.
Dimensional: glass wool is stable under varying conditions of temperature and Humidity when applied correctly. excellent tear strength and not prone to Sagging or settling. rigid slabs have inherently high compression resistance. thermal conductivity is 0.028 W/m.k

TES tank

TES tanks are the reservoirs used to store energy in chilled water district cooling systems. These specialty tanks are insulated and designed with special internal “diffuser” systems. This allows two bodies of water to reside in the tank during the charging and discharging of chilled water.
Thermal energy storage is like a battery for a building's air-conditioning system. It uses standard cooling equipment, plus an energy storage tank to shift all or a portion of a building's cooling needs to off-peak, night time hours. During off-peak hours, ice is made and stored inside Ice Bank energy storage tanks.

PCM IN THERMAL STORAGE TANK

The exponential increase in energy generation capacity using intermittent renewable sources necessitates the effective means of storing and balancing energy systems worldwide. Among the various forms of energy

storage, whenever thermal energy is available and thermal demands exist, thermal energy storage is the most desired method of energy storage, as it avoids the need to convert energy from one form to another with minimum conversion losses. Thermal efficiency of the TES system largely depends on the storage medium, temperature driving potential and the geometry of the tank. In particular, the existence of thermal stratification due to the difference in density between the hot and cold fluids in the storage tank, is highly beneficial to improve the efficiency of charging/discharging to a large extent.
With no physical barrier between the hot and cold regions of TES tank, the buoyancy is the only mechanism separating them that results in a region of steep temperature gradient called a 'thermocline 'For enhanced stratification, the thickness of thermocline is to be maintained at a minimal value and the degradation and destruction of the stratified thermocline significantly lowers the efficiency of the system . forced convection flow in charge and discharge cycles. The effect of the first and second factors can be minimized by including inner and outer insulation while the effect of last one is difficult to control

EXPERIMENT

The schematic layout of the experimental setup that consists of TES tank, thermostatic circulating bath, HTF loop and a data acquisition system. The TES tank had an internal diameter of 400mmand a total height of 1000 mm, in which 92% of total volume (115 L) was filled with water for thermal energy storage. The storage tank was insulated with 50 mm thick polyurethane foam to minimize the heat infiltration and it was coupled with a thermostatic bath with a volume capacity of 200 L. The bath was fitted with six immersion heaters of 3 kW capacity each.

The temperature of HTF (water) was maintained at the desired value through a proportionate temperature differential controller (PTDC)that regulated the output of the heater based on the temperature of the HTF inside the thermostatic bath. A centrifugal pump to circulate the HTF and an electronic mass flow meter (with an accuracy of ±0.75%) to measure the flow rate, formed the HTF loop, through which the hot HTF was circulated from the thermostatic bath to the top of the TES tank. Two perforated cylindrical plate of thickness 3 mm were positioned at a distance of 200 mm and 600 mm from the top of the tank.

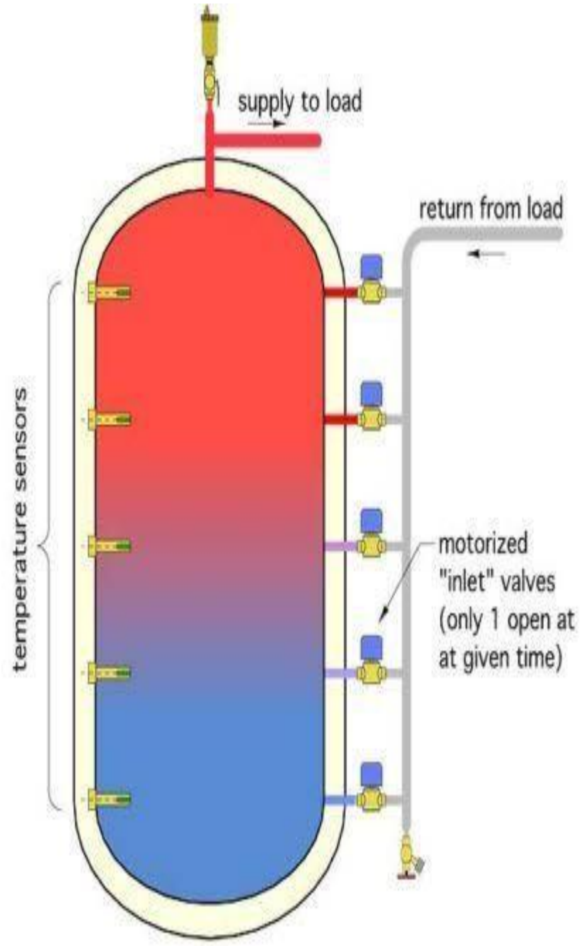
These two plates are utilized to hold the 120 spherical encapsulations filled with commercial phase change material (OM 48) within the TES tank. The PCM was procured from Pluss, India and the thermophysical properties of the PCM are presented in Table 1. The phase transition temperature, specific heat and latent heat were measured using the differential scanning calorimeter at cooling/ heating rate of 1 K min1. The thermal conductivity of PCM (both solid and liquid state) was measured at 35Ce50℃ .Causing a KD 2 Pro thermal analyzer, which works based on the principal of transient line heat source method and the value of density was taken from the manufacturer data.

The spherical encapsulations were made of high-density polyethylene (HDPE) with an average outer diameter of 75mmand a thickness of 2 mm. The tank was provided with a lid at the top for filling/refilling of PCM balls. Two sets of RTDs (Pt 100, Class A with an accuracy of ±0.1 C), were placed along the inner periphery of the storage tank at five different heights (T1, T2, T3, T4 and T5) in order to measure the transient temperature variation of water in the TES tank.
The inlet and outlet temperature of HTF were measured using another two RTDs placed at the respective sections of the tank.

STRATIFICATION NUMBER

The comparison between stratification behavior of sensible and combined TES system, in terms of stratification number as a function of non-dimensional time, for a given HTF inlet temperature of60℃ at various flow rates. the total time of charging for a given experimental condition respectively.

It is seen from the figure that there is an increasing trend in stratification number in the beginning of the charging process and its value any instantaneous time until it attains its peak value is primarily influenced by the depth of temperature penetration from the top, which is controlled by the rate of diffusion, HTF flowrate that varies the velocity of fluid entering the tank and the inlet temperature of HTF.



CHARGING EFFICIENCY

The charging efficiency is the ratio of instantaneous heat transfer to the maximum possible heat transfer. the variation of charging efficiency with nondimensional time in both the TES system at HTF inlet temperature of 60℃.

In sensible TES system, the charging efficiency remained very high in the order of 0.98 for nearly 65% of the charging duration and then decreased at a faster rate reaching a value of 0.2 at around 80% of the charging duration. However, in the case of combined TES system, the charging efficiency remained very high for only 30% of the charging duration, declining thereafter during the next 10% of charging duration and remained at a value of 0.2 during the 40e80% of charging duration.

At Ti ¼ 60 ℃, the sensible TES system possessed higher charging efficiency than the combined system at all the three different flow rates due to relatively higher heat transfer rate at any instant of time in sensible TES. The variation in charging efficiency between the two systems at maximum HTF inlet temperature of 80 ℃

TES TANK WITHOUT PCM TABLE:
MASS FLOW METER: 15 LPM

Table: Observations of TES Tank

Sensible Heat energy	Time	Solar radiation	Ta	Ti	To	T1	T2	T3
	10 AM	818.7 W/M²	28 °C	40°C	42°C	40°C	40°C	40°C
	11 AM	880.6	31.3°C	48°C	49°C	48°C	48°C	48°C
	12 AM	997.8	36.2°C	58°C	60°C	59°C	58°C	58°C
	1 PM	990	37.2°C	70°C	71°C	70°C	70°C	70°C
	2 PM	870.3	35.7°C	74°C	75°C	74°C	74°C	73°C

	3 PM	986.4	33.1°C	76°C	77°C	76°C	76°C	75°C
	4 PM	1073.2	32.3°C	76°C	77°C	76°C	76°C	75°C

EFFICIENCY PARAMETER WITHOUTPCM

Table: Parameter of SHES

PARAMETER	SYMBOL	VALUE
VOLUME	V	215 liters
INITIAL TEMPERATURE	Ti	28°C
HEAT RADIATION	Rin	945.28 W/m²
TIME ELAPSED	Δt	1 hr.
FINAL TEMPERATURE	To	76°C

TES TANK WITH PCM TABLE: MASS FLOW METER: 15 LPM

Table: Observations of TES Tank

Sensible Heat energy	Time	Solar radiation	Ta	Ti	To	T1	T2	T3
	10 AM	928.6 W/m²	28.1	39	41	41	40	40
	11 AM	1097.4	31.4	47	49	48	47	47
	12 NOON	991.2	41	57	60	60	59	59
	1 PM	808.3	38.1	68	69	69	68	68
	2 PM	885.0	43.1	73	74	74	73	72
	3 PM	861.7	41.7	75	76	75	74	73
	4 PM	801.9	37.4	77	78	78	77	76

EFFICIENCY PARAMETER WITH PCM

Table:Parameter of LHES

PARAMETER	SYMBOL	VALUE
VOLUME	V	215-8.835 = 206.165
INITIAL TEMPERATURE	Ti	28
HEAT RADIATION	Rin	910.58 W/m²
TIME ELAPSED	Δt	1 hr.
FINAL TEMPERATURE	To	78°C

3. DATA ANALYSIS

VOLUME OF THE TANK:

VOLUME= AREA ×LENGTH

Area (A) = $(\pi/4)D$

WHERE,

D - Diameter of inner tank = 500 mm

L - Length of inner tank = 1000 mm

VOLUME OF CYLINRICAL ENCAPSULATED PCM

VOLUME = $\frac{\pi}{4} d^2$ l

WHERE,

D is diameter of cylinder =d1 = 0.2 m d2 = 0.1 m

L is Length of cylinder =1 m

TES TANK WITHOUT PCM:

Heat energy storage $Q = m\,Cp\,(\Delta T)$

Similarly, Q = m Cp ($Tf - Ti$)

WHERE,

m is mass of water
ΔT is change of temperature $(Tf - Ti)$
Cp is specific heat of water (4.186 KJ/kg.K)
Tf is final temperature of the water after half one hour (in°C)
Ti is the initial temperature of the water before the starting experiment (in °C)

TES TANK WITH PCM:
Heat energy stored = mCp ΔT + mCp (pcm) + mCp ΔT (pcm)
Where, m is mass of paraffin wax (kg) Cp is specific Heat KJ/KgK ΔT is charge in Temperature
CALCULATION:
VOLUME OF TANK = $(\pi/4)D_L$

$$= \left(\frac{\pi}{4}\right)(0.5)^2(1.1)$$

V tank= 0.200 m^3 (or) 200 liters
VOLUME OF PCM = $(\pi/4)D_L$
= (π/4) (0.1)2 (0.1)
= 7.8 x 104 m3

TES WITHOUT PCM:
HEAT ENERGY ABSORBED Q = m Cp $(Tf - Ti)$
m = 215 liter or 0.215m
Cp = 4.18 KJ/kg

Q = m Cp $(Tf - Ti)$
Q= 0.200 ✕4.18 ✕(76-34)
Q = 35.11 KJ

Heat absorbed per day is 35.11 KJ
MAXIMUM THE AMOUNT OF ENERGY IN HOUR
In time interval of 12 noon to 1 pm is

Q = m Cp $(Tf - Ti)$
= 0.200✕4.18✕(70.2-58.6)
= 8.424 KJ

TES WITH PCM: HEAT ENERGY ABSORBED
Q = m Cp $(Tf - Ti)$ + m Cp + m Cp $(Tf - Ti)$
Q = 8.424 + 1900 + 57000
Q = 67.324 KJ

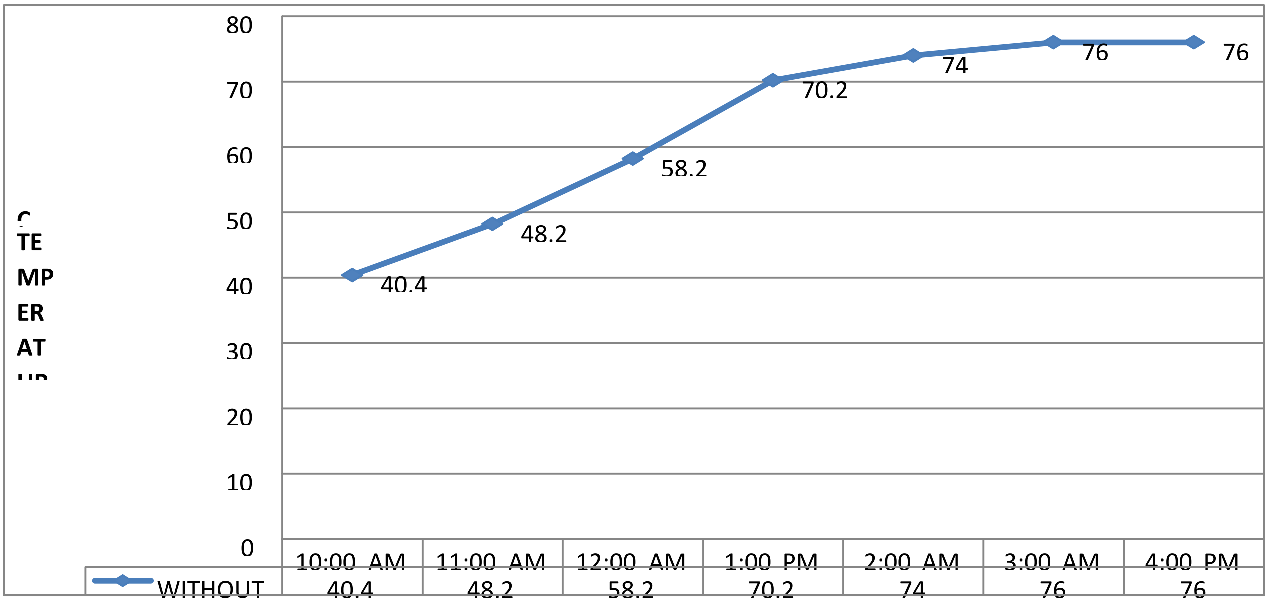
MAXIMUM AMOUNT OF ENERGY STORED
In time interval of 11 am to 12 noon is

Q =m Cp ΔT +mCp + m Cp ΔT
=191.17✕4.19+5.2(190)+5.2(2.89)(59-68.9)
= 9.540 KJ

The maximum energy storage is 11 am to 12 noon is 9.540 KJ

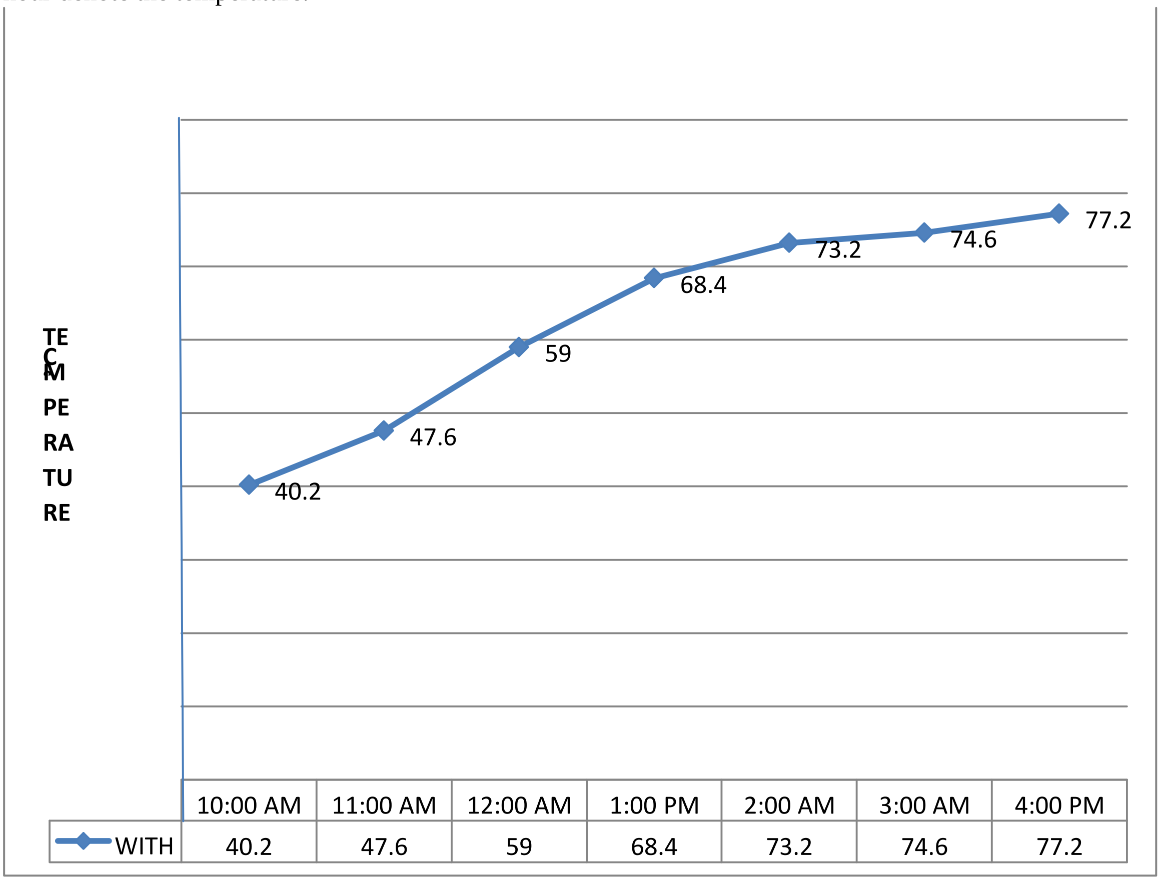
RESULTS AND DISCUSSION

TEMPERATURE OF TES TANK WITHOUT PCM
Below the graph shown different temperature of TES tank without pcm with time interval of 1 hour. The every one hour to denote the temperature.



TEMPERATURE OF TES TANK WITH PCM

Below the graph shown different temperature of TES tank with pcm with time interval of one hour. Every one hour denote the temperature.



5. CONCLUSION

Comparing the all aspect from TES tank with pcm has greater efficiency than TES tank without PCM.
Thermal performance of heat storage system depends on the degree of stratification. A well stratified tank is always capable of delivering higher energy plus improved degree of utilization with lesser amount of heat input

as compared to the mixed isothermal tank having the same energy content. The idea behind generating and maintaining a good thermal stratification is to keep a stable vertical temperature gradient during all the operation cycle of tank. To sum up, this information could be clubbed together with new modelling techniques and water consumption patterns to accommodate a better stratification enhancement right during design phase of TES system.

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