Thermal Energy analysis using TRNSYS in PCM Storage Tank

*A. Ponshanmugakumar
Research Scholar
Dept. of Mechanical Engineering
AMET University,
Chennai-603112
shnmgkmr8@gmail.com

A. Lakshmi Narayanan
Dept. of Mechanical Engineering
Sri Sairam Institute of Technology
Chennai-44
lakshmi2mechanical@gmail.com

R. Madhan
Dept. of Mechanical Engineering
Sri Sairam Institute of Technology
Chennai-44
madhan3555@gmail.com

R. Rajavel
Professor
Dept. of Mechanical Engineering
AMET University
Chennai-603112
rajavelmech@ametuniv.edu.in

Abstract: Energy is released from different processes into environment everyday across the globe. With the augmentation of the population it isn't realistic to expect the energy demand to decrease, therefore currently available energy should be used more efficiently .In that sense, latent heat storage (LHS) has been popularized in last few decades because it can improve energy savings of thermal energy systems. The present paper contributes in showing the effects on system of including phase change materials(PCM) in a thermal energy system. System analyzed here is hot water tank for domestic use purposes. Analysis of system has been done using simulation program TRNSYS. Results come in a form of graphs that show charging and discharging times, quantities of energy stored, and temperature profile of watertank.

Keywords: *Phase change materials (PCM), thermal energy storage(TES), model of water tank, latent heat storage(LHS), sensible heat storage(SHS)*

*****

I. INTRODUCTION

When a Phase change material is exposed to heat it changes its total phase. Depending upon the chemical composition, the phase change process occurs at different temperature. This process is made by introducing PCMs into different thermal energy systems where rejected heat from the systems can be stored in PCMs in form of latent heat. This is called latent heat storage, and it is becoming popular in thermal energy storage (TES) because of large amount of energy that can be stored in PCMs during the phase change.

Many system make of use PCMs and its benefits are:(i) internal combustion engines, (ii)air condition systems, (iii) heat pump system,(iv) waste heat recovery from different systems, (v)solar domestic hot water system,(vi) off peak power utilization, (vii) space applications, (viii)computer cooling, etc. [1]
The characteristics of introducing PCMs into system with water tank will be analyzed in this paper.

II. LATENT HEAT STORAGE MATERIALS

Nowadays, number of PCMs are available for different application. PCM materials should be selected based upon the system working condition. Depending on the application, first criteria for PCM selection should be based on their melting temperature. For air conditioning application PCM should have meting temperature below 288K and materials that melt above 363K are used for absorption refrigeration. Materials that melt between the set temperatures can be applied in solar heating and for heat load leveling applications. Materials that are used for latent heat thermal energy storage (LHTES) should have a large latent heat and high thermal conductivity.

They should also have high storage density in a relatively small volume, high melting enthalpy [J/kg] and a high density [kg/m³], i.e. a high volumetric melting enthalpy [J/m³]. Most widely used type of phase change is solid-liquid phase transformation, because of small change in volume during the process and its energy density [1].
In this paper Sodium Acetate + Graphite PCM materials are adopted for performing analysis and its thermal characteristics are given inTable 1.

Table1: PCM thermal storage properties [2]

PCM	SodiumAcetate+ Graphite
Melting Temperature [˚C]	56 to 60
Melting Enthalpy [kJ/kg]	240
Density [g/cm^3]	1.35

III. WATER TANK MODEL WITH PCM

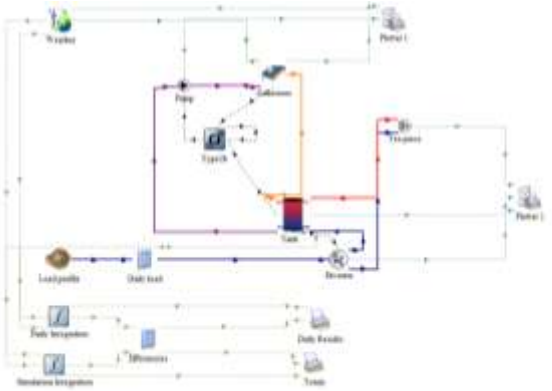

Figure1: TRNSYS model Setup for simulation

By using simulation studio-TRNSYS, TYPE840 is a model for water tank with possibility of PCM modules inclusion. The behavior of PCM introduced in certain system can be analyzed by this model.It can also be used to show the thermal characteristics of PCM material.

Due to change in thermal properties of PCM during the phase change of the PCM, the theoretical approach is carried out for modelling of phase change process. The multi-node storage model for water tank has been implemented into the stimulation environment where the nodes are obtained by sub dividing the PCM storage in vertical direction [3].

In order to calculate the time evolution of enthalpy and temperature an energy balance equation for each storage node is formulated. Fig.1 shows that the storage volume is divided into N vertical segments ~~(nodes).~~ Each node is characterized by the enthalpy hj ,the temperature Tj and the mass mj of the storage fluid in the node(j). Eq.(1) gives the energy balance equation for any (and each) storage node and it gives the enthalpy hj for j-th node and also the temperature Tj of the given j-th node:

$$m_j \frac{{h_j}^{p+1} - {h_j}^{p}}{\Delta t} = Q^p_{dp} + Q^p_{aux} + Q^p_{cond} + Q^p_{hx} + Q^p_{loss} + Q^p_{module} \quad (1)$$

InEq.(1), Q^p_{dp} [W] denotes the heat flow due to the mass flow through a double port (direct connection to the tank), Q^p_{hx} [W] is the heat flow exchanged with an internal heat exchanger, Q^p_{aux} [W] represents the heat input coming from a built-in electric heater, Q^p_{cond} [W] is the heat conduction to adjoining storage nodes, Q^p_{loss} [W] represents the heat losses to the ambient and Q^p_{module} [W]denotes the heat exchange with built-in PCM modules [3].

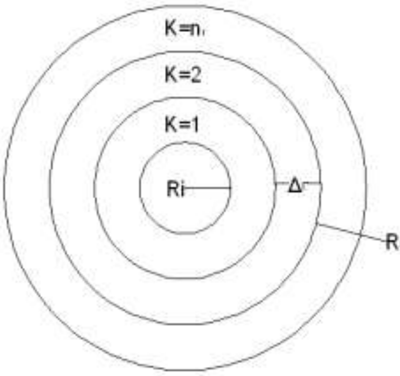

Figure 2 : Multi-node storage model with N nodes with the height Δz and the top and lower cross sectional area A; nodal network of a cylindrical PCM module (pipe module) with the vertical nodes (j) [3]

The evolution of the enthalpy with time is determined with the explicit approach as shown in Eq. (2):

$$h_j^{p+1} = h_j^p + \frac{\Delta t}{m_j} . \Sigma Q^p$$

Thus the enthalpy in the time (p+1) results explicitly out of the respective terms in the time
(p). [3]

IV. COMPARISON OF SENSIBLE HEAT AND LATENT HEAT

A simple experiment is done to calculate the heat storage difference between SHS and LHS. A 300l tank filled only with water is compared to a 300l tank filled with 70% of water and 30% of PCM. The TRNSYS simulation program is used to analyze the heat changing scenario of different tanks. Both the water tank and water tank with PCM modules are simulated using the model TYPE 840. InFig.2, it shows the model of the both water tank is presented, with parameters adopted in simulation. The division of tank into nodes is illustrated also in Fig. 2, as well as position of double ports, and PCM modules present in tank are schematically illustrated. Shape of PCM modules is chosen to be cylinder, over sphere, because it has both manufacturing and installing advantages.

Simulation parameters used in TRNSYS for tank with only water are presented in Table2. In Table 3 simulation parameters for the case of tank with both water and PCM are given. Basic simulation parameters are equal for both cases; the only difference is storage material (water vs water and PCM).

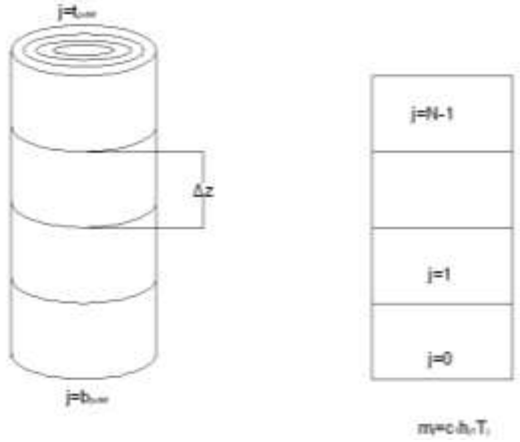

Figure 3: Left: schematic representation of water tank in TRNSYS, divided vertically in nodes; Right: water tank with PCM modules inserted, filling ratio of PCM is 30% [4]

Table2: Simulation parameters for tank with only water

Water tank and simulation parameters	
Tank storage fluid volume	0.3 m^3(water)
Tank height	1.4 m
Simulation time	24 h
Simulation time step	0.05 h
Number of nodes of the tank	20
TINLET_HX	65 ˚C
VHX	300 kg/h
Number of temperature sensors	5
TINITIAL_TANK	50˚C
TAMB	20˚C
Heat exchanger dimensions	
Outer Diameter of HX pipe, DO	22 mm
Length of HX pipe,L	20 m
Heat exchanger total volume	0.007598 m^3

Heat is delivered to system through internal heat exchanger (HX). Its dimensions, as well as temperature and mass flow rate of hot inlet water, are given in Table 2.

Table3: Simulation parameters for tank with water and PCM

Watervolume	0.21 m^3=70% of tank Storage volume
PCM Total Volume	0.09 m^3=30% of tank Storage volume
Number of nodes in PCM(radial)	4
Number of nodes(vertical)	20
PCM shape	Cylinders
Height	1.2 m
Number of modules	8
Diameter of module	109.3mm
PCM material	Sodium Acetate + Graphite

Quantity of heat expected to be stored in tank with 100% of water is:

$$Q = V \cdot \rho \cdot cp \cdot \Delta T = 5.18\text{kWh}.$$

Heat stored with both PCM and water can be estimated as:

$$Q_{w+PCM} = [V.\rho.C_{p,w}.\Delta T]_w + [V.\rho.C_{p,s}.\Delta T]_{PCM\_SEN1} + Q_{LAT\_PCM} + [V.\rho.C_{p,l}.\Delta T]_{PCM\_SEN2} = 8.825kWh$$

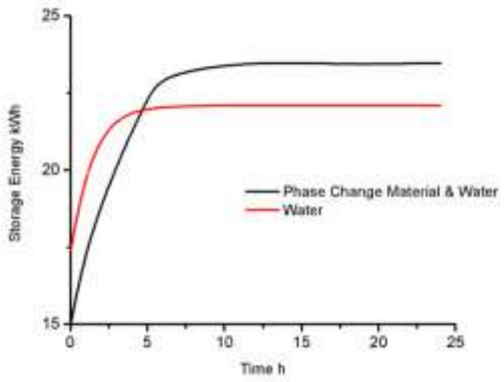

Figure 4: Total energy of storage fluid independence of time for two types of water tank [4]

Table3: Quantity of heat stored in two tanks

Heat stored in tank with water	4.9 kWh
Heat stored in tank with water	8.84 kWh

The results of simulation in TRNSYS give approximately expected quantity of stored heat as in Eq. (3) and Eq. (4). InFig.3, a characteristic of using PCM modules in the tank can be seen. The time needed to charge the storage material in the case of the tank with both PCM and water is greater than in the case of the tank filled with only water. Time needed to load the tank with water as a storage fluid in this case is 4.5h, and the time needed to load the tank with both PCM and water is 6.75 h.

However, in the tank that contains both water and PCM the so called speed of charging, is greater compared to the tank with only water. The speed of charging is the ratio of heat accumulated in the storage fluid and the time needed to achieve that. For the tank with water,

This parameter can be expressed as:

$$u_{water} = \frac{\Delta Q_{water}}{\Delta\tau} = \frac{22.05-17.22}{6.75} = 1.0733 kWh/h \tag{5}$$

And for the tank with water and PCM the speed of charging is 15.6 %larger:

$$u_{water+PCM} = \frac{\Delta Q_{water+PCM}}{\Delta\tau} = \frac{23.35-14.76}{6.75} = 1.2726\ kWh/h \tag{6}$$

Eq. (5) and (6) show that, even though more time is needed to heat up the tank with PCM, the quantity of heat accumulated per unit of time is greater in this tank.

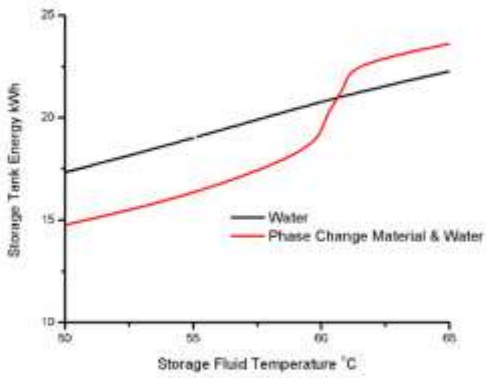

Figure 4: Temperature of water in tank for two types of tank [4]

InFig.4, total energy of the store independence of the temperature of the storage fluid (water) is compared for the two mentioned cases of water tanks: (i) with water only, and (ii) water and PCM.

It can be seen that in the temperature range where PCM goes through the phase change (56˚C-60˚C) the heat stored in the tank with both water and PCM, with just a few degrees of Temperature difference, is much greater than the heat stored in the tank that contains only water.

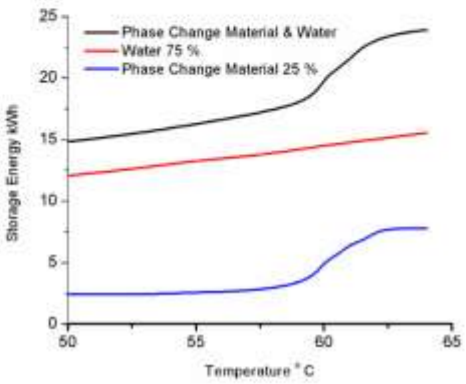

Figure5: Energy stored in tank with PCM modules separated into segments [4]

In Fig.5, the energy stored in storage fluids, for the tank with water and PCM, depending on temperature of tank water is presented. The top most curves represents the total energy stored in storage fluids of the tank (both water and PCM).The bottom two curves represent the heat stored in water and in PCM, separately. The heat stored in PCM during the phase change is 3.63kWh in the temperature range of approximately 2˚C. Using water, in the same temperature interval 0.6kWh can be stored.

The top most and the lower most curves at approximately 58˚C start to have a greater inclination. This goes on until around 62˚C, and the amount of energy rises up faster in this area of temperatures. In this part is the latent heat stored inside the PCM modules.

It is also important to observe that after the phase change the PCM material can store less energy via sensible heat than water. This is explained by the fact that the specific heat capacity of the water is greater than the specific heat capacity of PCM. Note that the volume of water in the case with PCM is smaller than in the tank with water only, in order to fit the PCM modules in the tank, keeping the same total volume of tank. In Table4 the latent and total heat stored in PCM, obtained with simulation, are presented.

Table 4: Heat stored in tank with water and PCM

Total heat stored in tank(water+PCM)	Q_{TOTAL}=8.84 kWh
Sensible heat stored in tank (75%water)	$Q_{SENSIBLE\_W}$=3.4 kWh
Latent heat stored in PCM	Q_{LAT_PCM}=3.63 kWh
Total heat stored in PCM(sensible+latent)	Q_{PCM}=5.29 kWh

The difference between and can be explained with quantity of heat lost into ambient, that is taken into account by water tank model in simulation program TRNSYS.

V. CONCLUSION

The comparison of sensible and latent heat storage is done in this paper. Behavior and possibilities of PCMs in thermal energy systems obtained are obtained by this work. In general characteristics of having PCMs present in water tank are having higher energy storage and stable water temperature in tank. Stored energy that cannot be used in given moment but it can be used later (instead of releasing it into environment). When PCM modules are included in system, the time needed to heat the tank is always longer compared to systems without PCMs. However, the speed of charging (the ratio of heat accumulated in the storage fluid and the time needed to achieve that) is greater for the case of tank with water and PCM. This shows that PCMs can help improve thermal energy system when they are used in adequate temperature range.

REFERENCES

[1] Om Nayak, A., Gowtham, M., Vinod, R., Ramkumar, G. Analysis of PCM Material in Thermal Energy Storage System. *International Journal of Environmental Science and Development, Vol. 2, No. 6, December 2011.0*

[2] A.Ponshanmugakumar, S.Badrinarayanan, P.Deepak, H.Sivaraman and R.Vignesh Kumar, Numerical investigation On Vertical Generator integrated with phase change materials In Vapour Absorption Refrigeration System, Applied Mechanics and Materials Vols 766- 767 (2015) pp 468-473

[3] Heinz,A.,Streicher, W. Application of phase change materials and PCM-slurries for thermal energy storage. Technische Universität Graz, Institutfür Wärmetechnik (IWT), Graz

[4] Heinz, A., Schranzhofer,H., TYPE840- Model for the transient simulation of water-or PCM slurry-tanks with integrated PCM modules. Technische Universität Graz, Institutfür Wärmetechnik (IWT), Graz, 2007.

[5] Trogrlic,M., Analysis and design of systems for thermal energy storage at moderate temperatures based on phase change materials, *Master Thesis*, Trondheim, Norway: Norwegian University of Science and Technology (NTNU), 2014.

[6] Ponshanmuga kumar, A, Sivashanmugam, M, Stephen Jayakumar, S. Solar Driven Air Conditioning System Integrated with Latent Heat Thermal Energy Storage. Indian Journal of Science and Technology, p. 1798-1804, Nov. 2014. ISSN 0974 -5645