© 2017 IJRTI | Volume 2, Issue 5 | ISSN: 2456-3315

# A Critical Review on Thermal Energy Storage Systems

**K. Ashok Reddy**

Professor
Department of Mechanical Engineering
MLR Institute of Technology, Dundegal (V), Hyderabad-43

***Abstract*: In this paper a review was carried for thermal energy storages on latest developments and the previous research work on using phase change materials. These systems having the potential to be used as material for energy storage are classified and divided with their melting point and latent heat of fusion. Different methods for improving the thermo-physical properties of phase change materials like heat transfer enhancement, heat balance, encapsulation, inclusion of nanostructures and shape stabilization are discussed. The effect of stability due to the corrosion of construction materials and different applications where the phase change material can be employed for energy storage like free cooling of homes, air-conditioning, refrigeration systems and cold packing are highlighted.**

***Keywords*: thermal energy storage, heat transfer, phase change material and heat exchanger.**

## 1. Introduction

Z.N. Meng and P. Zhang [1] presented in their technical paper the a tube-in-tank latent thermal energy storage unit using paraffin as phase change material was developed , which can be used in many applications. In order to enhance the thermal performance of the LTES unit, the composite PCM was fabricated by embedding copper foam into pure paraffin. The performances of the LTES unit with the composite PCM during the heat charging and discharging processes are investigated experimentally, and a series of experiments are carried out under different inlet temperatures and inlet flow velocities of the heat transfer fluid (HTF). The temperature evolutions of the LTES unit are obtained during the experiments, and the time-durations, mean powers and energy efficiencies are estimated to evaluate the performance of the LTES unit. Meanwhile, a three-dimensional (3D) mathematical model based on enthalpy-porosity and melting/solidification models was established to investigate the heat transfer mechanisms of the LTES unit and the detailed heat transfer characteristics of the LTES unit are obtained. It can be concluded that the LTES unit with the composite PCM shows good heat transfer performance, and larger inlet flow velocity of the HTF and larger temperature difference between the HTF and PCM can enhance the heat transfer and benefit the thermal energy utilization.

Radouane Elbahjaoui and Hamid El Qarnia [2] presented in their technical paper by using Paraffin Wax (P116) dispersed with Al2O3 nanoparticles in a rectangular latent heat storage unit (LHSU) was numerically obtained. The storage unit consists of a number of vertical and identical plates of nanoparticle-enhanced phase change material (NEPCM) separated by rectangular channels through which a heat transfer fluid flows (HTF: Water). A two-dimensional mathematical model was considered to numerically investigate the heat and flow characteristics of the LHSU. The heat transfer and fluid flow during the melting process were formulated using the enthalpy-porosity method. The finite difference forms of the governing equations are obtained using the finite volume approach.
Yang Xu et al [3] presented in their technical paper the melting performance of phase change materials (PCMs) in a horizontal concentric–tube thermal energy storage (TES) system using numerically in natural convection mode. Porous media were employed to enhance the thermal response of PCMs. Performances of different porous configurations were compared to optimize the location of porous insert, and the optimal filling ratio of porous insert was determined based on a new criterion proposed in this study, which was called TES rate density. This new criterion was proved to be effective to comprehensively evaluate the melting performance, including melting time, TES capacity, and total mass of materials. Best enhancement on melting performance of PCM and the optimal filling height ratio of porous media was 0.7. With the full-porous case, 3% better comprehensive performance with about 28% less porous material can be achieved. Adèle Caron-Soupart, Jean-François Fourmigué, Philippe Marty, Raphaël Couturier [4] presented in their technical paper thermal energy storage (TES) systems with phase change materials (PCM) are mainly analysed using conductive numerical models and compared doing an energy balance with the inlet and outlet heat transfer fluid (HTF) temperatures. In this paper, an alternative experimental performance analysis method was proposed. Experiments have been carried out on a single stainless steel tube, a steel tube with longitudinal fins and a copper tube with helical fins to validate the technique. The implementation of the method for the charging process demonstrated the interest of increasing the heat exchange surface to enhance the heat exchange power. The importance of natural convection in the liquid PCM and its impact on the heat transfer improvement has also been highlighted.
Mario Cascetta et al [5] presented in their technical paper the comparison between CFD and experimental results obtained on a sensible thermal energy storage system based on alumina beads freely poured into a carbon steel tank. Experimental investigations of charging and discharging phases were carried out at a constant mass flow rate using air as heat transfer fluid.

The experimental set-up was instrumented with several thermocouples to detect axial and radial temperature distribution as well as reservoir wall temperature. The experimental results were compared with those obtained from CFD simulations carried out with the FLUENT software. The computational domain consists of an axis symmetric tank of cylindrical shape filled with a porous bed coupled with the wall.

The porosity of the bed was considered variable in the radial direction, while the thermodynamic properties of both phases are temperature-dependent.

C. Veerakumar, and A. Sreekumar [6] presented in their technical paper a comprehensive review on recent developments and the previous research studies on cold thermal energy storage using phase change materials. Moe Kabbara et al [7] presented in their technical paper on a latent heat energy storage system consisting of a tank filled with phase change material , dodecanoic acid, coupled with a finned tube heat exchanger. The study included charging experiments under controlled experimental conditions with parametric alterations on the HTF flow rate and inlet temperature. Discharging experiments using municipal water looked at the discharge time and heat transfer rates based on an alteration of the HTF flow rate. The characterization of the LHESS showed that increasing the HTF inlet temperature during charging resulted in significantly faster melting time. A decrease of 3.5 hours was observed when increasing the HTF temperature from 60 to 70 °C, while another decrease of 2 hours was observed with an increase from 70 to 80 °C. Increasing the HTF flow rate during charging from 0.7 to 1.5 L $min^{-1}$ did not have any significant effects on heat transfer rates, however an increase from 1.5 to 2.5 L $min^{-1}$ resulted in higher heat transfer rates and decreased melting time by 1 hour..

M Martinelli et al [8] presented in their technical paper the design of a latent heat thermal energy storage system (LHTESS) for district heating. The tube was radially finned on its external wall to enhance the heat transfer in the phase change material. The test rig was operated with flow conditions corresponding to the proposed design. As the internal flow of heat transfer fluid (HTF) appears to be laminar and is highly influenced by buoyancy forces, which results in mixed convection regime, cross-sectional area reducers are installed inside the HTF tube in order to reduce the Rayleigh number and thus natural convection.

Zakir Khan et al [9] presented in their technical paper a two-dimensional finite element computational model which investigates thermal behaviour of a novel geometrical configuration of shell and tube based latent heat storage (LHS) system. Commercial grade paraffin was used as a phase change material (PCM) with water was employed as a heat transfer fluid (HTF). The parametric investigations are conducted to identify the enhancement in melting rate and thermal storage capacity. The parametric investigations are comprised of number and orientation of tube passes in the shell, longitudinal fins length and thickness, materials for shell, tube and fins, and inlet temperature of HTF. Numerical analysis revealed that the melting rate was significantly enhanced by increasing the number of tube passes from 9 to 21. In 21 passes configuration, conduction heat transfer was the dominant and effective mode of heat transfer. The length of fins has profound impact on melting rate as compared to fins thickness. Also, the reduction in thermal storage capacity due to an increase in fins length was minimal to that of increase in fins thickness. The influence of several materials for shell, tube and fins are examined. Due to higher thermal conductivity, the melting rate for copper and aluminium was significantly higher than steel AISI 4340, cast iron, tin and nickel. Similarly, the thermal storage capacity and melting rate of LHS system was increased by a fraction of 18.06% and 68.8% as the inlet temperature of HTF was increased from 323.15 K to 343.15 K, respectively.

Abdel Illah et al [10] pesented in their technical paper the experimental study of a PCM storage unit for storing latent heat thermal energy. Three different types of paraffin are tested as phase change material (PCM) and water was used as heat transfer fluid (HTF). The temperatures of PCM and HTF, solid fraction and thermal effectiveness are analyzed. The effects of inlet temperature of HTF, flow rate of HTF and the type of PCM used on the time for charging and discharging heat are discussed. Inlet temperature has a great effect on the exchanger performance with charging phase 54.5% and delay the discharging phase by 48.5%. Adding the oil engine to the paraffin can improve the speed of the charging and discharging heat process by 42.4 and 66%, respectively.

Cavazzuti M. et al [11] presented in their technical paper about computational fluid dynamics analysis to show operational parameters with different boundary conditions .A optimization technique was introduced for evaluating the process inside the concentric pipes heat exchanger. The application was found to be useful in industrial recuperative burners, where waste heat recovery play important role and to overcome the issue of fuel consumption can be solved by using Neilder and Mead algorithm technique.

Zhang B et al [12] presented in their technical paper the experimental validation taking into consideration about the ratio of container volume and tilt angle of a solar energy photovoltaic coupled heat pipe . Operational parameters like hot coolant circulation and output power were been evaluated . A TRNSYS software have been implemented and it can be inferred from the data obtained the hot coolant and power output shows decreasing firstly and when the change was made with container volume, the power out put was shown steep hike. With circulating container volume was made constant as 80 litres, the maximum efficiency was found to be 67.5%, where as the title angle and orientation of the collector heat pipe was made optimized , the average efficiency was found to be 4,37% and the heat storage capacity was about 2328 MJ/Year. Bia L., Zhang et al [13] presented in their technical paper the application and review of loop heat pipe which are used for maximum distance in crycocooling space studies. Different loop heat pipes were compared to evaluate the heat transfer rates using in supercritical conditions .

Han C., and Zou L.[14] presented in their technical paper an analytical method to evaluate the flow and temperature mapping for the inner and upper surface of the heat pipe under transient boundary condition for inside surface of the heat pipe. They also analyzed the heat transfer rates for moderate temperature keeping other parameters to be inline the extraction of heat dissipation in the inner surface.M. Patriknemec et al [15] have demonstrated experimentally different coolants with help of heat pipe test

rig. H.Shabgard et al [16] presented in their technical paper about high temperature coolants have been used for sensible and latent heat thermal capacity act ivies implementing heat pipe source for enhancing the heat transfer Rates .
Agyenim et al [17] presented in their technical paper for design the concept based heat pipe energy saving device. Hughes B R. et al [18] . presented in their technical paper the climatic condition data coupled with 19 cylindrical heat pipes operating under different temperatures conditions. A wind tunnel test was design and fabricated and integrated with climate responsive assumption with heat pipe sources temperatures.

By assuming 24 hour duration , a study was made with low Reynolds number air flow and cooling output was increased by 0.1 degree for 1 degree rise for the source temperature.
Huai-Zhi Han et al [19] presented in their technical paper three-dimensional heat transfer and flow model, a multi-objective optimization aims to fulfill the geometric design for double-tube heat exchangers with inner corrugated tube with RSM. Dimensionless corrugation pitch , dimensionless corrugation height , dimensionless corrugation radius and Reynolds number are considered as four design parameters. Considering the process parameters, the characteristic numbers involving heat transfer characteristic, resistance characteristic and overall heat transfer performance calculated by CFD, and are served as objective functions to the RSM. According to the Pareto optimal curves, the optimum designing parameters of double pipe heat exchanger with inner corrugated tube under the constrains of $Nu_c/Nu_s \geq 1.2$ are found to be $P/D = 0.82$, $H/D = 0.22$, $r/D = 0.23$, $Re = 26{,}263$, corresponding to the maximum value of $\eta = 1.12$
R. Velraj et al [20] presented in their technical paper acceptance and the economics of solar thermal technologies are tied to the design and development of efficient, cost-effective thermal storage systems. Thermal storage units that utilize latent heat storage materials have received greater attention in the recent years because of their large heat storage capacity and their isothermal behavior during the charging and discharging processes. One major issue that needs to be addressed is that most phase-change materials with high energy storage density have an unacceptably low thermal conductivity and hence heat transfer enhancement techniques are required for any latent heat thermal storage applications.
F. Tardy, et al [21] presented in their technical paper a mathematical model has been developed to predict the thermal behavior of heat pipes with thermal storage during a cooling cycle. A heat transfer model based upon the various mechanisms of conduction, convection as well as heat of fusion of the melted ice is presented. The thermal behavior of heat pipes has also been studied experimentally and analyzed under different conditions. Nourouddin Sharifi et al [22] presented in their technical paper heat pipe-assisted melting of a phase change material (PCM) housed within a vertical cylindrical enclosure was simulated and was compared to melting induced by heating from an isothermal surface, or with a solid rod or a hollow tube.

**References :**


[1].Z.N. Meng and P. Zhang , "Experimental and numerical investigation of a tube-in-tank latent thermal energy storage unit using composite PCM ", Applied Energy, 190(3), 2017, 524–539
[2].Radouane Elbahjaoui, Hamid El Qarnia Transient behavior analysis of the melting of nanoparticle-enhanced phase change material inside a rectangular latent heat storage unit Applied Thermal Engineering 112(2), 2017, 720–738
[3].Yang Xu, Qinlong Ren, Zhang-Jing Zheng, Ya-Ling He Evaluation and optimization of melting performance for a latent heat thermal energy storage unit partially filled with porous media Applied Energy 193(5), 2017, 84–95
[4].Adèle Caron-Soupart, Jean-François Fourmigué, Philippe Marty, Raphaël Couturier Performance analysis of thermal energy storage systems using phase change material Applied Thermal Engineering 98(4), 2016, 1286–1296
[5].Mario Cascetta , Giorgio Cau, Pierpaolo Puddu, Fabio Serra A comparison between CFD simulation and experimental investigation of a packed-bed thermal energy storage system Applied Thermal Engineering 98(4), 2016, 1263–1272
[6].C. Veerakumar, A. Sreekumar Phase change material based cold thermal energy storage: Materials, techniques and applications – A review International Journal of Refrigeration 67(7),2016, 271–289
[7].Moe Kabbara, Dominic Groulx Alain Joseph Experimental investigations of a latent heat energy storage unit using finned tubes Applied Thermal Engineering Volume 101, 25 May 2016, Pages 601–611
[8].M Martinelli , F Bentivoglio , R Couturier , J-F Fourmigué , P Marty " Experimental study of an externally finned tube with internal heat transfer enhancement for phase change thermal energy storage", Journal of Physics, Conference Series 745, 2016, 032029 doi:10.1088/1742-6596/745/3/032029 1-9
[9].Zakir Khan, Zulfiqar Khan , Kamran Tabeshf Parametric investigations to enhance thermal performance of paraffin through a novel geometrical configuration of shell and tube latent thermal storage system Energy Conversion and Management 127(11), 2016, 355–365
[10].Abdel Illah Nabil Korti, Fatima Zohra Tlemsani Experimental investigation of latent heat storage in a coil in PCM storage unit Journal of Energy Storage 5(2), 2016, 177–186
[11] Cavazzuti M., Agnani E. and Corticelli M., "Optimization of a finned concentric pipes heat exchanger for industrial recuperative burners", Applied Thermal Engineering 84(6) 2015, 110-117
[12] Zhang B., Lv J., Yang H., Li T. and Ren S. "Performance analysis of a heat pipe PV/T 1 with different circulation tank capacities", Applied Thermal Engineering 87(8), 2015,89-97
[13] Bia L., Zhang L., Lin G., He J. and Wen D. "Development of cryogenic loop heat pipes: A review and comparative Analysis", Applied Thermal Engineering 89(10), 2015,180-191
[14] Han C and Zou L. Study on the heat transfer characteristics of a moderate temperature heat pipe heat exchanger", International Journal of Heat and Mass Transfer 91(12) , 2015,302–310

[15] M. Patriknemec, Alexander Aja, "Thermal performance measurement of heat pipe," University of Ilina, Department of power engineering, Univerzitn, 2011
[16] H.Shabgard, T.L.Bergman, N. Sharifi, and A.Faghri, "High temperature latent heat thermal energy storage using heat pipes," Int.J.Heat Mass Transfer, 53(15), 2010 2979–2988
[17] M. S. F. Agyenim, P. Eames, "Heat transfer enhancement in medium temperature thermal energy storage system using a multitube heat transfer array," Renew. Energy, 35, 2010, 198-207
[18] Hughes B R., and Chaudhary N H , " Climate responsive behaviour of heat pipe technology for enhanced passive airside cooling Applied Energy 136(12), 2014, 32-42
[19] Huai-Zhi Han Bing-Xi Li Hao Wu Wei Shao, "Multi-objective shape optimization of double pipe heat exchanger with inner corrugated tube using RSM method", International Journal of Thermal Sciences 90(4), 2015, 173–186
[20] R. Velraj, R.V. Seeniraj, B. Hafner, C. Faber, K. Schwarzer , "Heat Transfer Enhancement In A Latent Heat Storage System", . Solar Energy 65(3), 1999, 171–180
[21] F. Tardy, Samuel M. Sami, "Thermal analysis of heat pipes during thermal storage, Applied. Thermal Engineering . 29(2-3), 2009, 329–333
[22] Nourouddin Sharifi, Shimin Wang, Theodore L. Bergman , Amir Faghri "Heat pipe-assisted melting of a phase change material, International Journal of Heat and Mass Transfer 55 (4), 2012, 3458–3469