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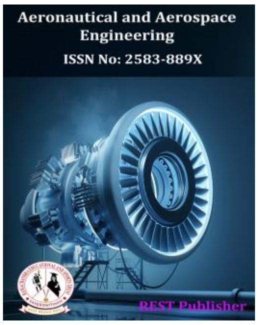

Experimental Investigation of the Effect of Phase Change Material in Mitigation of Heat

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Abstract. *The use of a latent heat storage system using phase change materials (PCMs) is an effective way of storing thermal energy and has the advantages of high-energy storage density and the isothermal nature of the storage process. PCMs have been widely used in latent heat thermal storage systems for heat pumps, solar engineering, and spacecraft thermal control applications. The uses of PCMs for heating and cooling applications for buildings have been investigated within the past decade. There are large numbers of PCMs that melt and solidify at a wide range of temperatures, making them attractive in a number of applications. This paper also summarizes the investigation and analysis of the available thermal energy storage systems incorporating PCMs for use in different applications.*

Keywords*: Thermal energy storage systems; Phase change material; Solar energy; Latent heat; Melt fraction*

1. INTRODUCTION

The increasing levels of greenhouse gas emissions and rising fuel prices have become driving forces behind the global efforts to harness renewable energy sources more effectively. Among these sources, direct solar radiation stands out as a highly promising energy resource in many parts of the world. As scientists worldwide seek new and sustainable energy solutions, energy storage technology has emerged as a critical component alongside the development of these new energy sources. Effective energy storage, capable of converting stored energy into the required form when needed, is a pressing challenge for today's technologists. Energy storage not only addresses the gap between energy supply and demand but also enhances the performance and reliability of energy systems while playing a vital role in conserving energy resources. It leads to savings in premium fuels and increases the cost-effectiveness of systems by minimizing energy wastage and capital costs. For example, energy storage can improve the performance of power generation plants through load levelling, resulting in energy conservation and reduced generation costs.

One promising technique for storing thermal energy is the use of phase change materials (PCMs). However, before this technology can be widely applied, numerous challenges need to be overcome during the research and development phase. In this context, various methods of energy storage are explored, including mechanical, electrical, and thermal energy storage. Mechanical energy storage encompasses technologies like gravitational energy storage, compressed air energy storage (CAES), and flywheels, which are suitable for different scales of utility energy storage. Electrical storage involves the use of batteries, where energy is stored as chemical potential and then converted to electrical energy as needed. The focus of this discussion lies in thermal energy storage, particularly latent heat storage. Thermal energy can be stored as sensible heat or latent heat, with the latter showing particular promise due to its ability to store energy at a constant temperature corresponding to the phase change temperature of PCM. Different forms of PCM transitions are examined, and the challenges related to their application are addressed.

The passage emphasizes the pivotal role of energy storage in addressing the intermittent nature of many energy sources and in enhancing overall energy efficiency. It underscores the importance of short-term and long-term energy storage solutions in various applications, from solar energy utilization to load levelling and building energy efficiency. In summary, this introduction sets the stage for a deeper exploration of energy storage methods, with a specific focus on the importance of thermal energy storage, its challenges, and its significance in the context of sustainable and efficient energy utilization.

2. LITERATURE REVIEW

Armin Ghodrati, Rahim Zahedi, Abolfazl Ahmadi discussed about the - highlights that incorporating Phase Change Materials (PCMs), such as water and ethylene glycol Addresses the growing need for efficient energy storage in various applications, notably in appliances**.** [1]

Nan Sheng, Zhonghao Rao, Chunyu Zhu, Hiroki Habazaki discussed about - To address the issues of leakage and enhance the thermal conductivity of paraffin PCM. [2]

XiaohuYang, Jiabang Yua,Tian Xiaoc, Zehuan Hua, Ya-LingHeb discussed about the performance of this enhanced thermal energy storage unit and compares it to other configurations, including a smooth tube. The evaluation is based on various indicators, such as complete melting/solidification time. [3]

M.E. Nakhchi, J.A. Esfahani discussed about - the use of lauric acid as a phase change material (PCM) in a rectangular LHTES The findings demonstrate significant improvements, with certain fin configurations achieving up to 65.5% faster PCM melting. [4]

Md. Hasan Zahir, Shamseldin A. Mohamed, R. Saidur , Fahad A. Al-Sulaiman - Explores the potential of inorganic salt-based (PCMs), known for their cost-effectiveness, high-energy storage capacity. However, it addresses persistent technical challenges, such as phase separation and supercooling, in these inorganic PCMs. [5]

P. McKenna, W.J.N. Turner, D.P. Finn - The study demonstrates that geo cooling and thermal energy storage (TES) It offer substantial energy and carbon reductions in cooling for Mediterranean climates, with potential savings of 24-45%. [6]

Rathod, M. K., & Banerjee, J. discussed about the latent heat energy storage systems relies on the thermal reliability and stability of phase change materials (PCMs). This review categorizes PCMs and compiles a database of test results to assist in selecting reliable PCMs. [7]

Conrad Volker, Oliver Konrad, Milan Ostry discussed about the Utilizing of phase change materials (PCMs) such as paraffin, reducing room temperatures up to 4 K. A validated mathematical model shows the potential for PCM integration in improving building comfort and energy efficiency. [8]

Zhang, D, Tian, S., & Xiao. D. - discussed about the experimental study on the phase change behavior of organic phase change materials (PCMs) in porous building materials is reported. Three kinds of porous materials and two kinds of PCMs were used. [9]

José M. Marín, Belén Zalba, Luisa F. Cabeza, Harald Mehling discussed about - Enhance the efficiency of TES systems, addressing the low heat transfer rates associated with conventional phase change materials (PCMs). In this context, free cooling refers to the storage of cold energy during night time hours to be used during the day for cooling purposes. [10]

Manuel Ibáñez, Ana Lázaro, Belén Zalba, Luisa F. Cabeza discussed about a methodological approach for the energetic simulation of buildings incorporating specific phase change materials within TRNSYS. Experimental validation is demonstrated using a concrete block containing PCM at a 5% kg PCM/kg concrete ratio. [11]

El-Dessouky, H, & Al-Juwayhel, F.- discussed about the Analysis for a phase-change thermal energy storage system involves determining entropy generation numbers (Ns) during a cyclic operation. This analysis considers various factors, such as the Reynolds number of the operating fluid, specific heat transfer area. [12]

Fr´ed´eric Kuznika, Damien Davida, Kevyn Johannesa, Jean-Jacques Rouxa evalutated the phase change materials used in building wall applications can be either organic materials or inorganic materials. The simplest method consists in the direct impregnation of the PCM into a gypsum, concrete or other porous materials to form mixed type PCMIBW. Khudhair et al explained the different impregnation techniques. The volume occupied by the PCM in the pores is small enough to prevent from the isolation of the solid PCM crust. The structure of the porous material transports the heat to the pores. [13]

D. Zhou1, C. Y. Zhao1, Y. Tian1-They reviewed the PCMs used for buildings and outlined the building applications such as enhanced gypsum wallboards, enhanced concrete and enhanced insulated materials. The materials in general for thermal energy storage and main applications of PCMs were presented. They gave a summary for the previous researches on incorporating PCMs into construction materials, such as concrete, gypsum wallboard, ceiling and floor. [14]

A novel shape-stabilized phase change material wallboard (PCMW) was prepared from expanded perlite as a supporting material and paraffin as a PCM in a research conducted [15]

Adeel Waqasan, Zia Ud Dinb evaluates that the commercially available PCM granules GR were used as the storage material. An economic feasibility analysis of the free cooling system conducted by Marin et al. It can be seen that the storage material (PCM) has a share of about 17% in the whole free cooling system. [16]

C. Veerakumar, A. Sreekumar evaluates that the hybrid nanophase change material (HyNPCM) as a viable material for cold storage application. f PCMs that consists of working material and a supporting material. The support ing material remains in solid phase even when the working material undergoes phase change. [17]

V.Antony AroulRaja,R.Velraj evaluates that Granules made by RUBITHERM GmbH were used as PCM granules in the experiment. The granules have a particle diameter of 1–3 mm and consist of 65% ceramic materials and 35% paraffin hydrocarbon by weight. [18]

Na Zhu, Zhenjun Ma, Shengwei Wang evaluates that in building applications, PCMs can be integrated into building covering materials such as concrete, gypsum wallboard, plaster, etc., as part of building structures for lightweight or even heavy weight buildings to increase the thermal mass. They can also be installed in water circuits or air circuits of HVAC systems as thermal energy storage tank to provide functional purposes. The use of PCMs in buildings can provide different functions for different applications. For instance, they can be used for free cooling of buildings, building peak load shifting, solar energy utilization, waste heat recovery, etc. These functions can be achieved passively or actively. Here, the passive means that the use of PCMs in the structure of buildings and the melting and freezing of PCMs are realized without resort to mechanical equipment. The active means that the charging and discharging of energy in PCM storages are achieved with the help of mechanical equipment. [19]

3. SELECTION OF MATERIALS

Annabelle Joulin, Zohir Younsi, Laurent Zalewski, Stéphane Lassue, Daniel R. Rousse d, Jean-Paul Cavrot used Various organic, inorganic, polymeric, and eutectic compounds, including polyethylene glycol (PEG) and its composites like PEG/SiO2, have been utilized as phase change materials and To enhance thermal conductivity, incorporated β-Aluminum nitride and expanded graphite into organic PCMs. Salt hydrates are also widely used PCM due to their high latent heat capacity. [20]

A. Pasupathy, L. Athanasius, R. Velraj, R.V. Seeniraj investigated the impacts of concrete alkalinity, temperature, immersion time, and PCM dilution on PCM absorption during the impregnation process. Wood lightweight concrete consists of a mixture of cement, wood chips or sawdust (not exceeding 15% by weight), water, and additives. This blend is suitable for both interior and exterior wall construction, explored the integration of two PCM materials, Rubitherm GR40 (1–3 mm) and GR50 (0.2–0.6 mm), into wood lightweight concrete [21]

Annabelle Joulin, Laurent Zalewski, Stéphane Lassue, Hassane Naji had done their work on a method capable of assessing the thermophysical properties of building materials through heat flux measurements. A conventional mortar and a micro-encapsulated PCM-based mortar (PCM-M, Micronal PCM DS 5001 X) are chosen as reference materials and thermally characterized and compared. The PCM-M, embedded in gypsum and reinforced with additives, has been studied experimentally in a recent work [22]

Bogdan M. Diaconu, Szabolcs Varga, Armando C. Oliveira used the microencapsulated PCM slurry comprised an aqueous dispersion of phase change material (RT6) encapsulated in polycyclic cells, resulting in microcapsules with a volume mean diameter of 2.24 µm. The thermal properties of the PCM slurry were investigated experimentally using differential scanning calorimetry (DSC) analysis performed on a Micro DSC III Differential scanning calorimeter (SETARAM). [23]

A.G. Entrop, H.J.H. Brouwers, A.H.M.E. Reinders used two concrete floors contain 5% PCMs, micro-encapsulated mixture of paraffins was used with a melting point of 23C. They are provided by BASF under the name of Micronal DS 500 [24]

D. Verdiera, A. Ferrièreb, Q. Falcozb, F. Sirosc, R. Couturierd selected Lithium carbonate (Li2CO3), an inorganic PCM substances from Zabla's list of PCMs due to their resistance to very high temperatures. Since Li2CO3 exhibits excellent thermal conductivity and relatively high latent enthalpy. Experimental analysis conducted at CNRS/PROMES revealed that Li2CO3 exhibits negligible differences between solid and liquid density and minimal undercooling. [25]

Yannick Berthou, Pascal Henry Biwole, Patrick Achard, Hébert Sallée, Mireille Tantot-Neirac and Frédéric Jay explores the performance of an unvented Trombe wall featuring a super-insulating layer of silica aerogels, termed Transparent Insulation Material (TIM) layer, along with a phase change material (PCM) layer. Silica aerogels are transparent materials known for their high insulation properties, characterized by high porosity and pore size less than 1µm [26]

4. FABRICATION METHODS

J.M. Khodadadi, S.F. Hosseinizadeh presented this paper provides valuable insights into the potential use of NEPCMs for thermal energy storage, with a focus on the impact of nanoparticle dispersion on heat transfer and freezing processes. It is part of the broader field of research in thermal energy storage and nano fluids. [27]

Manila Chieruzzi1, Adio Miliozzi, Tommaso Crescenz, Luigi Torre1 and José M Kenny aims to investigate the thermal properties of nanofluids with different nanoparticles and their potential for enhancing the specific heat of potassium nitrate-based nanofluids. The research involves both experimental analysis and microstructural characterization of the nanofluid samples. [28]

S. Harikrishnan, K. Deepak, S. Kalaiselvam prepared to develop composite PCMs with enhanced thermal properties for applications in thermal energy storage. The combination of paraffin with CuO and TiO2 nanoparticles can potentially improve the heat storage capacity of the material, making it suitable for various thermal energy storage applications. [29]

Vivekananthan Mayilvelnathana, Amirtham Valan Arasu Highlights the method of improving the thermal properties of PCMs,focusing on the use of graphene nanopraticles to create NDPCMs. This method involves characterizing the NDPCM’s structure, measuring its thermal properties,conducting thermal cycling tests to evaluates its thermal reliability.[30]

Xiangdong Liua, Yongping Huangb, Xuan Zhangb, Chengbin Zhangb, Bo Zhou studies and conducted analyse the melting phase change processand investigate the impact parameters like fill angles and central angle gradient on LTES device performance, offering guidance for optimal LTES design in engineering applications. This research aims to address to intermittent nature of solar energy by improving the efficiency of energy storage, making sustainable energy solutions more practical and accessible. [31]

5. EXPERIMENTAL WORK AND RESULTS

Peizhao Lv, Chenzhen Liu, Zhonghao Rao The experimental study investigates four paraffin/kaolin composites with varying kaolin particle sizes. Larger particles lead to reduced specific surface area but improved thermal conductivity. SEM images reveal irregular morphologies, while XRD and FTIR analyses confirm successful paraffin integration into the kaolin structure. The composites demonstrate enhanced thermal conductivity, reduced crystallinity, and higher phase change temperatures compared to pure paraffin. Leakage tests show varying degrees of paraffin escape, with K1 exhibiting the least. The composites display excellent thermal stability and significantly faster thermal storage/release rates than pure paraffin. The study underscores the importance of kaolin particle size in shaping the thermal properties and practical applicability of the composites. [32]

Chunjing Lin, Sichuan Xu, Guofeng Chang, Jinling Liu’s the experimental study investigated the thermal performance of battery packs with and without a passive Thermal Management System (TMS). Using paraffin as a Phase Change Material, the TMS significantly reduced battery temperatures by 32% and 37% during 1C and 2C-rate discharges, respectively. The system demonstrated effective temperature control, maintaining acceptable temperature gradients of 2.0°C and 3.8°C during the discharges. Moreover, the passive TMS exhibited a notable warm-keeping effect in cold conditions, sustaining the battery within the desired temperature range without active heating components. The study recommended a combination of passiv**e** and active TMS for optimal cooling in electric vehicles with varying usage patterns. [33]

Mohamed Rady has done the experimental study by employed a packed column with PCM (GR27 or GR41 granulates) to explore thermal behavior. During charging, temperature rose rapidly, slowed during phase change, and increased again after melting. Discharging stabilized temperature around 27 °C due to solidification, with GR41 showing less temperature flattening than GR27. Temperature differences during sensible heat and phase change revealed PCM content's impact. Results aligned with characteristics from DSC and T-history methods, providing insights into PCM behavior in the setup. [34]

Hussein J. Akeiber, Seyed Ehsan Hosseini, Mazlan A. Wahid, Hasanen M. Hussen and Abdulrahman Th. Mohammad - the study investigated the impact of Phase Change Materials (PCM) in building structures for enhanced thermal comfort and energy efficiency. Comparing a room with PCM to one without, the PCM-integrated room notably reduced peak temperatures by 5 °C during solar exposure in August, highlighting its effective heat storage. In January,the PCM room maintained stability while the non-PCM room experienced fluctuations. Analysis of walls indicated higher thermal resistance in PCM walls. Overall, PCM integration demonstrated potential benefits, including reduced temperature fluctuations, improved environmental friendliness, and lower heat transfer, with implications for building management and architecture. [35]

Jiajia Gaoa, Tian Yana, Tao Xub, Ziye Lingc, Gongda Weia, Xinhua Xua has the experimental setup included a Solid-Solid Phase Change Material (SSPCM) slab, aluminum-alloy plane, and cast-aluminum heater. Using simplified models, particularly the 4R2C model with four resistances and two capacitances, the study explored the thermal performance of the SSPCM slab. Results showed accurate predictions for temperature profiles and heat flux, demonstrating the model's efficiency in simulating SSPCM behavior for potential building applications. [36]

Xiaoqin Sun, Jovana Jovanovic, Siyuan Fan, Youhong Chu, Yajing Mo, Shuguang Liao The study focused on enhancing space cooling efficiency using phase change materials (PCM) in building envelopes. A paraffin-based PCM (OP28E) with a melting temperature of 27–29 °C was utilized. The PCM was encapsulated in high-density polyethylene spheres and integrated into walls with extruded polystyrene insulation. Experimental results showed that PCM integration significantly reduced outdoor wall temperatures during heating, leading to lower indoor temperatures during cooling. The PCM's phase transition process demonstrated improved thermal storage and release capabilities, contributing to energy efficiency in building environments. The study emphasized the potential of PCM-enhanced insulation for effective temperature regulation in varying climatic conditions. [37]

6. CONCLUSION

From the literature review, it is observed that mostly paraffin and nanomaterials and fluids are used in the fabrication and investigation of the PCMs. Mostly the PCMs are investigated in bulding walls or in the battery or in the mitigation of heat.

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