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# Experimental heat transfer analysis of macro packed neopentylglycol with CuO nano additives for building cooling applications

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ABSTRACT

The overall objective of the work reported in this paper was to experimentally study the effect of adding CuO nanoparticles on heat transfer performance of Neopentyl Glycol (NPG) in building cooling applications. Macro packed NPG added with 0.1% weight fraction of CuO nanoparticles were subjected to thermal cycling characterization and the thermal performance study in building application. Heat transfer performance analysis was conducted using the macro packed PCM in a building model with a 100 W incandescent bulb for simulating solar energy source. The differential scanning calorimetry (DSC) analysis showed that thermal cycling caused about 10.4% and 11.05% decrease in enthalpy of transition in the case pure NPG and NPG + 0.1% CuO respectively. The results of Thermogravimetry (TG) analysis and Fourier Transform Infrared (FTIR) analysis respectively confirmed the thermal and chemical stability of NPG +0.1% CuO in the application range of building cooling. The thermal conductivity measurement by T-history method showed an increase of 12.75% due to the addition of 0.1% CuO. The experimental results showed that the lower room temperature was reduced by about 3 °C by the use of macro packed NPG. The addition of CuO nanoparticles accelerated the rate of charging and discharging that lead to the decrease in charging and discharging time of macropacked NPG. It was observed that the addition of 0.1% weight fraction of CuO nanoparticles to NPG resulted in about 6.45% increase in the lower room temperature compared 11.6 7% increase observed in the case of pure NPG.



## 1. Introduction

Energy consumption in buildings accounts to 30–39% of total energy consumption in the world [1,2]. The energy efficiency of buildings can be improved by using thermal energy storage systems. Phase Change Materials (PCM) is latent heat storage materials that provide much higher thermal energy storage density than that of sensible heat storage materials. The inclusion of PCM into building materials is an effective way to reduce the energy consumption in buildings. Phase change materials are mainly classified as organic, inorganic, and eutectic [3]. PCM that undergo phase transition from solid to liquid and back to solid state are the most commonly used latent heat storage materials [4]. Paraffin and fatty acids are organic PCM that have been investigated by a number of researchers for lower thermal energy storage applications due to the favorable characteristics like good heat storage density with little or no sub cooling, chemical stability and low cost [5,6]. Even though solid–liquid PCM are mostly used in the field of thermal energy storage and heat transfer applications, they suffer from major issues like volume change and liquid leakage in their liquid phases. A simpler solution that solves the issues of leakage and volume change is the use of a PCM that undergoes a solid-solid phase transition. These materials change their crystalline structure from one lattice type to another at a fixed and definite temperature, and the transformation is accompanied with latent heats that are comparable to the most effective solid/liquid PCM [7]. Most PCM have very low thermal conductivity [6] that leads to poor thermal energy storage performance of the PCM-based TES systems. Improving the thermal conductivity of PCM by dispersing thermally conductive particles is one of the ways to improve the effectiveness of the PCM-based TES systems. Though the addition of nano particles enhances thermal conductivity of PCM, it was also reported in literature that phase change properties

*Abbreviations:* TES, thermal energy storage; PCM, phase change materials; NPG, neopentyl glycol; FTIR, fourier transform infrared spectroscopy; DSC, differential scanning calorimetry; TGA, thermogravimetric analysis.

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**Nomenclature**

Notations and Symbols

| | |
|---|---|
| $m_t$ | Mass of the test tube used for the T-History experiment |
| $C_{pt}$ | Specific heat of the test tube |
| $m_{gly}$ | Mass of the glycerin used |
| $Cp_{gly}$ | Specific heat of glycerin used |
| $m_{pcm}$ | Mass of PCM taken for the experiment |
| $t_f$ | Time for full solidification of the molten PCM |
| $\rho_{PCM}$ | Density of the PCM |
| R | the radius of the test tube |
| $H_m$ | Latent heat |
| $k_p$ | Thermal conductivity of the PCM |

were affected due to the presence of nanoparticles [8]. Among the different nanoparticles, carbon nano tubes (CNT) and carbon nano fibers (CNF) have exhibited very good thermo-physical properties which make them suited in the field of PCM based LHTES. Elgafy et al. [9] analytically and experimentally investigated the performance enhancement of paraffin wax based LHS system by adding 1 to 4% mass fractions of carbon nanofibres (CNF). Their study showed an almost linear increase in thermal conductivity corresponding to the increase in mass fraction of carbon nanofibres. Advanced nanocomposite phase change material based on calcium chloride hexahydrate added with aluminum oxide nanoparticles for thermal energy storage was proposed and studied by Xiang Li et al. [10]. They conducted thermal cycling test of the composite PCM containing 1% weight fraction of alumina particles and observed from the characterisation study that the chloride hexahydrate/aluminum nanocomposite PCM possesses acceptable thermal reliability, chemical stability, and heat transfer characteristics which makes them suited for low-temperature solar thermal energy storage applications. A number of works using CuO nanoparticles for improved storage properties of PCM have been reported in literature. D K Singh et al. [11] have conducted an experimental study on Myo-Inositol based nano PCM for solar thermal energy storage. In their experimental study, they have reported the thermal cycling characterisation of Myo-Inositol + CuO and $Al_2O_3$ (mass fractions of 1%, 2% and 3%) nanoparticles using DSC, TGA and FTIR methods. Based on the results obtained they have concluded that, myo-inositol based nano-PCM is a potential material for solar thermal energy storage applications in the temperature range of 160 °C to 260 °C. A theoretical and experimental study of unidirectional freezing of Cyclohexane + CuO nanoparticles was made by Liwu Fan et al. [12]. Mahdi Nabil et al. [13] experimentally determined temperature dependent thermal conductivity of solid eicosane + CuO nano particles of mass fractions ranging from 0 to 10%. Melting behaviour of n-octadecane + CuO nanoparticles in a square enclosure was experimentally and numerically studied by Nabeel S.Dhaidan et al. [14]. In another work, Nabeel S.Dhaidan et al. [15] have experimentally and numerically studied the constrained melting of n-octadecane + CuO nanoparticle dispersions in a horizontal cylindrical capsule subjected to a constant heat flux. Nabeel S.Dhaidan et al. [16] have also made an experimental and numerical investigation of melting of n-octadecane + CuO nanoparticle inside an annular container under a constant heat flux condition.

A variety of materials such as paraffin wax, bio-based organic materials, and eutectic salts etc have been tested for building applications. Phase change temperatures typically range from 20 to 40 °C in building applications. This temperature range can be varied to minimize the heating and cooling loads for the building in order to maintain the comfort of its occupants. The most important requirements for a good PCM can be categorized into physical, chemical or economical requirements [17]. PCM can be incorporated into building materials by employing methods such as inclusion of gypsum plaster boards and other structural boards, mixing PCM with thermal insulations, and macro-packaging. Various research works that studied impregnating gypsum wallboard and structural boards with phase change materials have been reported in literature [18–21]. Microencapsulation permits the incorporation of PCM simply and cost-effectively into usual construction materials. This has been investigated by quite a few researchers [22–27]. Baetens et al. [28] investigated the PCM deployment in the buildings to maintain a steady room temperature. Seong Jin Chang et al. [29] constructed a prototype of building using glass, and incorporated macropacked PCM (n-octadecane, n-eicosane, and n-docosane) in it inorder to study the effect of thermal mass in the reduction of room temperature. Tyagi et al. [30] presented an overview of research on micro-encapsulation technology for incorporating PCM in the building applications. Zhou et al. and Amar et al. [31,32] made a review of research works on latent heat energy storage in building applications. Ye et al.,[33] experimentally investigated the use of a shape-stabilized PCM for building application and evaluated its performance in terms of an energy saving index.

Polyalcohols such as pentaerythritol [PE], pentaglycerine [PG], and neopentylglycol [NPG] are known to have solid-solid transition enthalpies which are comparable to the fusion enthalpies of many types of paraffin [34]. At low temperature, polyalcohols and their amine derivatives have body-centered tetrahedral molecular structure ($\alpha$-phase). At solid–solid phase transition temperature, they change into a homogeneous face-centered cubic crystalline structure ($\gamma$-phase) accompanied with the absorption of the hydrogen bond energy [35]. Many studies on polyalcohols and amine derivative as potential solid-solid PCM have been reported in the literature [36–38]. Barrio et al. [39] studied the phase change mechanism in polyalcohols and reported that the reformation of the hydrogen bonds during cooling takes place at a lower energy than the breaking of the bonds during the heating transition. This causes the phenomenon of subcooling in polyalcohols. In our recent work [40], we have studied the thermal and chemical stability of pentaerythritol blended with low melting alloy of In, Sn, Bi and Zn for potential PCM for latent heat storage. Neopentyl Glycol (NPG) is an organic compound with the formula $C_5H_{12}O_2$. This polyalcohol shows a phase transition in the solid state between 40 and 48 °C (tetragonal to cubic structural change).

Buildings are one of the main consumers of energy worldwide. Building efficiency must be improved to provide the occupants with a comfortable, safe, and attractive living and work environment. One of the best ways to manage the energy consumption in building is to install climate control systems. Climate control in buildings includes the control of mechanical, electrical, and plumbing systems. It also includes the heating, ventilation, and air-conditioning (HVAC) systems. Poor design and inefficient functioning of HVAC system cause a large amount of energy to be wasted. Solar based HVAC systems are very effective to reduce the primary energy requirements [41–45].

The use of adequate thermal energy storage (TES) systems in the buildings provides high potential in energy conservation. The use of novel building materials containing active thermal components such as PCM is an effective method of achieving significant heating and cooling energy savings. The main advantage of using PCM is that it affords structures having improved thermal storage capabilities with minimal change to the existing