

**Research/Technical Note**

# Experimental Study on Phase Change Materials for Cold Energy Storage System

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**Abstract:** Cold Thermal Energy Storage (CTES) is a technology with a high potential for different cooling applications. Many previous works have investigated energy efficiency of different cold units by applying CTES systems using phase change materials (PCMs). Phase change materials (PCMs) are generally regarded as a promising material for storing thermal energy. This work presents an experimental study on phase change materials for cold storage application. The experimental process of phase-change materials is based on the following chemicals: water, propylene glycol ( $C_3H_8O_2$ ), glycerin ( $C_3H_8O_3$ ), paraffin oil (white oil LP-70), and sodium polyacrylate ( $C_3H_3NaO_2$ )<sub>n</sub>. The temperature changes over time as ice charging and discharging the phase-change materials are investigated. At the same time, the work try to analyze the physical and chemical properties of the aforementioned phase-change materials. The results indicate that the discharging process of paraffin and glycol is rapid. As for water and sodium polyacrylate, the discharging time is slower than that of paraffin and glycol. And finally, for glycerin, the loading time is slowest compared to other chemicals, the discharging time is also slowest compared to the other four chemicals. This indicates that the latent heat of glycerin has high value, long melting time and deep ice storage temperature. This is a suitable material for use in cold storage systems as a phase change material.

**Keywords:** Cold Thermal Energy Storage, Phase-Change Materials, Energy Saving, Air Conditioning

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## 1. Introduction

Phase change materials (PCMs) are generally regarded as a promising material for storing thermal energy. They have many advantages of high-energy storage density and the isothermal nature of the storage process. Phase change materials (PCMs) have been widely used in latent heat thermal-storage systems for heat pumps, solar energy storage, and cooling storage. Using the phase change materials provides higher thermal storage capacity and more isothermal behavior during charging and discharging compared to sensible heat storage [1-4].

The uses of phase change materials for heating and cooling applications for buildings have been studied within the past decade. Properties of many different phase change materials have been widely studied by many researchers over the years. Peng et al. [5] investigated paraffin and concluded that

paraffin has a melting temperature from -12 to 71°C with a latent heat of 128–198 kJ/kg. The latent heat during phase change of NaCl–H<sub>2</sub>O binary mixture was determined in various concentrations observing two different endothermic peaks, one due to a eutectic melting near -22°C, and the other for ice [6]. The salt solutions of NaCl and potassium chloride (KCl) were investigated as PCM for cooling storage systems. The tests were performed in a temperature range of -24 to -10°C [7]. The thermal properties of tetradecane (melting point of 5.8°C), hexadecane (melting point of 18.1°C), and pentadecane (melting point of 9.9°C) were discussed, and the results showed that these materials are promising PCM candidates for some cold storage applications [8]. Liesebach et al. [9] investigated experimentally the latent heat of freezing of different concentrations of ethylene glycol. The results showed the apparent heat of solution of ethylene glycol with initial concentrations ranging between 9% and

30%. Lopez et al. [10] studied the phase change in composite materials made of graphite and a phase-change material (PCM). The composites are fabricated by compressing a solid mixture of salt and graphite particles. The encapsulation of salts PCM material within elastic shells was investigated. The results shown that the encapsulated PCM particles can melt without cracking the coating shell only under specific conditions [11]. Nasrin Etesami and Samaneh Sami investigated the effective and facile microencapsulation of paraffin with polystyrene for thermal energy storage applications. The results indicated that the obtained microparticles were smaller, smoother and have greater microencapsulation ratios than other cases in previous studies [12]. The phase equilibrium point of a novel tetrabutylammonium bromide hydrate based cold storage material and the material performance in a cold energy thermal storage air conditioning system at various operation modes were investigated. The results showed the tetrabutylammonium bromide hydrate based phase change material has a suitable phase change temperature of  $12^{\circ}\text{C}$  and a large phase change enthalpy of  $209 \text{ kJ.kg}^{-1}$ . It shows a supercooling degree of  $3.65^{\circ}\text{C}$  in a small-scale measurement and  $1.90^{\circ}\text{C}$  in a large scale operation [13]. Gao et al. [14] developed a novel kind of composite phase change material using modified expanded graphite to adsorb  $\text{K}_2\text{HPO}_4 \cdot 3\text{H}_2\text{O}$ – $\text{NaH}_2\text{PO}_4 \cdot 2\text{H}_2\text{O}$ – $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ – $\text{H}_2\text{O}$  eutectic salt by impregnation method. The results showed the composite PCM has a phase change temperature of  $-5.3^{\circ}\text{C}$ , a large latent heat of  $161.8 \text{ kJ.kg}^{-1}$ , and a low supercooling degree of  $1.83^{\circ}\text{C}$ . The thermal conductivity of the composite PCM is higher 13.3 times than the eutectic salt.

The  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  composite phase change material was mixed using urea and ethanol as thermoregulation additives, strontium chloride hexahydrate ( $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$ ) and methyl cellulose as nucleating agent and thickening agent. The results indicated that  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  composite containing 15 wt% urea and 5.0 wt% ethanol had a promising

potential for air-conditioning application with phase change temperature of  $11.62^{\circ}\text{C}$  and phase change enthalpy of  $127.2 \text{ J.g}^{-1}$  [15]. Oleic acid is used as phase change material whereas carbon coated aluminum is combined as additive. The results showed that thermal conductivities of composite oleic acid using nanoparticles are significantly enhanced when compared with pure sample [16].

## 2. Experimental

In this paper, the experimental process of phase-change materials is based on the following chemicals: water, propylene glycol ( $\text{C}_3\text{H}_8\text{O}_2$ ), glycerin ( $\text{C}_3\text{H}_8\text{O}_3$ ), paraffin oil (white oil LP-70), and sodium polyacrylate ( $\text{C}_3\text{H}_3\text{NaO}_2$ )<sub>n</sub>. Specifically, we investigate temperature changes over time as ice charging and discharging the phase-change materials. At the same time, we try to analyze the physical and chemical properties of the aforementioned phase-change materials. The characteristics of heat storage and the application of phase-changing chemicals will be applied in the design of the calculation of water chiller's cold storage tank to save power consumption. The specific procedure for this experiment will be as below.

### 2.1. Setting-up an Experimental Model of Ice Charging for Phase Change Materials

Experimental process is conducted based on the following chemicals: water, propylene glycol, glycerin, paraffin and sodium polyacrylate. These chemicals are poured into 350ml-capacity bottles. Bottles containing such chemicals are fitted with thermal sensors to measure the temperature over time of the ice charging process from 0 to 200 minutes. Bottles containing phase-change materials are placed in the refrigerator freezer compartment. Figure 1 shows the experimental process of ice charging to a phase-change material (PCM).

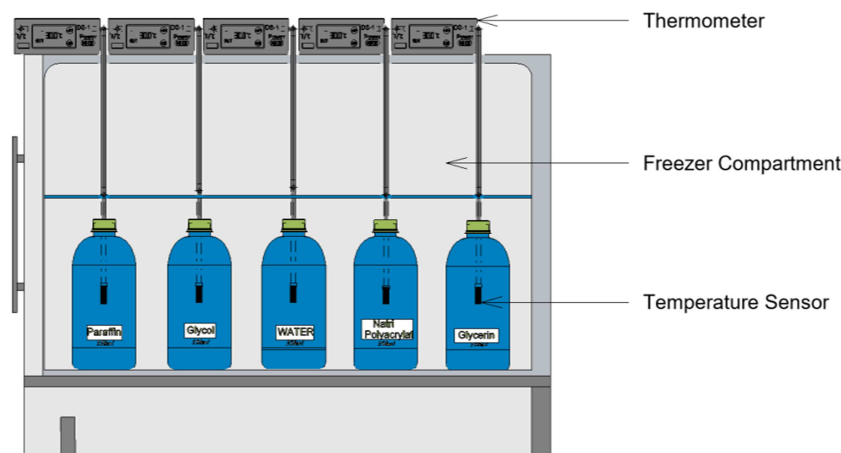


Figure 1. The experimental model of ice charging for phase change materials.

### 2.2. Setting-up an Experimental Model of Discharging Process for Phase Change Materials

For the discharging process, it is also called the process of

melting phase-change materials. After performing the ice creation process in the above experiment, bottles containing phase-change materials: water, glycol, glycerin, paraffin, and

sodium polyacrylate are stored to low temperatures, these bottles are dipped in water box covered with insulation. Each box containing one bottle of phase change material is installed with two temperature sensors, one temperature sensor is embedded in the center of the bottle containing phase-change materials, the other one temperature sensor will be embedded in the water and bottle that contains

phase-change materials. We observe changes in the temperature of the phase-change materials and the water in the container over time. Experimental model of defrosting process of phase-change materials is shown in Figure 2. Experimental process of defrosting and cooling water of phase-change materials is shown in Figure 3.

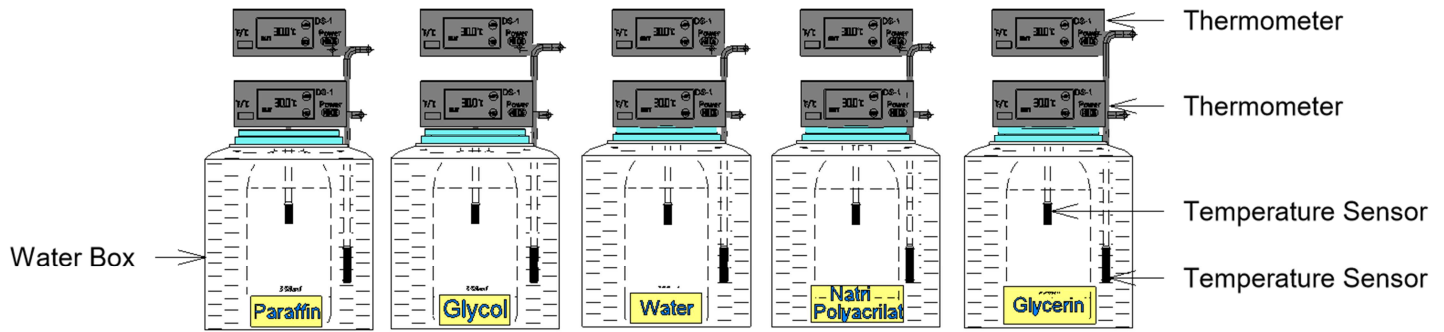


Figure 2. The experimental model of discharging process for phase change materials.



Figure 3. The picture of experimental process of discharging for phase change materials.

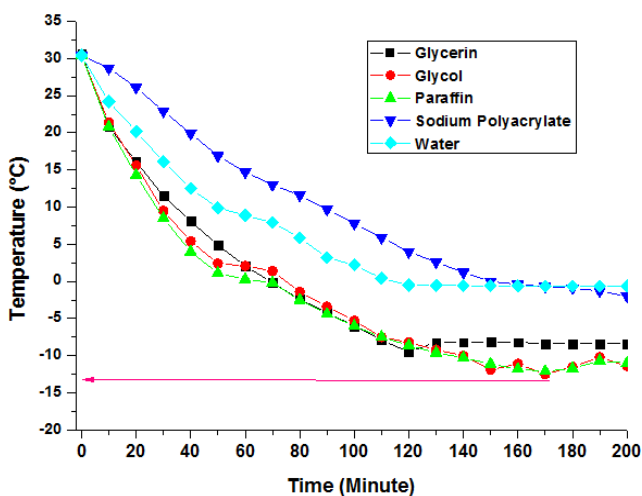


Figure 4. The temperature changing of phase change materials in ice charging process.

### 3. Results and Discussion

#### 3.1. The Ice Charging Process for Phase-change Materials

Through experiments, the results show that sodium polyacrylate freezes more slowly than paraffin and glycol, and finally water. Figure 4 shows that the temperature of paraffin and glycol drops faster than the temperature of water and sodium polyacrylate at the same time. The initial temperature of the phase-change materials was 30°C, after the first 50 minutes of loading, the temperatures of paraffin, glycol and glycerin were reduced to approximately 1.1°C, 2.4°C and 4.9°C respectively, while the water temperature was 9.9°C and temperatures of sodium polyacrylate about 16.9°C. Then the temperature of the phase-change materials continues to decrease over time. After 200 minutes, for sodium polyacrylate, the temperature is -2°C, which is equivalent to that of paraffin is -11°C, glycol is -11.4°C and glycerin is -8.4°C. At the same time, the water temperature is -0.5°C. At the corresponding temperatures above, chemicals such as sodium polyacrylate, paraffin, glycol and glycerin do not freeze, and the water freezes. As shown in Figure 4, after 110 minutes, the temperature of water is -0.5°C and remains constant after 200 minutes.

#### 3.2. The Discharging Process for Phase-change Materials

After performing the ice creation process in the above experiment, bottles containing phase-change materials: water, glycol, glycerin, paraffin, and sodium polyacrylate are stored to low temperatures. Bottles with low-temperature phase-change materials exchange heat with the water in the higher temperature water box. The phase change temperature increases gradually while the water temperature in the container will decrease over time. As shown in Figure 5, the results indicate that the phase-change material temperatures at the beginning of the discharging process are as follows: glycol is -11.4°C, glycerin is -8.4°C, paraffin is -11°C, water

is  $-0.5^{\circ}\text{C}$  and sodium polyacrylate is  $-2^{\circ}\text{C}$ . After 10 minutes, the temperature of the phase-change materials is as follows: glycol is  $23.6^{\circ}\text{C}$ , paraffin is  $24^{\circ}\text{C}$ , water is  $11.9^{\circ}\text{C}$ , glycerin is  $4^{\circ}\text{C}$  and sodium polyacrylate is  $3^{\circ}\text{C}$ . After 120 minutes, the temperature of the phase-change materials is as follows: glycol is  $28.1^{\circ}\text{C}$ , paraffin is  $29.4^{\circ}\text{C}$ , water is  $23.4^{\circ}\text{C}$ , glycerin is  $15.3^{\circ}\text{C}$  and sodium polyacrylate is  $22.9^{\circ}\text{C}$ . It was found that the two chemicals paraffin and glycol have the fastest discharging process, followed by water and sodium polyacrylate, the slowest discharging process is glycerin. This is because the specific heat affects the melting process, the higher the specific heat, the slower the melting process of phase-change materials.

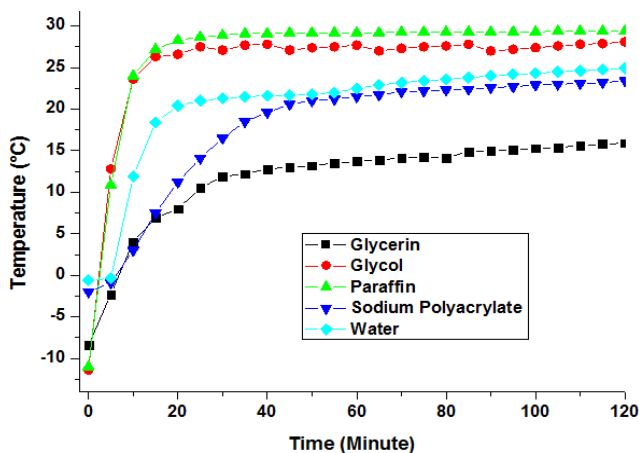


Figure 5. The temperature changing of phase change materials in discharging process.

In addition, bottles containing low-temperature phase-change materials will conduct heat conversion to receive heat when immersed in water containers with ambient temperature ( $30^{\circ}\text{C}$ ). Figure 6 shows a reduction in the temperature of the water inside the container of phase change bottles. At 20 minutes, the water temperature in the containers of the phase-change materials decreased while the temperature of the phase-change materials increased, the water temperature in the glycol container was  $24.9^{\circ}\text{C}$ , the paraffin container was  $27.6^{\circ}\text{C}$ , the water container is  $23^{\circ}\text{C}$ , the glycerin container is  $16.2^{\circ}\text{C}$  and the sodium polyacrylate container is  $18.6^{\circ}\text{C}$ . After 20 minutes, the water temperature in the water containers of paraffin, glycol and water bottles remained stable and increased slightly, the water temperature in the containers of sodium polyacrylate bottles increased faster than the rest, while the temperature of glycerin is decreasing. After 120 minutes, the water temperature in the boxes contains the phase-change materials, respectively: the temperature of the water in the glycol container is  $26.7^{\circ}\text{C}$ , the paraffin container is  $28.4^{\circ}\text{C}$ , the water container is  $24.7^{\circ}\text{C}$ , the sodium polyacrylate container is  $22.3^{\circ}\text{C}$  and the glycerin container is  $16.5^{\circ}\text{C}$ . The temperatures of water in water boxes are still high. This is due to the fact that the phase change ratio is much smaller than the water inside the box and the energy loss is outside the environment.

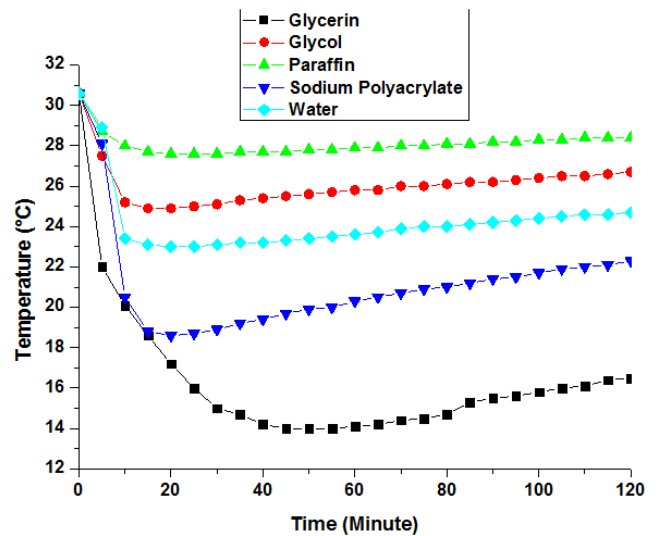


Figure 6. The temperature changing of waterbox in discharging process.

## 4. Conclusion

The final results indicate that the discharging process of paraffin and glycol is rapid, with temperatures down to about  $-11^{\circ}\text{C}$ . Besides, the discharging time is also fast. As for water and sodium polyacrylate, the discharging time is slower than that of paraffin and glycol, the discharging time of water and sodium polyacrylate is slow compared to paraffin and glycol. And finally, for glycerin, the loading time is slowest compared to other chemicals, the temperature drops to  $-8.4^{\circ}\text{C}$ , the discharging time is also slowest compared to the other four chemicals. This indicates that the latent heat of glycerin has high value, long melting time and deep ice storage temperature. This is a suitable material for use in cold energy storage systems as a phase-change material.

## Conflicts of Interest Statement

All the authors do not have any possible conflicts of interest.

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