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Performance Evaluation of a Plate Encapsulated Salt Hydrate PCM Mixed with a Gel

N.E Sibande[1], D. M. Madyira[1], T. O. Babarinde[1, 3] T Kumirai[1]

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[1]Department of Mechanical Engineering Science, University of Johannesburg, South Africa
[2]Department of Mechanical & Industrial Engineering Technology, University of Johannesburg, South Africa
[3]Mechanical Engineering Department, Covenant University Ota, Nigeria

Abstract-
An alternative method of cooling is required to meet cooling demands and simultaneously decrease conventional energy consumption. The current research aimed to investigate the feasibility of using a phase change material (PCM) in the form of a salt hydrate mixed with a CSIR-developed gel for PCM based cold storage that used nighttime cold to cool ambient air during the day. The experiments were conducted over a time period of three hours between 12:00 pm and 15:00 pm in the afternoon. The total temperature drops were found to be 3.8, 2.9 and 2.6 degrees for air flow rates of 0.03, 0.05 and 0.06kg/s respectively. The total energy transferred for each of the mass flow rates averaged 140.9, 144.4 and 158.9J for air flow rates of 0.03, 0.05 and 0.06kg/s respectively.

Keywords: cold storage, phase change material, salt hydrate

1. Introduction

According to the South African electricity public utility's (ESKOM) statistics, it is estimated that 50% of peak demand for energy in South Africa is associated with HVAC systems [1]. As the South Africa population is growing, it's evident that there will be an increase in energy demand by HVAC systems. In order to minimise the energy demand by HVAC systems, the use of phase change materials (PCM) for cold storage applications can provide a solution.

Cold storage is a method of temporarily storing night-time cold and utilising it at a later stage. It is focused on borrowing the night time cold to freeze the PCM, and during the day blowing warm ambient air over the solidified encapsulated PCM to cool the air. The PCM is a material that has the ability to store and dissipate the cold energy. The PCM, which is the storage medium, undergoes a phase change from liquid to solid during the charging and vice versa during the discharging process [2]. The importance of thermal cold storage (TCS) lies in the ability to ensure cooling whilst consuming minimum energy in the process. TCS is the method of retaining cold thermal energy and withdrawing it when it is needed. The process of retaining the cold thermal energy involves capturing and storing the energy until it accumulates within the storage medium. When the energy is needed, it can be obtained and utilised. The cold energy is retrieved at night or during off-peak hours, which makes this an energy-saving solution to the necessity of cooling. The storage methods that can be employed for the process of TCS are sensible storage, latent storage and thermochemical storage. However, the popular methods, in this case, are sensible and latent storage.

A previous experimental investigation conducted at the Council for Scientific and Industrial Research (CSIR) built Environment division South Africa showed that Paraffin PCMs met the condition of high instantaneous heat absorption but did not meet the condition of extended heat absorption duration [3]. Salt hydrate (SP24E) met the condition for extended heat absorption duration but had a lower instantaneous heat absorption capacity than the paraffin. Salt hydrate SP24E was selected for further development. The development seeks to enhance the thermal performance of the salt hydrates by the incorporation of highly conductive additive mixtures. This will enhance the instantaneous heat absorption capacity for salt hydrates in addition to their favourable extended heat absorption capabilities. In order to maintain homogeneity of the high thermal conductivity nanoparticles inside the salt hydrate PCM, a certain gelling agent was developed for this purpose. Madyira [4] carried out an experimental study to determine the effectiveness of cold storage using an inorganic paraffin based PCM known as RT25HC. The parameters that were used in this study were mass flow rates of 0.026, 0.064 and 0.073kg/s. It was found that as the mass flow rate of the air decreased, the heat transfer was more effective. Overall the PCM caused a temperature drop of up to 3°C at the measured flow rates.

The aim of the experiment was to monitor the variation in temperature of the air flowing through the PCM heat exchanger and to monitor the phase change duration of the PCM.

2.   Methodology
In this section, the materials, equipment and experimental procedures of the experiment are discussed.

2.1 Materials Description

The material that was used was a latent heat blended Rubitherm®SP material that had low flammability and was modified with CSIR inorganic components [3]. The SP24E material was used as an encapsulated material within a 0.9mm thick aluminium plate. The properties of the PCM that make it an exceptional PCM for passive and active cooling in wall elements were shown in Table 1.

Table 1: Properties of SP24E PCM [3]

Physical property	Value	Unit
Melting temperature range	24-25	°C
Congealing temperature range	21-23	°C
Heat storage capacity ± 7.5%	180	kJ/kg
Specific heat capacity	2	kJ/kgK
The density of the solid PCM at 15°C	1.5	kg/l
The density of the liquid PCM at 35°C	1.4	kg/l
Volume expansion	3-4	%
Heat conductivity	0.6	W/mK
Max operation temperature	45	°C

The encapsulation was two casing was a 450mmx300mmx0.9mm aluminium alloy 1100 plates that were attached to each other. The plates were jointed at two centre points and stuck together at the outer edges. The PCM plate is shown in figure 2.

Aluminium alloy 1100 was used because it enables a high heat transfer and it is non-corrosive [5]. The casing was also lined with anticorrosive material on the inner and on the outer surfaces of the plates. The encapsulation was flexible as it could be directly integrated into existing systems for various applications at broad temperature ranges. The properties of the plates are shown in Table 2.

Table 2: Properties of aluminium alloy 1100

Property	Value	Unit
Melting point	646	°C
Tensile strength	145	MPa
Elongation (at 50mm)	5	%
Thermal expansion	23.6×10^{-6}	/K
Thermal conductivity	205	W/mK
Electrical resistivity	2.69	Ω.cm
Density	2.6898	g/cm^3
Modulus of elasticity	68.3	GPa
Poisson's ratio	0.34	-

2.2 Experimental Setup

The test rig was a 6500 mm long rectangular duct that was made of galvanised steel with neopor material stuck onto it using wood glue. The purpose of the neopor material was to serve as insulation. The cross section of the test rig was a rectangular 305x327 mm section. On the left-hand side of the test, the rig was a conical inlet that was also constructed with galvanised steel. The inlet section was a cylindrical cross-section with a diameter of 245 mm and length of 322 mm, which was attached to a rectangular transition piece with a length of 280 mm attached to the test rig. The heating element was situated within the cylindrical inlet section with its circuit board attached to the outer surface of the cylindrical inlet section. The mixing propeller was situated within the inlet section directly behind the heating element. The mixing device in the form of a propeller fan was unpowered and actuated by the draft of air that flows into the test rig. The test section of 450x300 mm housing the PCM was placed in the mid-section of the test rig. There were 15 plates made up of 450mmx300mmx0.9mm casings placed vertically within the test section with a 5 mm gap in between each plate as specified in the ASHRAE standard 41.1 of 2006 for temperature measurement of 2006. The test section was a module that was made of plexiglass that was bolted shut and designed to depict a plate heat exchanger. A cylindrical extraction fan was situated on the opposite end of the test rig and attached to the rig with a galvanised steel transition piece resembling the inlet section transition piece. The function of the axial fan was to determine the mass flow rates of the air that flowed within the test rig. A flexible air duct was attached to the outlet section and passed through the window in order to expel the cool air. The actual test rig that was used to conduct the experiments is shown in Figure 1 and schematic diagram of the test rig indicating all the components and the dimensions of the test rig is illustrated in Figure 2.
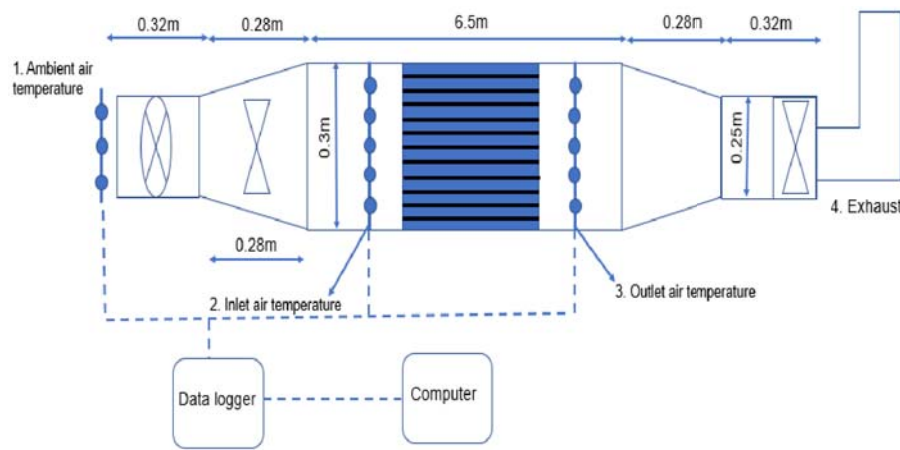
Figure 1: Experiment test rig

Figure 2: Schematic of the test rig

The tests section was situated in the middle of the test rig. The test section comprised of 15 PCM plates that were placed vertically in the test section with a 5mm gap in between, to depict a heat exchanger. The test section dimensions were 450x300 mm. The test section is shown in Figure 3.

Figure 1: Test section

2.3 Experimental Procedure

Before the experiment took place, power and energy balance calculations were performed to calculate the suitable voltage for the heating element to establish the required air inlet temperature. The fan and damper system was set for three various speeds for each of the mass flow rates of interest. For each measurement cycle conducted over a time period of three hours between 12:00 pm and 15:00 pm in the afternoon, a single fan speed and damper position were selected, and data logging was made every 5 seconds. The procedure was repeated for each of the selected fan speeds.

The formula used to determine the amount of energy stored using the sensible storage method is expressed below [6]:

$$Q = \int_{T_i}^{T_f} \dot{m}C_p \Delta T = \dot{m}C_p(T_f - T_i) \qquad (1)$$

where Q is the amount of energy stored in the PCM, T_f is the PCM final temperature, T_i is the PCM initial temperature, m is the mass flow rate, C_p is the thermal heat capacity and ΔT is the temperature difference.

3. Result and Discussion

Comparisons were done across all the PCM for the various flow rates and the corresponding summertime temperatures. The assumption made was that most of the heat in the air was transferred to the PCM because the test rig was well insulated with the neopor material to prevent heat from the outside affecting the system. The other assumption was that all the heating power of the heating element was transferred to the inlet air. The time frame that was considered was a three-hour window period during the hottest time of the day which was from 12:00 pm to 15:00 pm. The raw data is illustrated in a Temperature vs Time graph shown in Figure 4.
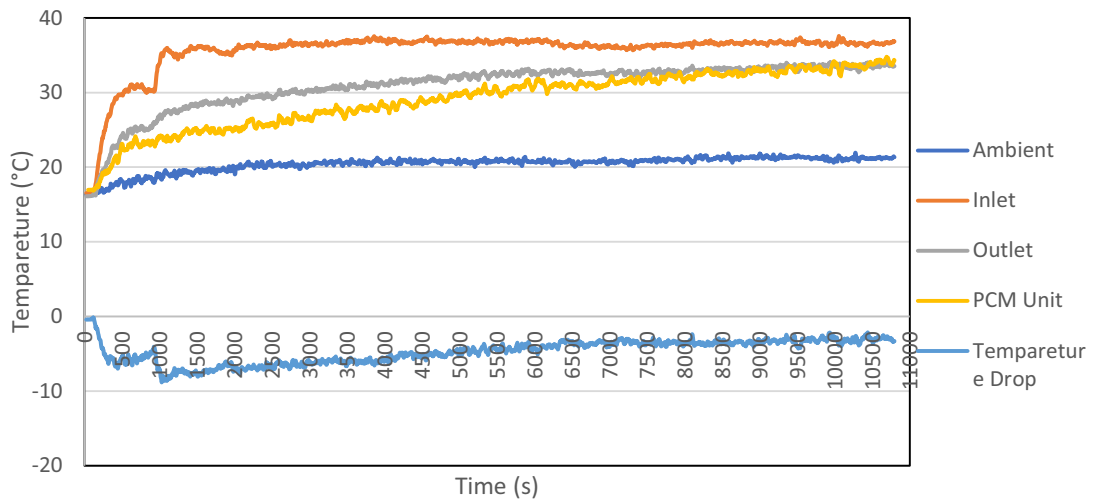
Figure 2: Temperature vs Time plot for raw data

The total temperature drops for the air as a result of the PCM is illustrated in Figure 5 for each of the mass flow rates of air. The total temperature drops were seen to be 3.8, 2.9 and 2.6 degrees achieved for air flow rates of 0.03, 0.05 and 0.06kg/s respectively.
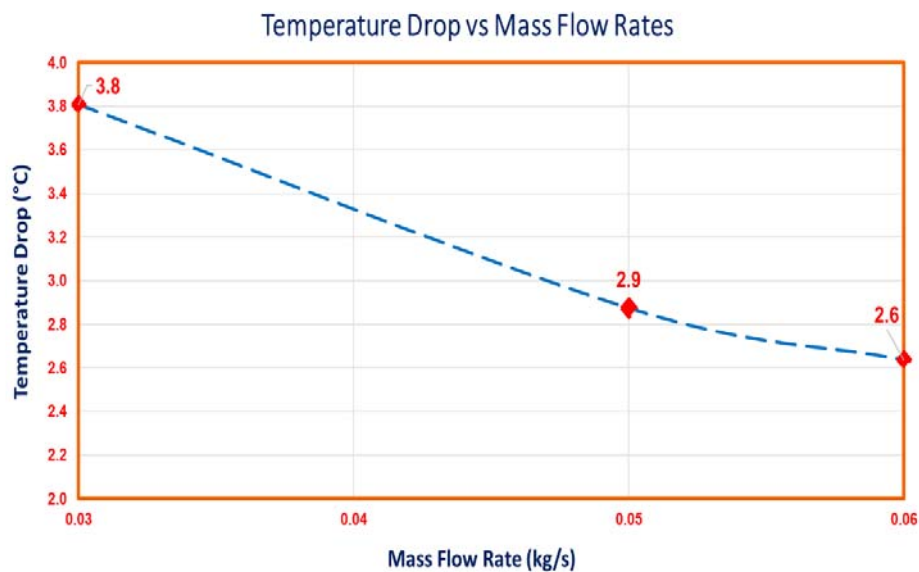

Figure 3: Temperature drops at each mass flow rate

The total energy that was transferred for each mass flow rate is shown in Figure 6. The total temperature drop was used in conjunction with the specific heat capacity of the air and each mass flow rate to determine the total energy transfer. The total energy transferred for each of the mass flow rates averaged 140.9, 144.4 and 158.9J for air flow rates of 0.03, 0.05 and 0.06kg/s respectively.
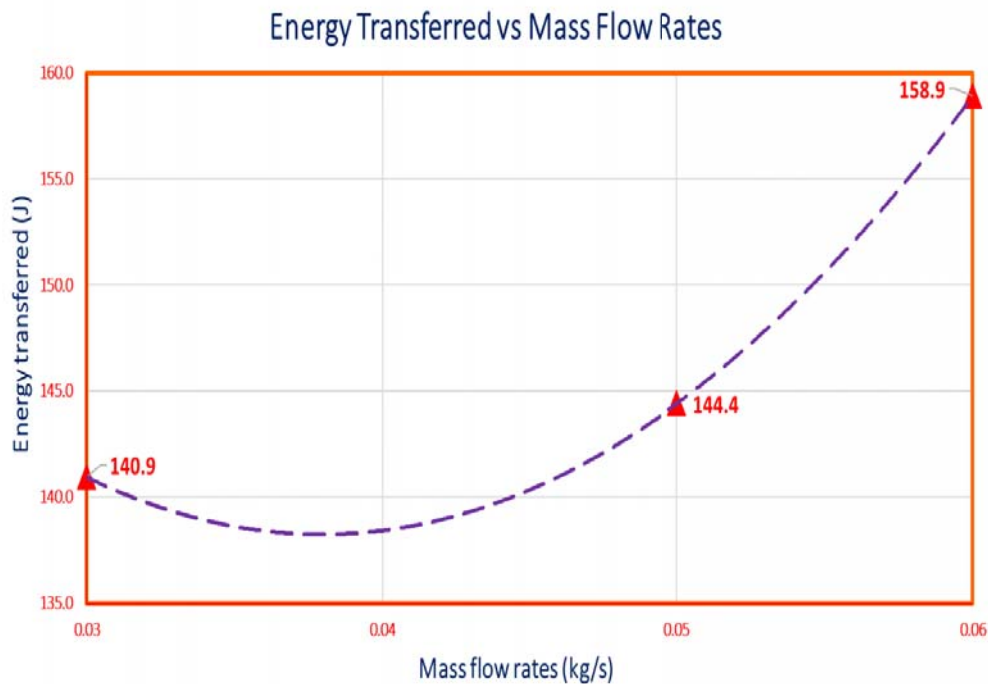
Figure 4: Temperature drop at each mass flow rate

It was observed that when the air mass flow rate of the air is increased it yields an increased energy transfer, however, the temperature drop is decreased due to the decreased residence time of the air in the PCM. The PCM was thus found to be thermally effective in cooling the air for mass flow rates as low as 0.03kg/s and below.

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4. Recommendation

Based on the work done and the results obtained, the following conclusions can be made:

- When the air flow rate was increased, the energy transfer was increased, and the temperature drop was decreased because of the residence time in the PCM being reduced.
- It can thus be said that the lower the air mass flow rate was, the more effective the PCM was at absorbing the heat from the inlet air.
- The total temperature drops were found to be 3.8, 2.9 and 2.6 degrees for air flow rates of 0.03, 0.05 and 0.06kg/s respectively.
- The total energy transferred for the temperature of 30°C for each of the mass flow rates averaged 140.9, 144.4 and 158.9J for air flow rates of 0.03, 0.05 and 0.06kg/s respectively.

To better understand the free cooling performance and applications of the PCM, the following recommendations are made:

- Both the discharging and the charging process of the salt hydrate PCM mixed with a gel should be analyzed in future.
- Another form of the additive mixture can be considered for the PCM to further increase the residence time and the effectiveness of the SP24E PCM.

- Summertime temperatures for other regions other than Gauteng should be tested.

A more energy-efficient means, e.g. solar collector, should be used to power the fan and damper system during the experiment

Reference

[1]   Alan ESKOM (2015). Heating, Ventilation and Air Conditioning (HVAC) systems: energy-efficient usage and technologies," ESKOM Holdings SOC, Sunninghill, Johannesburg.

[2]   Veerakumar, A., Sreekumar A. (2016) Phase change material-based cold thermal energy storage: Materials, techniques and applications - A review," *International Journal of Refrigeration,* no. 67, pp. 271-289.

[3]   Rubitherm, "Microencapsulation-CSM," Rubitherm Technologies, 2018. [Online]. Available: https://www.rubitherm.eu/en/index.php/productcategory/makroverkaspelung-csm. [Accessed 3 April 2018].

[4]   Madyira D.M. (2018). Cold storage for low-cost air-conditioning, African Journal of Science, Technology, Innovation and Development, DOI: 10.1080/20421338.2018.1439277

[5]   Rubitherm, "Microencapsulation-CSM," Rubitherm Technologies, 2018. [Online]. Available: https://www.rubitherm.eu/en/index.php/productcategory/makroverkaspelung-csm. [Accessed 3 April 2018].

[6]   Incropera, F., Dewitt, D.P., Bergman, T.L., & Lavine, A.S. (2013). Principles of heat and mass transfer, Seventh ed., Singapore: John Wiley & Sons, 2013, pp. 6-8.