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THE EFFECT OF USING PALMITIC ACID ON A SOLAR POND TEMPERATURE DISTRIBUTION

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ABSTRACT

Solar energy is one of the renewable energy sources and widely used to obtain thermal energy. The heat obtained from solar energy can be stored by using different systems. One of these systems is solar ponds. Solar ponds consist of layers whose salt density increases towards the bottom. In this study, the use of phase change materials to increase the heat storage performance of a model solar pond was investigated. The phase change material, Cetyl-palmitic acid eutectic mixture was prepared and its chemical properties were obtained by FT-IR spectroscopy. The thermophysical properties and surface morphologies were determined by using Differential Scanning Calorimetry and SEM. The obtained phase change material was applied to the inner surface of the heat storage zone. The temperature distribution of the solar pond was calculated numerically for with and without phase change material. As a result, it has been seen that the use of phase change materials with suitable thermophysical properties in solar ponds will contribute to long-term heat storage performance.

Keywords: *Solar energy, solar pond, heat storage, phase change materials*

PALMİTİK ASİT KULLANIMININ GÜNEŞ HAVUZUNUN SICAKLIK DAĞILIMI ÜZERİNE ETKİSİ

ÖZET

Yenilenebilir enerji kaynaklarından biri olan güneş enerjisi, termal enerji elde etmek için yaygın olarak kullanılmaktadır. Güneş enerjisinden elde edilen ısı farklı sistemler kullanılarak depolanabilir. Bu sistemlerden biri de güneş havuzlarıdır. Güneş havuzları, tuz yoğunluğu tabana doğru artan katmanlardan oluşur. Bu çalışmada, bir model güneş havuzunun ısı depolama performansını artırmak için faz değiştiren malzemelerin kullanımı araştırılmıştır. Faz değiştirici malzeme olan Cetyl-palmitic asitin ötektik karışımı hazırlanmış ve kimyasal özellikleri FT-IR spektroskopisi ile elde edilmiştir. Termofiziksel özellikler ve yüzey morfolojileri, diferansiyel taramalı kalorimetri ve SEM kullanılarak belirlenmiştir. Elde edilen faz değişim malzemesi ısı depolama bölgesinin iç yüzeyine uygulanmıştır. Güneş havuzunun sıcaklık dağılımı, faz değiştiren malzemeli ve faz değiştiren malzemesiz için sayısal olarak hesaplanmıştır. Sonuç olarak güneş havuzlarında uygun termofiziksel özelliklere sahip faz değiştiren malzemelerin kullanılmasının uzun süreli ısı depolama performansına katkı sağlayacağı görülmüştür.

Anahtar Kelimeler: *Güneş enerjisi, güneş havuzları, ısı depolama, faz değiştirici malzemeler*

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1. Introduction

Energy storage systems are very important in terms of the use of intermittent energy resources. For example, in solar energy applications, the need for energy storage is an inevitable. Energy storage systems reduce energy costs, energy consumption, initial and maintenance costs etc. [1]. Many studies have been performed on solar ponds and phase change materials. However, there are not many studies on the use of phase change materials connected with solar ponds. Sogukpinar et al. [2] investigated the saturation time and temperature of the solar ponds for different dimensions. The saturation temperature and the time duration were determined depend on the dimensions of the solar pond. Sogukpinar et al. [3] studied the heat loss caused by evaporation and precipitation for solar pond, in order to reduce the heat loss, a glass cover was designed numerically and compared with the experimental study. Bozkurt et al. [4] investigated the performance of an integrated system in which solar ponds and collectors are used together. The contribution of the number of collectors to the thermal energy storage performance of the system was determined. Tian et al. [5] proposed an active method of using an external magnetic field to prevent erosion in the brine layers occurring in the transition from the heat storage zone to the non-convection zone. A two-dimensional temporal model was developed using the lattice Boltzmann method with multi-relaxation time collisions, and it was observed that the external magnetic field could delay the concentration homogenization and improve the heat storage performance.

Colarossi et al. [6] investigated the temperature distribution of the solar pond experimentally by placing phase change materials in aluminum cylinders at the bottom of the heat storage zone of a small solar pond. The temperature distribution at the bottom of the solar pond was monitored both with and without PCM. Assari et al. [7] investigated the effect on adding PCM to a model solar pond, experimentally. Two solar ponds with the same dimensions, one with cylindrical capsuleted PCM and the other without PCM were used. It was determined that the pond with PCM added has more thermal and salinity stability during the heat extraction. Ines et al. [8] investigated the thermal behavior of a model solar pond exposed to a solar simulator, experimentally. The change in the temperature distribution of the pond was determined by adding PCM to the solar pond and compared. Wang et al. [9] investigated the use of paraffin wax as a phase change material in a solar pond in composite form. It has been observed that the composite obtained by adding steel wires to paraffin improves the heat transfer performance. Poyyamozhi and Karthikeyan [10] analyzed the temperature changes during the use of different phase change materials in solar ponds according to the time taken into account. It has been observed that the thermal conductivity and charge/discharge properties of the phase change materials increase with the addition of nanoparticles.

In this study, the effect of phase change materials on the temperature distribution of the solar pond was investigated numerically. For this purpose, a phase change material with thermophysical properties suitable for the annual temperature change of the solar pond was obtained. Thermophysical and chemical properties of the phase change material, cetyl palmitic acid, were determined by using FT-IR spectroscopy and differential scanning calorimetry. The obtained phase change material was applied to the inner surface of the heat storage zone. The temperature distribution of the solar pond was calculated numerically for with and without phase change material.

2. Materials and Calculations

The heat storage property of the solar pond has been known for many years. However, the presence of integrated systems increases heat storage efficiency or can store the heat for when needed. Phase change materials can act as a heat source to the environment by storing the heat by changing state when the ambient temperature reaches a certain level and giving it back to the environment when the temperature of the environment drops. Transformation of the phase change materials is not happens at a specific temperature value, but takes place in a certain temperature range. Therefore, the phase change is assumed to happens in a temperature range between Tpc − ΔT⁄2 and Tpc+ ΔT⁄2. In this range, the material phase is modeled with a smoothed function θ representing the phase fraction before the transition [9].

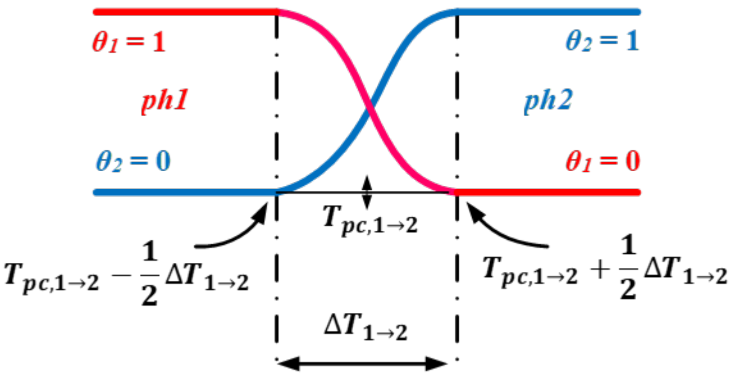


Figure 1. Modelling of phase change temperature transition interval [11]

Density, ρ, and specific enthalpy, H, are expressed as in terms of smoothed function:

$$\rho = \theta\rho_{ph1} + (1-\theta)\rho_{ph2} \tag{1}$$

$$H = \frac{1}{\rho}(\theta\rho_{ph1}H_{ph1} + (1-\theta)\rho_{ph2}H_{ph2}) \tag{2}$$

where, the indices ph1 and ph2 indicate a material in stage 1 or stage 2, respectively. Differentiating specific enthalpy with respect to temperature provides the following formula for specific heat capacity [11]:

$$C_p = \frac{1}{\rho}(\theta_1\rho_{ph1}C_{p,ph1} + \theta_2\rho_{ph2}C_{p,ph2}) + (H_{ph2} - H_{ph1})\frac{d\alpha_m}{dT} \tag{3}$$

Where, θ_1 and θ_2 are equal to θ and 1−θ, respectively. Mass ratio α_m is defined from, ρ_{ph1}, ρ_{ph2} and θ. Particular attention should be paid to density in time dependent simulations to ensure energy and mass conservation in phase change models. When the fluid density is not constant over time, depending on temperature, the transport velocity field and density should be defined so that the mass is locally conserved. Heat transfer in solids is calculated with the following equation [11].

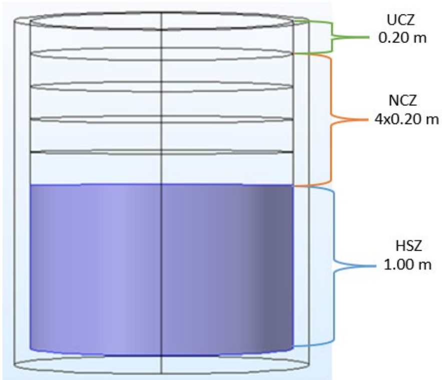
$$\rho C_P\left(\frac{\partial T}{\partial t} + \mathbf{u}_{trans}.\nabla T\right) + \nabla.(\mathbf{q} + \mathbf{q}_r) = \alpha T\left(\frac{\partial S}{\partial t}\right) + \mathrm{Q} \tag{4}$$

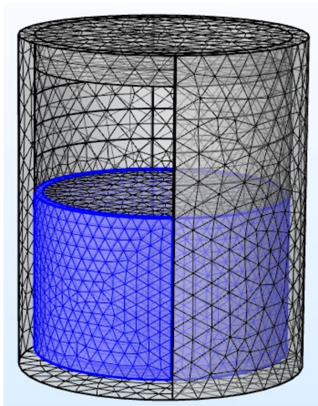
Where, ρ is the density, Cp is the specific heat capacity at constant pressure, T is the absolute temperature, **q** is the heat flux by conduction, $\mathbf{q}_r$ is the heat flux by radiation, α is the coefficient of thermal expansion, p is the pressure, Q contains heat sources. S is the second Piola-Kirchhoff stress tensor. In the steady-state problem, the temperature does not change with time and the time-derived terms disappear. It should be noted that the d⁄dt operator is the material derivative. Radiation with participatory medium, the medium is not completely transparent and the radiation interact with the medium with different way, such as absorbtion, emission and Scattering. The medium absorbs some of the incident radiation and emits radiation in all directions, and also some of the radiation coming from a particular direction is scattered in other directions. The balance of radiative intensity including all contributions (scattering, emission, absorption and scattering) can now be formulated. The general radiative transfer equation can be written as [11]:

$$\Omega \cdot \nabla I(\Omega) = \kappa I_b(T) - \beta I(\Omega) + \frac{\sigma s}{4\pi}\int_{4\pi} \mathrm{I}(\Omega')\varphi(\Omega',\Omega)d\Omega' \tag{5}$$

Here, I(Ω) is the radiation intensity at a particular location travelling in the direction of Ω, Ib(T) is the blackbody radiation intensity, n_r is the refractive index, σ is the Stefan-Boltzmann constant, κ, β, σ_s is the absorption, extinction and scattering coefficients are respectively; φ(Ω′, Ω) is the scattering phase function.

For the modelling, solar pond consists of three zone such as HSZ, NCZ and UCZ. HSZ is one layer and 1 m deep, NCZ has four layers, each with 0.2 m deep and filled with brine. UCZ is one layer, 0.2 m deep and filled with fresh water. PCM was applied to HSZ as a cylindrical shell with 5 cm thick and 1 m high. Cylindrical pond with PCM is presented in Fig. 2a. Mesh was created and tested by using mesh module in COMSOL [11]. General criteria for the numerical simulation is consistency with the experiment, therefore numerical data, consistent with experiment was chosen and finally tetrahedral mesh type with normal element size was decided for the final setting and 22615 tetrahedral element was created for the current model. Mesh distribution is shown in Fig. 2b. For numerical part, discrete ordinate method was used and PARDISO was preferred as the solver.Meterological data (ASHRAE, 2013) was taken for Adana. Because the referenced experiment for a solar pond was conducted in the same district and time.





a) b)

Figure 2. a) PCM embedded in Cylindrical pond b) Mesh distribution of the model

The phase change material, Cetyl-palmitic acid eutectic mixture was prepared and its chemical properties were obtained by FT-IR spectroscopy. The thermophysical properties and surface morphologies were determined by using Differential Scanning Calorimetry and SEM. Table 1 listed the obtained thermophysical properties of Cetyl-palmitic acid.

Table 1. Thermophysical properties of Cetyl-palmitic acid

Melting Temperature (°C)	Latent heat of Fusion (kJ/kg)	Solid density (kg/m^3)	Liquid density (kg/m^3)	Thermal conductivity (W/mK)
44.05	44.666	816.8	817.4	0.090

3. Results and discussion

The data were compared with a previous experimental study to show whether the numerical data were correct. Since the experimental study was carried out in 2014 [12], the physical parameters of the modeling were modeled with the same size, shape and the same boundary conditions as the experimental system. When the Figure 3 is examined, the numerical data shows a good agreement with the experimental study. this fit shows the accuracy of this modeling and predicts consistency for the next part.

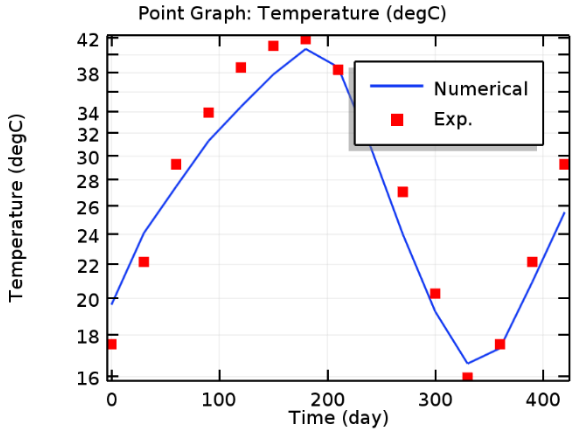


Figure 3. Numerical data vs. experiment

In the next step, the heat storage zone of the pond was covered with a 5 cm thick, shell-shaped phase change material and simulated and presented in Figure 4. Most of the heat losses in the solar pond occur from the upper surface and side walls. The salt gradient zone created in the middle of the pond prevents heat losses by convection. The temperature distribution of the solar pond is examined, it is seen that there are temperature drops as a result of heat losses from the side walls and the surface. Phase change materials applied to the side walls of the storage zone of the solar pond provide the thermal energy to be stored as latent heat. Thus, it is seen that the solar pond is more thermally stable.
As seen in Figure 4a, the phase change material for a longer time than normal solar ponds or stores it for future times. Although, normally, the entire pond is insulated with 10 cm thick foam, The PCM material in the HSZ region increases the insulation compared to the upper layers, as seen in Figure 4b.

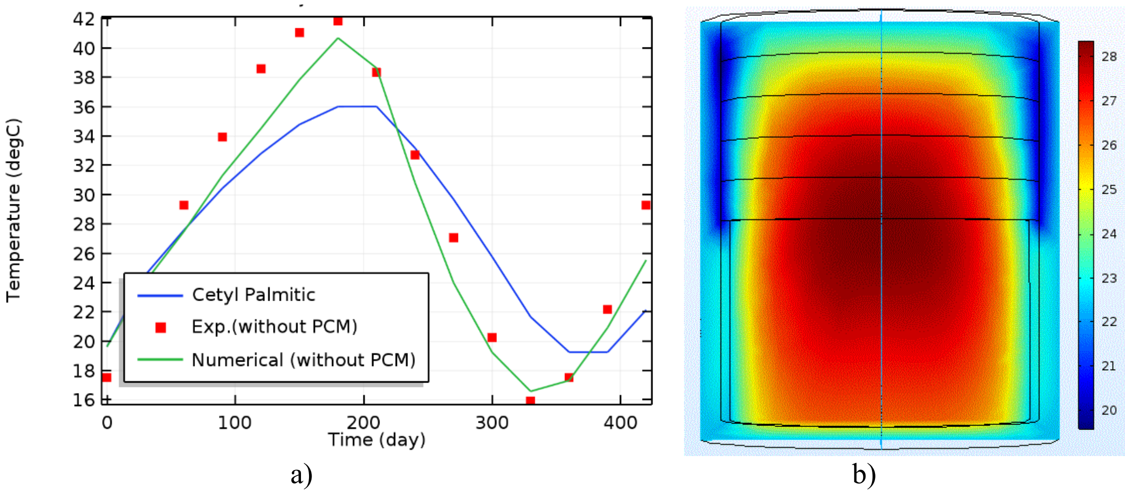


Figure 4. a) Temperature distribution of the solar pond, Cetyl Palmitic embeded in HSZ b) Temperature distribution in August all around the solar pond

4. Conclusions

In order to increase the long-term heat storage capacity of solar ponds where solar energy is collected and stored thermally, the latent heat storage feature of phase change materials can be utilized. In this study, the effect of using phase change materials on longer thermal energy storage in solar ponds was investigated. Phase change material with thermophysical properties suitable for the annual temperature change of the solar pond was selected. The phase change material, cetyl-palmitic acid eutectic mixture was prepared and its chemical properties were determined by FT-IR spectroscopy. Phase change material was applied to the inner surface of the heat storage zone of the solar pond, and the temperature distribution of the designed system was determined numerically. As a result, it has been observed that the solar pond, in which phase change material is used, cools down later, so that heat can be stored for a longer time.

Conflict Of Interest

The authors declare that they have no conflict of interest

Acknowledgment

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