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Thermal Analysis of a Solar Wall Equipped to Nano Phase Change Material

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ABSTRACT: In this paper, the thermal analysis of a solar wall equipped to nano phase change material is carried out, numerically. The governing equation of transient heat conduction is solved by a finite difference technique based on enthalpy method. The validation of numerical results of present study is carried out with the experimental data. There is a fair agreement between numerical results and experimental data. In parametric studies the volume fraction effect of carbon nano tubes and alumina nano particles and the thickness of phase change material is investigated. Present study results showed that suitable improvement in solar wall thermal performance is obtained due to the addition of carbon nano tubes and alumina nano particles to base phase change material. However, carbon nano tubes yield better performance. Performance improvement reasons include the increase of heat transfer speed due to the increase of thermal conductivity and the completion of melting and solidification process. Occurrences resultant leads to a 9% increase in the thermal efficiency of solar wall for 3% volume fraction of carbon nano tubes. Generally, the results of present study give the possibility of the design of a solar wall equipped to phase change material with about 40% of thermal efficiency.

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1- Introduction

The solar wall is the simplest and most commonly used plan for solar energy storage and space heating. A solar wall should save solar energy at high speed to prevent energy dissipation, and release it at the right time, according to need. Therefore, solar walls are equipped with phase change material (PCM). Conventional phase change material (paraffin and hydrated salts), despite their ability to save energy, have low storage and release speed due to the low thermal conductivity coefficient. Nanoparticles and especially carbon nanotubes, due to their unique thermophysical properties, can be used as a major candidate to improve the thermal conductivity coefficient of phase change material. Some studies have been carried out to enhance the thermal performance of phase change materials [1-5]. However, in these studies, the effect of adding nanoparticles and especially carbon nanotubes to paraffin phase change material has not been investigated to improve its thermal conductivity coefficient for solar wall application. Therefore, in the present study with a practical view, the numerical study of the effect of adding spherical nanoparticles of aluminum oxide and carbon nanotubes to the paraffin phase change material is proposed to improve its thermal performance for solar wall application.

2- Methodology

2- 1- Governing equations of problem

Fig. 1 shows the solar wall components in the present research.

The governing equation for analyzing the heat transfer of a solar wall equipped with improved phase change material by nanoparticles is presented as follow [2].

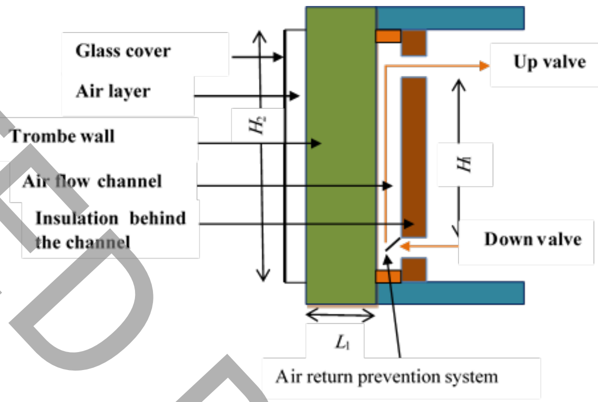

Fig. 1. Solar wall components in the present research

$$\frac{\partial T}{\partial t}=\frac{k_{eff}}{\rho_{eff}C_{p,eff}}\frac{\partial^2 T}{\partial x^2} \tag{1}$$

Where the parameters of T, x, t, k_{eff}, $C_{p,eff}$, and ρ_{eff} are temperature, location, time, thermal conductivity coefficient, specific heat capacity, and density, respectively.

The heat flux transferred to the room space is calculated as follows [2]:

$$q_{in}=h_2\left(T\left(L_1,t\right)-T_{mean}\right) \tag{2}$$

The solar wall efficiency is presented as follows [2]

$$\eta_{th}=\frac{q_{in}}{q_1}\times 100 \tag{3}$$

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The combination theory is used to predict the effective thermodynamic properties of improved phase change material by nanoparticles. Therefore, specific thermal capacity, density, and latent heat are presented as follows [5]

$$\rho_{eff} = \left(1-\Phi_{vol}\right)\rho_{PCM} + \Phi_{vol}\rho_{NP} \tag{4}$$

$$\left(\rho C_p\right)_{eff} = \left(1-\Phi_{vol}\right)\left(\rho C_p\right)_{PCM} + \Phi_{vol}\left(\rho C_p\right)_{NP} \tag{5}$$

$$\left(\rho L\right)_{eff} = \left(1-\Phi_{vol}\right)\left(\rho L\right)_{PCM} \tag{6}$$

The improved Nan model in the solid phase and the improved Yamda model in the liquid phase have been used to predict the effective thermal conductivity coefficient of the carbon nanotubes [6, 7].

$$\frac{k_{eff}}{k_{PCM}} = \frac{3+\Phi\left(B_x+B_z\right)}{3-\Phi B_x} \tag{7}$$

$$\frac{k_{eff}}{k_{PCM}} = \frac{\frac{k_{p,m}}{k_{PCM}} + \alpha - \alpha\Phi_N\left[1-\left(\frac{k_{p,m}}{k_{PCM}}\right)\right]}{\frac{k_{p,m}}{k_{PCM}} + \alpha + \Phi_N\left[1-\left(\frac{k_{p,m}}{k_{PCM}}\right)\right]} \tag{8}$$

The effective thermal conductivity coefficient of improved phase change material by the spherical aluminum oxide nanoparticles is calculated from following equations [8]:

$$k_{eff} = \frac{k_{NP} + 2k_{PCM} - 2\left(k_{PCM} - k_{NP}\right)\Phi_{NP}}{k_{NP} + 2k_{PCM} + \left(k_{PCM} - k_{NP}\right)\Phi_{NP}} k_{PCM}$$

$$+\beta k_1 s\, \rho_{PCM} C_{p,PCM} \sqrt{\frac{\underset{\sim}{k}T}{\rho_{NP} d_{NP}}} f\left(T, \Phi_{NP}\right) \tag{9}$$

2- 2- Numerical solution method and validation

Regarding the nonlinear nature of the governing equations, the numerical method of explicit finite difference based on enthalpy method was used to solve them [9]. In order to validate numerical method a comparison between the numerical results of the present study and experimental data of Zalewski et al. [1] for the parameter of heat flux transferred to the room's space have been carried out. Fig. 2 shows this validation.

3- Results and Discussion

In Table 1 the efficiency of the solar wall for paraffin and paraffin improved by carbon nanotubes and spherical nanoparticles (aluminum oxide) were calculated with three volume fractions of 3%, 5%, and 10%, and three different thicknesses of 6.25 mm, 12.5 mm, and 25 mm, and compared.

4- Conclusions

Main conclusions of the present study are as follows

- For paraffin containing carbon nanotubes, the highest efficiency is related to the largest thickness (25 mm).
- In terms of economic issue, due to the fact that in the thickness of 25 mm all material does not completely change the phase and in fact, not all material release and storage capacity is used, it is also better to use a thickness of 6.25 mm. Because the whole material completely converts to the solid phase at night and releases its latent energy, and during the day, it converts to the liquid phase and stores the entire amount of energy received from the sun. Therefore, according to the discussion, finally, a thickness of 6.25 mm is recommended.
- In high volume fraction of carbon nanotubes with the increase of the thickness of phase change material the heat flux transferred the room space increases due to the increase of the conductivity of phase change material.

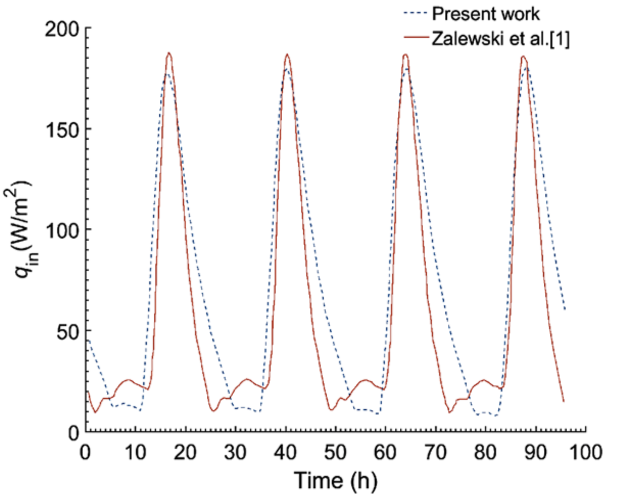

Fig. 2. Comparison of the numerical results of the present study with experimental data of Zalewski et al. [1] for the heat flux parameter transferred to the room's space

Table 1. Efficiency of the solar wall for conventional and improved phase change material in different thicknesses

PCM type	Thicknesses of PCM 6.25 mm	12.5 mm	25 mm
	η_{th} (%)	η_{th} (%)	η_{th} (%)
PCM (Paraffin)	42.17	41.34	4.066
PCM+3%Al_2O_3	42.52	42.06	41.51
PCM+5%Al_2O_3	42.57	42.22	41.88
PCM+10%Al_2O_3	42.7	42.3	42.12
PCM+3%CNT	42.95	43.02	43.84
PCM+5%CNT	43.07	43.16	43.97
PCM+10%CNT	43.16	43.21	44.14

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