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Nanoparticles Enhanced Phase Change Material (NPCM) as Heat Storage in Solar Still Application for Productivity Enhancement

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Abstract

Whereas other researchers used various active and passive techniques to improve the productivity of solar still, this paper uses nanoparticles impregnated in phase change material (NPCM) for productivity enhancement. The solar still is fabricated individually with phase change material (PCM) and NPCM and analyzed both experimentally and theoretically. It is found that the solar still with PCM yielded 1.96 kg/0.5m^2 whereas the solar still with NPCM yielded 2.64 kg/0.5m^2. There was 35% improvement in productivity observed in solar still with NPCM as against solar still with PCM. The experimental results were validated with the predicted results and the discrepancy was found to be ±10%. Hence it is concluded that NPCM has better potential than PCM for solar still applications

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Keywords: energy storage; solar still; phase change material; nano particles; productivity; paraffin

1. Introduction

Desalination is the only remedy to meet the growing demand for fresh water. There are various desalination techniques [1], among them solar still is one of the ancient economic technique to desalinate the saline water. There are various active and passive methods to increase the distillate yield in solar still [1]. Latent heat energy storage is one such methods which uses phase change materials (PCM) for energy storage. The main drawback of PCM is its thermal conductivity and energy storage density. To overcome this nanoparticles are being used in various applications.

Very few literatures have been reported using PCM in solar still application. Shalaby et al. [2] used paraffin in solar still and found that it improves the distillate yield by 12%. Kabeel and Abdelgaied [3] used paraffin in solar still and obtained 67.18% increase in productivity than that of the conventional stills. Ansari et al. [4] used paraffin in the solar still and achieved productivity of about 4.5 l/m^2. Dashtban and Tabrizi [5] used paraffin and achieved productivity of about 6.7 l/m^2. Mousa and Gujarathi [6] used paraffin as latent heat energy storage material in solar

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still application and achieved 49% increase in productivity. Sarhaddi et al. [7] used paraffin in cascade solar still and achieved the maximum energy efficiency up to 75%. However there is no literature available using nanoparticle enhanced PCM (NPCM) in solar still application. Thus the proposed work bridges the aforementioned research gap by analyzing the solar still with NPCM and comparing against PCM both experimentally and theoretically.

2. Mathematical modelling

The mathematical modeling was done by formulating energy balance equation for each components of the solar still. The schematic of solar still is depicted in [5 and 7]. The following assumptions are made:

1. Glass and water temperatures are uniform
2. Heat losses (from sides of the solar still) are negligible
3. There is no convection and temperature gradient in and throughout the PCM respectively

In the following equations the subscripts gl, w, a, sk, p, pcm, 1, 2 ins, c, ev, s and l represents glass, water, air, sky, absorber plate, PCM, heat transfer coefficient from absorber plate to water, water to glass cover, insulator, convection, evaporation, solid and liquid state respectively. The symbols A, T, I(t), α, τ, Gr, Pr, h, C, K, x´ represents the area, temperature, intensity of solar radiation, absorption co-efficient, transmission co-efficient, Grashof number, Prandtl number, heat transfer co-efficient, specific heat capacity, thermal conductivity, characteristic dimension for the rectangular surface respectively.

2.1. Energy balance equation for Glass cover

The energy balance equation for glass cover is given below [7]

$$\alpha_{gl} I(t) A_{gl} + h_2 A_w (T_w - T_{gl}) = h_{c,gl-a} A_{gl} (T_{gl} - T_a) + h_{r,gl-a} A_{gl} (T_{gl} - T_{sk}) + m_{gl} c_{gl} \left(\frac{dT_{gl}}{dt}\right)$$

where α_{gl} and c_g corresponds to 0.05 and 800 J/kg.^{0}C respectively

2.2. Energy balance equation for brine water

The energy balance equation for brine water is given below [7]

$$\alpha_w I(t) A_w T_w + h_1 A_p (T_p - T_w) = h_2 A_w (T_w - T_{gl}) + m_w c_w \left(\frac{dT_w}{dt}\right)$$

$$h_1 = 0.54 \left(\frac{K_w}{\acute{x}}\right) (Gr.Pr)^{0.25}$$

where x', K_w, A_p, C_w and α_w corresponds to 1 m, 0.57 W/m^2.^{0}C, 1 m^2, 4190 J/kg.^{0}C and 0.05 respectively

2.3. Energy balance equation for Absorber plate

The energy balance equation for absorber plate is given below [7]

$$\alpha_p I(t) A_p \tau_g \tau_w = h_1 A_p (T_p - T_w) + \left(\frac{K_{pcm}}{X_{pcm}}\right) A_p (T_p - T_{pcm}) + m_p c_p \left(\frac{dT_p}{dt}\right)$$

Where the values of α_p, τ_g, τ_w, A_p, C_p, K_{pcm}, X_{pcm}, m_{pcm} are 0.9, 0.9, 0.95, 1 m^2, 896 J/kg.^{o}C, 0.26 W/m^2.^{o}C, 0.02m and 9 kg respectively

2.4. Energy balance equation for PCM

The melting point of PCM and NPCM is 63.5 and 59 ^{o}C respectively. The energy balance equation for PCM when the temperature of PCM is less than that of melting point temperature is given by [7]

$$\left(\frac{K_{pcm}}{X_{pcm}}\right)(T_p - T_{pcm}) = \left(\frac{K_{ins}}{X_{ins}}\right)(T_{pcm} - T_a) + \frac{m_{pcm} c_{s,pcm}}{A_p} \left(\frac{dT_{pcm}}{dt}\right)$$

The energy balance equation when the PCM temperature is between melting point and incremental rise is given by [7]

$$\left(\frac{K_{pcm}}{X_{pcm}}\right)(T_p - T_{pcm}) = \left(\frac{K_{ins}}{X_{ins}}\right)(T_{pcm} - T_a) + \frac{m_{pcm} L_{pcm}}{A_p} \left(\frac{dT_{pcm}}{dt}\right)$$

The energy balance equation when the PCM temperature is more than the incremental rise of the melting point is given by [7]

$$\left(\frac{K_{pcm}}{X_{pcm}}\right)(T_p - T_{pcm}) = \left(\frac{K_{ins}}{X_{ins}}\right)(T_{pcm} - T_a) + \frac{m_{pcm} c_{l,pcm}}{A_p} \left(\frac{dT_{pcm}}{dt}\right)$$

where the incremental rise, $c_{s,pcm}$, $c_{l,pcm}$, L_{pcm}, K_{pcm}, X_{pcm}, K_{ins}, X_{ins} values are 3^o, 2.95 kJ/kg.^{0}C, 2.51 kJ/kg.^{0}C, 102 kJ/kg, 0.26 W/m^2.^{o}C, 0.02 m, 0.033 W/m^2.^{o}C and 0.03 m respectively. The same equation will be used for NPCM,