Mechanical Analysis Carrired out to a Single Basin Solar Still Integrated with Nano -Composite PCM

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Abstract
In this article, thermal modeling of a single basin solar still coupled with an evacuated tube solar collector under natural circulation mode has been carried out on the basis energy balance equations. The expressions of inner surface of glass cover, outer surface of glass cover, basin liner, and water mass have been derived for the numerical computation. The experiments were conducted under various meteorological conditions for 0.05 m water depth. This experimental setup has been installed at Solar Energy Park, Tamilnadu College of Engineering, Coimbatore, India (Latitude: 11ıN; Longitude: 77ıE; and an altitude of 409 m above sea level). Observation revealed that there was a considerable increase in the average daily yield of solar still when integrated with an evacuated tube solar collector. For all the cases, the correlation of coefficients (r) between theoretical and experimental values have been verified and they showed good agreement with 0:98 < r < 0:99 and root mean square present deviation of 10:26 < e < 39:7%.
Keywords- Modal analysis of lathe, vibration monitoring of machine tool.

1. Introduction

The severe shortage of fresh drinking water in remote and urban areas in the world, it is need to distillate the available saline water to compensate the shortage. The uncertinities of grid supply, the peoples are unable to use existing popular desalination devices to get fresh water. The utilization of solar energy for desalination shall be the best solution for rural as well as urban areas while exploitation of fossil fuels to run the exsiting desalination devices . The use of solar energy is a promising option for desalination of saline water because it locally available and zero energy cost (Tiwari, 2010).

The evaluation of energy efficiency and distillate output of any solar stills is primarily done by energy analysis, which is based on the first law of thermodynamics. It considers only the quantitative aspect of the energy transfer. The quality of energy or exergy, defined by the second law of thermodynamics is usually ignored. The technique of exergy analysis is proved to be the most effective thermodynamic tool for achieving the goal of more efficient resource use, as it enables the locations, types and true magnitudes of waste and loss to be determined. It has been successfully applied in the optimization of the entire system or specific variables in a single component of thermal systems, such as steam power plants, solar thermal power plants, steam or gas turbine, boiler, etc. This knowledge can also be used to design a solar still, to reduce the sources of inefficiency and irreversibility in the existing processes and components of the solar still. It may prove to be very useful to achieve higher cost-effective efficiency and productivity.

Mona Naim et al. (2002) signed a still with PCM like paraffin wax and paraffin oil as energy storage medium to store excess solar energy at noon with its latent heat of fusion, which could be utilized during the off shine hours for production of distillate. Tiwari et al.(1985) investigated the effect of water flow. Tiwari et al. (2009) have investigated the effect of the number of collectors and water depth on exergy and thermal efficiency of the active solar still. Kumar and Tiwari (2011) have analyzed the energy and exergy efficiency of a shallow basin passive solar still. It is found that with decrease in absorptivity (0.9–0.6) with time, the energetic and exergetic efficiencies decrease by 21.8% and 36.7%, respectively. The effect of glass cover tilt is found to be insignificant, and the respective efficiencies decrease by 0.75 and 0.47% per degree increase in tilt. These efficiencies increase rapidly up to a wind velocity of 2 *m/s*. Kianifar et al. (2012) have conducted an exergy analysis to show the effect of a small fan on the exergy efficiency in a pyramid-shaped solar still. The effect of seasonal change on exergy efficiency has also been reported here. Theoretical overall instantaneous exergy efficiency of a passive solar still having 308 tilt angle of glass cover and water depth of 0.04 m on a typical day in June was evaluated by Kaushik et al. (2013). They have found it in the range of 0.06–5.9% for the variation in experimental results of overall instantaneous energy efficiency from 8 to 87.2%. The daily energy and exergy efficiency of the solar still is 20.7 and 1.31%, respectively. The interest of the exergy analysis is to locate and characterize the causes of exergy destruction or exergy losses, as well as to quantify the corresponding rates. The concept of exergy destruction or rate of irreversibility is widely used for the exergy analysis of thermal systems. But its application in the analysis of passive solar still is a few.
The objective of this study is to analysis the exergy efficiency of solar still integarted with nano compoiste phase change materails with different weight ratio of materails on phase change materails for the given design and operating paramaters.

2. Descsription of the Systsem

A schematic diagram of the investigated solar still with built-in PCM as a storage medium is shown in Figure 1. It consists of three main components : (i) metallic basin –liner,(ii) saline water body and (iii)glass cover and (iv) Thermal energy storage. It operates on the basic principal of heating, evaporation and condensation similar to the phenomenon of natural raining but within a confined space.it relies on the distillation process to remove fresh water from saline or brackish water. The schematic diagram of single slope solar still incporated with nano-composite phase change matierails is considred for an investigations is shown in figure 1. It shows the major energy transfer mechanisms of the solar still producing potable water. The operating and climatic parameters of the selected passive solar distillation system are mentioned in Table 1 and Table 2

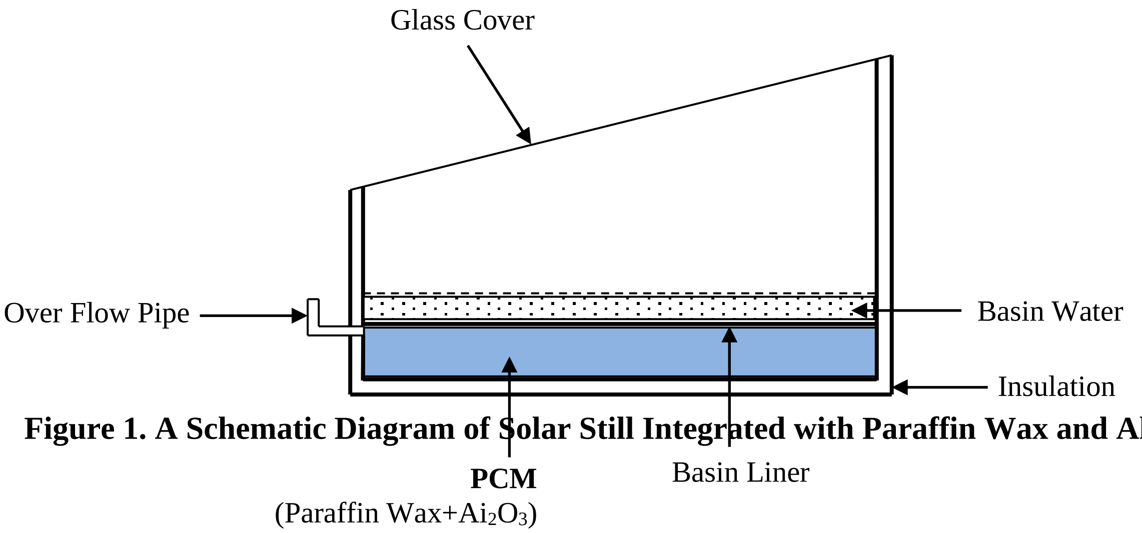

Figure 1. A Schematic Diagram of Solar Still Integrated with Paraffin Wax and Al_2O_3

The solar radiation transmistted through the glass cover and basin water is absorbed by the basin line; hence, its temperature increases, part of thermal energy is tramistted by convection to the basin water and other will transfreed by conduction to the PCM under the basin liner. When the basin linear temperature becomes higher that that of PCM, heat will be stored in the melted PCM as latent heat. When the solar radiation decreases, the still components starts cool down, latent heat PCM transfer heat to the basin liner and from the latter to the basin water until the PCM completely solidified. The still conitues to produce the fresh water after sunset even with thin layer of basin water. Basin water transfers heat to the bottom surface of the glass cover by radiation, convection and evaloration. The heat is conducted through the glass cover and then transfer to surroundings by adiation to the sky and by convection to ambient air.

Table 1.
Design parameters of the passive solar still.

Parameters	Value
Specific heat of saline water c_m	4190J/kgK
Latent heat of vaporization, h_{fg}	2260103 J/kg
Thermal conductivity of water k_w	0.590 W/m K
Depth of saline water in the basin, X_w	0.04 m s
Emissivity of glass	0.94
Time interval, Δt	3600 s
Area of basin-liner, A_b	1m×1m
Thermal conductivity of glass cover, K_g	0.78 W/m K
Thermal conductivity of insulating material, K_i	0. 35 W/m K
Thickness of glass cover, X_g	0.003 m
Thickness of insulation, X_i	0.005 m
Effective absorptance of basin-liner ,	0.5814

Effective absorptance of glass cover ,	0.05
Effective absorptance of water,	0.27
Glass cover tilt angle from horizontal,	308
Stefan Boltzmann constant,	$5.67 w/m^2 k^{-4}$

3. Thermodynamic Modeling

The components of basin-liner, saline water, glass cover and thermal energy storage materials of the solar still integrated with thermal energy storage are modeled based on first and second law of thermodynamics. The following assumptions have been considered.

(i). The conduction heat transfer mode between PCM and basin liner.
(ii). The temperature gradients across the basin-liner, saline water depth and PCM are negligible.
(iii). The heat capacity of the basin-liner, glass cover and insulating materials are negligible compared to those for the basin water and PCM.
(iv). The system is vapor tight and the side losses are neglible;
(v). The PCM is in good contact with the basin liner
(vi). The heat transfer coefficients are temperature dependent.
(vii). The inside and outside glass cover temperatures are different $(i.e. T_{gi} \neq T_{go})$.
(viii). The side heat loss from the solar still is negligible because of very small area of side wall of the still as compared with basin-liner area.
(ix). The selected nano-composite phase change materials are homogenous and its thermp physical properties are constant
(x). All properties of saline water are assumed to be similar to that of water for simplicity

3.1 Energy Analysis

3.1.2 nano Phase Change Materials

The thermophysical properties of paraffin wax and Al_2O_3 are listed in Table 2. The difference in solid and liquid temperature defines the transition from solid to liquid phase during the melting of PCM. The density, specific heat capcity, latent heat of nano PCM, dynamic viscosity and thermal conductivity are computed from the following correlations (Chow and Zhong, 1996)

$$\rho_{n-pcm} = \phi \rho_{np} + (1-\phi)\rho_{pcm} \tag{1}$$

$$c_{p,n-pcm} = \frac{\phi(\rho c_p)_{np} + (1-\phi)(\rho c_p)_{pcm}}{\rho_{n-pcm}} \tag{2}$$

$$L_{n-pcm} = \frac{(1-\phi)(\rho L)_{pcm}}{\rho_{n-pcm}} \tag{3}$$

$$\mu_{n-pcm} = 0.983 e^{12.959\phi} \mu_{pcm} \tag{4}$$

$$K_{n-pcm} = \frac{K_{np} + 2K_{pcm} - 2(K_{pcm} - K_{np})\phi}{K_{np} + 2K_{pcm} + (K_{pcm} - K_{np})\phi} K_{pcm} + 5x10^4 \beta_k \zeta \phi \rho_{pcm} c_{p,pcm} \sqrt{\frac{BT}{\rho_{np} d_{np}}} f(T,\phi) \tag{5}$$

The effect of thermal conductivity of the nano PCM which includes the effecs of particle size, particle volume fraction and temperature dependence as well as properties of the base PCM and the particle subject to Brownian motion. where *B* Boltzman constant 1.381x10-23 J/K and

$$\beta_k = 8.4407(100\phi)^{-1.07304} \tag{6}$$

$$f(T,\phi) = (2.8217x10^{-2}\phi + 3.917x10^{-3})\frac{T}{T_{ref}} + (-3.0669x10^{-2}\phi - 3.91123x10^{-3}) \tag{7}$$

Where Tref is the reference temperature 273 K. The first part Kn-pcm is obtained from the directly the Maxwell model while the second par accounts for Brownian motion. Which causes the temperature dependenc of the effective thermal conductivity.Note that there is a correction factor ζ in the Brownian motion term, since there should be no Brownian motion in solid phase.

Table 2
Properties of Paraffin Wax and Aluminium Oxide (Al_2O_3.)

Property	Paraffin wax	Al_2O_3
Density ((kg/m^3))	750/((0.001(T-319.15)+1)	3600
Specific heat (J/kgK)	2890	765
Thermal conductivity (W/mK)	0.21 if T < T*solidus* 0.12 if T > T*liquidus*	36
Viscosity (Ns/m^2)	0.001 exp (-4.25+1790/T)	-
Latent heat (J/kg)	173400	-
Solidus	319	-

temperature (K)		
Liquidus temperature (K)	321	-

The amount of thermal energy stored and delivered during the charging and discharging period are computed from the following correlations

$$E_{stored} = m_{n-pcm}c_s(T_m - T_{in}) + m_{n-pcm}L_{n-pcm} + m_{n-pcm}c_l(T_{out} - T_m) \quad (8)$$

$$E_{delivered} = m_{n-pcm}c_l(T_m - T_{out}) + m_{n-pcm}L_{n-pcm} + m_{n-pcm}C_s(T_{in} - T_m) \quad (9)$$

Energy efficiency of thermal energy storage material is

$$\eta_{I,n-pcm} = \frac{E_{delivered}}{E_{stored}} \quad (10)$$

3.1.2 Energy efficiency of basin liner

It is defined as the ratio of thermal energy transferd to the water to thermal energy absorbed in the basin liner asn mathmmatically expressed as

$$\eta_{I,basinliner} = \frac{m_w c_{pw}(T_{wo} - T_{wi})}{\tau_g \tau_w \alpha_b G_s} \quad (11)$$

3.1.3 Solar Still

The theoretical overall instantaneous energy efficiency of a solar still with nano composite material at any time defined as the ratio of heat transfer rate in the still by evaporation – condensation ($q_{e,w-g}$) to the rate of incident solar radiation (Gs) on the glass cover of solar still (Sampathkumar et al., 2010), i.e.

$$\eta_{I,still} = \frac{q_{e,w-g}}{G_s} = \frac{h_{e,w-g}(T_w - T_g)}{G_s} \quad (12)$$

The expression for the houraly distillate output (m_{wo}) from the solar still *(kg/m^2 h)* is calculated using the following Eq.

$$m_{wo} = \frac{h_{e,w-g}(T_w - T_{gi})}{h_{fg}} \times 3600 \quad (13)$$

Where $h_{e,w-g}$ is evaporative heat transfer coefficient between saline water and glass cover (kg/$m^2\,h$), and h_{fg} is the latent heat of vaporization of water (J/kg).

The daily productivity and daily energy efficiency of a solar still with nano-composite material PCM is calculated as follows;

$$m_{wo,daily} = \sum_{24hours} m_{wo} \quad (14)$$

$$\eta_{I,daily} = \frac{\sum m_{wo} \times h_{fg}}{\sum G_s \times 3600} \tag{15}$$

3.2 Exergy Analysis

The exergy (work potential) of heat or exergy transfer accompanying heat, Ex_q (in W/m2) connected to internal and external heat transfer of passive solar stills through conduction, convection or evaporation (i.e. excluding radiation) is expressed as follows (Moran and Shapiro, 2010)

$$\mathrm{E}x_q = q\left(1 - \frac{T_a}{T}\right) \tag{16}$$

The exergy transfer associated with blackbody radiation $Ex_{radiation}$(Petala, 2010) at surface temperature T, i.e. thermal radiation q_r from the component of the solar still, with reference to a reference temperature T_a, is expressed similar to the solar exergy described in the next section:

$$Ex_{radiation} = q_r\left[1 + \frac{1}{3}\left(\frac{T_a}{T}\right)^4 - \frac{4}{3}\left(\frac{T_a}{T}\right)\right] \tag{17}$$

3.3 nano Composite Phase Change Materials

The mass of nano composite materials is fixed and conduction heat transfer process, the exergy transfer during input, stored, deliverd and exergy efficiency of the nano composite phase change materials are expressed as follows (Rezaei, 2013)

$$Ex_{input} = m_{n-pcm}c_{n-pcm}\left[\left(T_{n-pcm,in} - T_{n-pcm,out}\right) - T_o \ln\left(\frac{T_{n-pcm,in}}{T_{n-pcm,out}}\right)\right] \tag{18}$$

$$Ex_{output} = m_{n-pcm}c_{n-pcm}\left[\left(T_{n-pcm,out} - T_{n-pcm,in}\right) - T_o \ln\left(\frac{T_{n-pcm,out}}{T_{n-pcm,in}}\right)\right] \tag{19}$$

$$Ex_{stored} = m_{n-pcm}c_{n-pcm}(T_{n-pcm,in} - T_{n-pcm,out})\left(1 - \frac{T_o}{T_m}\right) \tag{20}$$

$$\eta_{II,n-pcm} = \frac{Ex_{output}}{Ex_{input}} \mathrm{x}100 \tag{21}$$

3.3.3 Glass cover

$$Ex_{d,g} = \alpha_g Ex_{t,w-g} - Ex_{t,g-a} \tag{22}$$

where α_g is the absorptivity of glass cover and $Ex_{t,g-a}$ is the exergy loss associated with heat losses from glass cover to the atmosphere owing to radiation $Ex_{r,g-a}$ and convection $Ex_{c,,g-a}$ and is given as:

$$Ex_{t,g-a} = Ex_{t,g-a} + Ex_{c,g-a} \tag{23}$$

The glass cover can be assumed to work as a performaing useful work by helping in the condensation of the distillate by rejecting heat to tha atmosphere.therefore, exergy efficiency of the glass cover can be expressed as the ratio of exergy in the distillate yield and the maximum possible work obtainable from the total heat gained by glass cover (Energy efficiency), hence, the exergy efficiency of the glass cover may be given as :

$$\eta_{ex,glass\,cover} = \frac{m_{wo} h_{fg}\left(1-\frac{T_a}{T_w}\right)}{\alpha_g Ex_{sun} + Ex_{t,w-g}} \tag{24}$$

$$\eta_{ex,glasscover} = \frac{Ex_{e,w-g}}{\alpha_g Ex_{sun} + Ex_{t,w-g}} \tag{25}$$

Exergy efficiency on saline water

$$\eta_{ex,salinewater} = \frac{Ex_{t,w-g}}{(\tau_g \alpha_w) Ex_{sun} + Ex_w} \tag{26}$$

3.3.4 Basin-liner

Exergy of the solar radiation on the solar still per unit area, Ex_{sun} (in W/m2), is given as :

$$Ex_{sun} = G_s\left[1 + \frac{1}{3}\left(\frac{T_a}{T_s}\right) - \frac{4}{3}\left(\frac{T_a}{T_S}\right)\right] \tag{27}$$

Exergy efficiency on basine –liner

$$\eta_{ex} = \frac{Ex_w}{(\tau_g \tau_w \alpha_b) Ex_{sun}} \tag{28}$$

3.3.5 Exergetic Efficiency

The overall instantaneous exergy efficiency of the solar still with composite PCM is defined as the ratio of exergy output of solar still to the exergy of the incident solar radion, i.e. Exergy output of the solar still with composite PCM is the useful exergy associated with heat transfer through evaporation,i.e.$Ex_{e,w-g}$, which is responsible for the transportation of the water vapor from saline water surface to the glass cover and distillate is produced after condensation.hence,

$$\eta_{ex} = \frac{Ex_{e,w-g}}{Ex_{sun}} \tag{29}$$

$$\eta_{ex} = \frac{q_{e,w-g}(1-\frac{T_a}{T_W})}{Ex_{sun}} \tag{30}$$

$$\eta_{ex,solar\,still} = 1-\left[\frac{Ex_{d,b}+Ex_{d,w}+Ex_{d,g}}{Ex_{sun}}\right] \tag{31}$$

4. Numerical Results and Discussion

Thermophysical properties of Al_2O_3 nano materails disperesed in melted praffin wax with 2%weight and 4%weight is computed for the different temperature based on the equations mentioned in thermal modeling section. The Figure 1 shows the variation of density of nano composite phase change materails with temperature. It decreases slowley to increase in temperature for the different weight ratio of Al_2O_3 and paraffin wax alone.

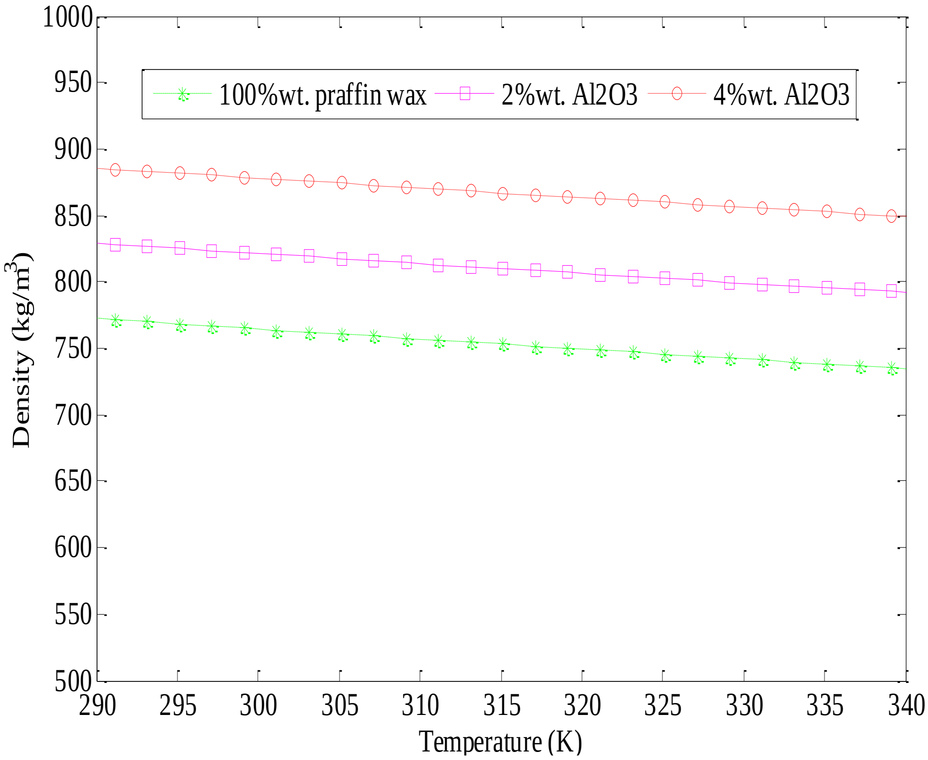

Figure 1 Variation of density with respect to temperature and weight ratio of nano particles

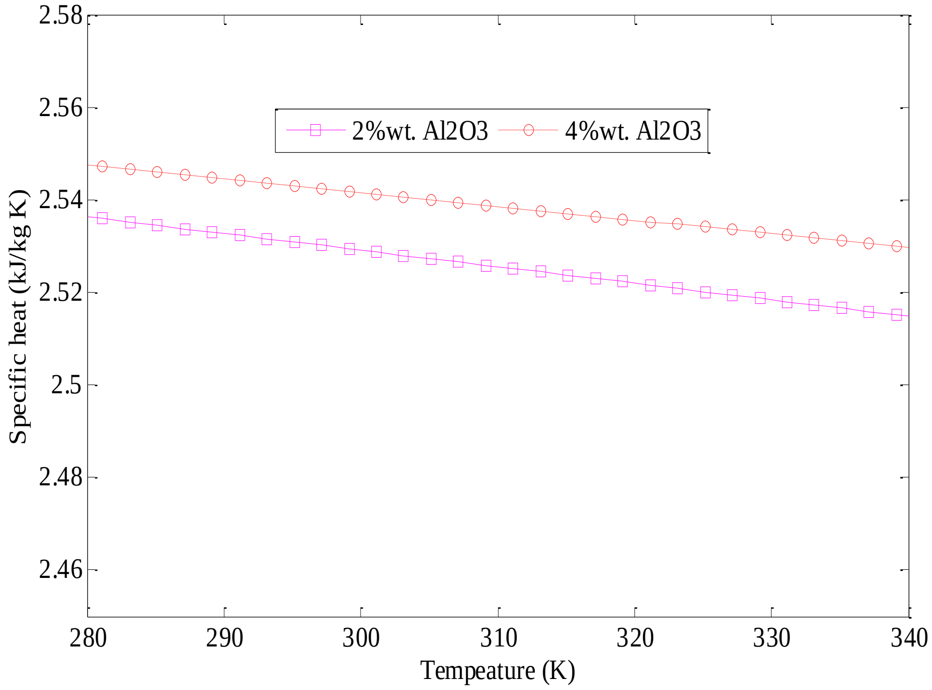

Figure 2 Variation of specfic heat with respect to temperature and weight ratio of nano particles

The Figure 2 shows the specfic heat value of nano composite phase change materails for 2% and 4% weight ratio and it decreases slowly for increase in temperature. The Figure 3 shows the variation of latent heat value of nano composite phase change materails with temperature and it decrease while increase in it temperature

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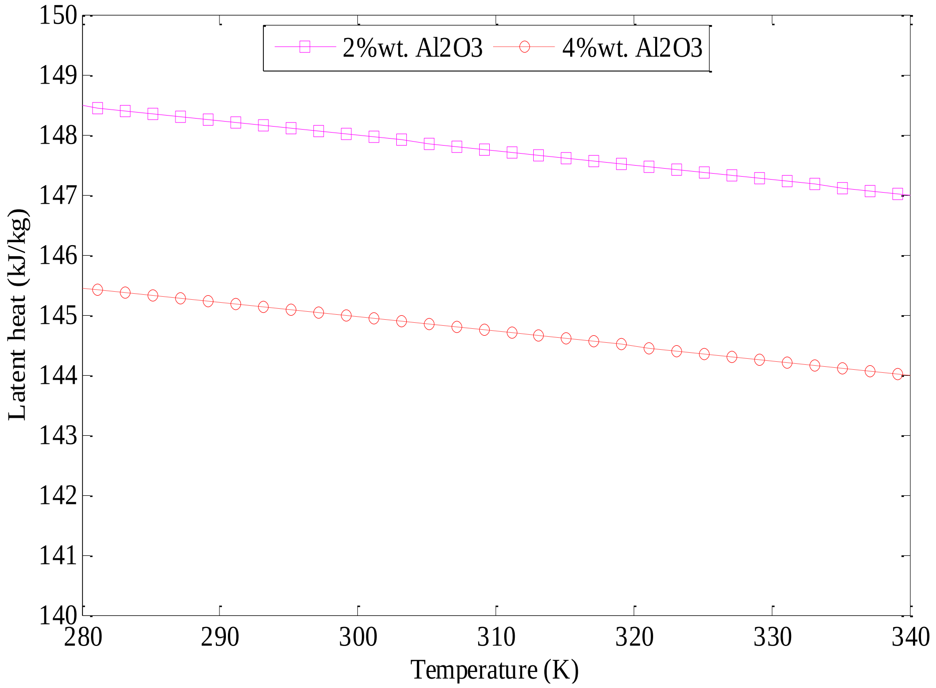

Figure 3 Variation of latent heat with respect to temperature and weight ratio of nano particles

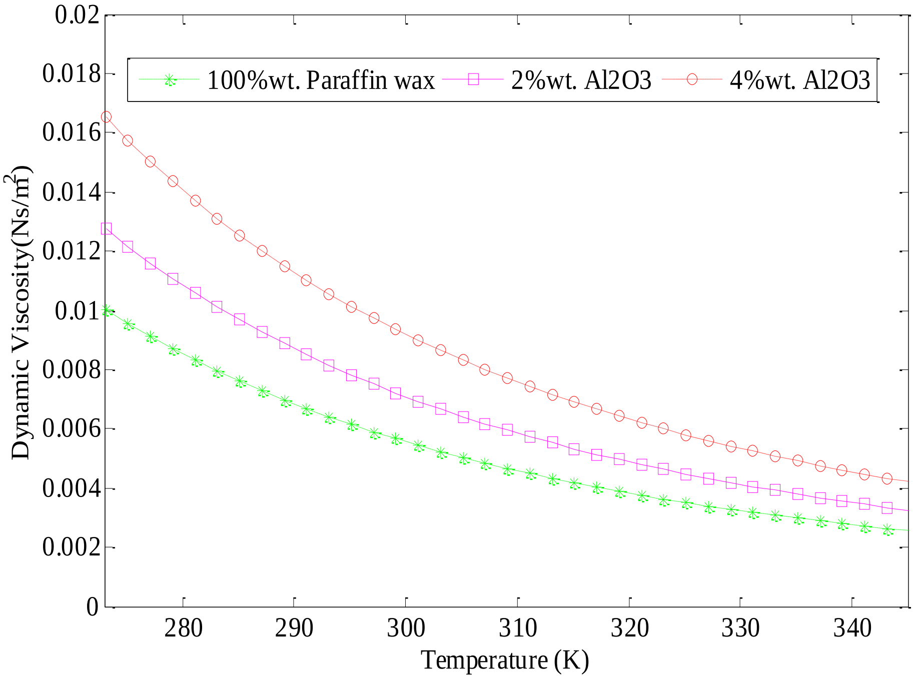

Figure 4 Variation of dynamic viscosity with respect to temperature and weight ratio of nano particles

The Figure 4 shows the dynamic viscosity variation with temperature for 2%wt and 4%wt Al_2O_3 and paraffin wax alone. The dynamic viscosity values are decrease for increase in temperature and its value differences are minimum at higher temperature compared to minimum temperature

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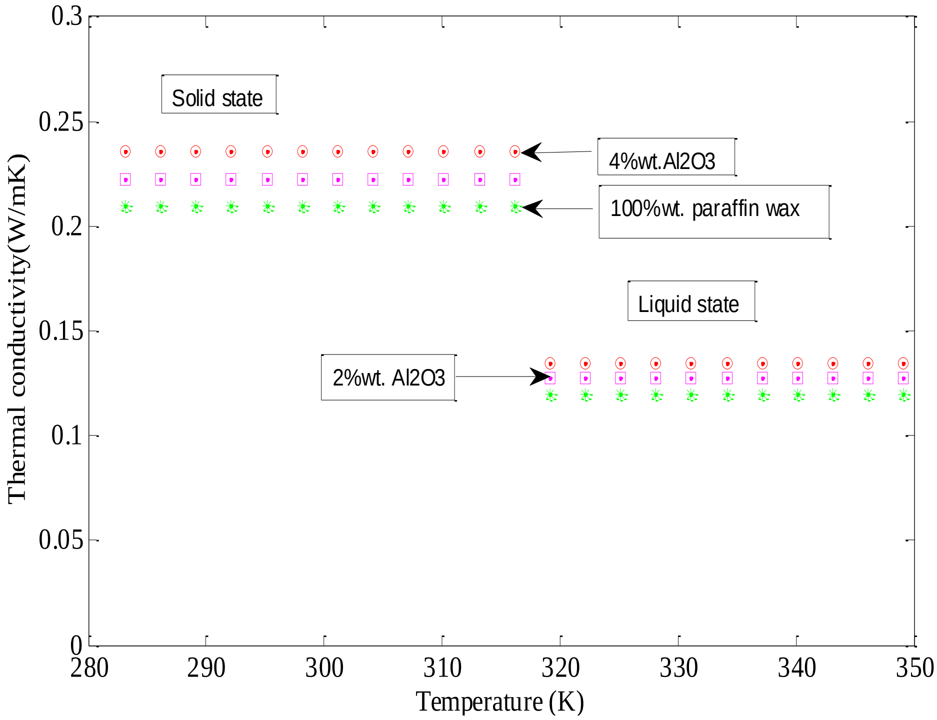

Figure 5 Variation of thermal condutivity with respect to temperature and weight ratio of nano particles

The Figure 5 illustrates the variation of the thermal conductivity with respect to temperature and weight ratio of nano particles. Values are high at solid state when comapred to liquid state.

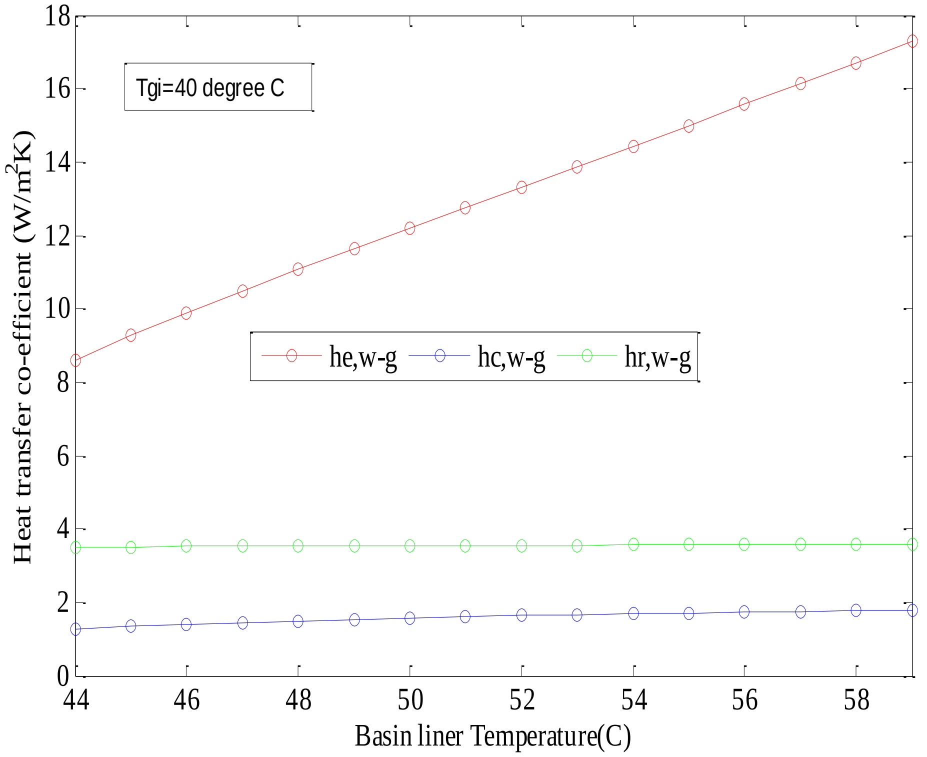

Figure 6 Variation of heat transfer co-efficient with respect to basin liner temperature

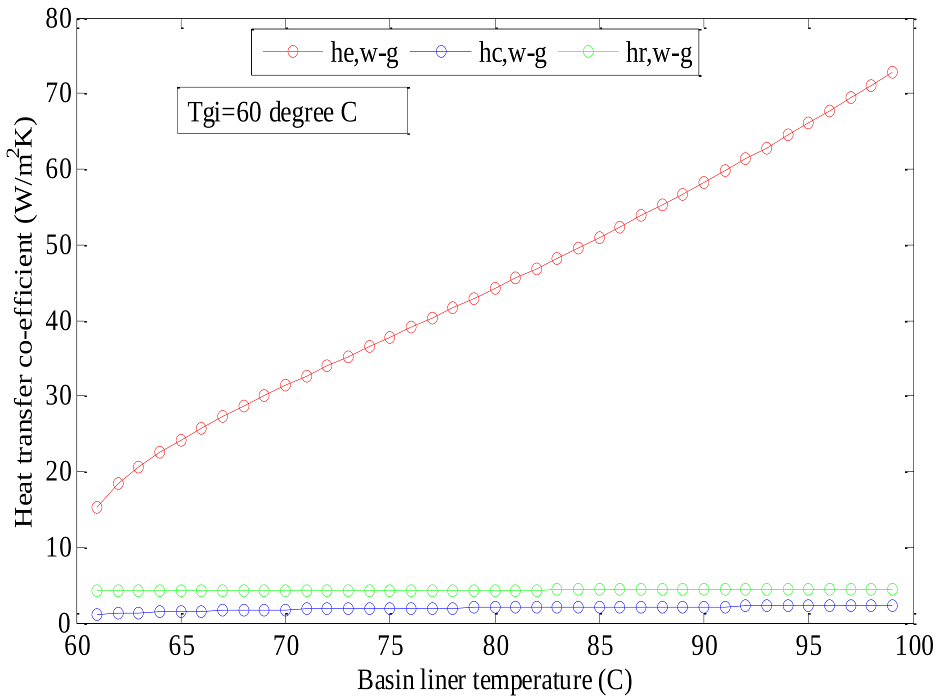

Figure 7 Variation of heat transfer co-efficient with respect to basin liner temperature

The Figure 6 and Figure 7 shows the evaporative heat transfer co-efficient, radiative heat transfer co-eeffcient and convective heat transfer co-efficient value between the diferent termperature of basin liner and a values of inner glass cover temperature. The evaporative heat transfer co-efficient is dominat factor compared to convective and radiative heat transfer co-efficient values for both cases.

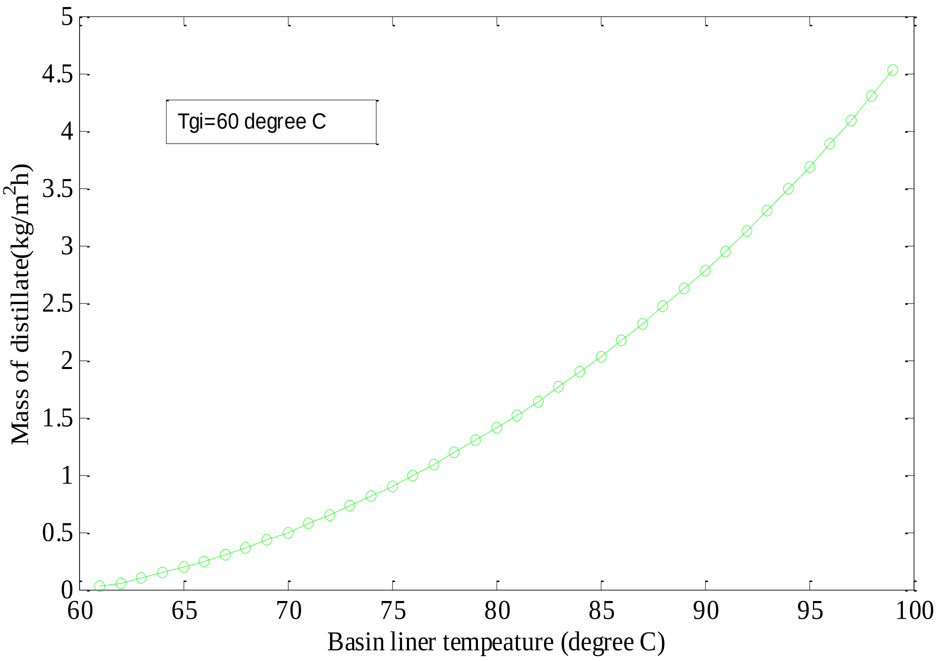

Figure 8 Variation of mass of distillate for basin liner temperature

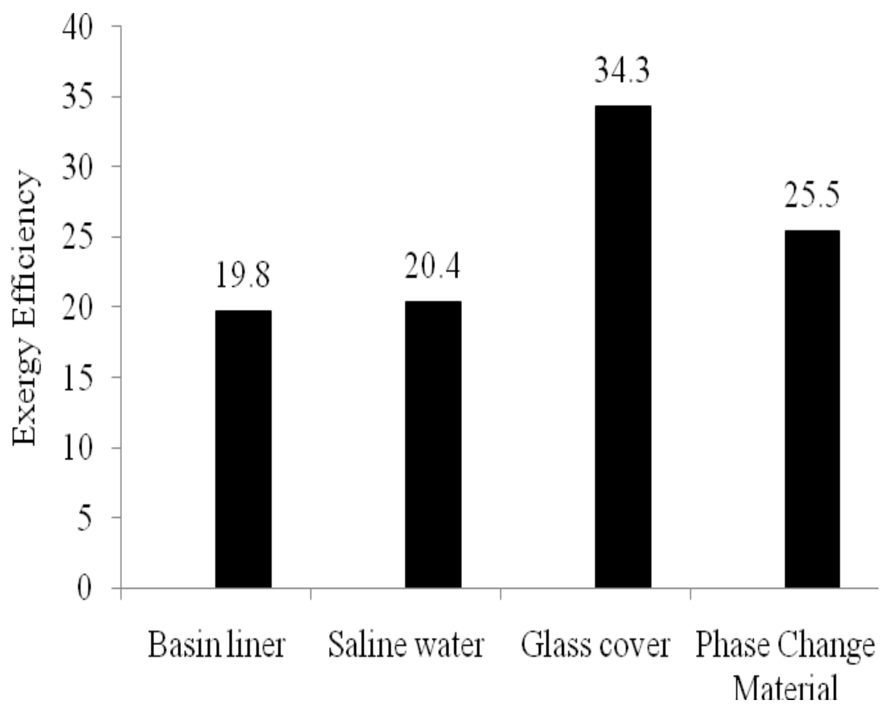

Figure 9 Exergy efficiency on various components of solar still

The exergy effciency of the various component of solar still are computed from the available correlation in section3. The Figure 9 shows the exergy effciency of sub components of solar still basin liner, saline water, glass cover and phase change materails. The glass cover gives maximum exergy effciency 34.3% and minimum exergy effciency value of 19.8% at basin liner. It shows maximum exergy losses occurs in basin liner compared to glass cover.

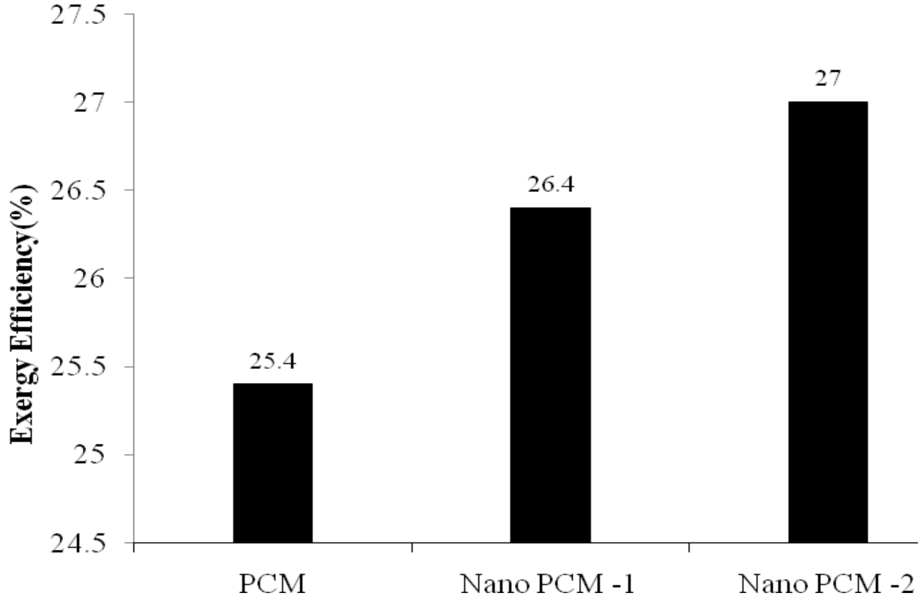

Figure 10 Exergy effieicny on different nano PCM

The Figure 10 shows the exergy efficieny of solar still integarted with nano composite phase change materails for PCM, 2% weight Al2O3 represented by Nano PCM-1 and 4% weight of Al2O3 represented by Nano PCM-2. The higher weight ratio of Al2O3 gives maximum exergy effciency value of 27% compared Nano PCM-1 and PCM alone.

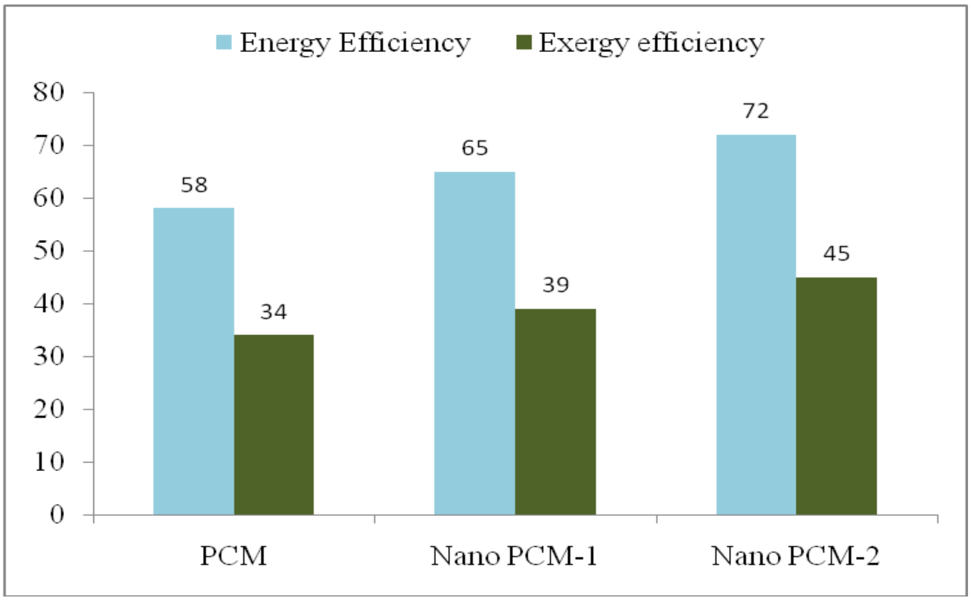

Figure 11 Comparison of Energy and Exergy Efficiency of Solar Still

The Figure 11 shows the comparative analysis of energy and exergy efficiency of solar still by PCM, Nano PCM-1 and Nano PCM-2 for set of operating parameters mentioned in the Table 1 and Table 2. The Nano PCM-2 shows the higher energy efficiency of 72% and exergy efficiency of 45% than Nano PCM-1 based solar still having the energy efficiency of 65% and exergy efficiency of 39% and PCM based solar still having energy efficiency of 58% and exergy efficiency of 34%. It is recommended for the higher weight ratio Al2O3 based solar still gives better performance and thermo-economic study will helps the financial feasibility in the further study.

Conclusion

An exergy analysis was carried out to a single basin solar still integrated with nano-composite phase change materials for the given design and selected operating parameters. The subsystems like basin liner, thermal energy storage, glass cover were considered along with different weight ratio of nano materials and paraffin wax. The causes, factors and exact locations responsible for lower energy and exergy efficiency and ultimately less productivity of the passive solar still are ascertain. Some concluding remarks from this study are as follows:

1) Thermo physical properties of nano-composite phase change material are increased with increases in temperature.
2) The maximum instantaneous overall energy and exergy efficiency and hourly yield are 49.29%, 9.48% and 0.69 l/m2, respectively.
3) Daily average energy efficiency, exergy efficiency and productivity are found to be 30.42%, 4.93% and 4.17 l/day, respectively.
4) Low exergy efficiency obtained in the basin-liner than water body and glass cover.
5) It is observed exergy efficiency increases with increases in weight fraction of nano particle.

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