A Performance Analysis Study of a Single Slope Solar Still with Integrating Fins and Nanofluid for Productivity Enhancement

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Abstract: The present paper deals with the thermal performance of solar desalination system. The mean objective of this work is to enhance the productivity of fresh water by integrating fins in basin liner and using Cu_2O nanoparticles in the base fluid, based on the experimental data (solar radiation and ambient temperature) (lat 34°00′47″ N, Rabat). A finite element based 3D mathematical model has been developed using COMSOL Multiphysics 5.2a.the numerical results showed that the daily productivity increase by20% for the finned basin liner with nanofluid (Brackish water/Cu_2O) and by 12.6% for the finned basin liner with base fluid compared to the conventional solar still.

1 INTRODUCTION

Solar desalination is one of various technologies developed for water purification; it is an effective and an ecological technology, but the low productivity of freshwater is the mean and essential problem to solve for solar stills.

A lot of research works are developed to improve the productivity of solar stills desalination systems. (Tiwari and Tiwari, 2007) highlighted the effect of different parameters such as water depths and ambient air velocities on the productivity of solar still, in their others works (Sahota and Tiwari,2016) studied impacts of different concentrations of Al_2O_3 nanoparticles on thermal properties of the passive double slope solar still (DSSS) with 35kg and 80kg of basefluid, Moreover, they investigated the effect of three different nanoparticles (Al_2O_3,TiO_2 and CuO)on the performance of passive double slope solar still, this study showed that the thermal energy efficiency was higher for nanofluids compared to basefluid. Also, incorporation of AL_2O_3 nanoparticles in saline water (Water/Al_2O_3) gives more productivity than others nanofluids (Water/TiO_2 and Water/CuO). (Rabhi et al, 2017) developed experimentally a modified single basin solar still with pin fins absorber and external condenser. It can be concluded from the results that using solar still with pin fins enhance the productivity of fresh water by 32.18% compared to the conventional still. Other experimental work highlighted graphite and copper oxide effects as new nanoparticles on the still yield. Also different basin water depths and different film cooling flow rates is experimentally investigated. The obtained results showed that the solar still productivity increase by about 44.91% and 53.95% using the copper oxide and graphite, respectively, compared with the conventional solar still, however by adding the glass cooling the daily efficiency is 47.80% and 57.60% using copper oxide and graphite, respectively (Sharshir et al, 2017).

(El Sebaii et al, 2009) studied experimentally and numerically the performance of a single solar still with PCM (Stearic Acid) during charging and discharging periods. It was founded that the daily productivity is doubled by using 3.3cm of PCM compared to conventional solar still. Moreover, they investigated the effect of fin configuration parameters (El Sebaii et al, 2015) (El Sebaii and El-Naggar, 2017) such as numbers of fins, thickness and height, also by using different materials (aluminum, iron, copper, stainless steel).It was concluded that productivity increase by 13.7% using seven fins with a thickness and height of 0.001m and 0.04m respectively.(Ansari et al, 2013) Conducted a

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numerical study which highlighted the improvement of passive solar still performances by using separately three kinds of phase change materials (Paraffine C18, Paraffin52–54, Paraffin wax) as a storage medium. They reported that using heat energy storage enhances both the productivity and the efficiency of the distillation system.

Furthermore, this last research work was undertaken by (Asbik et al, 2016) to determine the exergy losses during the charging/discharging periods. They deduced that the use of the latent heat storage process allows the increasing of the water productivity but it also reduces the exergy efficiency of the system. For the same goals mentioned above.

(Ragupathy and Velraj, 2018) Studied experimentally the effect of floating absorbers acted as storage material and bubble-wrap (BW) insulation on the single slope solar still (SSSS).the results showed that the daily productivity increase to 3.1l/m².day compared with 1.9 l/m².day for the Conventional solar still. (Kabeel et al, 2011) fabricated three solar still designed with a same construction, the first one is a conventional type, the second is a finned still and the third one is a corrugated still. They compared the performance of both stills with the conventional one, it was concluded that integrating nineteen fins on the bottom of solar still increase the amount of distillate water by 40%; however an amount of 21% is measured for a corrugated still.

The mean objective of this paper is enhancing the rate of heat transfer between basin liner and brackish water by integrating fins in the basin liner. Moreover, improving the productivity by using Cu_2O nanoparticles in the base fluid (Brackish Water).

2 MATERIALS AND METHODS

2.1 System Description

The geometry configuration used in this study is shown in Figure.1. The single basin desalination system is constructed with a basin area of 1m².Based on the results of (El Sebaii et al, 2015). The absorber plat is integrated with seven fins where the thickness and the height are 0.001m, 0.04m respectively. Cuprous oxide nanoparticles (Cu_2O) have been added to the saline water (40kg) to obtain a nanofluid whose thermal and optical properties will be enhanced (Table.1). The whole system is insulated by the Foam layer (5cm of thickness) to minimized heat losses between the system and ambient area; also it is covered by a transparent glass with a thickness of 3mm and inclination angle of 34°. The solar still is south facing in order to have a maximum solar radiation.

The weather data (ambient temperature and solar radiation) were measured in the “Ecole Normale Superieure de l’Enseignement Technique-ENSET” localized at Rabat city (Morocco) whose geographical coordinates are: Latitude: 34°00′47″ N, Longitude: 6°49′57″ W. On a typical day of 26/05/2018 (Figure.2).

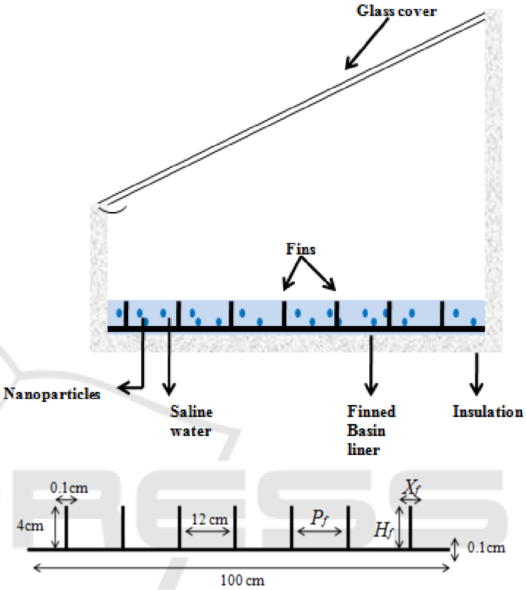

Figure.1: A Schematic diagram of desalination system with finned basin liner with nanofluid (Brackish Water/Cu_2O).

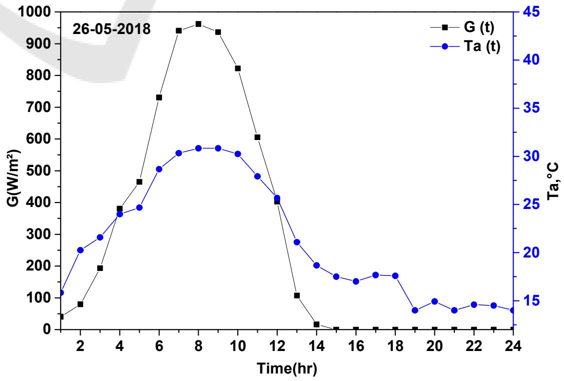

Figure.2: Hourly variation of solar radiation and ambient temperature for 26-05-2018

2.2 Numerical Model

In order to define the thermal energy process through different components of the system, three physical processes are simulated in this study: heat transfer by conduction, convection and radiation.

2.2.1 Heat Transfer: Conduction

Heat transfer in solid region like glass, finned absorber and insulated material is by conduction only. The heat equation to solve is

$$\rho_i . C_{p_i} . \frac{\partial T_i}{\partial t} = k_i . \left(\frac{\partial^2 \mathrm{T}_{\mathrm{i,x}}}{\partial^2 x} + \frac{\partial^2 \mathrm{T}_{\mathrm{i,y}}}{\partial^2 y} + \frac{\partial^2 \mathrm{T}_{\mathrm{i,z}}}{\partial^2 z} \right) \quad (1)$$

Where *T* is the temperature,ρ, *Cp and k* are the density, the specific heat and the thermal conductivity of the material.
i: glass/finned absorber/insulation.

2.2.2 Heat Transfer: Convection

Heat transfer from finned basin liner to brackish water happens by convection .In this case, the energy equation between solid fluid interfaces is defined as

$$\rho_w . C_{p_w} . \frac{DT_w}{Dt} = k_w . \nabla^2 \mathrm{T_w} \quad (2)$$

2.2.3 Heat Transfer: Radiation in Participating Media

The glass cover is exposed to solar radiation intensity. Qr(t) is the heat flux radiation defined as

$$Qr(t) = \alpha I(t) \quad (3)$$

Where α the solar absorption coefficient (Table.2) and I (t) is the solar radiation intensity.

Table.1: Thermophysical properties of nanofluid (Brackish Water/Cu_2O).

Correlations	Expressions
(Taylor et al, 2013)	$\rho_{nf}=(1-\varphi_p).\rho_{bf}+\varphi_p.\ \rho_p$
(Taylor et al, 2013)	$Cp_{nf}=[(1-\varphi_p).Cp_{bf}+\varphi_p.Cp_p]/(\rho_{bf})$
(Alawi et al,2018)	$k_{nf}=k_{bf}.[1+1.0112.\varphi_p+2.4375.\varphi_p.(47/d_p)-0.0248.\varphi_p.(k_p/0.613)]$
(Kabeel et al, 2017)	$\mu_{nf}=\mu_{bf}.(1+2.5\varphi_p)$

2.2.4 Boundaries Conditions

The governing equations of thermal model are developed and written using the following initial and boundary conditions:

- Initially (t=0), all the domains of the system are at constant temperature (T_{ini}=288.95K).
- The external surface of the desalination system exchanged energy by convection with the ambient area (Ta (t)).

$$n.(k\nabla T) = q_0 = h.(T_{ext} - T_g) \quad (4)$$

Were T_{ext}=Ta (t) and h is the heat transfer coefficient.

- No slip at the solid-liquid interfaces.
- Water layer is supposed to be an isothermal domain.

2.3 Mesh Generation

Free tetrahedral mesh has been used (Figure.3), to be sure that smaller geometries are discretized with 232468 numbers of elements.

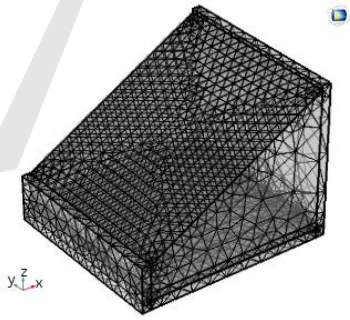

Figure.3: Meshed solar still desalination geometry.

Table.2: Technical specifications and numerical constants of the developed solar still (Sahota and Tiwari, 2016; Ansari et al, 2013; Kabeel et al, 2017)

Thermal Properties	value	Numerical constants	value
Glass		x_g	0.003(m)
λ_g	0.78(W/m.K)	x_b	
ρ_g		x_{ins}	0.002(m)
Cp_g	2800(kg/	α_g	

ε_g Water λ_{bf} ρ_{bf} Cp_{bf} ε_{bf} Absorber λ_b ρ_b Cp_b Cu_2O ρ_p Cp_p λ_p	m³) 840(J/kg.°C) 0.88 0.64(W/m.K) 1000(kg/m³) 4190(J/kg.°C) 0.9 73(W/m.K) 7897(kg/m³) 452(J/kg.°C) 6320 (kg/m³) 550 (J/kg.°C) 76.5 (W/m.K)	τ_g Ag α_w α_b μ_{bf} d_p L_{bf}	0.05(m) 0.05 0.09 1(m²) 0.05 0.9 $0.469.10^{-3}$ (N.s/m²) 20(nm) 2350(kJ/kg.K)

2.4 Validation Model

In order to validate the current model, a numerical simulation has been carried out using COMSOL Multiphysics and taking into account the initial and boundaries conditions defined in section (2.2.4).

A comparison with experimental results of (El Sebaii et al, 2015) has been done. It is clear from the results of figure.4, that the current model showed good agreement with those reported in the reference (El Sebaii et al, 2015).

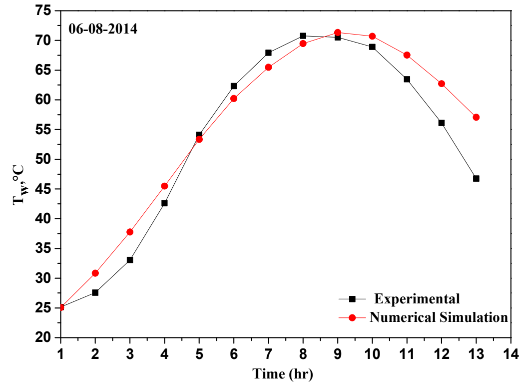

Figure.4: Experimental and numerical Hourly temperature variation of brackish water

3 RESULTS AND DISCUSSION

Numerical simulations have been carried out for modified solar still by using the nanofluid based on cuprous oxide (Cu_2O) nanoparticles with integrating fins in the basin liner.

It can be observed from Figure.5 that the maximum average temperature (T_{nf}-T_{bf}) of 4.6°C occurred when using Cu_2O concentration of 0.25%.thermal conductivity of nanofluid plays a vital role in enhancing productivity of the system. It is the most significant property. So, by applying this conditions thermal properties of the system enhanced.

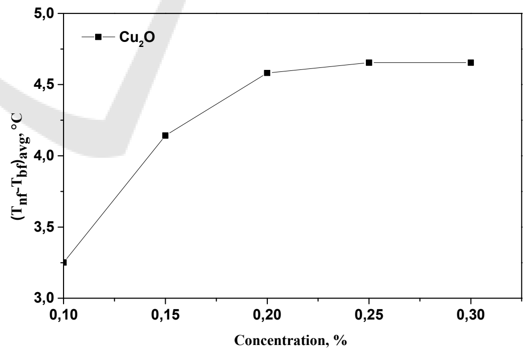

Figure.5: Average temperature variation between nanofluid (Brackish water/Cu_2O) and base fluid for different concentration

Figure.6 highlights variations of temperature during time for different components (finned basin liner, nanofluid and glass cover). The solar radiation absorbed by basin liner is transferred by convection to the brackish water. It is generally observed that the temperature of nanofluid increases with nanoparticles concentration (φ=0.25%) and by using finned basin liner.

The viscosity correlation (see Table 1), as known, is a function of volume fraction φ and therefore the Nusselt number vary with this parameter. Also, it had been inferred that the nanofluid's temperature increases due to the energy received from finned basin liner and cuprous oxide nanoparticles.

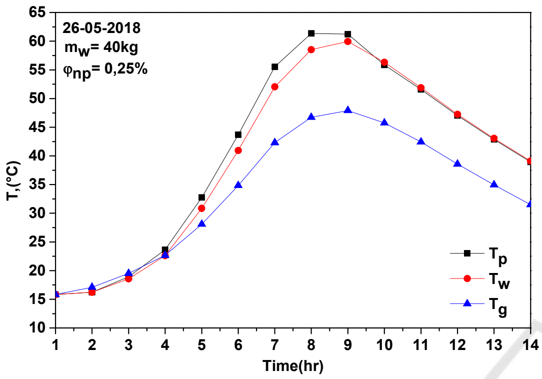

Figure.6: Hourly temperature variation for modified solar still with integrating fins and nanofluid (Brackish water/Cu_2O)

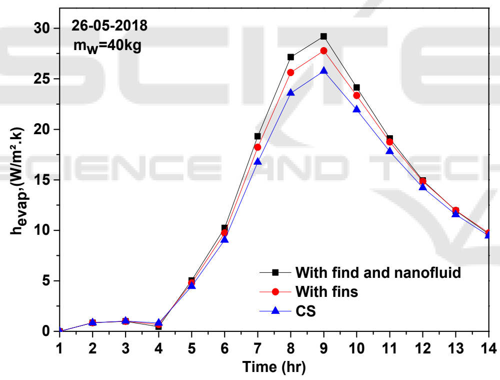

Figure.7: Evaporative heat transfer coefficient.

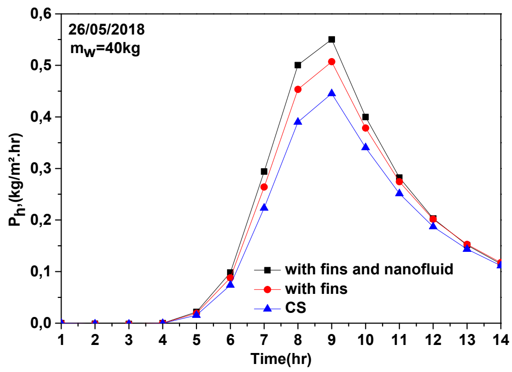

Figure.8: Variation of hourly freshwater productivity for developed solar still and conventional solar still, 26-05-2018.

Three modes of heat transfers occurred between base fluid and the bottom surface of the glass cover, by radiation, convection and evaporation. Figure.7 illustrates a significant increase of h_{evap} for finned basin liner with nanofluid where the maximum value is (29W/m².k), during the sunny period of the specific day, compared to the conventional solar still (h_{evap}=26 W/m².k).

Besides, the hourly and daily productivity are defined using the following equations (Ansari et al, 2013)

$$P_h = (Q_{e,f\text{-}g}.3600)/L_f \quad (5)$$

$$P_d = \Sigma_t P_h(t) \quad (6)$$

From the results of Figure.8, it has been found that the hourly variations of the yield increase over time as solar radiation increase. It is due to the coefficient of evaporation enhanced by the effect of nanofluid and fins compared to the conventional solar still.

It has also obvious that the daily productivity of the conventional solar still , the SSSS integrating fins in the basin liner with nanofluid ,and the SSSS with only integrating fins are 2.17 kg/m².day, 2.45 kg/m².day and 2.61 kg/m².day, respectively (Figure.9). Moreover, the equation used to define the overall thermal efficiency is:

$$\eta = (L_f.\Sigma_t P_h(t))/A_g.\Sigma_t G(t) \quad (7)$$

So, it is the report between evaporative heat flux ($Q_{e,f\text{-}g}$)and total solar radiation incident (G(t)). Figure.10 illustrates these variations, where we show the significant increase for the developed SSSS with fins and nanofluid of 25% compared to 20% for the single slope solar still (SSSS) without fins and nanofluid.

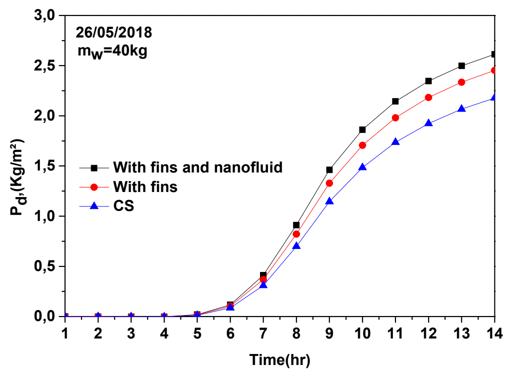

Figure.9: Accumulated daily productivity on a typical day of 26-05-2018

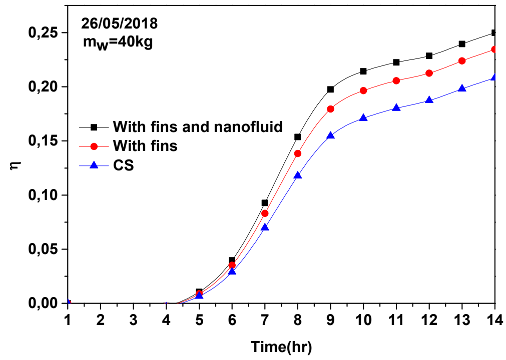

Figure.10: Overall thermal efficiency of developed solar still with fins and nanofluid, only with fins and for the conventional solar still

4 CONCLUSION

In this work, the effect of nanofuid based cuprous oxide nanoparticles (Cu_2O) with integrated fins has been studied for the single slope solar still (SSSS) under real climatic conditions of Rabat city Morocco. Moreover, the physical processes encountered in the heat transfer by conduction, convection and radiation can be developed numerically using COMSOL Multiphysics.

The results showed that the daily productivity registered for modified SSSS with fins and nanofluid (Brackish water/Cu_2O), for modified SSSS only with fins and for conventional solar still are 2.61 kg/m².day, 2.45kg/m².day and 2.17 kg/m².day respectively.

NOMENCLATURE

A	Surface Area, m²
Cp	Specific heat, J/Kg. °K
h	Heat transfer coefficient, W m^{-2} K^{-1}
H_f	height of fins, m
G	Incident solar power, W m^{-2}
L	Latent heat, J/Kg
m	Masse, Kg
P_h	Distillation mass flow rate, Kg/m².h
P_f	Distance between two fins, m
Q	Heat flux, W/m²
T	Temperature, °C
t	Time, hour
X_f	Thickness of fins, m

GREEK LETTERS

λ	Thermal conductivity, W/m. K
μ	Viscosity, N.s/m²
ρ	Density, Kg/m³
ε	Emissivity
φ	Nanoparticles concentration
α	Absoptivity
β	Thermal expansion coefficient of nanoparticle, K^{-1}

SUBSCRIPTS

a	Ambient
b, abs	Absorber
bf	Base fluid
d	Daily
e	Evaporation
g	Glass
h	Hourly
nf	nanofluid
r	Radiation
w	Water

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