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Second law analysis of Cu/water nanofluids in flat plate solar collector

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Abstract: The performance of heat transfer applications may be considerably enhanced using the nanofluids as an alternative. Present works the performances of a (Cu) based flat plate solar collectors (FPSC) and water based were examined numerically. In this work we have determined the impact of nanofluids that is distributing of copper (Cu) nanoparticles in the water. A numerical model was also presented to present the influence of the nanofluid in the thermophysical properties of nanofluids which are density, Specific heat and thermal conductivity over the base fluid collector. The effect of adding nanofluids as compared to water based collector have been compared for the on second law efficiency of the both FP collector

Key Words: Nanofluid, Flat-plate solar collector, Density, Efficiency

1. INTRODUCTION

The performance of heat transfer applications may be considerably enhanced using nanofluids as an alternative. The performance of a flat plate solar collector (FPSC) was examined numerically in this work to determine the impact of distributing copper (Cu), copper oxide (CuO), and aluminium (Al2O3) nanoparticles in pure water a numerical model was also proposed.

The impact of the type of nanofluid on thermal efficiency was carefully examined and addressed. Analysis and discussion of the mass flow rate's impact on performance were also conducted. A sensitivity analysis was done to examine the effect of the nanoparticles on the base fluid based on correlations of the thermophysical properties of nanofluids.

The results show that FPSCs utilizing Cu/water nanofluid performed better than those using CuO/water or Al2O3/water nanofluids. The efficiency of the FPSC was significantly higher when the mass flow rate of the nanofluids was 8.0 L/min than it was at 5.0 L/min and 2.0 L/min. When 2.0 L/min of Cu/water, CuO/water, or Al2O3/water nanofluids were applied, a mean improvement in thermal efficiency of 4.44%, 4.27%, and 4.21% was noted, respectively.

Improvements in thermal efficiency of 2.76%, 2.53%, and 2.47% occurred when 8.0 L/min was applied.

Nanofluid is a colloidal mixture of nano-sized particles in a host fluid to improve the heat transfer characteristics, suited for practical applications [1-7].
Basically, conversion and transportation of energy take place in atomic or molecular levels, but nanotechnology provides a significant role in energy utilization of thermal systems without having any environmental impact.
There are many research works that concentrate on nanofluids containing different nanoparticles with various volume concentration and size.
Originally various base fluids such as ethylene glycol, form amide, water etc., have been used in many heat transfer applications [7]. Thermal conductivity and convective heat transfer of base fluids (such as ethylene glycol, form amide, water etc) had been increased by mixing micro-sized particles with a base fluid. Erosion in pipelines, sedimentation and clogging leads to high pressure drop caused by these particles. The enhancement in thermal properties is attained by mixing nano-sized particles which dispersed uniformly in the base fluids.

Nanofluids is a colloidal suspension of nanoparticles of size 1 to 100nm (10-9m) in the base fluid (water, ethylene glycol, oil etc.). The Choi in the year 1995 at the Argonne National Laboratory to develop a new form of nanotechnology-based heat transfer fluids. Nanoparticles have larger relative surface area since particle size is very less, high mobility, better suspension stability, improved thermal conductivity and less particle momentum of the mixture than micro-sized particles. Due to these properties, nanofluids are being used as coolants, lubricants, hydraulic fluids and metal cutting fluids.

Depending on the application, nanofluids are made by different materials such as metals, metal oxides, ceramics and carbon nanotubes (CNT) [7-8, 25]. Carbon nanotubes provide more heat transfer when compared to other materials but the synthesis

processing of carbon nanotubes is difficult and also unaffordable in cost. Metal and metal oxide nanoparticles can be synthesized easily even from naturally available green leaves.
The objective of present paper is to explore the effect of Cu nanoparticle in flat collector and investigate the enhancement in the second law efficiency and compared over the H_2O based flat collector.

LIST OF ABBREVIATIONS/ SYMBOLS/NOMENCLATURE

A_c	Collector area	m^2
C_b	Conductance of Bond	W/m^2K
C_p	Specific heat	J/kg K
D	Tube Diameter	m
Di	Inner diameter of tube	m
Do	Outer diameter of tube	m
Dp	Size of nao particle	m
F	Fin efficiency	–
F'	Collector efficiency factor	–
F_R	Heat removal factor	–
h	coefficient of Heat transfer	W/m^2K
P	Pressure	Pa
P_m	Pumping power	W
Qu	Useful heat gain	W
T_{sun}	Sun temperature	K
T_g	Temperature of glass	K
T_{fo}	Outlet air temperature	K
T_s	Temperature of Sky	K
T_{fi}	(Ti) Air Temperature (Inlet)	K
T_a	Ambient temperature	K
T_{pm}	Mean plate temperature	K
hw	Wind heat transfer coefficient	W/m^2K
I	solar radiation (Insolation)	W/m^2
Kp	plate Thermal conductivity	W/m K
K_g	Thermal conductivity of glass cover	W/m K
K_i	Thermal conductivity of glass wool insulation	W/m K
L	Length of Collector	m
L_g	glass cover (Thickness)	m
m	Mass flow rate of air	kg/s
Ng	Number of glass covers	-
ΔP	Pressure drop	N/m^2
U_b	coefficient for Bottom loss	$W/m^2 K$
U_s	coefficient for Side loss	$W/m^2 K$
U_t	coefficient for Top loss	$W/m^2 K$
V	Average velocity of fluid in collector	m/s
V_w	Wind velocity	m/s
w	Width of solar air heater duct	m
W	Riser tube spacing	m
Wp	Pumping power	W
T_{fm}	temperature of fluid (Mean)	K
U_L	coefficient for Overall heat loss	$W/m^2 K$

DIMENSIONLESS PARAMETERS

f	Friction factor
F_R	SC heat-removal factor
F'	SC efficiency factor

Nu	Nusselt number
Pr	Prandtl number
Re	Reynolds number

GREEK SYMBOLS

μ	Absolute viscosity fluid	N s/m^2
ρ	density	kg/m^3
Ø	Volume fraction (%)	
σ	Stefan-Boltzman's constant	W/m^2 K^4
$(\tau\alpha)$	Effective transmittance-absorptance product	
α_c	Absorptivity of the glass cover	-
ε_p	absorber plate Emissivity	-
ε_b	bottom plate Emissivity	-
ε_g	glass cover Emissivity of	-
δ_i	Insulation thickness	m
β	Tilt angle of collector surface	degree
ν	Kinematic viscosity of air	m^2/s
η_{th}	(η_E) Thermal efficiency	-
α_p	Absorptivity of absorber plate	-
τ	Transmissivity of glass cover	-

OTHERS

in	Inlet
out	Outlet
NP	Nanoparticles
NF	Nanofluid
BF	Basefluid
amb	Ambient
max	Maximum
min	Minimum
ave	Average
T	Temperature

2. RESEARCH METHODOLOGY

Many research works have been carried out using nanofluid as the heat transfer medium, an attempt is made to analyze the heat transfer characteristics of nanofluid under solar radiation by keeping the following objectives in mind.

To enhance heat transfer of CuO nanofluids by varying the nanoparticle concentrations and mass flow rates.
To understand the application of CuO nanofluids on density, Specific heat and thermal conductivity over the base fluid collector. The effect of adding nanofluids as compared to water based collector and it have been compared for the parameters; Reynolds number, Fluid outlet temperature and Nusselt number under various fluids flow rate and volume fraction (Ø).

3.MODELLING ANALYSIS

PROPERTIES OF NANOFLUIDS

3.1. The nanofluid density (ρ_{nf}), is evaluated as follows [19-23];

$\rho_{nf} = \phi\rho_p + (1-\phi)\rho_{bf}$	1

3.2. The nanofluids specific heat $(C_{P,nf})$ is evaluated by using [19-23]

$$C_{P,nf} = \frac{\phi(\rho C)_p + (1-\phi)((\rho C)_{bf}}{\rho_{nf}} \quad (2)$$

3.3. Thermal Conductivity

The thermal conductivity of nanofluids can be evaluated as the equation given by Maxwell [19-23]:

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} - 2\phi(k_{bf} - k_p)}{k_p + 2k_{bf} + \phi(k_{bf} - k_p)} \quad (3)$$

The conductivity of the base fluid is evaluated by the following equation:

$$k_{bf} = [1.488445 + 4.12292(T_{avg}/298.15) - 1.63866(T_{avg}/298.15)] \times 0.6065 \quad (4)$$

3.4. Dynamic Viscosity

Dynamic Viscosity of nanofluids can be calculated by the equation which is given by Brinkman's model [19-21]

$$\frac{\mu_{nf}}{\mu_{bf}} = \frac{1}{(1-\phi)^{2.5}} \quad (5)$$

In Eq. (5) the viscosity of the base fluid, is given by the equation as

$$\mu_{bf} = 2.414E^{-5} \times 10^{247.8/(\mathrm{Tavg}-140)} \quad (6)$$

3.5. EFFICIENCY OF THE SOLAR COLLECTOR

The energy efficiency of SC is evaluated by [20]

$$\eta_{th} = \frac{Qu}{A_c I} \quad (7)$$

3.6. In above Eq., Qu is useful heat gain obtained from solar energy

$$Qu = mCp(T_{out} - T_{in}) \quad (8)$$

3.7. Useful heat gain (Qu) can also be calculated as

$$Qu = A_c F_R[I(\tau\alpha) - U_L(T_{fi} - T_a)] \quad (9\ (a))$$

$$Qu = A_c[I(\tau\alpha) - U_L(T_{pm} - T_a)] \quad (9\ (b))$$

3.8. The collector heat removal factor, F_R, which is calculated as

$$F_R = \frac{mCp(T_{out} - T_{in})}{A_c[S - U_L(T_{in} - T_a)]} \quad (10)$$

The collector heat removal factor, F_R, which is also can be calculated as

$$F_R = \frac{mCp}{A_c U_L}\left[1 - \exp\left(-\frac{U_L F' A_c}{mCp}\right)\right] \quad (11)$$

In above Eq., (F') is the SC efficiency factor which is calculated as

$$F' = \frac{1/U_L}{W[1/[U_L(D + (W-D)F] + 1/\mathrm{C_b} + 1/\pi \mathrm{Dh_f}]} \quad (12)$$

In above Eq., (W)= Tube spacing, (F)= Fin efficiency, (D) = Diameter of tube, (C_b)= Bond Conductance

The Fin efficiency (F) is obtained by.

$$F = \frac{\tanh[m(W-D)/2]}{[m(W-D)/2]} \quad (13)$$

3.10. New absorber plate mean temperature can be calculated as

$$T_{pm} = T_{in} + \frac{Qu}{A_c F_R U_L}(1 - F_R) \quad (14)$$

3.11. The collector's heat transfer coefficient can be calculated as [27-28]

$$h_{fi} = \frac{Nu.k_{nf}}{Di} \quad (15)$$

3.12. The Reynolds number can be calculated as

$$\mathrm{Re}_{nf} = \frac{\rho_{nf} V D_i}{\mu_{nf}} \quad (16)$$

3.13 Prandtl number can be calculated as

$$\mathrm{Pr}_{nf} = \frac{\mu_{nf} C_{p,nf}}{k_{nf}} \quad (17)$$

3.14. air temperature (Average) is calculated as

$$T_{avg} = T_{fm} = \frac{T_{fo} + T_{fi}}{2} \quad (18)$$

3.15. PUMP WORK

Pump work is given by the equation [17,21];

$$W_p = \dot{m}\Delta P / \rho \quad (19)$$

3.16. Pressure drop (ΔP) in the collector is obtained by utilizing the equation;

$$\Delta P = f \frac{\rho V^2}{2} \frac{L}{D} + \frac{\rho V^2}{2} \quad (20)$$

3.17. The friction factor for FP Collector having water and nanofluid as circulating fluid can be evaluated as equation [17,21].

$$f = \frac{64}{\mathrm{Re}} \quad (21)$$

The above equation is valid for laminar flow.
The friction factor for FP Collector having water and nanofluid as circulating fluid for the turbulent flow [17,21].

$$f = \frac{0.079}{(\mathrm{Re})^{1/4}} \quad (22)$$

3.18. The Nusselt number (Nu) for FP Collector having nanoparticle, is evaluated by using the correlation [29].

$$Nu_{NP} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \quad (23)$$

The above equation is valid for turbulent flow
The (Nu) for nanoparticle base Collector having laminar flow ($\mathrm{Re} \leq 2100$) is evaluated as

$$Nu_{NP} = 0.000972\,\mathrm{Re}^{1.17}\,\mathrm{Pr}^{1/3} \quad (24)$$

The (Nu) for water based FP Collector is evaluated by using is evaluated by using

$$Nu_{NP} = 0.021\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/2} \quad (25)$$

3.19. Exergy Efficiency

The exergy efficiency (η_{EX}) is evaluated by:

$$\eta_{EX} = \frac{E_n}{E_S} \quad (26)$$

3.1. INPUT DATA

The nanofluid water enters the collector through circular shape riser tube as shown in Fig. for the present analysis collector is have a single glass cover and proper insulation is provided in the bottom and on the sides.
The values of environmental conditions like; solar intensity (I), velocity of wind (Vw), and ambient temperature (Ta) and other details of the FP collector and assumptions are given in Table 1.

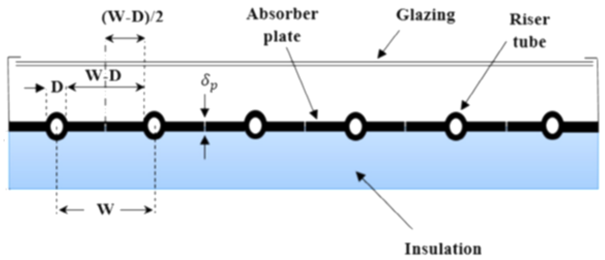

Fig.1. A schematic of structure and basic components of flat plate solar collector.

Table 1. Specifications and input data's of the collector for the present analysis

S. No	Parameter	Value
1	Collector dimension	Length=2.0 m width = 0.95 m H = 0.095 m
2	Absorption area (Ac)	1.90 m^2
3	Header pipe diameter (D_H)	22 mm and t = 0.9 mm
4	Distance between the tubes (W)	0.145 m
5	Riser pipe diameter (Di)	10 mm and t = 0.9 mm
6	Tubes diameter Collector	0.009 m
7	Working fluid	Al_2O_3–water nanofluid, Cu nanofluid and water
8	No. of Glazing (Ng)	1
9	Emission (absorption sheet) (εp)	0.07
10	Absorption (absorption sheet)	0.95
11	Emissivity Glass cover, (εg)	0.88
12	Absorber plate thickness (t)	0.005 m
13	Plate (thermal conductivity) (kp)	383 W/mK
14	Collector tilt, β	45°
15	Thermal conductivity (Insulation), (ki)	0.05 W/mK
16	Insulation thickness (tb)	0.05 m
17	Solar radiation (I)	800 W/m^2
18	Sun temperature (Tsun)	4350 K
19	Wind velocity (Vw)	3.2 m/s
20	Ambient temperature (Ta)	300 K
21	Inlet temperature (Ti)	302 K

Table 2. Thermo-physical Properties of different nanomaterials and base (water) fluids

S.No	Nanoparticle Type	Formula	Density (ρ) (kg/m^3)	Specific Heat (Cp) (J/kg.K)	Thermal Conductivity (k) (W/m.K)	Ref. Number
1	Aluminium Oxide	(Al_2O_3)	3690	774	40	[19-23]
2	Copper oxide	(CuO)	6000	551	34	[19-23]
3	Water	(H2O)	997	4180	0.607	[19-23]
4	Copper	(Cu)	8978	388	381	[19-23]

4.RESULT AND DISCUSSION

4.2. Effect of Nanofluid on Thermal efficiency

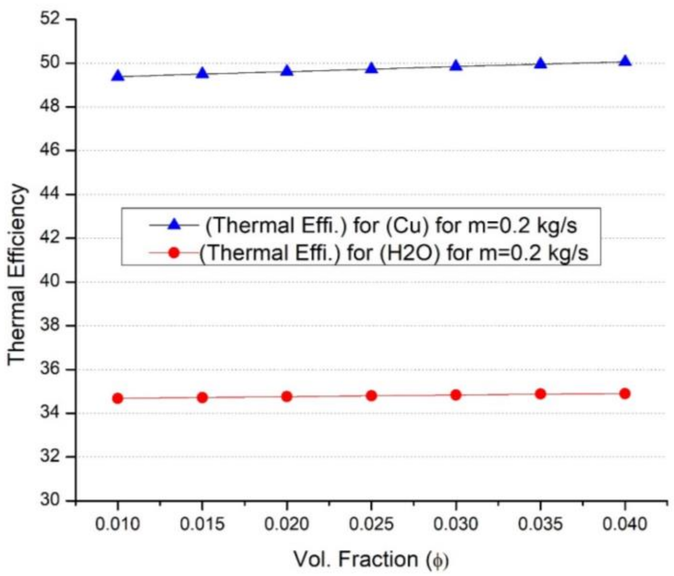

Fig. 2. Variation of Thermal efficiency for (Cu) and H2O for Turbulent flow region with different Volume fraction.

Fig. 2 shows the deviations of SC thermal efficiency with different volume fractions (Ø) for (Cu) & water based FP collectors.

According to Fig. 2, it is visible that thermal efficiency of a SC using nanofluids is directly proportional with the (Ø) i.e it increases with increasing the (Ø).

The working fluid's heat gain can be calculated from Eq. (3.8) to (3.9) and substituting the result in the Eq. (3.7) to compute thermal efficiency.

The thermal efficiency is evaluated by fluid density, specific heat, and mass flow rates. In order to compute the efficiency, mass flow rates were first calculated for volume flow rates 0.005 and 0.2 kg/s .

According to Figure 4.8, utilizing (Cu) nano fluid as the working fluid have collector efficiency 49.38 % for lower value of (Ø) while for highest value of (Ø) collector efficiency is 50.06 %.

While using H2O author have found 34.60 % and 34.90 % efficiency respectively for lower and higher values of (Ø).

Nanofluids solar collector have higher fluid output temperature over the base fluid based SC and also higher values of useful heat gain. These values are directly proportional to the collector efficiency hence higher efficiency have been obtained for the nanofluids based solar collector.

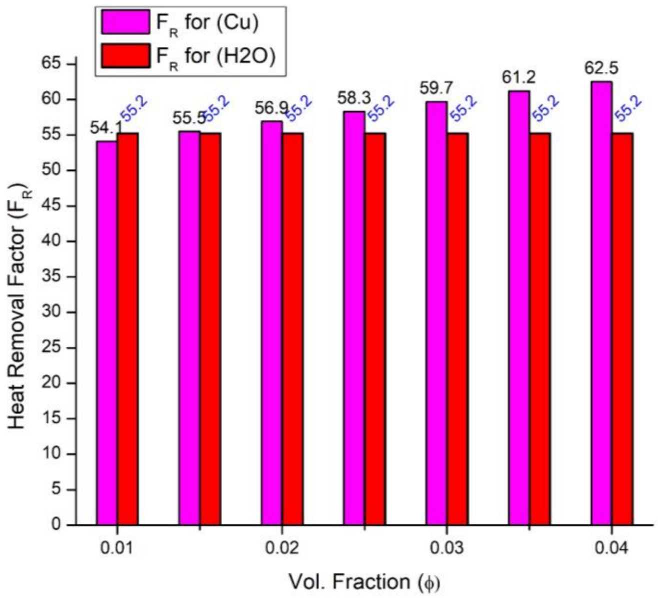

Fig. 3. Variation of Heat removal factor for (Cu) and (H2O) for different Volume fraction.

In Fig. 3, the heat removal factor (F_R), is plotted against (Ø) for (Cu) and water based FP collectors and it is presented in the form of percentage here.

It is clear that the factor (F_R) increases as (Ø) increases.

In Figure 3, it is discovered that the highest value of the heat removal factor is 62.5 % at a volume concentration of 0.04 while for the H2O based FP it shows 55.2 %.

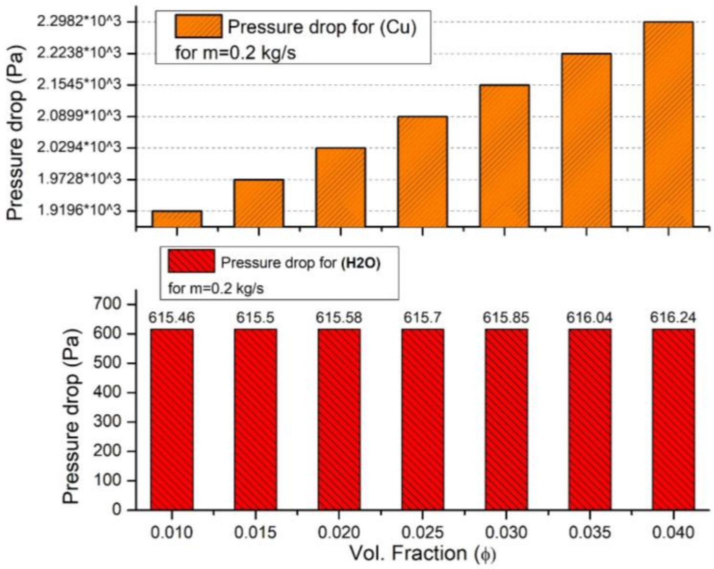

Fig. 4. Variation of pressure drop for (Cu) and H2O for different Volume fraction.

In Fig. 4, the pressure drop (ΔP), is plotted against (Ø) for (Cu) and water based FP collectors. According to Eqs. (3.23) and (3.24), the SC pumping power and pressure drop which are depends upon the friction, density, fluid velocity and length of the FP riser tube or duct length.

According to graph, (Cu) nanofluid and H2O based FP increases with the (Ø).

The pressure drop, which dramatically rises with increasing concentration after the 0.020.

In it, pressure drop is increasing with slower rate between 0.010% and 0.015%. Highest value of pressure drop is found 2298.2 Pascal for m= 0.2 kg/s for the (Cu) based FPC.

On the other hand, it can see for H2O FP the rate of pressure drop is almost negligible for all values of the (Ø).

Pressure drop in the SC are functions and depends on friction factor and density of the fluids, furthermore the friction factor also depends on the fluids viscosity in the present case the nanofluid have higher values of density and viscosity over the base fluid therefore we have higher value of pressure drop in the collector for the nanofluid based SC.

4.3. Effect of Nanofluid on Exergy efficiency

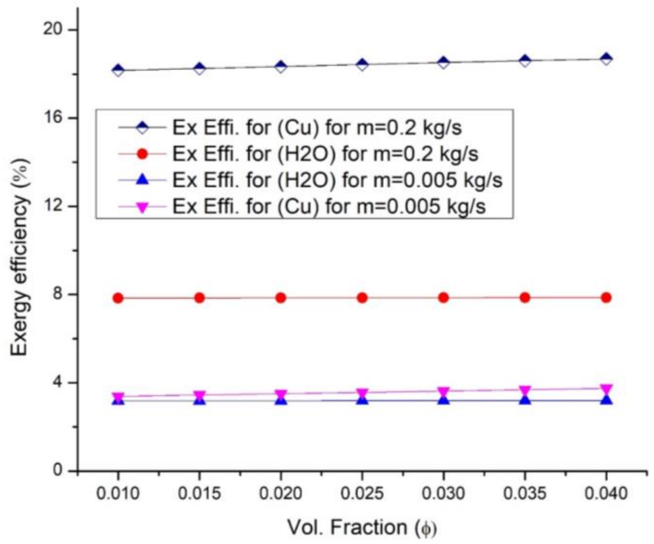

Fig. 5. Effect on Exergy efficiency for (Cu) and H_2O for Laminar and Turbulent flow region with different Volume fraction.

The fluctuation of exergy efficiency in percent is shown in Fig. 5 for 2 values of flow rate.

The exergy efficiency of the SC by using (Cu) and (H2O) nanofluid as an absorbing medium was estimated from Eq.3.26

Increasing the (Ø) improve the exergy efficiency for both FP collectors.

It is find from the present analysis that the highest value of the exergy efficiency is 18.69% at a volume concentration of 0.04 and m= 0.2 kg/s while for the same value of (Ø) and (m) H2O based FP shows 7.86 %.

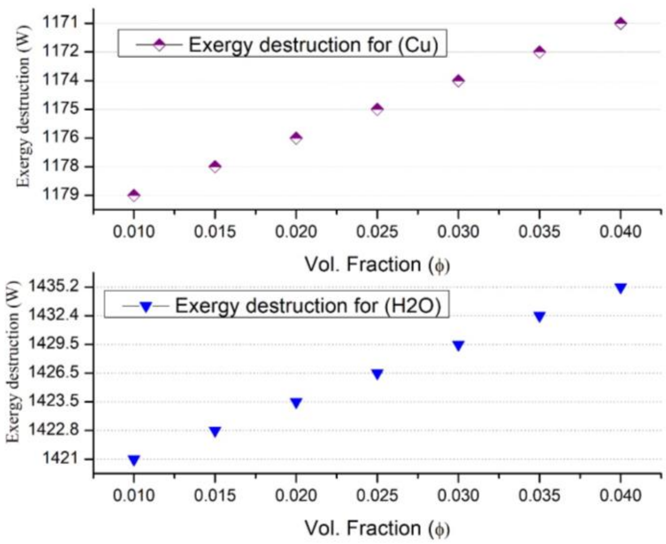

Fig. 6. Variation of Exergy efficiency for (Cu) and H2O for Laminar and Turbulent flow region with different Volume fraction.

Exergy destruction is depicted in Fig. 6 with regard to various volume concentrations for the turbulent region.

It can see from this Fig. that (Cu) nanofluid based FP exhibits less energy destruction as compared to H2O based FPC.

Increased fluid flow on the absorber plate causes the decrease in outlet air temperature, which leads towards to more Exergy destruction.

As the volume concentration of the nanoparticles rises, this leads to higher thermal conductivity, which further improves thermal conductance. Due to heat transfer, which reduces irreversibility by having an impact on entropy generation that is significantly bigger than that of viscous effects.

5. CONCLUSIONS

Nanofluid based FPC also rises the thermal efficicney, fluid outlet temperature and also the heat removal factor.

1. There is significantly rise in pressure drop loss by using the nanofluids in FPC. Highest value of pressure drop obtained 2298.2 Pascal for m= 0.2 kg/s, (Ø)=0.040 for the (Cu) based FPC.

2. For water based FPC have negligible effect on the pressure drop.

3. The results of the analysis showed that when compared to water as the absorbing fluid, Cu nanofluid have highest exergy efficiency 18.69% while for the water it is 7.86 %.

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