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Numerical Simulation of Cooling a Solar Cell by Forced Convection in the Presence of a Nanofluid

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Abstract

In this paper we study by numerical simulation, the cooling of a solar cell by forced convection in the presence of a nanofluid. The inclined walls of the cavity are adiabatic but the silicon solar cells are subjected to a constant heat temperature. The nanofluid is introduced into the cavity with a constant vertical speed and subjected to room temperature. The equations governing the flow hydrodynamics and heat transfer are described by the Navier-Stokes and energy equations. For the physical parameters of Al₂O₃-Water nanofluid, we use the model of Brinkman and Wasp. The finite elements method is used to solve the system of differential equations that is based on the Galerkin method. We consider the effect of solid volume fraction for different values of Reynolds number on the results in the form of isotherms and modified local and average Nusselt number.

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Keywords: Forced convection, Nanofluid, Cooling, Finite Elements Method

Nomenclature

A	Aspect ratio, L/H	H	Height of a rectangular cavity, m
C _p	Specific heat, Jkg ⁻¹ K ⁻¹	k	Thermal conductivity Wm ⁻¹ .K ⁻¹
g	Gravitational acceleration, ms ⁻²	L	Characteristic length, m

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Nu	Modified Nusselt number		Greek letters
P	Pressure, Nm ⁻²	α	Thermal diffusivity, m ² s ⁻¹
P*	Dimensionless pressure,	φ	Solid volume fraction
Pr	Prandtl number	μ	Dynamic viscosity, Pa s
Re	Reynolds number	ν	Kinematics viscosity, m ² s ⁻¹
T	Temperature, K	ρ	Density, kgm ⁻³
T*	Dimensionless temperature		Subscript
t	Time, s	f	Fluid
t*	Dimensionless time	m	Average
U, V	Components of velocity, ms ⁻¹	nf	Nanofluid
U*, V*	Dimensionless components of velocity	s	solid
x, y	Cartesian coordinates, m		
x*, y*	Dimensionless Cartesian coordinates		

1. Introduction

Nanofluids are solutions obtained while dispersing in a basic fluid of the solid particles of nanometric size. With very weak concentration, some of these solutions proved very effective to improve, under certain conditions, the transport of heat. However, the studies devoted to the nanofluids were focused mainly on the analysis of their thermal conductivity which can be considerably larger than that envisaged by the usual macroscopic models. Also, the behaviour of the nanofluids in modes of free convection is to date badly known. Indeed, at the time of the setting in flow of the nanofluids, only thermal conductivity is not sufficient any more to evaluate the effectiveness of heat exchange. Complementary studies are necessary to analyze the weight of the other thermo physical parameters.

The term “nanofluid” is proposed firstly by Choi [1] to indicate the suspension of the solid nanoparticles in a basic liquid. It found that the effective thermal conductivity of the water- Al₂O₃ mixture increased by 20% for a volume fraction from 1 to 5% of Al₂O₃. The problem of the natural convection in a cavity differentially heated is studied numerically by Khanafer and al. [2]. They used the model of Brinkman [3] to evaluate the viscosity of the nanofluid and the model of Wasp for the effective conductivity of the nanofluid. Tiwari and Das [4] studied the behaviour convective of the nanofluid in a rectangular cavity differentially heated where the two side walls are mobile. They found that the direction of movement of the wall affects the transfer of heat in the cavity. Roy and al. [5] showed that the addition of 10% in volume of Al₂O₃ can increase the rate of transfer of heat of 100% compared with that of the basic fluid. The results of Wang and al. [6] indicate that the presence of the nanoparticles in suspension increases the heat transfer for the various values of the Grashof number. For a concentration in volume of 10%, this increase is about 30% for alumina Al₂O₃ and which can reach 80% for copper oxide CuO. Putra et al. [8] undertook an experimental study on the heat transfer in natural convection for nanofluids inside a horizontal roll heated and cooled of the two respectively with dimensions ones. They used alumina and copper oxide like nanoparticles and water like basic liquid. They found that for a Rayleigh number of the nanofluid pertaining to the interval [10⁶ 10⁹], the heat transfer is affected by the nanoparticles volume

fraction as of the factor of form which represents the relationship between the height and the diameter of the cylinder. Wen and Ding [9] finely have an experimental study of the natural convection of solution an aqueous oxide TiO_2 titanium contained in a cavity formed by two discs with a diameter 240 mm differentially heated. They found that for by the Rayleigh lower than 10^6 the heat transfer decreases with the increase in the volume fraction. In the literature we did not find any work which treats the influence of the vibrations on the natural convection of nanofluids. Bilal Elhajjar and al. [12] studied the influence of nanoparticles on conductive and convective heat transfer. It is shown that adding nanoparticles in a fluid delays the onset of convection. Contrary to what is argued by many authors, They prove by direct numerical simulations that the use of nanofluids can reduce heat transfer instead of increasing it.

The main objective of this study is to evaluate the possibilities for improvement of the transfer of heat by the use of nanofluids, as well as the influence of the volume fraction of nanofluid. We wish to apprehend the fundamental mechanisms concerned in these modes of heat transfer starting from a theoretical approach by simulation of the dynamic and thermal fields.

2. Physical model and formulation

2.1 Physical model

We consider the flow of a nanofluid (aluminium oxide-water) in the case of the convection forced in a rectangular cavity square cavity of length L and height H which its aspect ratio is taken to be equal to five unit (Fig.1) which represents the solar panel whose angle of inclination is equal to 30° (case of Bechar in the south-west of Algeria). The right and left walls are adiabatic and impermeable, but the solar cells are maintained at constant hot temperature T_h . The nanofluid subjected to a constant cold temperature T_c , penetrates in the drain with a vertical velocity V_0 . To the exit of the drain the nanofluid is subjected to a convective flow and an atmospheric pressure.

Nanofluid used is supposed to be isotropic and homogeneous, the flow is two-dimensional and incompressible, the mode is laminar, and the physical properties of the nanofluid are supposed to be constant.

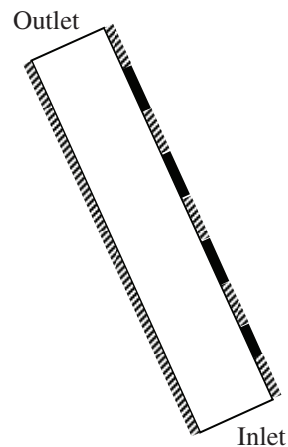


Fig.1: Physical model

2.2 Mathematical formulation

In Cartesian coordinates and taking account of the simplifying assumptions supposed above, the equations governing the problem are:

- Continuity equation

$$\frac{\partial U}{\partial x} + \frac{\partial V}{\partial y} = 0 \quad (1)$$

- Motion equations

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} = -\frac{1}{\rho_{nf}} \frac{\partial P}{\partial x} + \frac{\mu_{nf}}{\rho_{nf}} \left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2} \right) \quad (2)$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} = -\frac{1}{\rho_{nf}} \frac{\partial P}{\partial y} + \frac{\mu_{nf}}{\rho_{nf}} \left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} \right) \quad (3)$$

- Energy equation

$$\frac{\partial T}{\partial t} + U \frac{\partial T}{\partial x} + V \frac{\partial T}{\partial y} = \alpha_{nf} \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \quad (4)$$

$$\text{with } \alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}} \quad (5)$$

$$\text{and } (\rho C_p)_{nf} = (1 - \phi)(\rho C_p)_f + \phi(\rho C_p)_s \quad (6)$$

The thermal conductivity of nanofluid is expressed by the relation of Wasp.

$$k_{nf} = k_f \frac{(2 - 2\phi)k_f + (1 + \phi)k_s}{(2 + \phi)k_f + (1 - \phi)k_s} \quad (7)$$

The effective dynamic viscosity of nanofluid can be calculated by using the relation of Brinkman for a mixture.

$$\mu_{nf} = \frac{\mu_f}{(1 - \phi)^{2.5}} \quad (8)$$

The density of nanofluid is expressed by using the volume fraction.

$$\rho_{nf} = (1 - \phi)\rho_f + \phi\rho_s \quad (9)$$

Equations (1) to (4) can be converted to the dimensionless forms by using the following parameters:

$$(x^*, y^*) = \frac{(x, y)}{H}, (U^*, V^*) = \frac{(U, V)}{V_0}, T^* = \frac{(T - T_c)}{(T_h - T_c)}, P^* = \frac{P}{\rho_{nf} V_0^2}$$

Therefore using the above parameters leads to dimensionless forms of the governing equations as below:

$$\frac{\partial U^*}{\partial x^*} + \frac{\partial U^*}{\partial y^*} = 0 \quad (10)$$

$$\frac{\partial U^*}{\partial t^*} + U^* \frac{\partial U^*}{\partial x^*} + V^* \frac{\partial U^*}{\partial y^*} = -\frac{\partial P^*}{\partial x^*} + \frac{1}{(1-\varphi + \varphi R_\rho)(1-\varphi)^{2.5}} \frac{1}{\text{Re}} \left(\frac{\partial^2 U^*}{\partial x^{*2}} + \frac{\partial^2 U^*}{\partial y^{*2}} \right) \quad (11)$$

$$\frac{\partial V^*}{\partial t^*} + U^* \frac{\partial V^*}{\partial x^*} + V^* \frac{\partial V^*}{\partial y^*} = -\frac{\partial P^*}{\partial y^*} + \frac{1}{(1-\varphi + \varphi R_\rho)(1-\varphi)^{2.5}} \frac{1}{\text{Re}} \left(\frac{\partial^2 V^*}{\partial x^{*2}} + \frac{\partial^2 V^*}{\partial y^{*2}} \right) \quad (12)$$

$$\frac{\partial T^*}{\partial t^*} + U^* \frac{\partial T^*}{\partial x^*} + V^* \frac{\partial T^*}{\partial y^*} = \frac{1}{1-\varphi + \varphi R_{(\rho C_p)}} \frac{2-2\varphi + (1+\varphi)R_k}{2+\varphi + (1-\varphi)R_k} \frac{1}{\text{Pr Re}} \left(\frac{\partial^2 T^*}{\partial x^{*2}} + \frac{\partial^2 T^*}{\partial y^{*2}} \right) \quad (13)$$

Where figure the following dimensionless numbers and ratio:

$$\text{Pr} = \frac{\mu_f}{\rho_f \alpha_f}, \quad \text{Re} = \frac{\rho_f V_0 H}{\mu_f}, \quad R_\rho = \frac{\rho_s}{\rho_f}, \quad R_k = \frac{k_s}{k_f}, \quad R_{(\rho C_p)} = \frac{(\rho C_p)_s}{(\rho C_p)_f}$$

The dimensionless boundaries conditions are given in Table1

Table1: dimensionless boundaries conditions

Right and left walls	$U^* = V^* = 0; \frac{\partial T^*}{\partial n^*} = 0$
Solar cells	$U^* = V^* = 0; T^* = 1$
Inlet	$U^* = 0; V^* = 1; T^* = 0$
Outlet	$P^* = 0; \frac{\partial T^*}{\partial n^*} = 0$

3. RESULTS AND DISCUSSION

The finite elements method is used in our model for discretizing the governing equations ((10) to (13)) along with the boundary and initial conditions.

To describe the structure of the flow in the cavity we fix the following parameters of the nanofluid (Al_2O_3 -water):

$$\text{Pr} = 7; R_\rho = 3.885; R_k = 60; R_{(\rho C_p)} = 0.718$$

Figures 2 at 5 present the effects of solid volume fraction and Reynolds number on the isotherms. Some is the value of the Reynolds number and the solid volume fraction; the cavity is composed of two distinct zones: one hot and the other cold one. By fixing the Reynolds number, the hot zone increases with the increase in the volume fraction. Thus there will be an increase in the rate of heat transfer between the solar cells and the nanofluid.

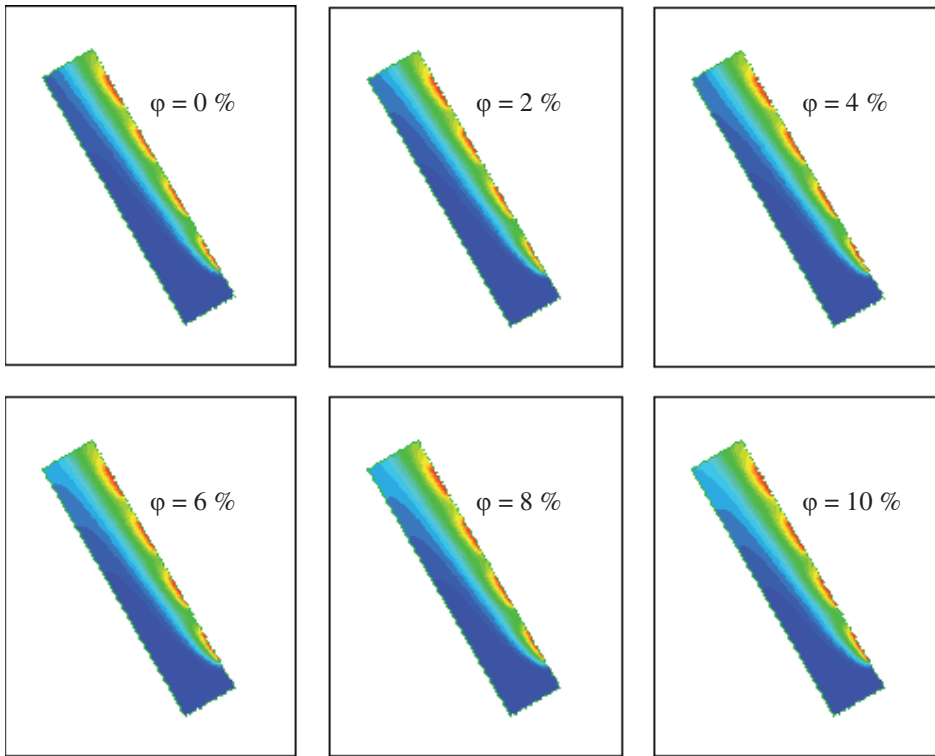


Fig.2: Contours of Isotherms for $Re = 5$

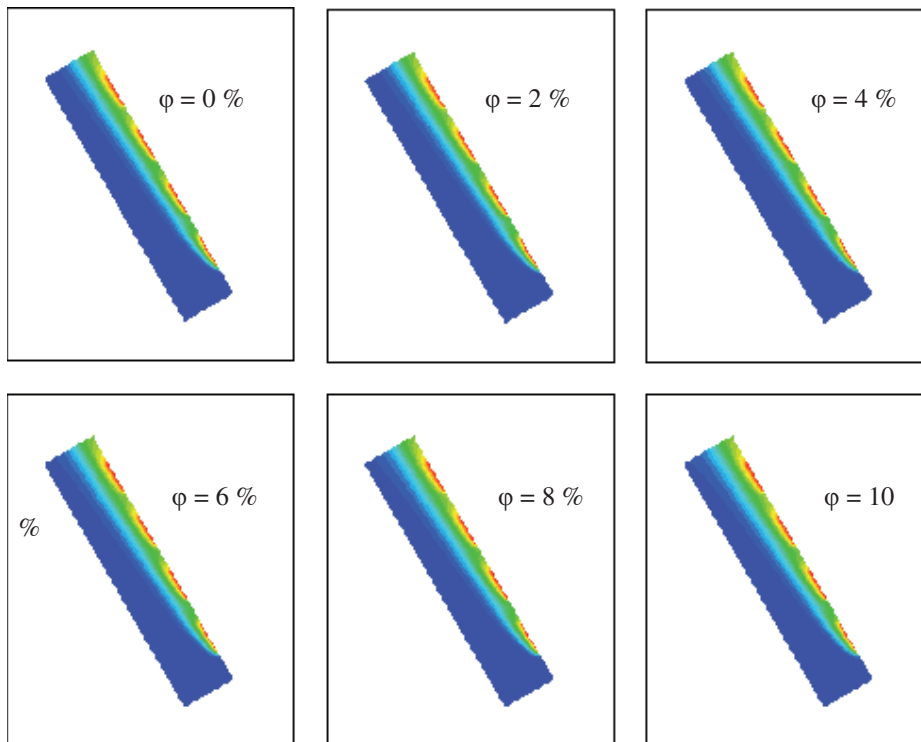
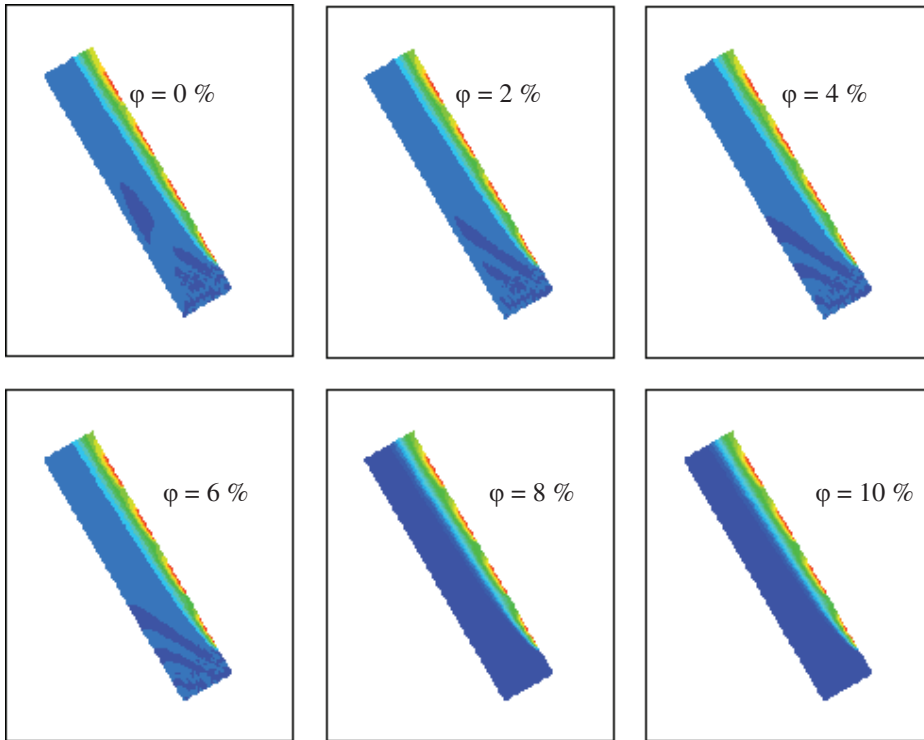
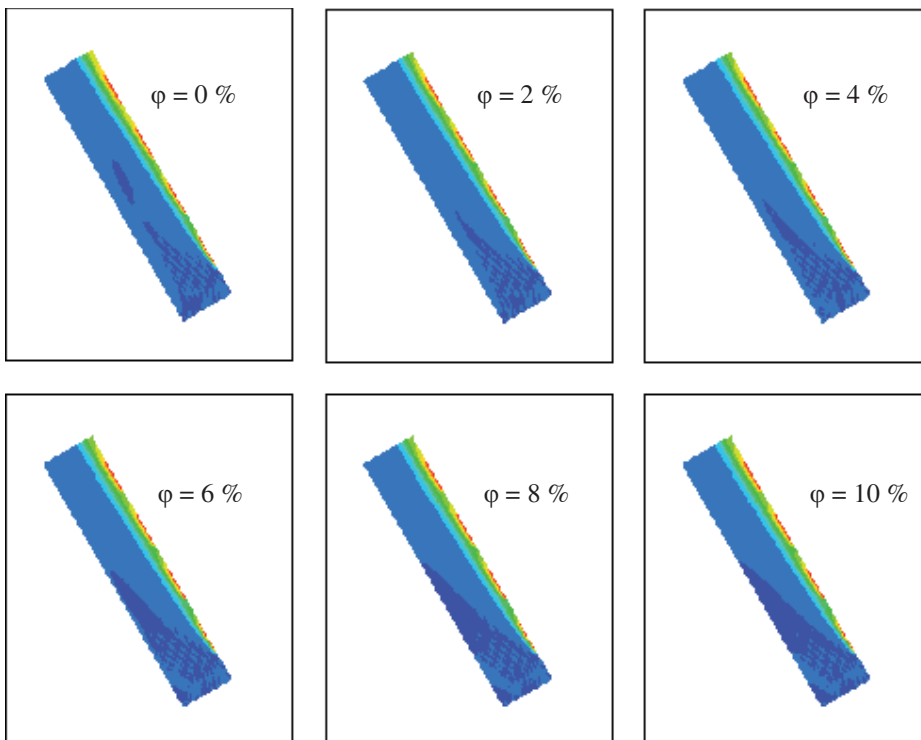


Fig.3: Contours of Isotherms for $Re = 10$

Fig.4: Contours of Isotherms for $Re = 25$ Fig.5: Contours of Isotherms for $Re = 50$

On the other hand, for a given solid volume fraction, the transfer rate decrease with the increase in the Reynolds number. In order to estimate the heat transfer enhancement, we have calculated local modified Nusselt number and modified average Nusselt number.

$$Nu_l^* = \frac{k_{nf}}{k_f} \frac{\partial T^*}{\partial n^*}$$

Figures 6 to 8 showing the variation of modified Nusselt number along the outlet for values of Reynolds number equalize to 5 and 10.

The preceding remark is also observed in the computation of the local and average Nusselt numbers. The increase in Reynolds number decreases the effect of solid volume fraction on the isotherms and velocities field. The variation of modified local Nusselt number according to ϕ , along the outlet of the cavity, presents a maximum which increases by increasing the nanofluid concentration. The modified average Nusselt number. The modified average Nusselt number varies almost linearly according to the solid volume fraction. For low value of Reynolds ($Re=5$) and while varying the concentration from 0% to 10%, the transfer rate increases by 27%

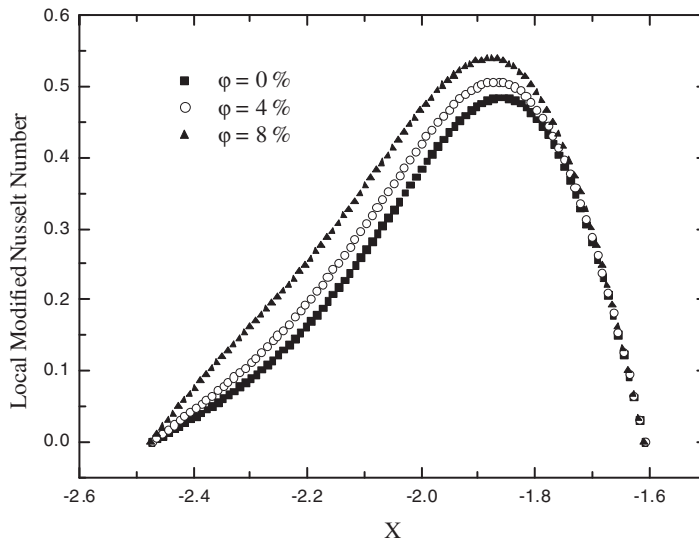


Fig.6: Variation of local Nusselt number along the outlet for $Re = 5$

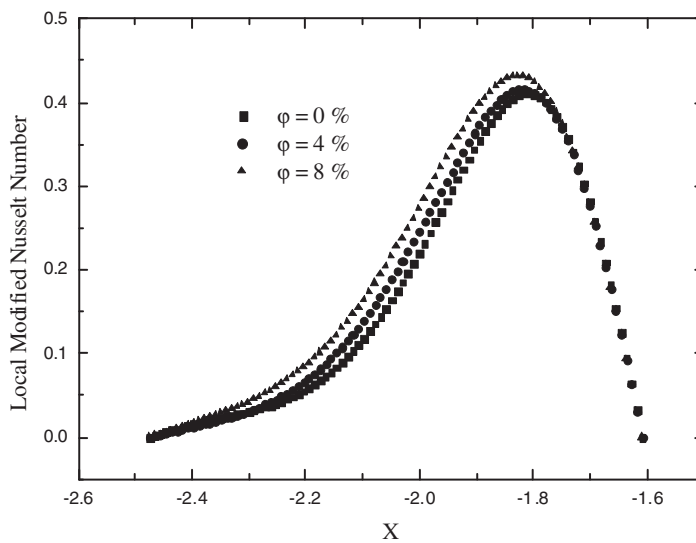


Fig.7: Variation of local Nusselt number along the outlet for $Re = 10$

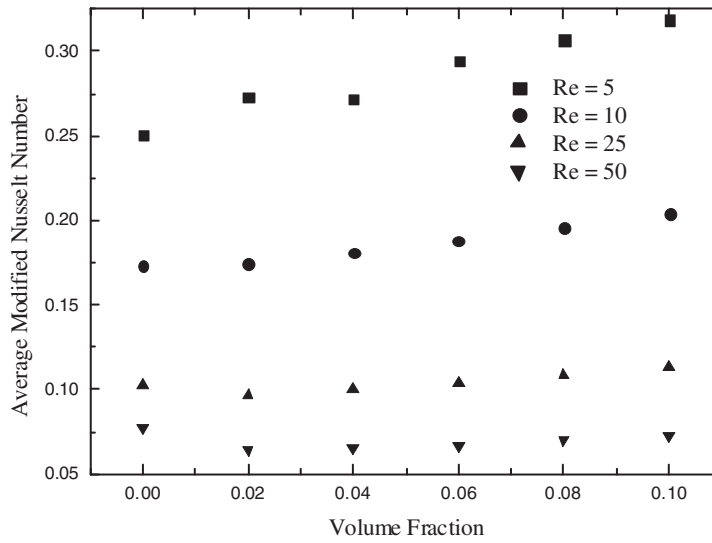


Fig.8: Variation of average modified Nusselt number solid volume fraction

4. CONCLUSION

The heating of the solar cells poses a major problem for their operation, which obliges us to cool them. In this study we simulated the cooling of the solar cells by the use of nanofluid.

The first results obtained indicate that the use of Newtonian nanofluids with an aim of improvement of the heat transfer in forced convection is not so obvious. The addition of nanoparticles to a basic fluid does not affect the structure of the flow but the increase in the thermal conductivity of the mixture increases the rate of heat transfer. In this study the effect of solid volume fraction and Reynolds number on the flow pattern and heat characteristics were investigated.

The presence of nanoparticles in the fluid increases the rate of transfer of heat in comparison with the basic fluid ($\phi=0$) thus improving cooling of the solar cells what leads us to have a good performance of the solar panel.

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