

NUMERICAL INVESTIGATION INTO ENTROPY GENERATION IN A CHANNEL FLOW OF NANOFLUIDS WITH CONVECTIVE HEATING

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Abstract- This study is based on numerical investigation into entropy generation in a channel flow of nanofluids with convective heating. Channel flow was for water based nanofluids containing Copper (Cu) and Alumina (Al₂O₃) as nanoparticles. Both first and second laws of thermodynamics also Newton Law of Cooling are utilized to analyze the model problem in horizontal geometric with no effect of gravitation flow in a channel flow. By use of semi discretization finite difference method together with Runge-Kutta Fehlberg, numerical investigation was conducted. Graphical results on the properties of parameter variation on velocity, temperature and entropy generation rate are presented and discussed with effects of increasing Reynolds number, Eckert number, Nanoparticles Volume Fraction, Prandtl number and Pressure Gradient.

I. INTRODUCTION

In industrial heating or cooling equipment, convective heating is very significant process. Nanofluids are more useful in these fields of engineering and industrial applications now days. According to Azari et al., (2013) depict that an innovative way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluid. They focused on develop fluids applicable in a machines.

Maxwell (1873 - 1881) showed the possibility of increasing thermal conductivity of a mixture by adding a volume fraction of solid particles. These fluids containing suspended colloidal nanoparticles have been called nanofluids". Nanofluids introduced first by Choi .S in 1995 for a suspension of nanoparticles in base fluids. Nanoparticles could be silica, polymers, metal dioxides, metals and carbon nanotubes. Oil, water and ethylene glycol are the common base fluids. Nanofluid is a mixture of nanoparticles with base fluids in which the diameter (nanometer-size) of these nano-particles are less than 100 nm.

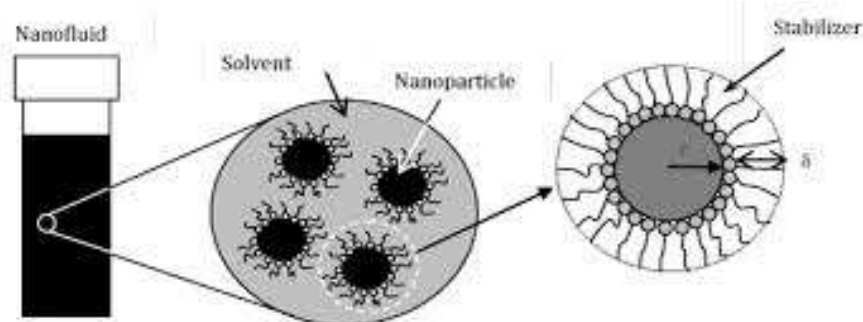


Figure 1: Nanofluid

A nanofluid is a mixture between nanoparticles like alumina and base fluid like water. These mixtures have greater application in today world of science and technology. Examples of nanoparticle are pure metals (Au, Ag, Cu, and Fe), metal oxides (CuO, SiO₂, Al₂O₃, TiO₂, ZnO, and Fe₃O₄), Carbides (SiC, TiC), Nitrides (AlN, SiN) and different types of carbon (diamond, graphite, single/multi wall carbon nanotubes) (Zhen-Hua Lui, and Yuan- Yang Li. 2012). Base fluids are water or oil.

There are two techniques for preparation of nanofluids which are single-step method and two-step method. By single-step method, nanoparticles are evaporated directly into the base fluid and the two-step method in which nanoparticles are first prepared by either the inert gas-condensation technique or chemical vapour deposition method and then dispersed into the base fluid thus it is two-step. The figure below represents applications of the nanofluids in a different field of machines.

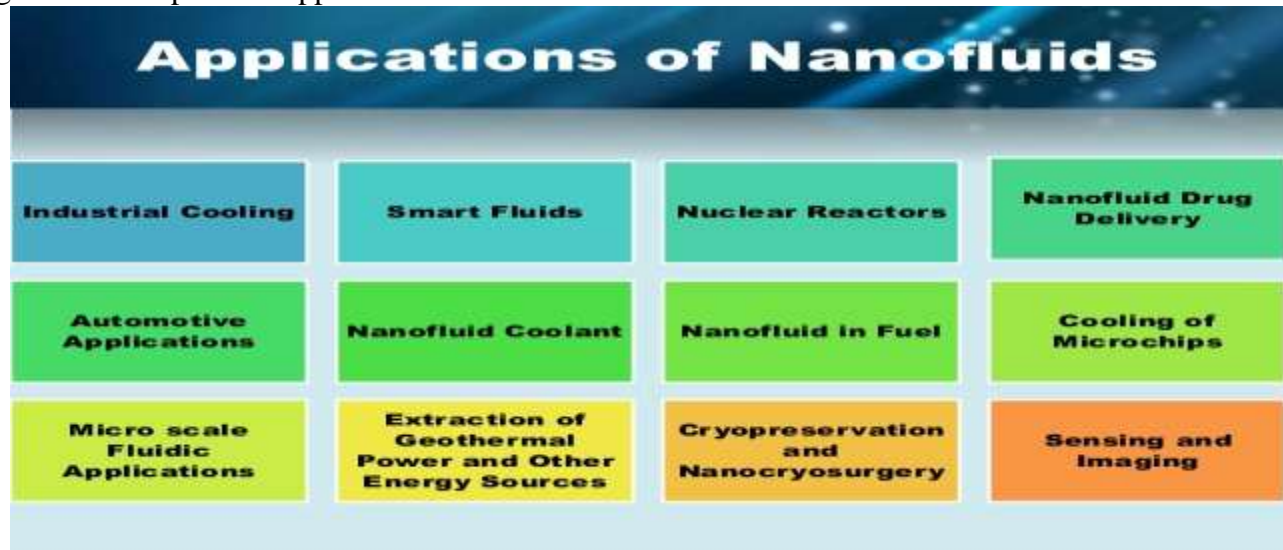


Figure 2: Applications of Nanofluids

The concept of entropy is that nature tends from order to disorder in isolated systems. Entropy, on the other hand, is a measure of the disorder of a system. Disorder refers to the number of different microscopic states a system can be given that the system has a particular fixed composition, volume, energy, pressure, and temperature. By "microscopic states" that mean the exact states of all the molecules making up the system. As entropy-generation takes place the quality of energy decreases, so to preserve the quality of energy, entropy generation in fluid flow should be reduced. Entropy increases as distance between one particle and another particle increase. As the state of matter change also there is entropy change. Thus the entropy in a gas state is larger than in a liquid state and in a liquid state is more than the solid state of matter.

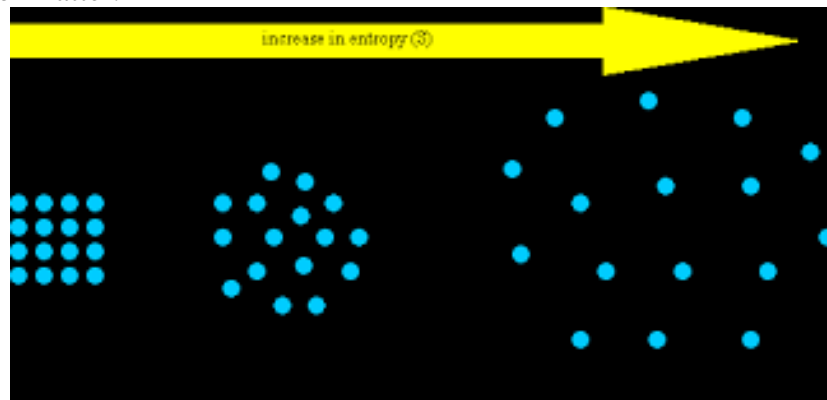


Figure 3: Entropy Variations

Mkwizu and Makinde (2014) have investigated entropy generation in a variable viscosity channel flow of nanofluids with convective cooling and found that, by careful combination of parameter values, the entropy production within the channel flow of a variable-viscosity water-based nanofluid in the presence of convective cooling can be minimized. These parameters are Eckert number (Ec), Biot number (Bi), thermophoresis parameter (Nt) and so on.

According to investigation conducted by Yarmand .H et al. (2014), results show that the optimal

volume concentration of nanoparticles to minimize the entropy generation increases when the Reynolds number decreases. They found that the thermal entropy generation increases with the increase of nanoparticle size whereas the frictional entropy generation decreases. Thus ZrO_2 -water provides the highest entropy generation compare with other nanofluids (including Al_2O_3 , SiO_2 and CuO nanoparticles in water).

Makinde and Eegunjobi (2013) made investigation in analysis of inherent irreversibility in a variable viscosity magneto-hydrodynamic (MHD) generalized Couette flow with permeable walls. They found that the optimal design and the efficient performance of a flow system or a thermally designed system can be improved by choosing the appropriate values of the physical parameters. And this was because of there are effect towards the upper and lower moving plates.

Chen et al., (2014) through investigation made, they have found that for a lower Brinkman number, the local Nusselt number of the nanofluid on the hot wall is greater than that of pure water and increases with an increasing nanoparticle concentration. Vice-versa is true for higher Brinkman number. Finally, the average entropy generation number of the nanofluid is less than that of pure water.

Singh et al., (2010) investigated in Entropy generation due to flow and heat transfer in nanofluids. They analysed advantage or disadvantage of alumina–water nanofluid that can be predicted for micro-channel and conventional channel with laminar and turbulent flow by considering approximation based on order of magnitude analysis. The use of alumina–water nanofluids with high viscosity in micro-channel with laminar flow and conventional channel with turbulent flow is not suggested. So for full advantages there is a need to develop low viscosity alumina–water nanofluids.

Bianco et al. (2011), investigated an entropy generation analysis to find the optimal working condition for the given geometry under given boundary conditions. They proposed a simple analytical procedure to evaluate the entropy generation and its results are compared with the numerical calculations. A comparison of the resulting Nusselt numbers with experimental correlations available in literature is accomplished. They found that to minimize entropy generation, the optimal Reynolds number must be determined.

Mkwizu and Makinde (2015) did an investigation in second law analysis of buoyancy driven unsteady channel flow of nanofluids with convective cooling and results were Alumina-water nanofluid tends to flow faster than Cu-water nanofluid, the temperature of Alumina-water nanofluid rises higher than Cu-water nanofluid, the Cu-water nanofluid produces higher skin friction than Alumina-water nanofluid, the Alumina-water nanofluid produces higher entropy than Cu-water nanofluid.

Rashidi et al., (2013) based in entropy generation in steady magneto-hydrodynamic (MHD) flow due to a rotating porous disk in a nanofluid. The main purpose of this research was to use the second law of thermodynamics efficiently in calculations of rotating fluidic systems. Also fundamental objective of the second law thermodynamics analysis had also been achieved such that the minimization of entropy in the swirling disk flow regime, when the magnetic interaction parameter, suction parameter and nanoparticle volume fraction decreased.

Mkwizu et al., (2015) conducted numerical investigation into entropy generation in a transient generalized Couette flow of nanofluids with convective cooling and come with these results such that the Alumina–water nanofluid tends to flow faster than Cu–water nanofluid, the temperature of Cu–water nanofluid rises higher than Alumina–water nanofluid and Cu–water nanofluid produces higher skin friction than Alumina–water nanofluid. The Alumina–water nanofluid produces higher entropy generation rate than Cu–water nanofluid near the lower wall, but as it approaches the upper wall, Cu–water nanofluid produces higher entropy generation rate than Alumina–water nanofluid.

The heat transfer of nanofluid depends on type of nanoparticles, size of nanoparticles and concentration of nanoparticles in base fluid. Nanofluid is a passive method to optimize the operational parameters play a key role in enhancement of heat transfer rate after the design of heat exchanger (Chavda et al, 2014).

In the present study, we analyse numerically entropy generation in a channel flow of nanofluids with convective heating in an unsteady channel flow of water-based nanofluid under the influence of convective heat exchange with the ambient surroundings. Such flows are very important in engineering, solar water heating, improving diesel generator efficiency, cooling of heat exchanging devices, improving heat-transfer efficiency of chillers, domestic refrigerator and freezers. In the following sections, the problem is formulated, numerically analysed, and solved. Pertinent results are displayed graphically and discussed.

II. MATHEMATICAL MODEL

Consider unsteady flow of viscous incompressible nanofluids containing Copper (Cu) and Alumina (Al₂O₃) as nanoparticles. The exchange energy in form of heat with the ambient surrounding follows the Newton's law of cooling. T stands for the temperature of the nanofluid, T_w for ambient surrounding temperature, u for the nanofluid velocity in the x -direction a is the channel width and y stands for distance measured in the normal direction. From the problem geometry figure 4 below, continuity equation, momentum equation and energy equation are presented.

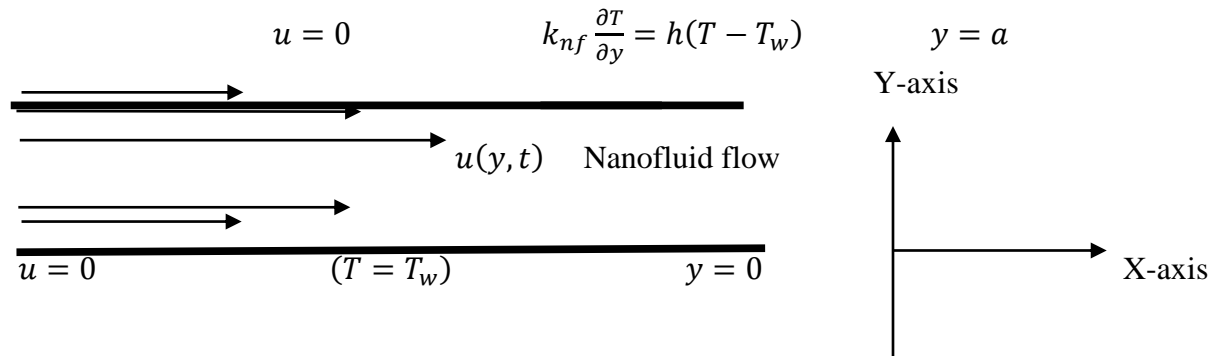


Figure 4: Problem Geometry

The Navier–Stokes nanofluids momentum and energy balance equation in one dimension for the transient flow can be written as (Olanrewaju & Makinde 2013; Motsumi & Makinde 2012; Makinde 2012, 2013b; Oztop & Abu-Nada 2008; Wang & Mujumdar 2007; Buongiorno 2006)

$$\frac{\partial u}{\partial x} = 0 \quad (1)$$

$$\frac{\partial u}{\partial \bar{t}} = - \frac{1}{\rho_{nf}} \frac{\partial P}{\partial x} + \frac{\mu_{nf}}{\rho_{nf}} \frac{\partial^2 u}{\partial y^2} \quad (2)$$

$$\frac{\partial T}{\partial \bar{t}} = \alpha_{nf} \frac{\partial^2 T}{\partial y^2} + \frac{\alpha_{nf} \mu_{nf}}{k_{nf}} \left(\frac{\partial u}{\partial y} \right)^2 \quad (3)$$

Where P is the nanofluid pressure, \bar{t} is the time, μ_{nf} represents the dynamic viscosity of the nanofluid, k_{nf} implies the nanofluid thermal conductivity, ρ_{nf} stands for the density of the nanofluid and α_{nf} means the thermal diffusivity of the nanofluid. The dynamic viscosity of nanofluid will be assumed to be temperature independent as follows:

$$\mu_{nf} = \frac{\mu_f}{(1 - \phi)^{2.5}}, \rho_{nf} = (1 - \phi) \rho_f + \phi \rho_s, \alpha_{nf} = \frac{k_{nf}}{(\rho c_p)_{nf}}, \tau = \frac{(\rho c_p)_s}{(\rho c_p)_f}, \frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{(k_s + 2k_f) + \phi(k_f - k_s)}, (\rho c_p)_{nf} = (1 - \phi)(\rho c_p)_f + \phi(\rho c_p)_s \quad (4)$$

The nanoparticles volume fraction represented by ϕ ($\phi = 0$ correspond to a regular fluid), ρ_f and ρ_s are the densities of the base fluid and the nanoparticle respectively, k_f and k_s are the thermal conductivities of the base fluid and the nanoparticles respectively, $(\rho c_p)_f$ and $(\rho c_p)_s$ are the heat capacitance of the base fluid and the nanoparticle respectively. The initial and boundary conditions for the problem are;

$$\begin{aligned} u(y, 0) = 0, T(y, 0) = T_w, u(0, \bar{t}) = 0, T(0, \bar{t}) = T_w \\ u(a, \bar{t}) = 0, k_{nf} \frac{\partial T}{\partial y}(a, \bar{t}) = h(T(a, \bar{t}) - T_w) \end{aligned} \quad (5)$$

(6) Table 1 below presents thermo physical properties of water, copper and alumina at the reference temperature.

Table 1: Thermophysical properties of the fluid phase (water) and nanoparticles

Physical properties	Fluid phase (water)	Cu	Al ₂ O ₃
c_p (J/kg K)	4179	385	765
ρ (kg/m ³)	997.1	8933	3970
k(W/m K)	0.613	401	40

We introduce the dimensionless variables and parameters as follows:

$$\left. \begin{aligned} \theta = \frac{T - T_w}{T_w}, W = \frac{u}{U}, t = \frac{\bar{t}U}{a}, v_f = \frac{\mu_f}{\rho_f}, \bar{P} = \frac{Pa}{\mu_f U}, \\ A = -\frac{\partial \bar{P}}{\partial X}, X = \frac{x}{a}, \eta = \frac{y}{a}, Pr = \frac{\mu_f c_{pf}}{k_f}, Ec = \frac{U^2}{c_{pf} T_a}, \\ \tau = \frac{(\rho c_p)_s}{(\rho c_p)_f}, m = \frac{(k_s + 2k_f) + \phi(k_f - k_s)}{(k_s + 2k_f) - 2\phi(k_f - k_s)}, Re = \frac{Ua}{\nu_f} \end{aligned} \right\} \quad (7)$$

The dimensionless governing equations with an appropriate initial and boundary conditions can be written as:

$$\frac{\partial w}{\partial t} = \frac{A}{Re(1 - \phi + \phi \rho_s / \rho_f)} + \frac{1}{(Re(1 - \phi + \phi \rho_s / \rho_f)(1 - \phi)^{2.5})} \frac{\partial^2 w}{\partial \eta^2} \quad (8)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{m * Pr * Re(1 - \phi + \phi \rho_s / \rho_f)} \frac{\partial^2 \theta}{\partial \eta^2} + \frac{Ec}{(Re(1 - \phi + \phi \tau)(1 - \phi)^{2.5})} \left(\frac{\partial w}{\partial \eta} \right)^2 \quad (9)$$

With

$$W(\eta, 0) = \theta(\eta, 0) = 0 \quad (10)$$

$$W(0, t) = \theta(0, t) = 0 \quad (11)$$

$$W(1, t) = 0, \frac{\partial \theta}{\partial \eta}(1, t) = mBi\theta(1, t)$$

Where Bi is the Biot number, Gr is the Grashof number, Pr is the Prandtl number, Ec is the Eckert number and A is the pressure gradient parameter.

III. ENTROPY ANALYSIS

The second law of thermodynamics is an important tool to scrutinize the irreversibility effects due to flow and heat transfer. Thermodynamic irreversibility is closely related to entropy production. Convection process involving channel flow of nanofluids is inherently irreversible due to the exchange of energy and momentum, within the nanofluid and at solid boundaries. Following Woods (1975), the local volumetric rate of entropy generation is given by

$$S''' = \frac{k_{nf}}{T_w^2} \left(\frac{\partial T}{\partial y} \right)^2 + \frac{\mu_{nf}}{T_w} \left(\frac{\partial u}{\partial y} \right)^2 \quad (12)$$

The first term in equation (12) is the entropy generation due to heat transfer while the second term is the entropy generation due to fluid friction. Using dimensionless variables from equation (7), we express the entropy generation number in dimensionless form as,

$$N_s = \frac{a^2 S'''}{k_f} = \frac{1}{m} \left(\frac{\partial \theta}{\partial \eta} \right)^2 + \frac{Br}{(1-\phi)^{2.5}} \left(\frac{\partial W}{\partial \eta} \right)^2, \quad (13)$$

where $Br = Ec Pr$ is the Brinkmann number.

Let

$$N_1 = \frac{1}{m} \left(\frac{\partial \theta}{\partial \eta} \right)^2, \quad N_2 = \frac{Br}{(1-\phi)^{2.5}} \left(\frac{\partial W}{\partial \eta} \right)^2, \quad (14)$$

The irreversibility distribution ratio is define as $\Phi = N_2/N_1$. Heat transfer irreversibility dominates for $0 \leq \Phi < 1$ and fluid friction irreversibility dominates when $\Phi > 1$. The contribution of both irreversibilities to entropy generation are equal when $\Phi = 1$. We define the Bejan numbers (Be) mathematically as

$$Be = \frac{N_1}{N_s} = \frac{1}{1 + \Phi}. \quad (15)$$

Equation (15) shows that the Bejan number ranges from 0 to 1. The zero value of the Bejan number corresponds to the limit where the irreversibility is dominated by the effect of fluid friction while $Be = 1$ is the limit where the irreversibility due to heat transfer dominates the flow system. The contribution of both heat transfer and fluid friction to irreversibility are the same when $Be = 0.5$.

IV. NUMERICAL PROCEDURE

The nonlinear initial boundary value problem (IBVP) in equations (8 and 9) is solved numerically using a semi-discretization finite difference method known as method of lines. We partition the spatial interval $0 \leq \eta \leq 1$ into N equal parts and define grid size $\Delta\eta = 1/N$ and the grid points, $\eta_i = (i - 1) \Delta\eta$, $1 \leq i \leq N + 1$. The discretization is based on a linear Cartesian mesh and uniform grid on which finite-differences are taken. The first and second spatial derivatives in equations (3.21)-(3.22) are approximated with second-order central finite differences. Let $W_i(t)$ and $\theta_i(t)$ be approximation of $W(\eta_i, t)$ and $\theta(\eta_i, t)$, then the semi-discrete system for the problem becomes.

$$\frac{dw}{dt} = \frac{A}{Re(1-\phi + \phi\rho_s/\rho_f)} + \frac{W_{i+1} - 2W_i + W_{i-1}}{(Re(1-\phi + \phi\rho_s/\rho_f)(1-\phi)^{2.5})(\Delta\eta)^2} \quad (16)$$

$$\frac{d\theta}{dt} = \frac{\theta_{i+1} - 2\theta_i + \theta_{i-1}}{m \cdot Pr \cdot Re (1 - \phi + \phi \rho_s / \rho_f) (\Delta\eta)^2} \frac{Ec}{(Re(1 - \phi + \phi\tau)(1 - \phi)^{2.5})} \left(\frac{W_{i+1} - W_{i-1}}{2\Delta\eta} \right)^2 \quad (17)$$

with initial conditions

$$W_i(0) = \theta_i(0) = 0, 1 \leq i \leq N + 1, \quad (18)$$

and boundary conditions

$$W_1 = 0, \theta_1 = 0, W_{N+1} = 0, \theta_{N+1} = \theta_N (1 + mBi\Delta\eta) \quad (19)$$

Equations 16 and 17 is a system of first order ordinary differential equations with known initial conditions (18) and boundary condition (19). These can be easily solved iteratively using Runge-Kutta Fehlberg integration technique implemented on computer using Matlab.

V. RESULTS AND DISCUSSIONS

In this paper, the pure water has been considered as the base fluid, copper (Cu) and Alumina (Al_2O_3) as nanoparticles. The Prandtl number of the base fluid (water) is kept constant at 6.2 and the effect of solid volume fraction is investigated in the range of $0 \leq \phi \leq 0.3$. Numerical solution for the representative velocity field, temperature field, skin friction, Nusselt number, entropy generation rate and Bejan number has been carried out by assigning some arbitrary chosen specific values to various thermophysical parameters controlling the flow system (figures 2–27). Moreover, it is important to note that $\phi = 0$ correspond to base fluid scenario while $\phi > 0$ correspond to nanofluids scenario. The detailed discussion and graphical representation of the results of above equations are reported in this section.

5.1 Nanofluid Temperature Profile

Figure 5 below shows the effects of parameter variation on temperature profile of both Copper-water and Alumina nanofluids. The graph of Temperature against time with constant parameters, those are Ec, Re, Pr and Bi. Note that direction of arrow shows changes of space parameter values such as 0.6, 0.7, 0.8 and 0.9 in each nanofluid.

For the copper-water nanofluids depicts that at lower plate degree of temperature is small compared to that at upper plate. It seems that at lower plate space parameter increase with increasing the temperature while at upper plate space parameter increase with decreasing the temperature. It is the same phenomenon in Alumina-nanofluids. Also for Alumina as nanoparticles in nanofluids, graph depicts that temperature is zero degree at fixed lower plate while upper plate region has higher value of temperature compared to that at lower plate which reflect also Copper-water nanofluids.

Thus the temperature increases with time increase while in a middle of plates space parameters are neither ascending nor descending but its temperature range is intermediate between lower and upper plate. Therefore for combination of both two nano-particles (Copper and Alumina), it shows that at fixed lower value both have zero degree of temperature and at upper plate region Alumina nanofluids has higher temperature value compare to copper-water nanofluids.

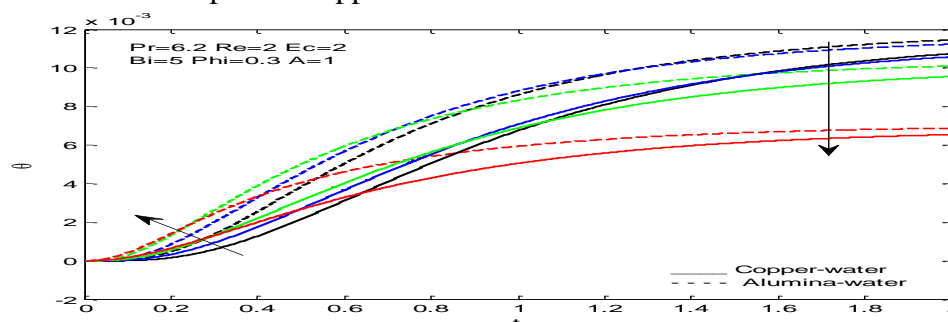


Figure 5: Nanofluid temperature profile with increasing time

5.2 Nanofluid Velocity Profile

Figure 6 shows the effects of parameter variation on velocity profile of both Copper-water and Alumina nanofluids. This is a graph of Temperature against time with constant parameters which are Ec , Re , Pr and Bi . Also direction of arrow shows changes of space parameter values such as 0.6, 0.7, 0.8 and 0.9 in each nanofluid. The figure below depicts Copper-water nanofluids has zero value of velocity at lower fixed point and higher value of velocity in a region of upper plate compare to lower plate that is the same as Alumina-water nanofluids. As the space parameters (0.6, 0.7, 0.8 and 0.9) increase implies that decrease in velocity which means space of 0.5 has higher values of velocity at different time compare to 0.8 space value.

Both Copper-water and Alumina-water nanofluids in a velocity profile have a tendency to reach steady state (to have the constant velocity with change in time goes). It shows in the same space parameter from lower plate to higher plate through-out the time until they reach same steady velocity, velocity of Alumina-water nanofluids is higher than Copper-water nanofluids.

Alumina-water nanofluids has a tendency to reach steady state in a velocity profile early than Copper-water nanofluids and although Alumina-water nanofluids reach steady state first but also both of them after a certain time t reach a steady state with the same constant velocity except for the space parameter 0.5, there is very small slight different in a steady velocity.

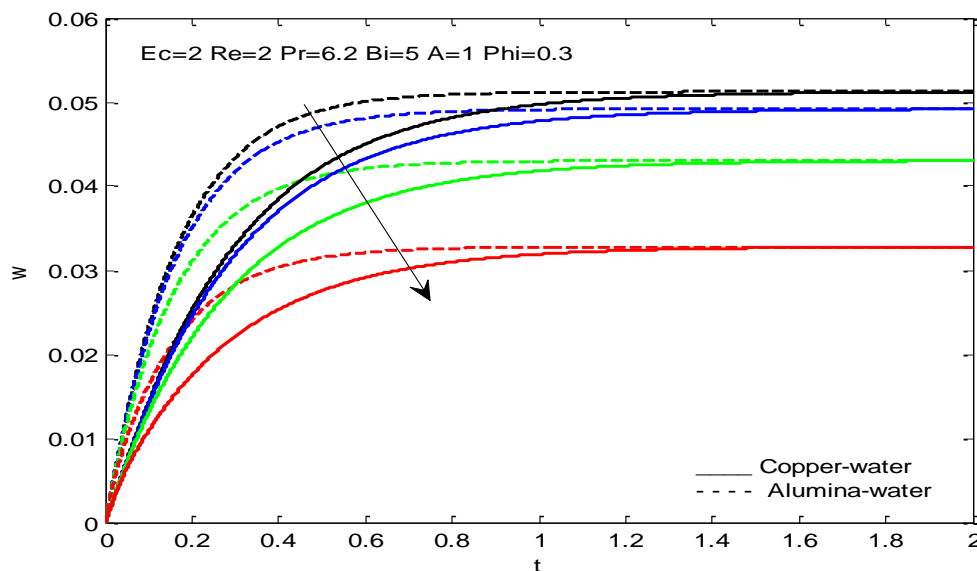


Figure 6: Nanofluid velocity profile with increasing time

5.3 Effect of Flow Parameters Variation on Entropy Generation

It is observed from figure 7 that, the variation of Entropy generation with space between Copper-water nanofluids and Alumina-water nanofluids when other parameters are kept constant. This variation on Alumina-water nanofluids is too fast compare to that of Copper-water nanofluids that raise a fact that for minimization of entropy generation between nanofluids, Copper-water be investigated more in this research-study of Numerical Investigation into Entropy Generation in a Channel Flow of Nanofluids with Convective Heating. Thus Alumina-water nanofluids have high value of a temperature compare to the Copper-water nanofluids. In entropy generation consideration is done for the copper-water nanofluids due to its response in temperature. By application of copper-water nanofluids, scientist and engineer can minimize negative effects of temperature in their field.

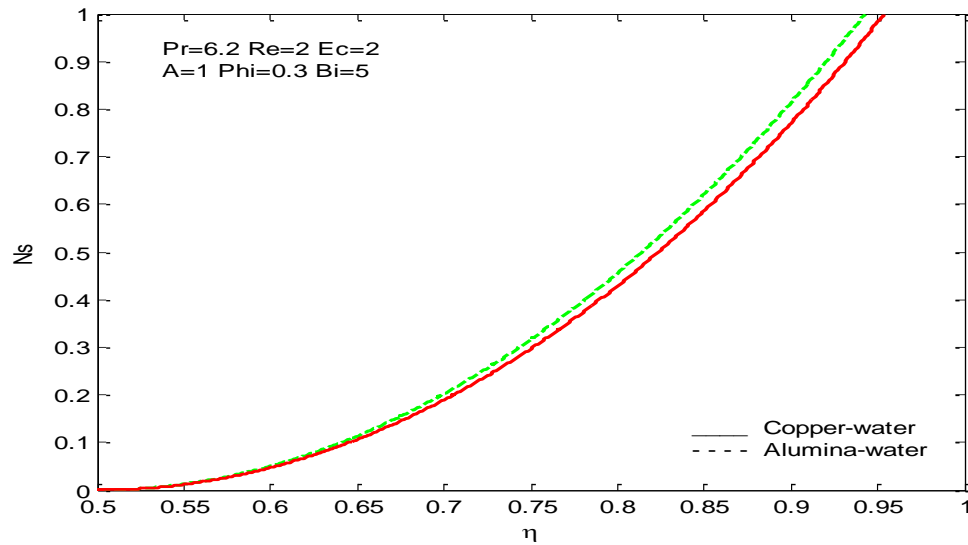


Figure 7: Entropy generation with change in Nanofluids

5.4 Effect on Pressure Gradient on Entropy Generation

The impacts of a pressure gradient (A) in an entropy generation of Copper-water nanofluids with constant parameters which are Ec , Re , Pr , ϕ and Bi are; Direction of arrow shows changes of pressure gradient values such as 1.1, 1.2, 1.3 and 1.5 in each Copper-water nanofluids. From Figure 8 it is revealed that at lower plate and upper plate, entropy generation are low and high value respectively. Relation is nonlinear between entropy and space value that implies space value increase fast than entropy generation. As pressure gradient increase thus space value of the system decrease. For the system with supportive conducive environment is at higher value of pressure gradient.

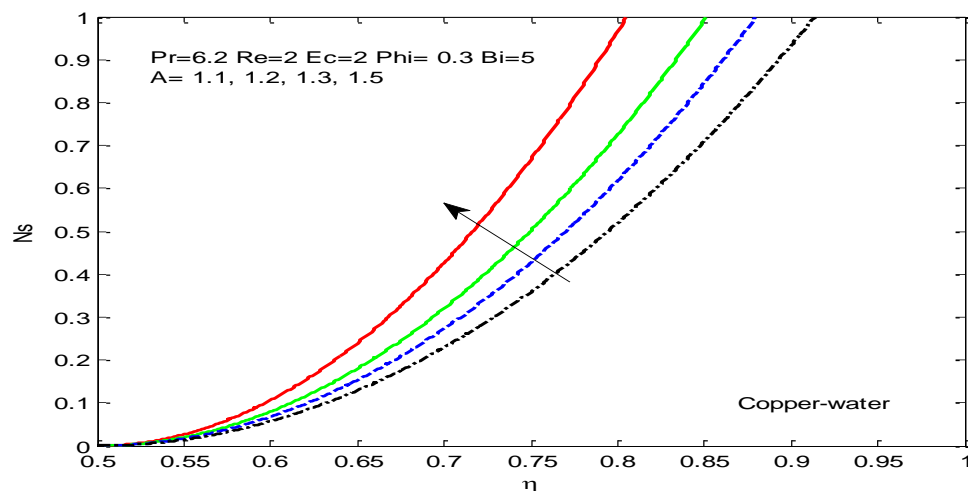


Figure 8: Entropy generation with increasing pressure gradient

5.5 Effect of Eckert Number on Entropy Generation

Impacts of Eckert Number (Ec) in an entropy generation of Copper-water nanofluids with constant parameters which are A , Re , Pr , ϕ and Bi is that, arrow shows changes of Eckert Number values such as 3, 4, 5 and 6 of Copper-water nanofluids. For the system with supportive and conducive environment work is at higher value of Eckert Number. It's low and high value at lower plate and upper plate respectively. Entropy and Eckert number are nonlinear relation that implies space value increase

fast than entropy generation and Entropy varies inverse with space value of the system as showed in figure 9 below.

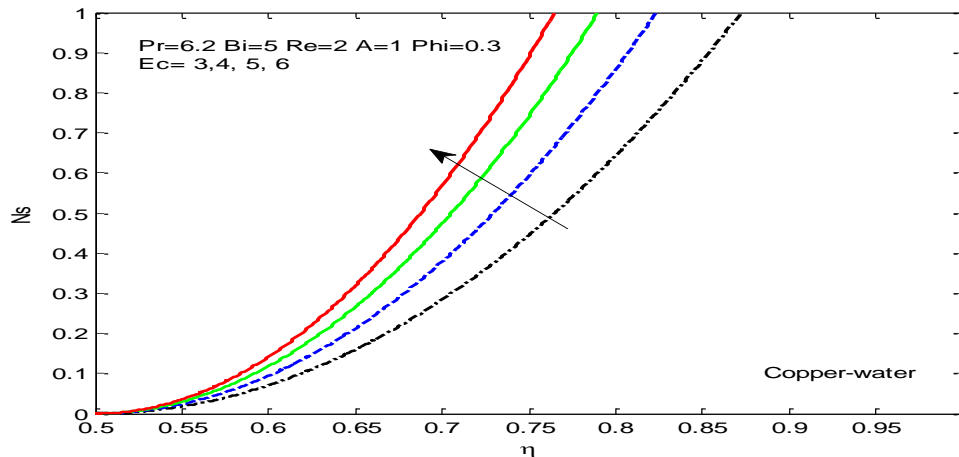


Figure 9: Entropy Generation with increasing in Eckert Number

5.6 Effect of nanoparticles volume fraction on Entropy Generation

Figure 10 shows the impacts of ϕ on entropy generation rate of Copper-water nanofluids with constant parameters which are A, Re, Pr, Ec and Bi which shows that, the increase in ϕ values from 0 to 0.3 lead to decrease of entropy generation rate. As copper-water nanofluids flow from lower to upper plate, there is increase in entropy generation. That means the variation ϕ , entropy generation varies.

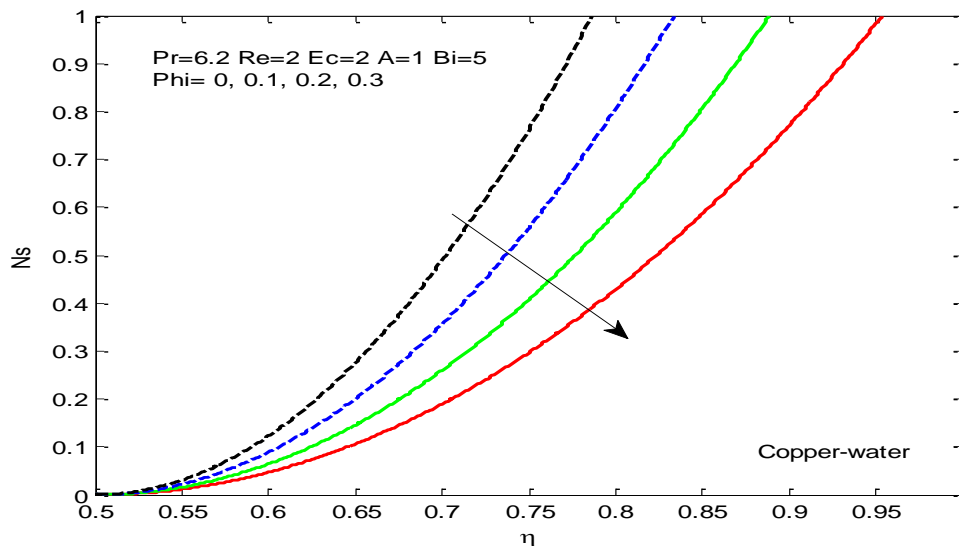


Figure 10: Entropy Generation rate with increasing in ϕ

5.7 Effect of Prandtl Number on Entropy Generation

Impacts of (Pr) in an entropy generation of Copper-water nanofluids with constant parameters which are A, Re, Phi, Ec and Bi have follows; Direction of arrow shows changes of Prandtl number such as 6.4, 6.8, 7.2 and 7.6 of Copper-water nanofluids. Prandtl number varies directly with entropy generation in such a way that space value increase as Prandtl number decrease.

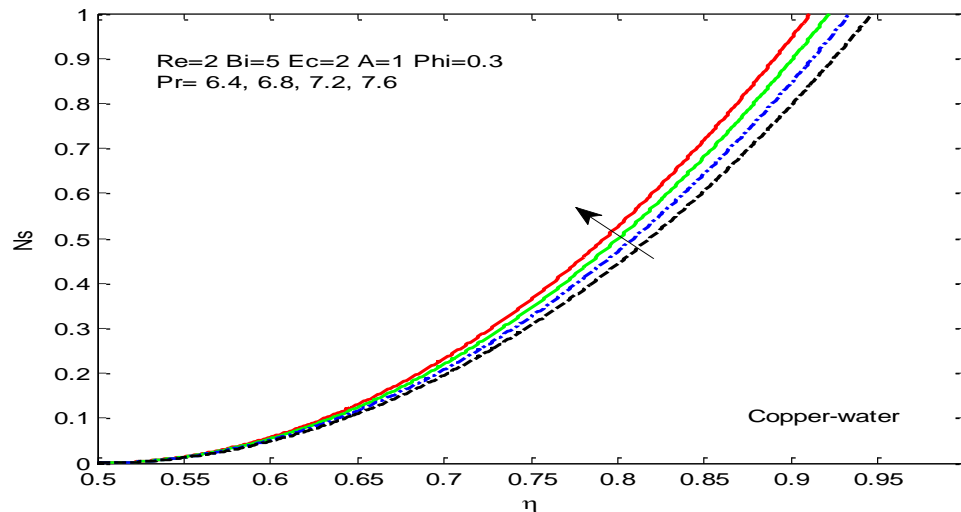


Figure 11: Entropy Generation rate with increasing in Pr

5.8 Effect of Biot Number of Entropy Generation

Impacts of (Bi) in an entropy generation of Copper-water nanofluids with constant parameters which are A, Re, Pr, Ec and Phi have follows from figure 4.1.7; Direction of arrow shows changes of Biot values such as 500, 1000, 5000 and 10000 of Copper-water nanofluids. The figure depicts that Biot number has no effect on the entropy generation of the nanofluids of copper- water. This due to variation of Biot number gives the same nature of the graph

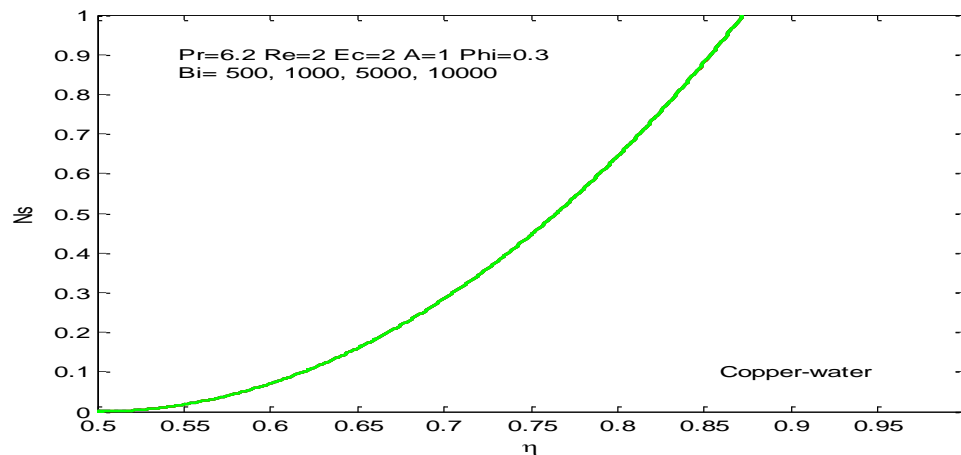


Figure 12: Entropy Generation rate increasing in Bi.

5.9 Effect of Reynolds Number of Entropy Generation

Impacts of (Re) in an entropy generation of Copper-water nanofluids with constant parameters which are A, Phi, Pr, Ec and Bi have follows; Direction of arrow shows changes of (Re) value values such as 3, 4, 5 and 6 of Copper-water nanofluids. As copper-water nanofluids flow from lower to upper plate, there is increase in entropy generation. For the variation Re value, entropy generation varies in such a way that as Re value increase there is increase space value for flow of nanofluids stay long in a specified region.

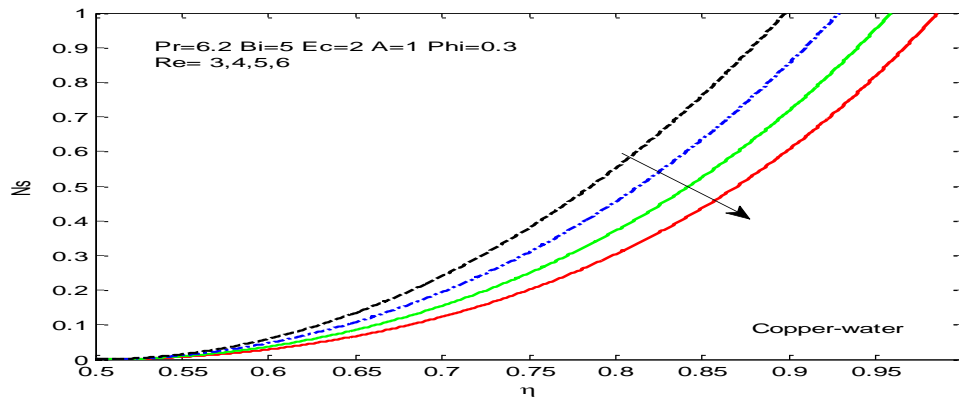


Figure 13: Entropy Generation rate with increasing in Re

VI. CONCLUSION

Minimization of entropy generation has the most important area of research by regulation of the flow parameter according to its effects on the entropy of the system in a flow process. This research analysed numerical investigation into entropy generation in a channel flow of nanofluids with Convective Heating. Fourth-order Runge-Kutta-Fehlberg integration scheme together with shooting technique were employed and numerically solve the governing equations. Results obtained are:

- Alumina-water nanofluids have higher temperature value compare to copper-water nanofluids.
- Alumina-water nanofluids have a tendency to reach steady state in a velocity profile early than Copper-water nanofluids and at the certain time both will reach steady state.
- Entropy generation is directly proportional to pressure gradient (A), Eckert number (Ec), Prandtl number (Pr).
- Entropy generation is inversely proportional to Reynolds number (Re) and nanoparticles volume fraction (ϕ). When $\phi = 0$ entropy generation rate is so faster than when ϕ not equal to zero value.
- There is slight change in entropy generation with an increase Biot number.

Generally, copper-water nanofluid is the best than alumina-water nanofluids for minimization of entropy generation and it can be regulated more by considering other variations in choosing appropriate value of the flow parameters. Due to fact that at fixed lower value both have zero degree of temperature and at upper plate region alumina nanofluids has higher temperature value compared to copper-water nanofluids. It is better to use nanofluids than base-fluids for the purpose of minimizing entropy generation rate in the system.

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