Numerical Analysis of Laminar Free-Convection Fluid Flow and Heat Transfer Over A Vertical Plate with Constant Heat Flux with Thermo Ionic Nanofluid

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ABSTRACT: Laminar natural convection fluid flow and heat transfer over a vertical plate with constant heat flux is presented thermo ionanofluids numerically. Ionic liquids are a new class of fluids to be considered for heat transfer due to their remarkable thermophysical properties. Ionanofluids consists in suspending little amounts of high conductive nanoparticles in ionic liquids. In spite of a lot of inconsistent reports mainly due to the deficient understanding of the involved mechanisms ionanofluids have been demonstrated as a new favourable heat transfer fluid. The enhanced thermal conductivity of ionanofluids over the basic ionic liquids is considered one of the driving factors for enhancing convection. The unique nonlinear coupled partial differential equations of flow are altered to a pair of simultaneous nonlinear ordinary differential equations altered by means of similarity transformation. Then, they are reduced to first order system. The computer codes are developed for this numerical analysis in Matlab bvp4c environment. The effect of velocity and temperature profiles for various Prandtl number are illustrated graphically under constant heat flux with different convectional and hybrid nanofluids Flow and heat transfer parameters are derived as functions of Prandtl number alone. The results of the present simulation are then compared with data published in literature and find a good agreement.

KEYWORDS: Vertical Plate, Constant Heat Flux, Free Convection, Heat Transfer, convectional nanofluid ionanofluids, Numerical Simulation.

I. INTRODUCTION

Ionic fluids are an awfully new class of fluids, which consist fully of ions and have melting points lower than 100 ◦C [1],[2]. Recently, the improvement of room temperature ionic liquids has conventional enormous awareness starting ionic liquids intellectual and industrial civilization due to their melting temperatures being under 300C which allows these fluids to be used in an extensive variety of applications [3]. Because these liquids are non-flammable, non-volatile, and also ecological they are considered as green fluids [4],[5] and new realistic applications are envisaged in concentrated solar power plants. Further on, a few research groups [6] to [16] urbanized the so-called ionanofluids, with better heat transfer capabilities. França et al.[7] recognized that the amalgamation of nanoparticles among ionic liquids shows enormous prospective as innovative heat transfer fluids during the thermal properties augmentation. Wang et al. [14] reported for the first time the preparation of vastly constant graphene-based nanofluids with ionic liquid as base fluids exclusive of any surfactant and performed experimental investigations on their thermal conductivity, specific heat, and viscosity. Their mainly significant conclusion is that ionanofluids show evidence of lower viscosity than their base fluids, which is not demonstrated yet in regard to other ionanofluids, as will be shown also in this learn by in view of the work of Paul et al. [6]. Paul et al. [6],[16] considered several ionic liquids improved with alumina nanoparticles (both whiskers and spherical particles) and found a considerable increase in ionanofluids viscosity in comparison with their base ionic liquids. Ferreira et al. [15] also found that the addition of a small concentration of MWCNT [Micro- walled carbon nanotubes] (0.05vol%) in [(C6)3PC14)] (Phosph) and [(C6)3PC14)][NTf2] ionic liquids extensively reduced their viscosity. The authors judge that the change in viscosity of INFs is because of the interactions between the ions of ILs and the MWCNT. Still, if studies on nanofluids viscosity (see for example Zyla et al. [17],[18]) augmented over the last years, in view of ionanofluids viscosity, the research is still continuing. In regard to specific heat, only a few studies [6],[14] were recognized

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in the open literature and the results indicated a slight increase of specific heat with temperature and a minor decrease while adding the nanoparticles to the ionic liquid. Thermal conductivity was the most studied parameter and the results indicated an increase in the thermal conductivity while adding nanoparticles to the base ionic liquids [6] to [25]. This increase depends on the considered heat transfer fluid and also on the inhabitant thermal conductivity of the nanoparticle itself. In order to recap some research, Franca et al. [19] added 0.5–3 wt% concentrationof MWCNT in [C4mim][(CF3SO2)2N] and [C2mim][EtSO4] ionic liquids and measured their thermal conductivity at dissimilar MWCNT nanoparticles concentrations and the outcome showed that the thermal conductivity of the ionanofluids increased with adding nanoparticles. Thermal conductivity of various ionic liquids and their ionanofluids with 1 wt% of MWCNT at room temperature was also studied by de Castro et al. [24] and the thermal conductivity improvement is up to 35%. An additional broad study was consummate by Paul et al. [6],[16]who premeditated the minority ionic liquids improved with alumina nanoparticles. Their results will be outlined in this article since a good number of the properties used for this study were extracted from these innovations. Mostly, he noticed a comprehensible positive effect of with ionanofluids in natural and in forced convection, as well. Their results are extremely hopeful for ongoing research on these new heat transfer fluids engineered by the addition of nanoparticles to ionic liquids. Still if present are no illustration studies in this area, this small review of state of the art in ionic liquids properties, as well as ionanofluids studies determined this author to this author to perform a numerical study by implementing some experimentally determined properties of two ionic liquids and their alumina ionanofluids. Also, reviewing the available literature was noticed a lack of complete studies in implementing these new fluids in close to real applications and also the absence of numerical studies on ionanofluids. Further on, two ionic liquids and six ionanofluids (three alumina concentration will be considered for each ionic liquid) fully characterized in the literature will be implemented in a numerical code, and their heat transfer behaviour will be discussed. The numerical set-up was built on the experiment of Sunder et al. [26] and validated in Minea [27]. Very recently Sharma K.Vet. Al. [28] analyse the numerical approach for ionic nanofluid for laminar and turbulent flow in pipe. The present scope of the paper is to conduct numerical experiments with water-based and ionic based nanofluid with the same nanoparticle concentration. The nonlinear coupled partial differential equations are converted to ordinary differential equations and solved numerically with MATLAB code for different Pr and different concentration nanoparticles in the base fluid. The behaviour of velocity and temperature profiles and local Nusselt number and Grashof numbers. The results are represented graphically which made a reasonable conclusions.

II THERMOPHYSICAL PROPERTIES OF IONIC NANOFLUIDS

The investigated base ionic liquids are two from the one used for experimental by Paul et al. [6]: 1-butyl-3-methylimidazolium *bis*{(trifluoromethyl) sulfonyl}imide[C4mim][NTf2]); Chemical Abstracts Service (CAS) registry number:174899-83-3; molecular formula: C10H15F6N3O4S2; molecular weight:419.36 g/mol and *N*-butyl-*N*-methylpyrrolidinium *bis*{trifluoromethyl) sulfonyl} imide ([C4mpyrr][NTf2]); CAS: 223437-11-4; molecular formula: C11H20F6N2O4S2; molecular weight: 422.41 g/mol. Alumina nanoparticles are c-phase with particle size < 50 nm (TEM), and surface area >40 m^2/g (BET) [6]. Al_2O_3 were dispersed in the base ionic liquid using a vortex mixture to produce ionanofluids which was further agitated for 90 min to break any possible agglomeration of nanoparticles.The weight percentage of nanoparticles were 0.5, 1.0, and 2.5 [6]. The thermophysical properties measurements were done just after synthesis of ionanofluids [6] and are illustrated in Table 1. Moreover, in Fig. 1, it can notice the variation of Prandtl number while adding alumina nanoparticles to the ionic liquids. Prandtl number increases significantly, while the weight concentration increases mainly because of viscosity increase, as one can see in Table 1.

Ionic fluid	*Cp* *Kj/kgK*	*P* *Kg/m^3*	*K* *W/mK*	*μ* *N-s/m^2*
C4min[NTf2]	1740	1412	0.126	0.035
C4min[NTf2]+0.5%Al2O3	1956	1450	0.129	0.037
C4min[NTf2]+ 1%Al2O3	2230	1460	0.132	0.048
C4min[NTf2] +2% Al2O3	2460	1506	0.136	0.099
C4mpyrr[NTf2]	1580	1385	0.122	0.052
C4mpyrr[NTf2]+0.5% Al2O3	1750	1395	0.126	0.065
C4mpyrr[NTf2] 1% Al2O3	1950	1417	0.129	0.094
C4mpyrr[NTf2]+2%Al2O3	2630	2630	0.133	0.227

Table.1.0 Thermal properties of Ionic nanofluids with different concentration

III. MATHEMATICAL MODEL:

Consider a vertical hot flat plate with constant heat flux immersed in a quiescent fluid body. We assume the natural convection flow to be steady, laminar, two dimensional, no dissipation, and the fluid to be Newtonian with constant properties, including density, with one exception: the density difference $\rho - \rho_\infty$ is to be considered since it is this density difference between the inside and the outside of the boundary layer that gives rise to buoyancy force and sustains flow.(*Boussinesq approximation.*). We take the

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upward direction along the plate to be x, and the direction normal to surface to be y

The governing equations for the present problem are equation of continuity, momentum equation ,and energy equations are

The equation of continuity

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

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+\beta g(T-T_\infty) \quad (2)$$

The energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2} \quad (3)$$

The boundary conditions on the solution are:

at $y=0; u=v=0; \; = k\frac{\partial T(y=0)}{\partial y}=q_w$ (4)

at $y=\infty; u\to 0, T\to T_\infty$ (5)

The continuity equation (1) is automatically satisfied through introduction of the stream function

$$u=\frac{\partial\psi}{\partial y}; v=-\frac{\partial\psi}{\partial x} \quad (6)$$

The similarity transformation is possible $\psi = Ax^{0.8}F(\eta)$ where $\eta = Byx^{-0.2}$ where $B^5=\frac{g\beta q_w}{5k\nu^2}$ and $A^5=\frac{5^4 g\beta q_w \nu^3}{k}$ (7)

Then the velocity components can be written as $u = ABx^{\frac{3}{5}}F'(\eta)$ and $v=A\frac{\eta F'(\eta)-4F(\eta)}{5x^{1/5}}$ (8)

Now, with the dimensionless temperature

$$\theta = A\frac{(T_\infty - T)k}{x^{1/5}\,q_w} \quad (9)$$

The partial differential equations (2) and (3) are transformed to ordinary differential equations (with a prime denoting differentiation with respect to η)

$$F''' - 3(F')^2 + 4FF'' - \theta = 0 \quad (11)$$

$$\theta'' + \Pr(4\theta' F - \theta F'') = 0 \quad (12)$$

Where $\Pr = \frac{C_p\mu}{k}$ where Prandtl number of fluid

Eqs (11) and (12) constitute a pair of simultaneous nonlinear ordinary differential equations for the velocity and temperature functions, F' and θ. They must be solved subject to the following boundary conditions:

At $y=0; u=0$ i.e $at\ \eta=0; F'=0$ (13)

At $y=0; v=0$ i.e $at\ \eta=0; F=0$ (14)

At $y=0\ -k\frac{\partial T(y=0)}{\partial y}$ i.e at $\eta=0; \theta=1$

For large y: $u\to 0$ i.e., for large η: $F'=0$ (15)

For large y: $T\to T\infty$ i.e., for large η: $\theta=0$ (16)

The fact that the original partial differentials have been reduced to a pair ordinary differential equations confirms the assumptions that similarity solutions do in fact exist.

IV. NUMERICAL SOLUTION PROCEDURE

Eqs (11) and (12) are coupled and must be solved simultaneously, which is always the case in free-convection problems. No analytic solution is known, so numerical integration is necessary. There are two unknown initial values at the wall. One must find the proper values of $F''(0)$ and θ(0) which cause the velocity and temperature to vanish for large η. The Prandtl number is a parameter. The solved for different values of Pr values for water, water based Al2O3 nanofluid, C4min[NTf2]+Al2O3at different volume concentration. The transformed nonlinear nondimensional differential equations are solved with bvp4c Matlab code and compare the fluid flow and heat transfer analysis and compare the results.

V. FLOW AND HEAT TRANSFER PARAMETERS

Besides the velocity and temperature distributions, it is often desirable to compute other physically important quantities (for example, shear stress, drag, heat-transfer-rate) associated with the free-convection flow.

Shear stress is defines as: $\tau = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0}$ (17)

Local Nusselt number is defined as $Nu_x = \frac{hx}{k} = \frac{q_w}{T_w - T_\infty}\frac{x}{k}$

$$\frac{Nu_x}{(Gr_x)^{0.2}} = -\frac{1}{5^{\frac{1}{5}}\theta(0)} \quad (18)$$

VI. RESULTS AND DISCUSSIONS

Figure 1.0 and figure 2.0 represents the comparison between the velocity , velocity gradient and non dimensional temperature profile for water as base fluid with different concentrations [0.0%,0.5%,1.0%,2.5%].

The non dimensional velocity and velocity gradient are decreases with increasing the nanofluid concentrations. The figure 2.0 represents the effect of nanofluid concentrations on nondimensional temperature with distance. The temperature profiles are also decrease with increasing the concentrations of nanofluid. With increasing in the thermal conductivity of nanofluid with concentration.

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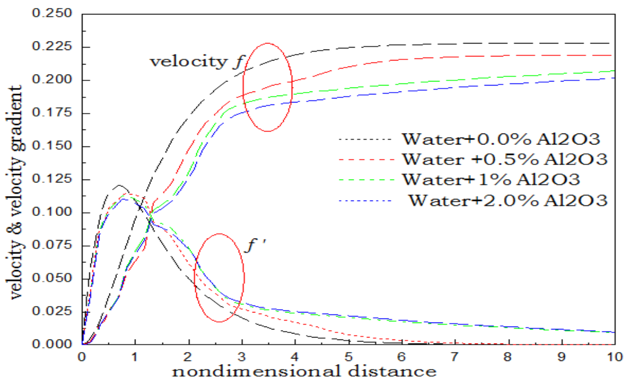

Fig1.0:Effect of nanoparticle concentration on nondimensional velocity and velocity gradient with nondimensional distance water as base fluid

The numerical experimental were conducted for both water based nanofluid and ionic based nanofluid with concentration of nanoparticle [0.0%, 0.5%, 1.0% 2.5%] Fig3.0 the variation of temperature distribution for ionic nanofluid with different nanoparticle concentration

Fig 4.0 and Fig5.0 represents the comparison between the nondimensional velocity and velocity gradient for water based nanofluid and ionic based nanofluid. The velocity and velocity gradient is ionic nanofluid is decreases with increasing the nano particle concentration due to higher viscosity and density.

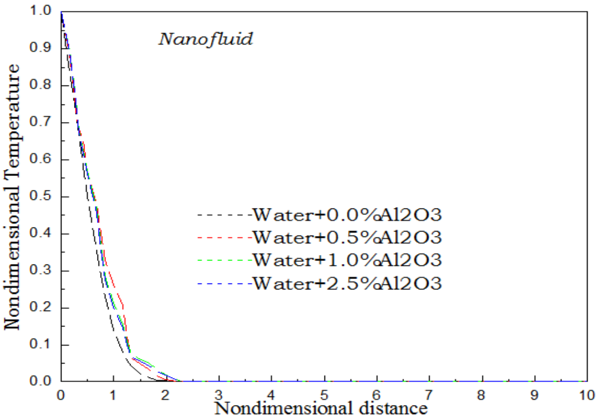

Fig2.0 Effect of nanoparticle concentration on nondimensional temperature with nondimensional distance water as base fluid.

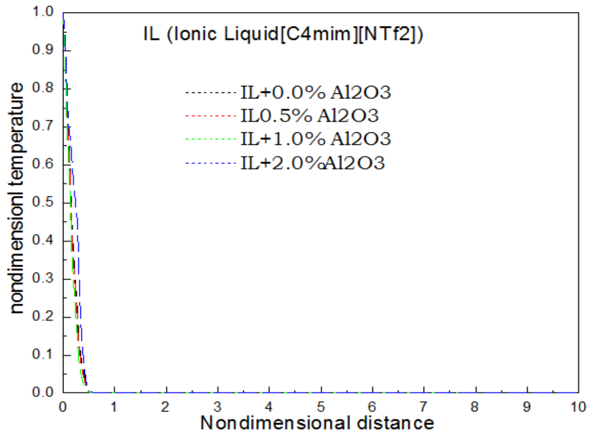

Fig3.0: Effect of nanoparticle concentration on nondimensional temperature with nondimensional distance ionic fluid as base fluid.

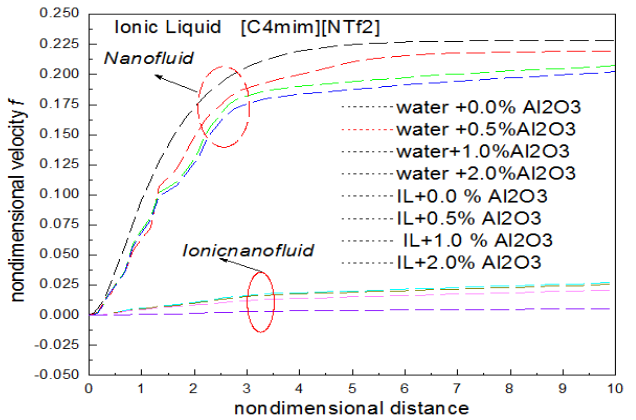

Fig4.0 Effect of nanoparticle concentration on nondimensional velocity with nondimensional distance with ionic fluid as base fluid

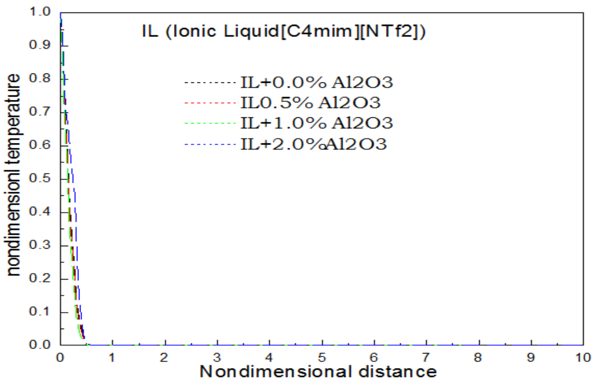

Fig5.0: Effect of nanoparticle concentration on nondimensional temperature with nondimensional distance ionic fluid as base fluid.

Fig6.0 & fig7.0 represents the variation of velocity gradient for water based nanofluid and ionic based nanofluids. The velocity gradients for the ionic based nanofluid are deceases with increasing the concentration of nanoparticle and also higher gradient than for water based nanofluid.

Fig 8.0 &Fig9.0 reads the variation of local Grashof number and Nusselt number with nondimensional distance for ionic nanofluid with different concentrations. The local Grashof number and Nusselt numbers are increases with increasing the nanoparticle concentration.

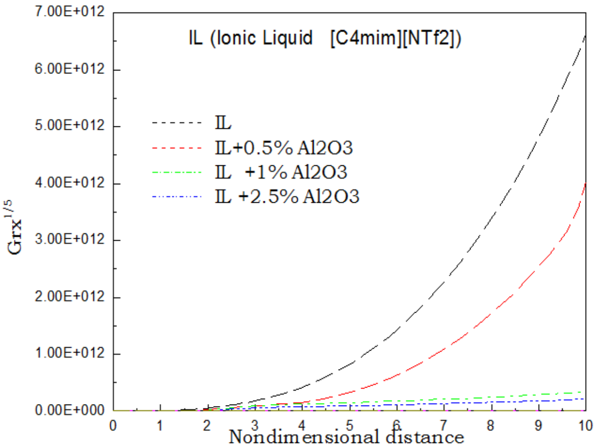

Fig6.0 Effect of local Grashof number on concentration of nanofluid with nondimensional distance.

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Fig10.0 represents the comparison between the velocity profiles for water based nanofluid and ionic based nanofluid the velocity profiles are decreases with increasing the concentration of nanofluid.

Fig 11.0 represents the variation of nondimensional temeprature profiles for water based nanofluid and ionic based nanofluid The temperature profiles are decreses with incresing the concnetion of nanopaprticle. For inonic nanolfuid the tmeprasture prifles are very large gradient in comparsion with water based nanofluid.

Fig12.0 represents the comparison between the local Nusselt numbers for both water based and ionic based nanofluid. The Nusselt numbers are increases with increasing the nanofluid concentration.

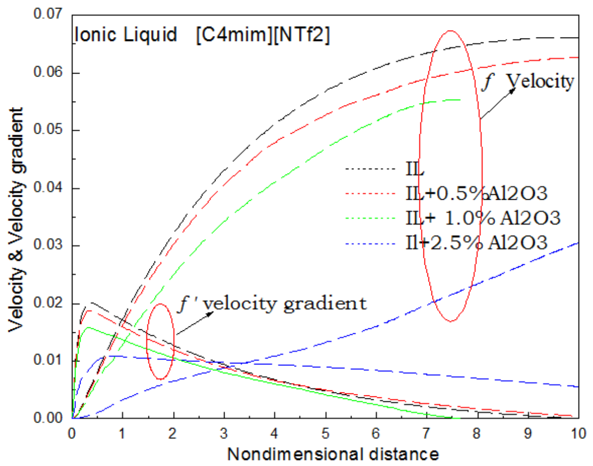

Fig7.0: Comparison between the velocity and velocity gradients with effect of Effect of nanoparticle concentration with nondimensional distance for water and ionic fluid as base fluids.

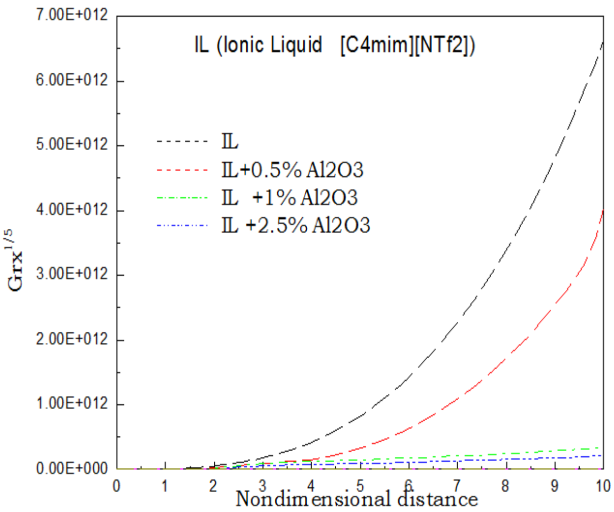

Fig8.0 Effect of local Grashof number on concentration of nanofluid with nondimensional distance for ionic nanofluid .

VI. CONCLUSIONS

In the present mathematical replica, laminar free-convection flow and heat transfer over a vertical plate with constant heat flux is presented. The solution of and flow and heat transfer parameters giving physically as a function of Prandtl only. The computed outcomes of the current simulation results for the water based nanofluid and ionic based nanofluids are compared. The velocity,velocity gradient and are decreases with increasing the nanofluid concentration. When compare with nanofluid and ionic based nanofluids the velocity,velocity gradient and temperature gradients are more increases due to the enhanced thermal properties of the ionic based nanofluid than water based nanofluids. The temperature profiles are also increases with increasing more concentration than ionic based nanofluids. From the above numerical predictions the ionic nanofluid are very much advantage than water based nanofluids and storages the higher heat transfer rates due to its enhanced thermal properties. In future thermionic nanofluid will play an significance role. To storage more thermal energy and water based nanofluid with same concentrations.

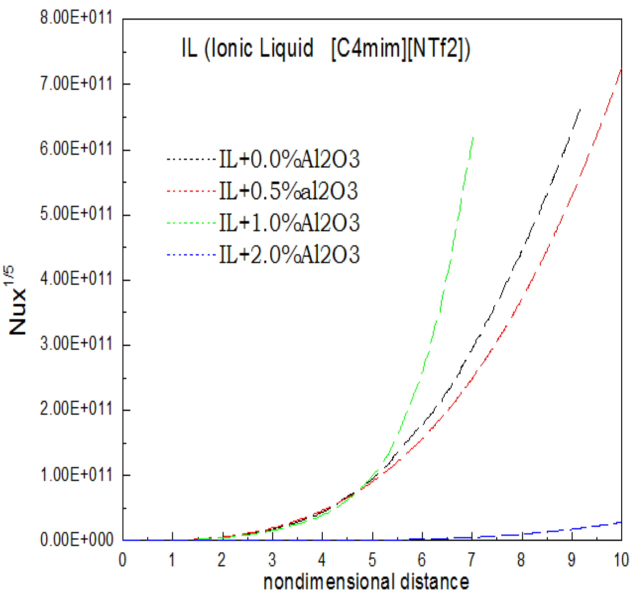

Fig9.0: Effect of nanoparticle concentration on local Nusselt number with nondimensional distance ionic fluid as base fluid

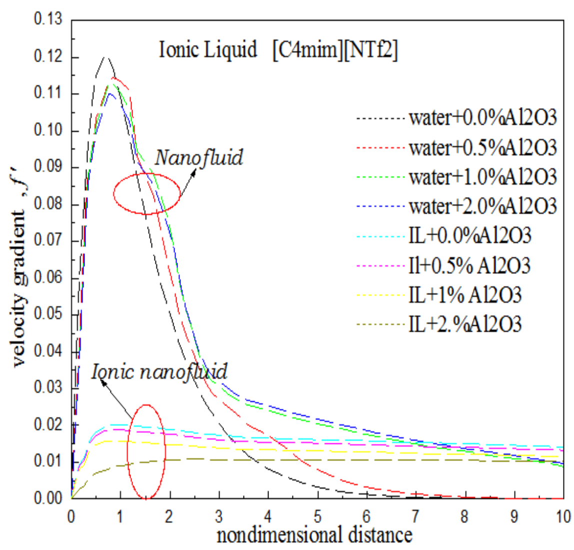

Fig 10.0 Variation of velocity gradients with concentration For water based nanofluid and ionic based nanofluid with different concentrations

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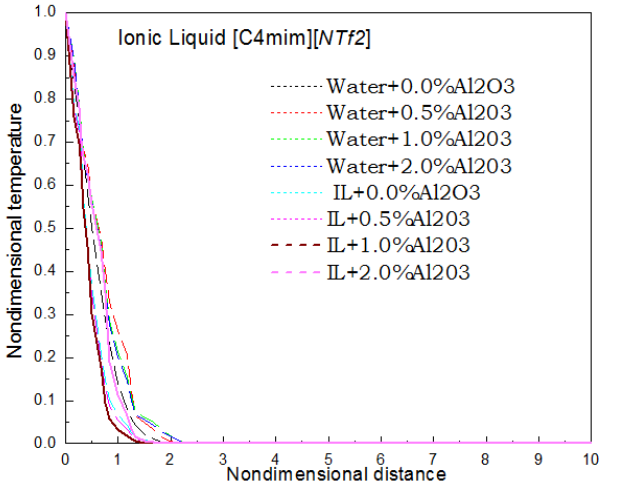

Fig11.0: Comparison between the nondimensional temperature profiles with effect of effect of nanoparticle concentration with nondimensional distance for water and ionic fluid as base fluids

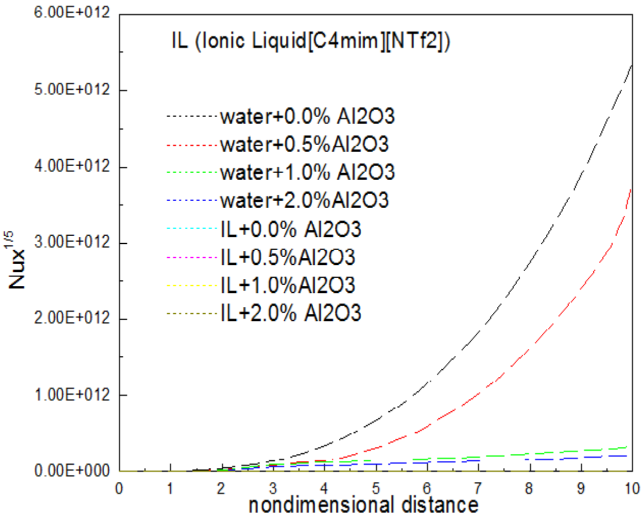

Fig12.0: Comparison between local Nusselt number with nondimensional distance for water base nanofluid and ionicnanofluids

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