American Journal of Engineering Research (AJER) 2020
American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-9, Issue-1, pp-330-337
www.ajer.org
Research Paper
Open Access

Heat Transfer By Ionic Nanofluids In The presence of magnetic field Via Finite Volume Method

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Abstract: *Nanoparticles enhanced ionic liquids (NEILs) are unique and ingenious types of heat transfer fluids (HTFs). Ionic liquids possess distinguished thermophysical properties that make them eco-friendly. This paper represents the numerical analysis of the thermal behavior of (NEIL) in a square enclosure under the impact of a horizontal magnetic field. The two vertical sides are thermally insulated, whereas the top wall is kept at low temperature and a heat source situates on the bottom side. The numerical investigation is carried out by solving the governing equations using Fortran software. The numerical examination gives considerations to the impacts of* ($10^3 \leq Ra = 10^5$), ($0 \leq Ha \leq 60$), *and* ($0\% \leq \phi \leq 2.5\%$) *on the thermal behavior of (NEIL). At the end of the numerical analysis, the results reveal that the magnetic field diminishes the rate of heat transfer. On the other hand, the rise of Rayleigh number leads to an improvement in the heat transfer rate. Moreover, adding nanoparticles does not always improve heat transfer because they can cause negative impacts on the heat transfer relying on the operating conditions which are the value of Rayleigh number and the value of Hartman number.*

Keywords: *Hartman number,Lorentz force,Natural convection, Square enclosure.*

List of Symbols

B_0	Magnetic Induction, Tesla=N/Am^2
C_p	Specific heat J/Kg K
g	Acceleration of gravity, m/s^2
h	heat transfer coefficient,W/m^{2}k
Ha	Hartman number
k	Thermal conductivity, W/mK
L	Cavity Width, m
Nu	Average Nusselt Number, Nu=hL/k
Nu_L	Local Nusselt Number
p	Pressure, N/m2
P	Dimensionless Pressure
Pr	Prandtl number
Ra	Rayleigh number
T	Local Temperature, K
T_c	Cold wall Temperature K
T_h	Hot wall Temperature K
u	Velocity component in the x-direction
v	Velocity component in the y-direction
U	Dimensionless velocity component in X direction
V	Dimensionless velocity component in Y direction
x,y	Dimensional coordinates
X, Y	Dimensionless coordinates
w	The hot element length, m

Greek Symbols

α	Thermal diffusivity, m2/s
ß	Coefficient of thermal expansion, K^{-1}
θ	Dimensionless Temperature
μ	Dynamic viscosity, kg/m. s
ν	Kinematic viscosity, m^2/s
ρ	Density, kg/m3
φ	Volume concentration of nanoparticles
σ	Electrical Conductivity, S/m

Subscript

f	Base Fluid
ionf	Ionic nanofluid
nf	Nanofluid
s	nanoparticles

I. INTRODUCTION

Over the past few decades, there has been a revolution in the field of heat transfer because of the introduction of nanofluids to enhance heat transfer. The formation of nanofluid is accomplished by dispersion of nanoparticles, whose diameter is between 1-100 nm, in conventional liquids such as water and Ethylene Glycol. The usage of nanofluids in the field of heat transfer caused an improvement in thermal conductivity and reduction in energy consumption**(Varade et al., 2017**);**(Choi et al., 1995)**.As a consequence of the positive impacts of nanofluids on the performance of heat transfer, researchers have concentrated on the development of nanofluids. The studies led to the introduction of Ionanofluids (INFs). Ionanofluid is considered a particular type of nanofluids that can be formed by the dispersion of nanoparticles in ionic liquids. Ionanofluids combine the advantages of both ionic liquids and solid particles. Ionic liquids possess distinctive characteristics that make them superb heat transfer fluids such as minimal vapor pressure and high thermal stability **(Minea & Murshed, 2018)**.Several publications were carried out to investigate the performance of Ionanofluids as heat transfer fluids.A recent study by**(Khan et al., 2019)**indicated that Ionanofluidspossess impressive thermophysical properties that give them the ability to be used in heating applications.It was reported in the literature that **(Chereches et al., 2018)** carried out a numerical investigation of the behavior of two types of Ionanofluids under the impact of forced convection in laminar and turbulent flow regimes. They declared that there is an enhancement of the heat transfer.The heat capacity of different types of IONFs was examined by**(Hardacre a et al., 2018).**They found that the improvement of the heat capacity as a function of temperature was 34% during the usage of graphite-doped ionanofluids.Seminal contributions have been made by**(Alizadeh & Moraveji, 2018)**.They performed an experimental examination of different thermophysical properties of graphene-based IONF.They used different concentrations of polycarboxylate functionalized graphene nanoplatelets (GNPs) as nanoparticles. They declared that there is a slight reduction of surface tension of ionanofluids with increasing temperature.One of the foremost studies ofthe thermal conductivity of IONFs was performed by**(França et al., 2018)**.Theyconducted research to examine the thermal conductivity of different Ionanofluids. They found that there is a remarkable increase in thermal conductivity. **(Jorjani et al., 2018)**studied the thermal conductivity of Ionanofluid consisted of the ionic liquid [BMIM] [BF_4] as the base fluid and nanodiamond represented the nanoparticles. They concluded that there was an increase in the thermal conductivity by 9.3% at the heights concentration of nanoparticles.Recently, **(Zhang et al., 2019)** investigated the thermal conductivity of the Ionanofluid composed of the ionic liquid (IL) ([EMIm]Ac) and graphene nanoplatelets (GNPs) as nanoparticles.The study revealed that the maximum increase in thermal conductivity was 43.2%.A numerical study to investigate the thermal behavior of the Ionanofluid [C_4mim NTF_2] + ϕ Al_2O_3 inside a square enclosure with two different heating configurations was performed by **(Minea & El-Maghlany, 2017).** At the end of the study, they found an enhancement in heat transfer because of adding nanoparticles. It is clear from the literature that there is no study involves the investigation of the thermal behavior of IONFs under the impact of magnetic field. Consequently, thisstudygives consideration to the assessment of the thermal behavior of the Ionanofluid C_4mim[NTF_2]ϕ+ Al_2O_3in a square enclosure that is impacted by botha horizontal magnetic field and the existence of natural convection.The assessment was accomplished bya numerical analysis of the governing equations and the boundary conditionsby using FORTRAN software.

II. PHYSICAL DESCRIPTION AND COORDINATE SYSTEM

The illustration of the examined physical geometry with the associated factors and the coordinates of the system is made clear in Fig. 1. In the present case, there is a heat source situated on the bottom side of the square cavity.The two vertical sides are supposed to be thermally insulated boundaries. The top wall is kept at a low temperature (T_c).The cavity is filled with ionic nanofluid ([C_4mim] [NTf_2]) + ϕAl_2O_3 and the physical properties of the fluid are supposed to be changeless. Finally, an unchanged magnetic field is applied horizontally. Furthermore, some assumptions are considered. These assumptions arediscussed below:

- The length of the heat source is considered to be half of the square enclosure length.
- Ionanofluid, which is examined in the present study, is supposed to be a Newtonian, incompressible, steady flow,and two-dimensional flow.
- The base fluid is ([C_4mim] [NTf_2]) and the Ionanofluid was acquired by the process of the insertion of different concentrations [0.5 %, 1%,and 2.5%] of Al_2O_3 with spherical nanoparticles.
- The Thermophysical Properties of the ionanofluid are assumed to be uniform and constant.

The Thermophysical Properties of the used Ionanofluid are illustrated inTab. 1

Figure 1:A schematic diagram of the case study, clarifying coordinates orientation andboundary conditions in dimensionless form

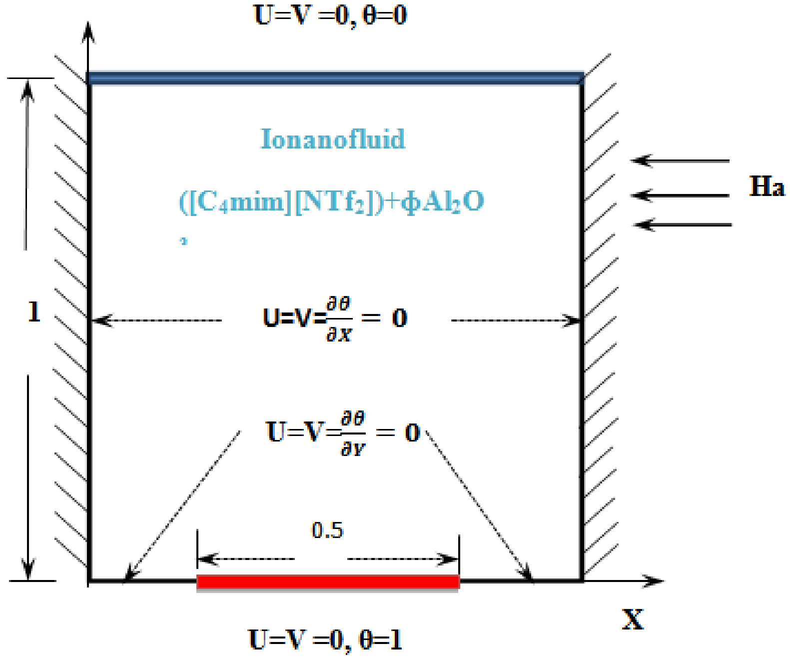


***Table 1:** Thermophysical Properties of the used Ionanofluid*

Physical Properties	$[C_4mim]$ $[NTf_2]$	$[C_4mim]$ $[NTf_2]$ + 0.5%Al_2O_3	$[C_4mim]$ $[NTf_2]$ + 1%Al_2O_3	$[C_4mim]$ $[NTf_2]$ + 2.5%Al_2O_3
Specific heat, Cp (J/kg K)	1749	1900	2100	2400
Viscosity, μ (kg/ms)	0.06283	0.064	0.075	0.125
Thermal conductivity, k (W/m K)	0.126	0.129	0.134	0.138
Density, ρ (kg/m^3)	1411.98	1450	1460	1506
Thermal expansion, ß x10^4 (K^{-1})	6.34	6.31	6.28	6.18

Source:(Minea & El-Maghlany, 2017)

III. MATHEMATICAL FORMULATION

The flow is governed by the continuity equation, the energy equation, and Navier-Stokes momentum equations. The viscous dissipation term, which is mentioned in the energy equation, is ignored. In order to explicate the governing equations in dimensionless form instead of dimensional form, using dimensionless parameters is accomplished.These dimensionless parameters are:

$$X = \frac{x}{L} \qquad Y = \frac{y}{L} \qquad U = \frac{uL}{\alpha_f} \qquad V = \frac{vL}{\alpha_f}$$

$$P = \frac{pL^2}{\rho_{ionf}\, {\alpha^2}_f} \qquad \theta = \frac{T - T_c}{T_h - T_c} \qquad Pr = \frac{\nu_f}{\alpha_f} \qquad W = \frac{w}{L}$$

$$Ra = \frac{g\beta_f L^3 (T_h - T_c)}{\nu_f \alpha_f} \qquad Ha = B_o L \sqrt{\frac{\sigma_f}{\rho_f \nu_f}} \tag{1}$$

Where $$\alpha = \frac{k}{\rho C_p} \qquad \nu_f = \frac{\mu}{\rho} \tag{2}$$

The electrical conductivity of the INF can be calculated by the following equation:

$$\sigma_{ionf} = (1-\phi)\sigma_f + \phi\sigma_s \tag{3}$$

3.1 Governing Equations

After using the previously mentioned dimensionless parameters, the continuity equation, the Navier-Stokes momentum equations,and the energy equation are expressed using the following formulas:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \tag{4}$$

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\mu_{ionf}}{\rho_{ionf}\,\alpha_f}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) \tag{5}$$

$$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + \frac{\mu_{ionf}}{\rho_{ionf}\,\alpha_f}\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) - \frac{\rho_f\sigma_{ionf}}{\rho_{ionf}\,\sigma_f}{H_a}^2 PrV + \frac{\beta_{ionf}}{\beta_f}RaPr\theta \tag{6}$$

$$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \frac{\alpha_{ionf}}{\alpha_f}\left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \tag{7}$$

The Local Nusselt number on the heat source surface can be estimated in the following way:

$$Nu_L(x) = \frac{hL}{k_f} \tag{8}$$

where h is the convection heat transfer coefficient.

$$h = \frac{q}{T_h - T_c} \tag{9}$$

The Local Nusselt number for the hot element can be calculated with the following equation :

$$Nu_L = -\frac{k_{ionf}}{k_f}\left(\frac{\partial\theta}{\partial Y}\right) \tag{10}$$

The average Nusselt number for the hot element will be calculated using the following equation:

$$Nu = \int_{hot\ element} Nu_L\, dx \tag{11}$$

3.2 Boundary Conditions in Dimensionless Form can be expressed as follows:

- U=V=0 at all solid sides of the enclosure.
- θ=1 at the heat sourcesituated on the bottom side
- θ=0 at the cold side of the enclosure.
- At the thermally insulated walls $\frac{\partial\theta}{\partial x} = 0$ for the vertical sides and $\frac{\partial\theta}{\partial y} = 0$ for the horizontal side.

IV. NUMERICAL APPROACH

In the present case study, anumerical method was used to investigate the behavior of the convection heat transfer inside the square enclosure by solving the governing equations. The process of analysis was accomplished using an in house code. The code was written in Fortran software depending on the finite volume method thatwas improved by(**Patankar, 1980**).The Finite Volume Method (FVM) is a numerical technique that converts the partial differential equations, which represent the conservation laws of mass, momentum, and energy, into discrete algebraic equations to solve them easily.The discretization process is done over finite volumes.

4.1 Impact of Grid Size and iteration stability on the numerical analysis

In the present study, a mesh testing procedure was performed to ensure a grid-independent solution. Five different square matrix grids were used for the test. These grids (20×20, 40×40, 60×60, 80×80 and 100×100) were investigated in two cases. The first case (M1) includes the following conditions: Ha=30, ϕ=2.5%, and Ra=10^3. The second case (M2) includes these conditions: Ha=45, ϕ=1%, and Ra=10^4. The 60x60 grid size was found appropriate to solve the governing equations. The results ofbothcases are illustrated in Fig. 2. In order to obtain an accurate and precise solution, many iterations were carried out. These iterations were executed at Ra=10^4, ϕ=1%, and Ha=15. It has become apparent that 4000 iterations are satisfactory to achieve the accurate solution of the code. Fig.3 represents the number of iterations that wereused to reach a stable and constant solution.

Figure 2: *Check of Grid Independence*

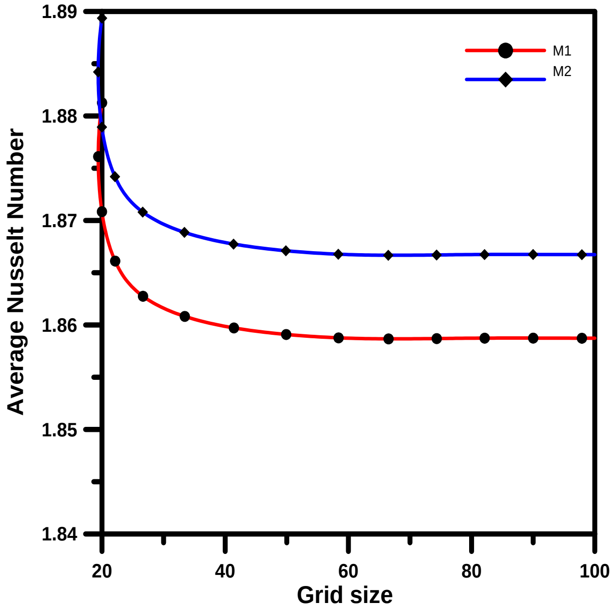
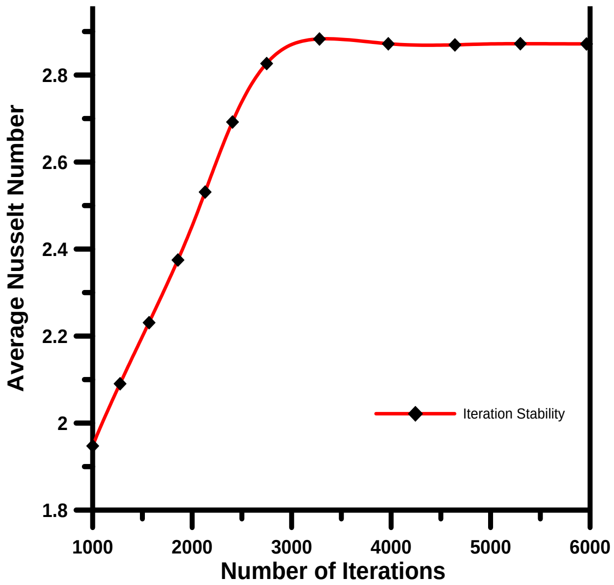


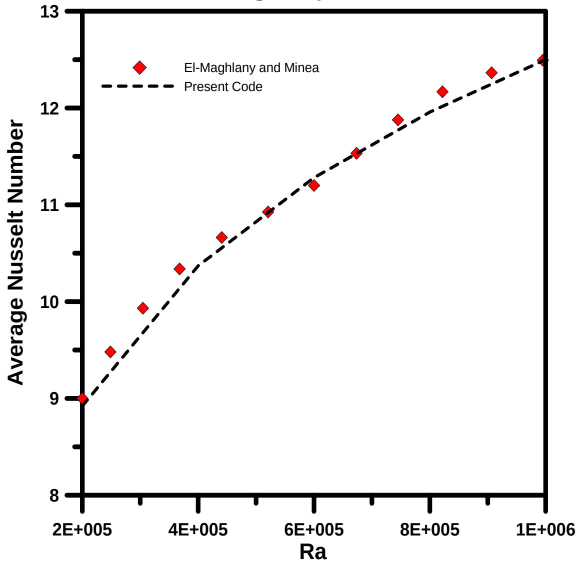
Figure 3: *Number of Required Iterations*



4.2 Endorsement of the Computational Program

For checking the accuracy and the correctness of the present code, a validation method was performed for the code. A comparison was made with the previously published study of (Minea & El-Maghlany, 2017). The comparison demonstrated a satisfying agreement between the results. The comparison is shown in Fig.4.

Figure 4*: Comparison of the Average Nusselt Number at different Ra between the present workand* **Minea & El-Maghlany, 2017**



V. RESULTS AND DISCUSSION

In this numerical study, the impact of the magnetic field on heat transfer was investigated by studying the relation between Hartman number and Rayleigh number. Furthermore, the effect of the solid volume fraction of nanoparticles was also studied at different values of Hartman number. In the examined case, the Prandtl number is constant. The Rayleigh number (Ra), the Hartmann number (Ha), and the solid volume fraction (ϕ) are varied according to these ranges ($10^3 \le Ra \le 10^5$),$0 \le Ha \le 60$, and $0 \le \phi \le 2.5\%$. The results of the numerical study will be reported and discussed in detail.

Impact of Hartmann Number and Rayleigh Number on the Average Nusselt Number

The impact of Hartman number and Rayleigh number on the average Nusselt number can be identified from Fig. 5. According to the analysis of Eq.6,it can be seen that there is an opposition between the sign of the Hartmann Number (Ha) and the sign of the Rayleigh number (Ra) in the source term. As a consequence, the Rayleigh number (Ra) and Hartmann Number (Ha) have an opposite impact on the average Nusselt number. According to the analysis of the previously mentioned figure, the following deduction was concluded: the increase of Hartman number has an undesirable impact on the average Nusselt Number because the rise of Hartman number leads to a decrease in the average Nusselt Number at constant Rayleigh number. On the other hand, the increase in the Rayleigh number leads to an increase in the average Nusselt Number at constant Hartman number.

Impact of Solid Volume Fraction on Heat Transfer

For the purpose of assessing the impact of the solid volume fraction of alumina nanoparticles on the value of average Nusselt number, Nu_{avg} was estimated at different values of the nanoparticles concentrations, Hartman number.The solid volume fraction was altered according to this range ϕ = (0, 0.5%, 1%, and 2.5%). The impact of the variation of Hartman number and the solid volume fraction on the value of the average Nusselt number is depicted in Fig.6. At $Ra=10^4$, It is obvious that at Ha=0, the increase of nanoparticles concentration from $0\% \le \phi \le 1\%$ has a positive effect on the heat transfer performance because the addition of nanoparticles has the ability to overcome the unfavorable impact of the increase of viscosity. On the other hand, at Ha=0, and ϕ=2.5%, adding nanoparticles to the ionic liquid [C_4mim] [NTF_2] caused an undesirable impact on heat transfer performance because of the significant increase of the dynamic viscosity of the fluid. At low values of the Hartman number, there is a high impact of natural convection. Moreover, adding nanoparticles improves thermal conductivity. Therefore, thermal diffusivity is improved. That's why the flow overcomes the negative impact of the viscosity. As a result of the gradual increase of Hartman number, the average Nusselt number diminishes. This happened because of the impact of the Lorentz force. Moreover, the negative impact of nanoparticles, which causes an increase in the viscosity of the Ionanofluid. When Hartman number is increased to higher values, Lorentz force reduces the circulation of the flow, so heat is transferred by conduction and the addition of nanoparticles from $0\% \le \phi \le 2.5\%$ improves heat transfer because it improves the thermal conductivity.

Figure5: *Average Nusselt Number for different Ra and Ha at ϕ=0.01 (Ionanofluid [C_4mim] [NTf_2] +Al_2O_3*

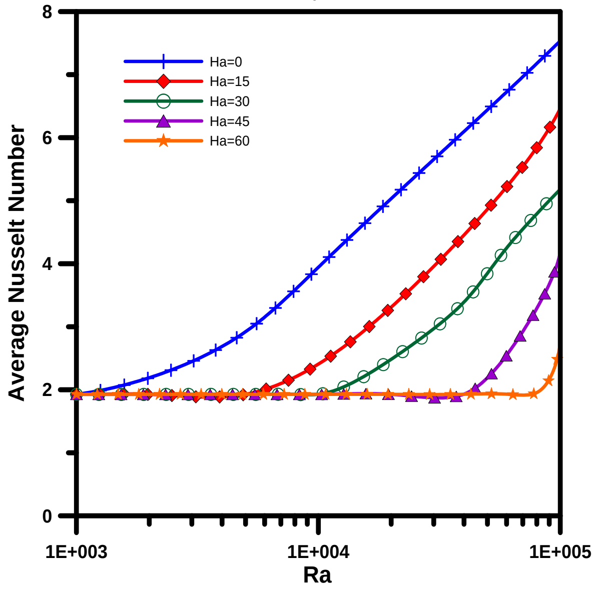
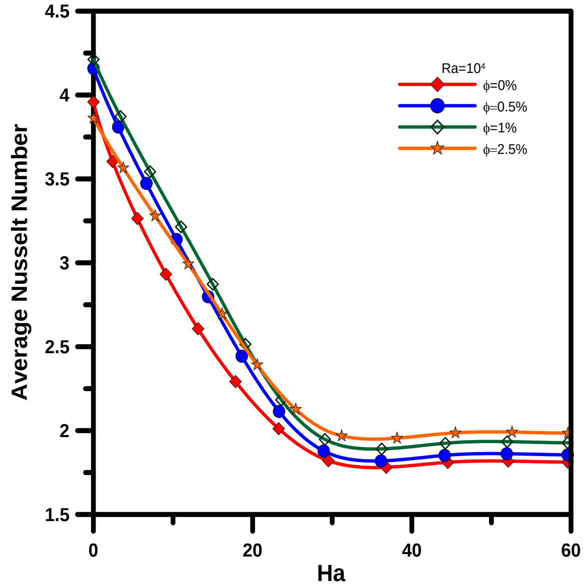


Figure 6*: Average Nusselt Number for different Ha and different ϕ at Ra=104 Ionanofluid [C_4mim] [NTf_2] +Al_2O_3*



VI. CONCLUSION

The performance of the Ionanofluid, which consisted of [C_4mim] [NTF_2] as the base fluid and alumina particles Al_2O_3 as the nanoparticles, inside a square enclosure under the impacts of natural convection and magnetic field was examined numerically by using Fortran code based on the governing equations. The process of investigation is concerned with several parameters, which affect the performance of heat transfer. These parameters are the Rayleigh number, the concentration of nanoparticles, the Hartman number, and the thermophysical properties of ionanofluid. At the end of the examination process, the following conclusions were obtained:

- Generally, the existence of the magnetic field diminishes the rate of heat transfer and the strength of the flow field as well. On the other hand, the rise of the value of the Rayleigh number leads to an improvement in the heat transfer rate.
- Adding nanoparticles does not improve the heat transfer all the time. But, they can cause negative impacts on the heat transfer relying on the operating conditions, which are the value of Rayleigh number and the value of the Hartman number.

- At a moderate value of the Rayleigh number (Ra=10^4), the addition of nanoparticles from $0\% \leq \phi \leq 1\%$ at low Hartman number raises the heat transfer, while at high values of Hartman number the Lorentz force suppressed the impact of natural convection and heat is transferred by conduction, which is improved by adding nanoparticles for all values $0\% \leq \phi \leq 2.5\%$because of the rising in the thermal conductivity.

REFERENCES

[1]. Alizadeh, J., Moraveji, M. (2018). An experimental evaluation on thermophysical properties of functionalized graphene nanoplatelets ionanofluids. International Communications in Heat and Mass Transfer,vol. 98, pp.31-40.

[2]. Chereches, E., Sharma, K. and Minea, A. A. (2018). A numerical approach in describing ionanofluids behavior in laminar and turbulent flow. Continuum Mechanics and Thermodynamics. vol. 30, doi: 10.1007/s00161-018-0634-x

[3]. Choi, S, U. S. and Eastman, J. A. (1995). Enhancing Thermal Conductivity of Fluids with Nanoparticles, Developments and Applications of Non-Newtonian Flows. ASME International Mechanical Engineering Congress & Exposition, November 12-17, 1995, San Francisco, CA, 99-105.

[4]. França, J., Lourenço, M., Murshed, S. M. S., Pádua, A. and Nieto de Castro, C. (2018). Thermal Conductivity of Ionic Liquids and IoNanofluids and Their Feasibility as Heat Transfer Fluids. Industrial & Engineering Chemistry Research,vol. 57. doi: 10.1021/acs.iecr.7b04770

[5]. Hardacre a, C., Oster, K., Jacquemin, J., Ribeiro, A. P. C.and Elsinawi, A. (2018). Understanding the heat capacity enhancement in ionic liquid-based nanofluids (ionanofluids). Journal of Molecular Liquids,vol. 253, pp. 326–339.

[6]. Jorjani, S., Mozaffarian, M. and Pazuki, G. (2018). A novel Nanodiamond based IoNanofluid: Experimental and mathematical study of thermal properties. Journal of Molecular Liquids,vol. 271,pp. 211-219. doi: 10.1016/j.molliq.2018.08.116

[7]. Khan, I., Bhat, A., Sharma, D., Usmani, M., Khan, F. (2019). Overview of Nanofluids to Ionanofluids: Applications and Challenges, Springer Singapore,pp. 199-227.

[8]. Minea, A. A., El-Maghlany, W. (2017). Natural convection heat transfer utilizing ionic nanofluids with temperature-dependent thermophysical properties. Chemical Engineering Science, vol.174,13-24 .doi: 10.1016/j.ces.2017.08.028

[9]. Minea, A. A. and Murshed, S. M. S. (2018). A review on development of ionic liquid based nanofluids and their heat transfer behavior. Renewable and Sustainable Energy Reviews, vol.91, pp.584–599. doi: 10.1016/j.rser.2018.04.021

[10]. Patankar, S. (1980). Numerical Heat Transfer and Fluid Flow.CRC press

[11]. Varade, S., Patil, C.and Wadkar, S. P. (2017). A Study of Heat Transfer with Nanofluids. International Journal of Current Engineering and Technology, (Special Issue-7 (March 2017)).

[12]. Zhang, F.-F., Zheng, F.-F., Wu, X.-H., Yin, Y.-L.and Chen, G. (2019). Variations of thermophysical properties and heat transfer performance of nanoparticle-enhanced ionic liquids. Royal Society Open Science, 6, 182040. doi: 10.1098/rsos.182040

Nourhan M.Gaber,etal. “Heat Transfer By Ionic Nanofluids In The presence of magnetic field Via Finite Volume Method”. *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp. 330-337.