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ENHANCEMENT OF HEAT TRANSFER COEFFICIENT AND FLOW IN TUBE FILLED WITH A POROUS MEDIUM BY USING HYBRIDNANOFLUIDS

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ABSTRACT

This research involved the enhancement of heat transfer and flow in a tube filled with a porous medium by using hybrid nanofluids. The theoretical model contains the governing equations to the flow and heat transfer through porous media by using the Darcy flow model with uniform heat flux on the surface tube. The porous medium consist of glass beads (dp = 20 mm) and one type of filling material. The simple algorithm is used to solve momentum and continuity equations after combined these equations to configure the pressure correction formula. The results of this study represented by different parameters such as Rayleigh number ($Ra=10^3,10^5,10^6$), type of hybrid nanoparticles,volume fraction (Φ =1, 3 and 5% vol), and angles of tube ($\alpha =30^0$, 45^0 and 90^0) through contour secondary flow and isotherms. The results also show that average Nussult number various with Rayleigh number, type of the hybrid nanoparticles and constant of Peclet number (Pe =20). The results of numerical solution indicated that the impact of free convection appears at the start region of the tube and its maximum impact happen in the horizontal position then this effect decreases to the vertical position when inclination of the tube increses. Moreover the concentration of hybrid nanoparticles has an insignificant impact on the stream lines, tangential and radial velocities distribution, skin friction coefficient and porous media. The heat transfer increases with the increase concentration of hybrid nanoparticles and Rayleigh number. On the other hand the type and synergistic of hybrid nanoparticles play important role in improvement of heat transfer. The improvement for hybrid nanofluid is (Cu(25nm)+Al(25nm)+Dw) (33%) while for hybrid nanofluid it is (Al_2O_3(50nm)+TiO_2 (50nm)+Dw) was (24%) respectively.

KEY WARDS: hybrid nanofluid, syngeristic of hybrid nanoparticles, porous medium

تحسين معامل انتقال الحرارة وسرعة الجريان في انبوب مملوء بوسط مسامي باستخدام جزئيات نانوية هجينة

د خالد فيصل سلطان د منى صباح قاسم عمار موسى حسن

الخلاصة

في هذه البحث يشتمل على تحسين معامل انتقال الحرارة ومعدل الجريان في انبوب مملوء بوسط مسامي باستخدام موائع نانوية هجينة . النموذج النظري يتضمن على المعادلات الحاكمة للجريان وانتقال الحرارة من خلال الوسط المسامي باستخدام نموذج دارسي للجريان مع فيض حراري منتظم على سطح الانبوب. الوسط المسامي يتألف

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من كرات زجاجية بقطر (20 mm) ونوع واحد من مواد الاملاء . الخوارزمية البسيطة استخدمت لحل معادلات الزخم ومعادلة الاستمرارية بعد ربط هذه معادلات لتكوين معادلة تصحيح الضغط . ومثلت نتائج هذه الدراسة بعدة عوامل مختلفة منها قيم عدد رايلي ($Ra=10^3,10^5,10^6$) ونوع المائع الفائق الدقة الهجين ونسب الحجوم (Φ=1 , 3, 5vol%) وزوايا ميلان الانبوب بمخططات الجريان الثانوي ودرجة الحرارة بالإضافة لتغير قيم عدد نسلت المعدل بتغير قيم عدد رالي($Ra=10^3,10^5,10^6$) ونسب الحجوم وقطر الجزئية الفائقة الدقة الهجينه وعدد بكلت. بينت نتائج الحل العددي ان تأثير الحمل الحر يظهر في بداية الانبوب وأقصى قدر من التأثير، يكون في الوضع الأفقي ثم يقلل هذا التأثير إلى الوضع الرأسي عندما يزيد الميل للأنبوب . علاوة على ذلك ان تركيز الجزئيات النانويه الهجينه ليس له تأثير هام على خطوط الجريان وتوزيع السرعة القطرية والمماسية و معامل الاحتكاك السطحي و الوسط المسامي. أن معدل انتقال الحرارة يزداد مع زيادة نسب الحجوم وعدد رايلي . من جهة اخرى النوع والتناغم بين الجزئيات النانويه الهجينه يلعب دورا مهما في تحسين انتقال الحرارة حيث كانت أعلى قيم لذلك التحسين في حالة (Cu+Al+Dw) (33%) بينما في حالة (Al_2O_3+ TiO_2 + Dw) هي (24%) على الترتيب .

الكلمات المفتاحية : المواد النانوية الهجينة، تناغم الجزئيات النانوية الهجينة، الوسط المسامي

NOMENCLATURE

r	radius of pipe (m)	Dw	Distilled water (–)
Pe	Peclet number (–)	dp	Particle diameter (nm)
Cp_{Hn}	Specific heat of hybrid nanofluid at constant pressure (kJ/kg.k)	ADI	Alternating direction implicit (–)
g	Gravity acceleration (m/s^{2})		**`Greek symbols**
G	Dimensionless gravity acceleration (–)	α_{Hnf}	Thermal diffusivity of the hybrid nanoluid (m^2/s)
h	Heat transfer coefficient (W/m^2.k)	β_{Hnf}	Thermal Expansion Coefficient of the hybrid nanofluid (1/K)
p	Pressure (N/m^{2})	μ_{Hnf}	Dynamic viscosity of the hybrid nanofluid (Kg/m.s)
R, Ø,Z	Dimensionless cylindrical coordinates (–)	ν_{Hnf}	Kinematic viscosity of the hybrid nanofluid (m^2/s)
Nu	Nusselt number (–)	ρ_{Hnf}	Density of the hybrid nanofluid (kg/m^3)
S	Relaxation factor (–)	Ω	Vorticity (1/s)
t	Temperature (^{o}C)	Ψ	Stream function (m^2/s)
Ur	Radial velocity component (r) (m/s)	α	Angle of inclination of tube (degree)
Vt	Tangential velocity component (m/s)	Φ	Volume fraction (Vol%)
W	Axial velocity component (z) (m/s)		**Subscripts**
Pr_{Hnf}	Prandtl number for Hybrid nano fluid (–)	Hn	hybrid nanofluid
k_{Hnf}	Thermal conductivity of the Hybrid nanofluid (W/m.k)	r	radial
P	Dimensionless pressures (–)	t	tangentional
UHF	Uniform heat flux (–)		

INTRODUCTION

Many literature survey which deals with the fluid flow through a porous media has exposed the Darcy law which indicates linearly the flow velocity to the pressure gradient across the porous medium. The basic feature of the porous medium is known as permeability and this feature is a measure of the flow conductivity in the porous medium. Darcy model is one of the models used in the porous medium in addition to other models such as the equation of Forchheimers and the equation of Brinkmans Rami et al. [2001] whose application in high flow velocities and other takes into consideration the boundary effects. The natural convection heat transfer and radiation are analyzed by using Rosseland approximation with the radiative heat flux used in a porous medium Raptis [1998]. Chamkha [1997] Solar radiation and natural convection are studied in vertical flat plate with uniform porous medium by using Darcy Forchheimer – Brinkman flow model. Kairi [2011] Free convection and the impact of viscous dissipation are handled in porous medium saturated by using non – Darcy and non – Newtonian fluid with variable viscosity. Murthy [2004] The combined radiation and mixed convection are studied in a permeable vertical wall with a non – Darcy porous media. Mohammadein and El – Amin [2000] The thermal radiation phenomena of non – Newtonian fluids is investigated through porous medium in horizontal plate with variable surface temperature. Kuznetsov et al. [2010 a. 2010b, 2011a] They studies porous medium uniformly and Buongiorno's equations to indicated the impact of nanoparticles migration on the convective heat transfer and nanofluids flowing through the circular tube. The results reveal the lower wall shear stress and higher heat transfer coefficient due to irregular distribution. Thus the migration of nanoparticles plays role in improvement of the coefficient of heat transfer for nanofluids. The hybrid nanofluids consist of two types of nanoparticles as well as the base fluid. There are applications for hybrid nanofluid such as convective and boiling heat transfer. The basic feature of hybrid nanofluids has larger thermal conductivity than mono nanofluids due to the effect of synergistic Wang , Mujumdar [2008a,2008b]. The characteristics of pressure drop and heat transfer has been conducted in most of the studies. Suresh et al. [2012, 2014] Introduce experimental studied through circular tube for laminar flow with uniform heated by using hybrid nanofluids (Cu+ Al_2O_3 –water).This study indicates that the average increase in Nu for this type of hybrid nanofluids was 10.9% and the turbulent heat transfer enhancement was 8% as compared to the distilled water. The mean increase in coefficient of convective heat transfer to hybrid nanofluid was 24.35% at 0.1% of concentration (Cu+ Al_2O_3) Selvakumar , Suresh [2012]. The experimental study is done for measuring the pressure drop and coefficient of heat transfer in circular tube with uniform heat flux. The hybrid nanofluid used multiwall nanotube, Iron oxide and water (MWCNT + Fe_3O_4) + water. The experimental results showed the maximum improvement is 31.1% in Nu and the penalty pumping power is 1.18 times Madhesh et al. [2014] .

The aims of this research is to indicate that the impact of many parameters such as concentration of hybrid nanoparticles, type, hybrid nanoparticles size, synergistic between nanoparticles and cooling efficiency in systems that use hybrid nanofluid as well as on flow and heat transfer in tube filled with a Porous medium.

PROBLEM DESCRIPTION AND MATHEMATICAL MODEL

The governing equations for flow of hybrid nanofluids in a circular pipe and filled with porous media (consist of glass beads (dp =12 mm) are based on Darcy model. The assumptions for this model was porous media which is homogeneous, symmetric (Isotropic), and porous and the thermal conductivity coefficient does not based on the direction and solid material in thermal equilibrium with hybrid nanofluid passing through at any point within the porous media. The Navier – Stokes equations (mass, momentum and energy) in hydro dynamic and fully developing cylinder coordinates (r, ϕ , z) can be written as follows, L. Badea [2008]. This problem indicated in figure (1).

Continuity Equation

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\,u_r\right)+\frac{1}{r}\frac{\partial}{\partial \phi}(ut)+\frac{\partial \omega}{\partial z}=0 \tag{1}$$

Momentum Equation

By using the assumptions mentioned above and Darcy law. The velocities components in cylindrical coordinate are as follows, Anderson [1984]:

$$u_r=\frac{-k}{\mu}\left(\frac{\partial P}{\partial r}-\rho\, g\, \mathrm{Cos}\,\phi\, \mathrm{Cos}\,\alpha\right) \tag{2}$$

$$ut=\frac{-k}{\mu}\left(\frac{\partial P}{\partial \phi}+\rho\, g\, \mathrm{Cos}\,\phi\, \mathrm{Sin}\,\alpha\right) \tag{3}$$

$$\omega=\frac{-k}{\mu}\left(\frac{\partial P}{\partial z}\pm\rho\, g\ \mathrm{Sin}\,\phi\right) \tag{4}$$

Energy Equation

$$u_r\frac{\partial T}{\partial r}+\frac{u_t}{r}\frac{\partial T}{\partial \varphi}+w\frac{\partial T}{\partial z}=\alpha\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 T}{\partial \varphi^2}+\frac{\partial^2 T}{\partial z^2}\right] \tag{5}$$

PROPERTIES OF THE HYBRID NANOFLUIDS :-

Density ,Jahar **et al.** [2015].

$$\rho_{hb,nf}=\Phi_{np1}\rho_{np1}+\Phi_{np2}\rho_{np2}+\left(1-\Phi_{np1}-\Phi_{np2}\right)\rho_{Dw} \tag{6}$$

Viscosity Jahar **et al.** [2015]..

$$\mu_{hb,nf}=\left(1+2.5\left(\Phi_{np1}+\Phi_{np2}\right)\right)\mu_{Dw} \tag{7}$$

Specific heat , Jahar et al. [2015] .

$$\rho_{hb,nf}Cp_{hb,nf}=\Phi_{np1}\rho_{np1}Cp_{np1}+\Phi_{np2}\rho_{np2}Cp_{np2}\left(1-\Phi_{np1}-\Phi_{np2}\right)\rho_{Dw}Cp_{Dw} \tag{8}$$

Recently Huang et al.[2010] presented an effective thermal conductivity model (Eq.9)

$$\frac{k_{hb,nf}}{k_{Dw}}=\left|\frac{Cp_{hb,nf}}{Cp_{Dw}}\right|^{-0.023}\times\left|\frac{\rho_{hb,nf}}{\rho_{Dw}}\right|^{1.358}\times\left|\frac{\mu_{Dw}}{\mu_{hb,nf}}\right|^{0.126} \tag{9}$$

Thermal diffusivity Barozzi, et al [1985].

$$\alpha_{nf} = \frac{k_{nf}}{(1-\Phi)(\rho Cp)_f + \Phi(\rho Cp)_s} \tag{10}$$

Thermal expansion coefficient, Khanafer, K. et al. [2003].

$$\beta_{nf} = \left[\frac{1}{1+\frac{(1-\Phi)\rho_f}{\Phi\rho_s}} \frac{\beta_s}{\beta_f} + \frac{1}{1+\frac{\Phi}{(1-\Phi)}\frac{\rho_s}{\rho_f}} \right] \tag{11}$$

BOUNDARY CONDITIONS-

The Boundary condition of the mathematical model was derived depending on the Darcy model.

$T_R(1, \varphi, Z) = 0.5$, $T_\varphi(R, 0, Z) = 0$, $T_\varphi(R, \pi, Z) = 0$

Inlet (Z = 0), $T(R, \varphi, 0) = 0$

$\psi_R(R, 0, Z) = 0$ $\psi(R, \pi, Z) = 0$

$\psi_R(R, \pi, Z) = 0$ $\psi(R, 0, Z) = 0$

VALIDATION AND GRID TESTING

Before determining the number of grid points, the test of grid has been conducted independently by calculating the average Nusselt number around the circumference of the pipe. The number of grid points used in this study are (50x60) and these values are very suitable to obtain exact results and guarantees in this study. The figures that follow indicated the validation of numerical solution. Figure.(2) Show mesh network for flow region representation and Figure (3) reveals grid points used in this study at $Ra=10^4$ and $\Phi = 0$. Figure (4) indicates the comparison of the present work with reference Mohanned [2000] to stream and isotherms lines in tube filled with porous medium. Figure (5) depictes the results of Carlo and Guidice [1996] with the present results for (Nusselt number).

NUMERICAL SOLUTION

The solution starts with the Navier – Stokes equations in the cylindrical coordinates (equations 1, 2, 3,4and 5) and boundary conditions solved by finite difference method. The central difference approximation and the partial derivatives are used to solve the finite difference equation while the convective terms are solved by upwind difference formula. The derivative at the boundary is approximated through three point forward and backward difference. The energy fields are solved by the Alternating Direction Implicit (ADI) method while the relaxation method is used to calculated the stream function and the time increase $\Delta t = 10^{-5}$ has been utilized for $Ra=10^3$, 10^5 and 10^6. The heat transfer rate around the circumference of tube is evaluated through many parameters such as Rayleigh number to

Peclt number, hybrid nanoparticles concentration and theta. It is necessary to observe of the change the Local Nusselt number on the circumference of the pipe .
The local and average Nusslet number around the circumference of pipe are as follows Anderson , et al. [1985].

$$Nu_{nt}^{k+1} = \frac{Nu^{k}}{\Delta R}\left[3T_{mt,n}^{k} - 4T_{mt-1,n}^{k} + T_{mt-2,n}^{k}\right] \tag{12}$$

The average Nusslet number around the circumference of inner cylinder at location (k+1) is extract by integrating local Nusselt number as follows:

$$Nu^{k+1} = SNu^{K} + \left(1 - S\right)\frac{2}{\pi}\int_{0}^{\pi} Nu_{nt}^{k+1}\, d\varphi \tag{13}$$

The Simpson's rule 1/3 method is used to calculate average Nusslet number equation (13). the surface temperature at the location (k+1) is calculated by Nusselt number. The boundary conditions lead to unstable state in the solution at the value of relaxation factor (S =0). The relaxation factor value used in numerical solution to stability state(S = 0.8). The computer program written in **FORTRAN** power station and Tech plot is used for drawing counter. The flow chart of the computer program is shown in Figure (6) .

RESULTS AND DISCUSSION

The numerical results are obtained from the investigation in heat transfer and hybrid nanofluid flow through tube filled with saturated porous medium. This article includes different parameters such as size, type, concentration of hybrid nanoparticles ,synergistic of hybridnanoparticles and hybrid nanofluid flow patterns across the pipe.
Figures (7 – 8) shows the effect of Ra (Rayleigh number =10^3,10^5,10^6), Φ (volume fraction (1, 3 and 5 % vol) on two types of the hybrid nanofluids (Cu(25nm)+Al(25nm)+Dw) and (Al_2O_3(50)+TiO_2 (50nm)+Dw) at the Peclet number (Pe=20) and α = 0 (horizontal) .These figures indicatedthat the progress is to the top then dawn toward the center of tube due to the impact of buoyancy force for hybrid nanofluids . The patterns of the secondary flow exhibit a circular cells. These patterns based on the balance of the inertia force of the secondary flow at the vertical plane (symmetry plane) and the buoyancy force. The existence of porous media which consist of glass beads with hzbrid nanofluids lead to much eddies. Figure.(8).reavel the impact of adding hybridnanoparticles in distilled water which consist of (Cu(25nm)+Al(25nm)+Dw) and (Al_2O_3(50)+TiO_2 (50nm)+Dw). These additions lead to increase the thermal conductivity of hybrid nanofluids with molecular heat diffusion. These adding lead to increase the thermal conductivity and molecular heat diffusionfor hybrid nanofluids. The hybrid nanofluid temperature (isotherms) becomes more uniform when hybrid nanoparticles increases at UHF**.** The center of secondary flow is located top and bottom of the horizontal axis to eddy formed. The circulation strength between hybrid nanofluids and distilled water are similar roughly. It is also observed that the small second eddy is formed beside the main eddy where pushed upward and making asymmetrical. The contour of isotherms tend to become horizontal at the regions away from the wall pipe

furthermore it is a stably layer of hybridnanofluid. The insignificantly change is in the secondary flow although the high heat flux to keep Ra constant to high concentration of hybrid nanoparticles. The heat transfer in horizontal position was better than angles of the other pipe due to strength of secondary flow in natural convection where the temperature difference decreases in the pipe. Fig.(9) shows the impact of change in inclination angles to tube and the secondary flow is equal to zero when the angle of the tube equals ninety (α =90°). This indicates that the accuracy of the numerical method used in solution of the governing equations to flow. Its also observed that the isotherms contour on the right hand side are roughly circular and have the same center which is located in the center of tube where the little impact to convection heat transfer is indicated . The isotherms contour is a concentric circles with the center of tube due to vanishing effect of natural convection in radial and tangential direction as well as the weakness of secondary flow currents. The center of secondary flow is close to the wall at the horizontal position then it moves gradually from the wall when the inclination angles of tube increase toward the vertical axis. The strength of secondary flow for two types of the hybrid nanofluids (Cu(25nm) + Al (25nm) +Dw), and (Al_2O_3(50nm) + TiO_2 (50nm) + Dw) are better than distilled water. The hybrid nanofluid temperature become more uniform when concentration of hybridnanoparticles increase. The hybridnanoparticles size for (Cu(25nm) + Al (25nm)) was smaller than (Al_2O_3(50nm) + TiO_2 (50nm)) that leads to the result that the enhancement of heat transfer for the first type of hybridnanoparticles was better than that the of the second type of hybridnanoparticles. Fig.(10) reveal the variation in radial velocity of the hybridnanofluid (Cu(25nm)+Al(25nm)+Dw) and (Al_2O_3(50)+TiO_2 (50nm)+Dw) at Pe=20, Φ= 5 % vol ,different Ra number ($3x10^{4}$, $6x10^{4}$) and locations along the tube. When the decreased of the Ra number the radial velocity of the hybridnanofluid was small at the entrance of the tube (Z=0.01,0.05,0.1) the increase started at the entrance (Z=0.1,0.3,0.5). The cause of the increase and decrease return to secondary flow strength result of the effect of free convection. In the near region of the tube surface the radial velocity strength increases and reverses direction to become toward the center and faraway from the surface at the (Z=0.3,0.5). The radial velocity increases with Ra number and this velocity is similar to the pervious radial velocity with the rise in values for these velocities at the same locations along the tube **.** **Fig (11)** repersents the change in tangential velocity of the hybrid nanofluid to the same boundary condition in radial velocity. The tangential velocity equals zero at near regions of the center and it increases in the opposite direction to the center of tube. The maximum value for this increase at the surface of tube The tangential velocity increases with Ra number at the same previous pattern and Ra number (Ra=6x104). Fig.(12) shows the radial velocity change for the hybrid nanofluid with vertical axis to same B.C mentioned above. The location of this component is at top surface near and towards the center of the tube. The increased intensity for this component decreases then it becomes close to zero at the center and the opposite direction away from the center of the tube.The flow patterns were the same when Ra number increase only for the tremendous values due to increase intensity of secondary flow **.** **Fig. (13)** depicted the average of Nu number with different angles of the tube ($\alpha=0^0$, 30^0,45^0, 90^0), Ra=10^5, Pe=20 and Φ= 1% vol, 5 % vol. This figure indicated that the Nu number in horizontal position was greater than Nu number in vertical position due to the impact of natural convection and buoyancy force. The buoyancy force which driven the secondary flow depends on the the magnitude of vorticity as a function of the flow where the values specify the magnitude of the radial and tangential velocity which are in turn based on the angles of the tube . **The** buoyancy force was maximum at horizontal position then gradually decrease to vertical position. When Ra number increases with buoyancy force this leads to improvement of Nu number in fully developed region **.** **Fig.(14)** shows the average skin friction coefficient of the hybridnanofluid (Cu(25nm)+Al(25nm)+Dw) and (Al_2O_3(50)+TiO_2 (50nm)+Dw) at constant (Ra=10^5), Pe=20, Φ= 0, 1, 5 vol% and different angles of the tube ($\alpha=0^0$, 30^0,45^0,90^0). The Nu number increases with concentration of hybrid nanoparticles but the skin friction coefficient is insignificantly change. The velocity profiles and secondary flow are insignificantly affected by the concentration of hybrid nanoparticles. When Ra number increases with the concentration of hybrid nanoparticles does not have significant effect on Cf. In general, the flow acceleration near wall will be inhanced by increasing the tube inclinations and then the skin friction will increase too .

CONCLUSION

The conclusions can be drawn from the results of numerical study were as follows:

1. The type of hybridnanofluid and synergistic of hybris nanoparticles play role impartant in enhancement of heat transfer.
2. The improvement for hybrid nanofluid is (Cu(25nm)+Al(25nm)+Dw) (33%) while for hybrid nanofluid it is (Al_2O_3(50nm)+TiO_2 (50nm)+Dw) was (24%) respectively.
3. Skin friction coefficient is enhanced by increasing the tube inclination, moreover the heat transfer rate increases with the decrease of the hybrid nanoparticles size.
4. The metallic hybrid nanoparticles give higher heat transfer enhancement than oxides metallic hybrid nanoparticles due to the high thermal conductivity of metallic hybrid nanoparticles.
5. The impact of free convection appears at the start region of the tube and its maximum impact is in the horizontal position then this effect decreases to the vertical position when inclination of the tube increases.

Table .1. Properties of the nanoparticles

Nano sized Particles	ρ (kg/m^3)	Cp (J/kg K)	k (W/m K)	β *10^5 (k^{-1})	Mean diameter (nm)	Concentrations %
Copper (Cu)	8933	385	401	1.67	25	1
Aluminum (Al)	2707	896	236	2.4	25	3
Titanium Oxide (TiO_2)	4250	686.2	8.9538	0.9	50	
Aluminum oxide (Al_2O_3)	3970	765	40	0.85	50	5

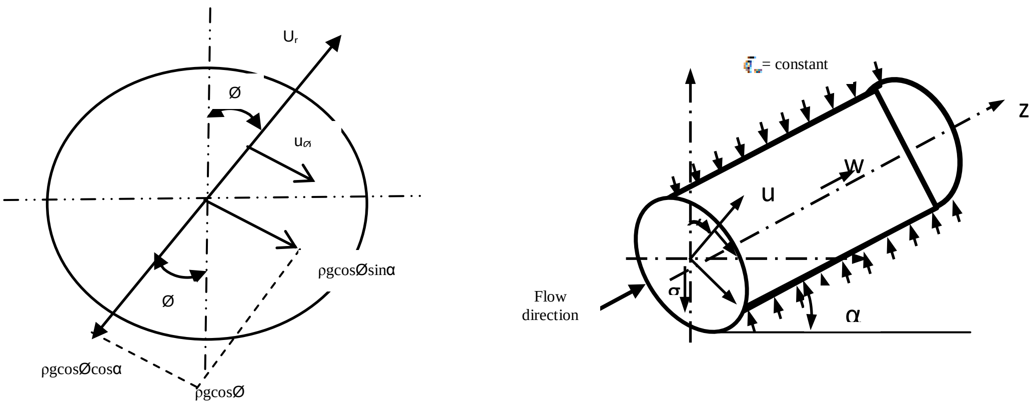


Fig.(1) Physical Representation for Problem By Polar Coordinate (Analysis of the weight forces in the flow section)

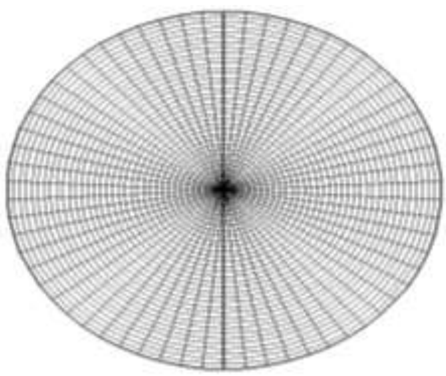


Fig. (2) Mesh network for flow region representation

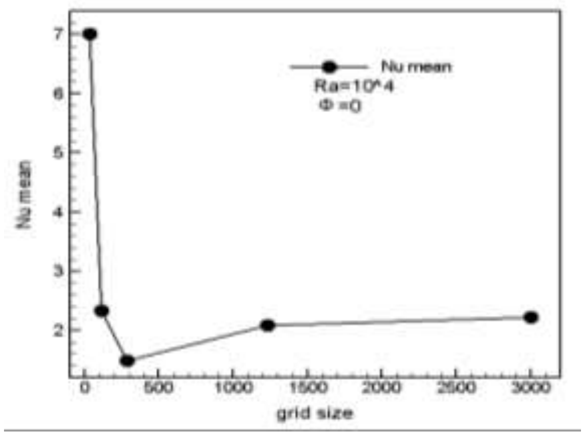


Fig (3) Grid Size in this Study

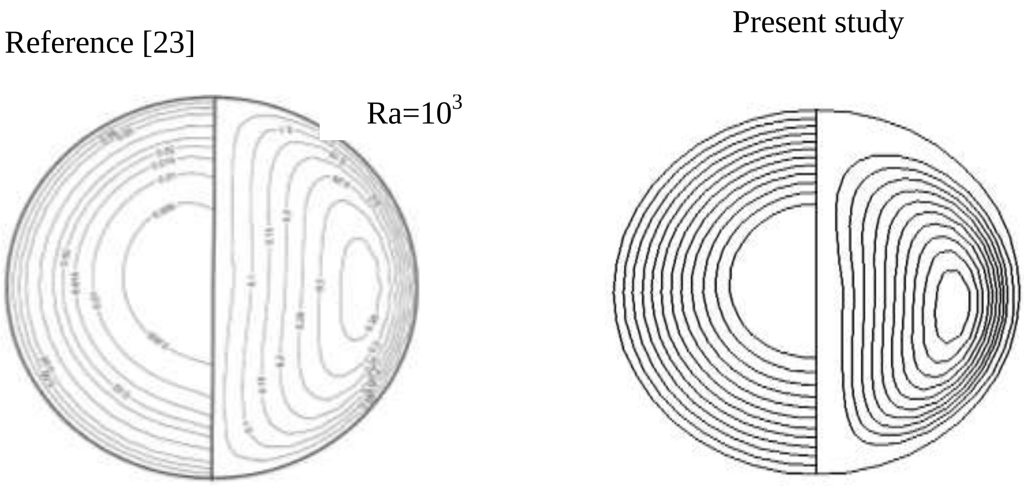


Fig (4) Comparison present work with reference (23) [2000] for the stream and isotherms lines in tube filled with porous medium

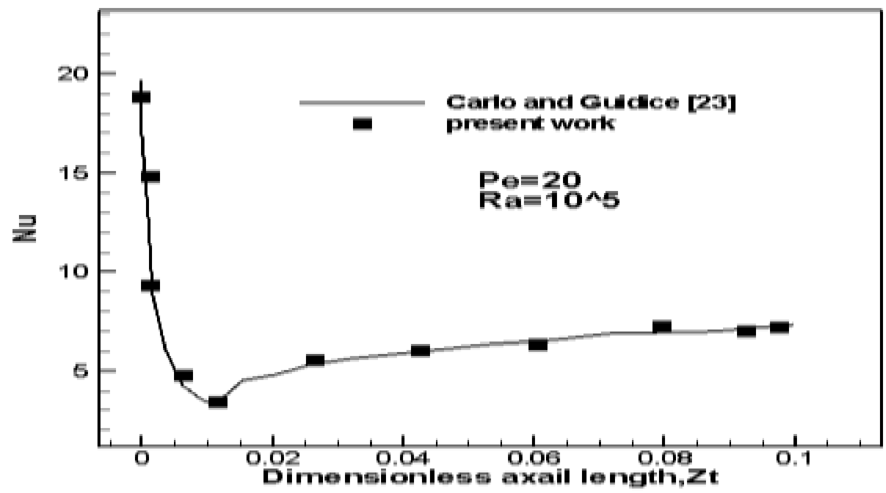


Fig (5) Comparison the results of Carlo and Guidice [1996] with the present results for (Nusselt number)

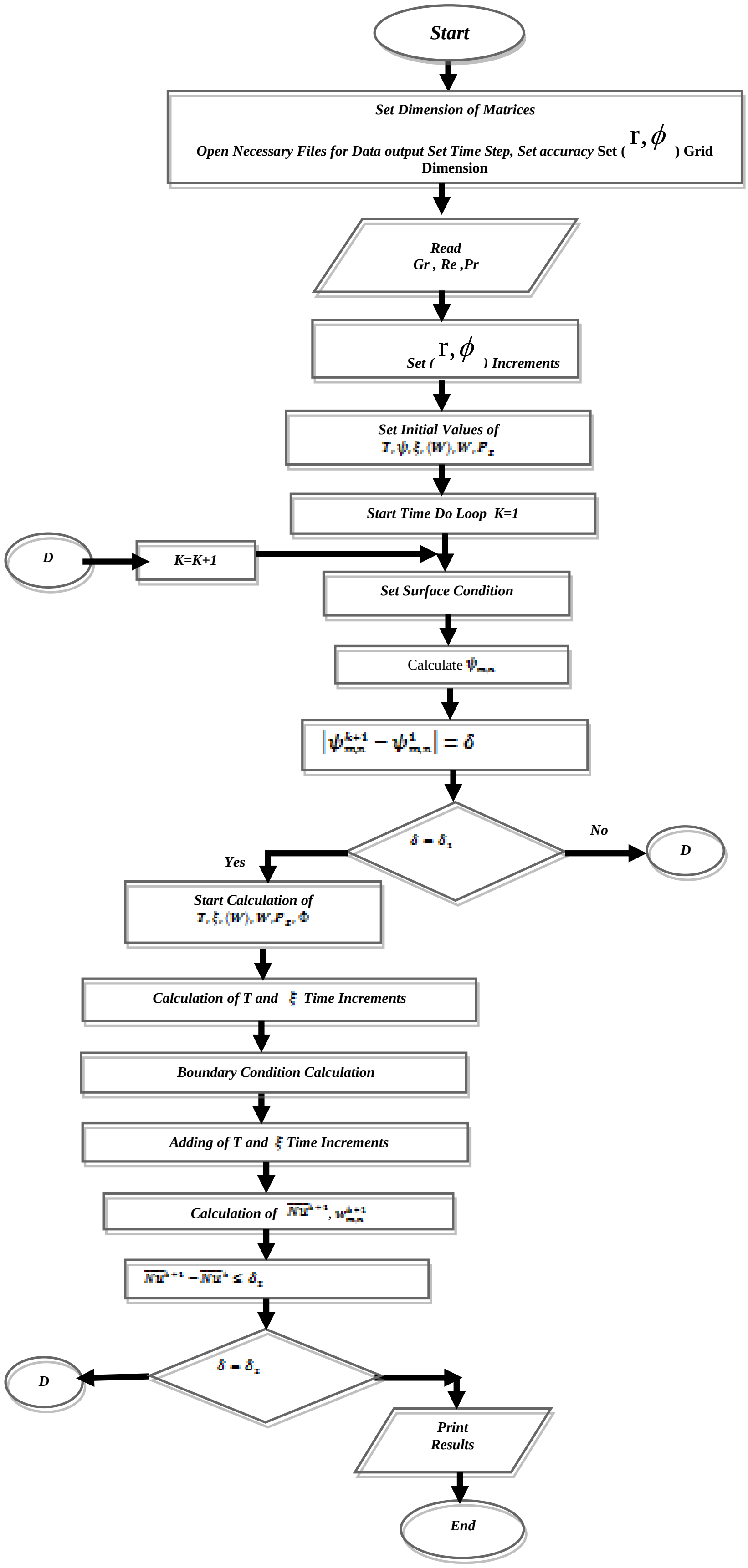


Fig .(6) The flow chart of the computer program

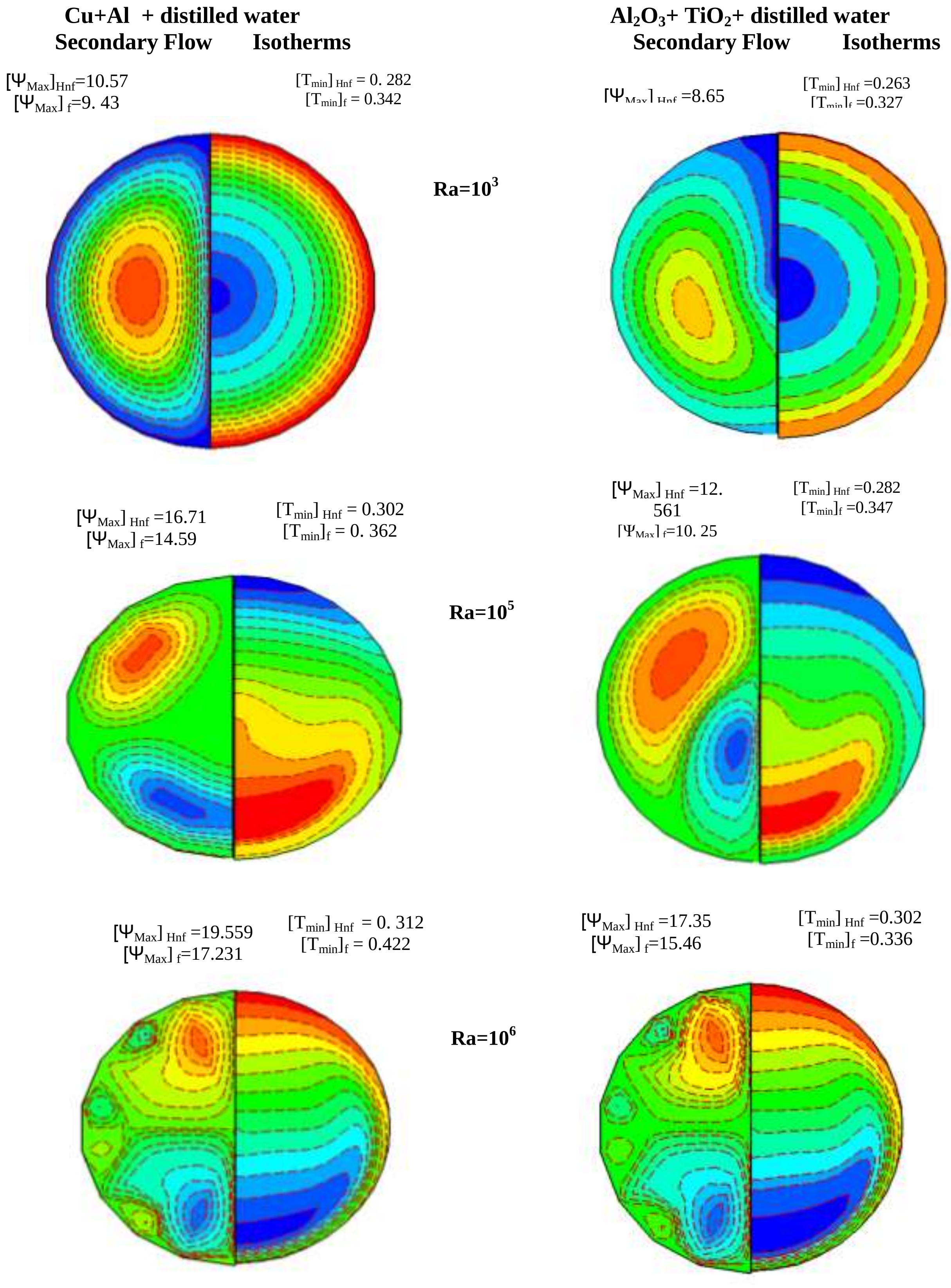


Fig.(7) : Secondary flow (on the left) and Isotherms (on the right) for Cu+Al, Al_2O_{3+} TiO_2 + Dw Hybridnanofluids with different Ra , Pe=20 , α =0^0 (Horizontal) ,(glass beads(dp=20 mm)) and UHF

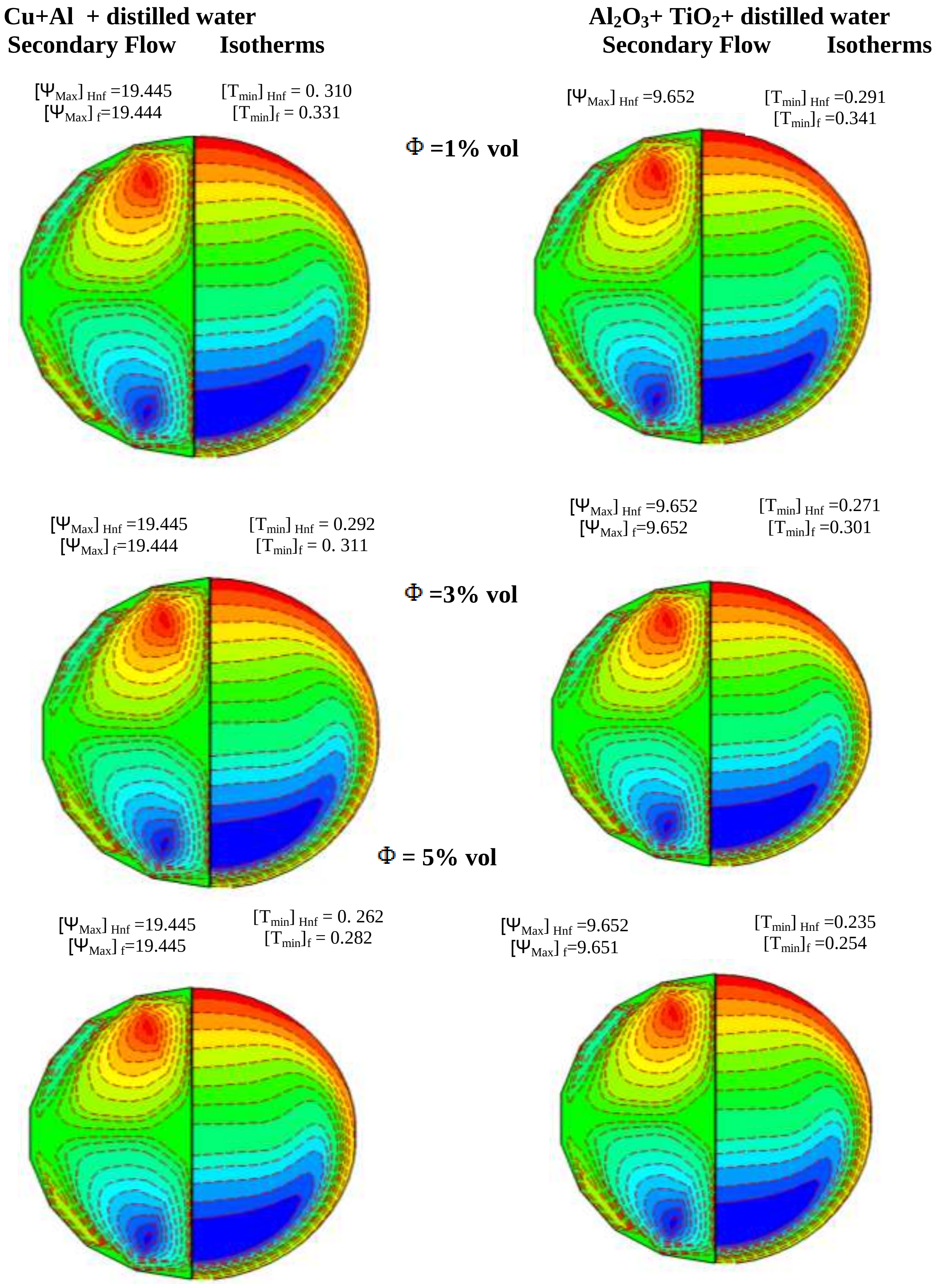


Fig.(8) : Secondary flow (on the left) and Isotherms (on the right) for Cu+Al, Al_2O_{3+} TiO_2 + Dw Hybridnanofluids with different Φ , Pe=20 , α =0^0 (Horizontal) ,(glass beads(dp=20 mm)) and UHF

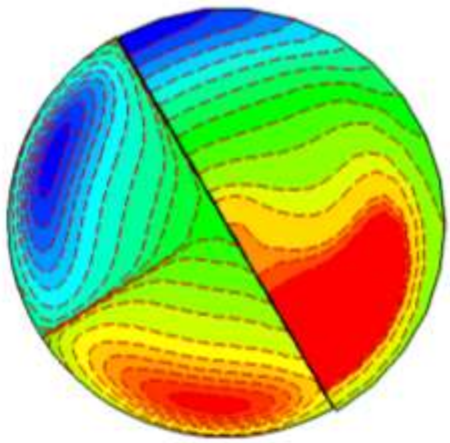
Cu+Al + distilled water
Secondary Flow Isotherms

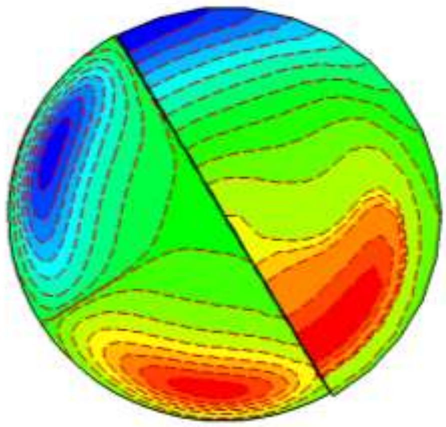
$[\Psi_{Max}]_{Hnf}$ =11.421 $[T_{min}]_{Hnf}$ = 0.282
$[\Psi_{Max}]_{f}$=10.182 $[T_{min}]_{f}$ = 0. 251

Al_2O_3+ TiO_2+ distilled water
Secondary Flow Isotherms

$[\Psi_{Max}]_{Hnf}$ =9.321 $[T_{min}]_{Hnf}$ =0.26
$[\Psi_{Max}]_{f}$=7.335 $[T_{min}]_{f}$ =0.331

α =30



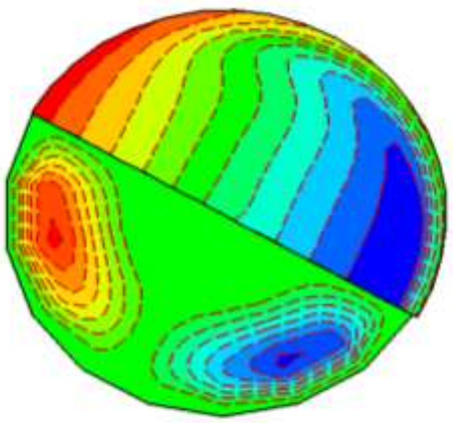


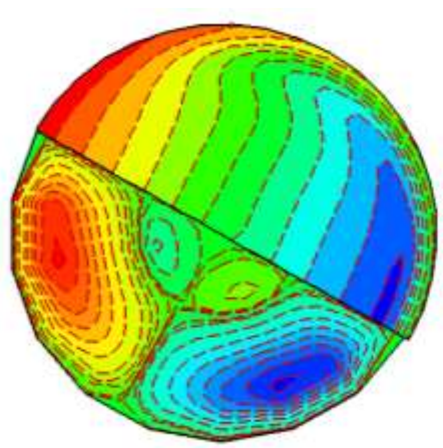
$[\Psi_{Max}]_{Hnf}$ =16.421 $[T_{min}]_{Hnf}$ = 0.260
$[\Psi_{Max}]_{f}$=15.423 $[T_{min}]_{f}$ = 0. 301

$[\Psi_{Max}]_{Hnf}$ =13.04 $[T_{min}]_{Hnf}$ =0.241
$[\Psi_{Max}]_{f}$=11.54 $[T_{min}]_{f}$ =0.271

α =90

α =60

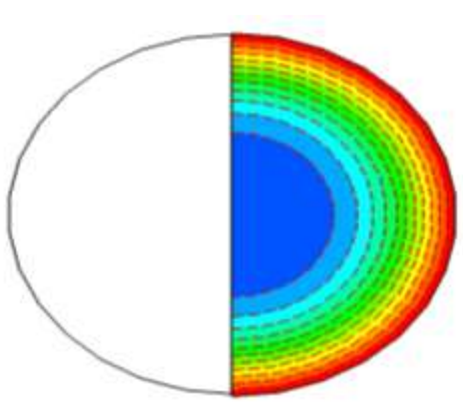




$[\Psi_{Max}]_{Hnf}$ =0.0 $[T_{min}]_{Hnf}$ = 0. 280
$[\Psi_{Max}]_{f}$=0.0 $[T_{min}]_{f}$ = 0.361

$[\Psi_{Max}]_{Hnf}$ =0.0 $[T_{min}]_{Hnf}$ =0.222
$[\Psi_{Max}]_{f}$=0.0 $[T_{min}]_{f}$ =0.248

α =90



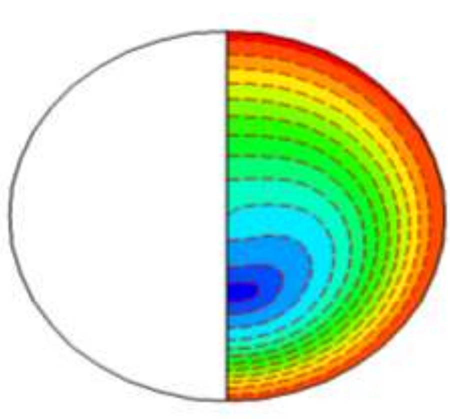


Fig.(9) : Secondary flow (on the left) and Isotherms (on the right) for Cu+Al, Al_2O_{3+} TiO_2 + Dw Hybridnanofluids with different α, Pe=20 , (glass beads(dp=20 mm)) and UHF

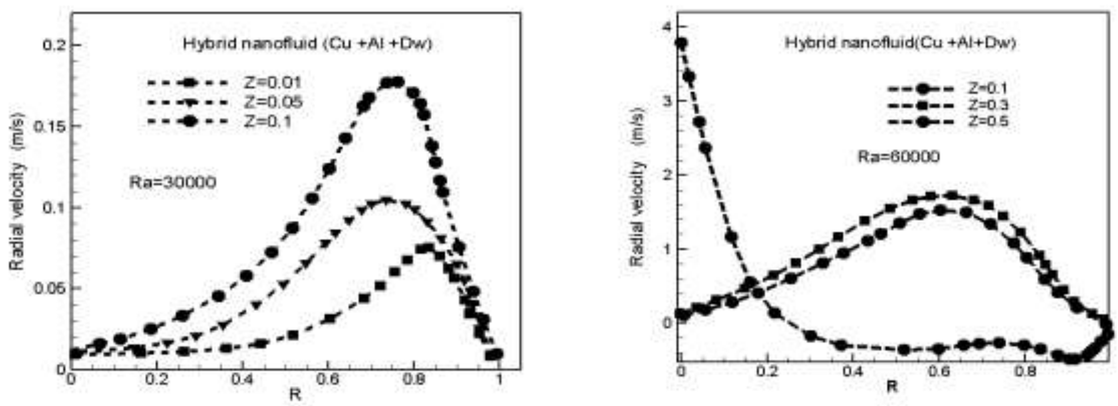


Fig. (10): Variation the radial velocity **of the hybrid nanofluid (Cu+Al+Dw) with horizontal axis for Pe=20, Φ= 5%vol ,(glass beads(dp=20mm)) at different Ra and position**

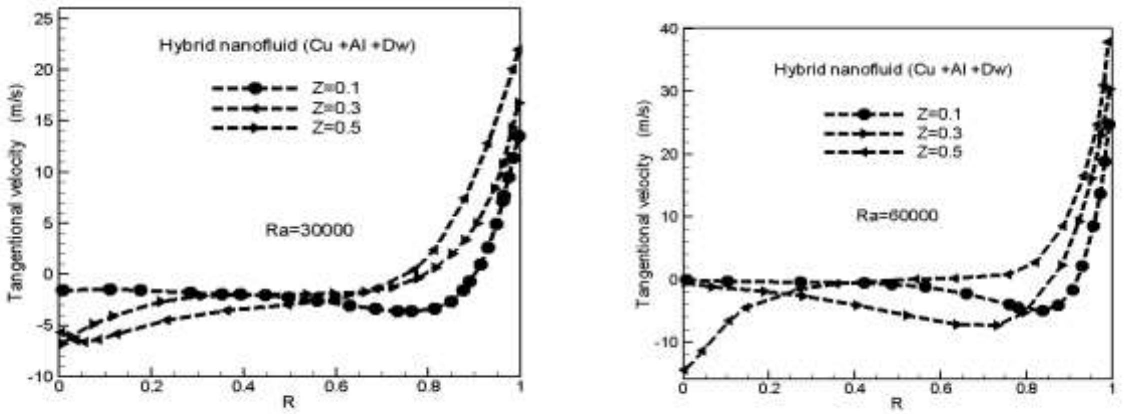


Fig. (11): Variation the tangential velocity **of the hybrid nanofluid (Cu+Al+Dw) with horizontal axis for Pe=20, Φ=5%vol ,(glass beads(dp=20mm)) at different Ra and position**

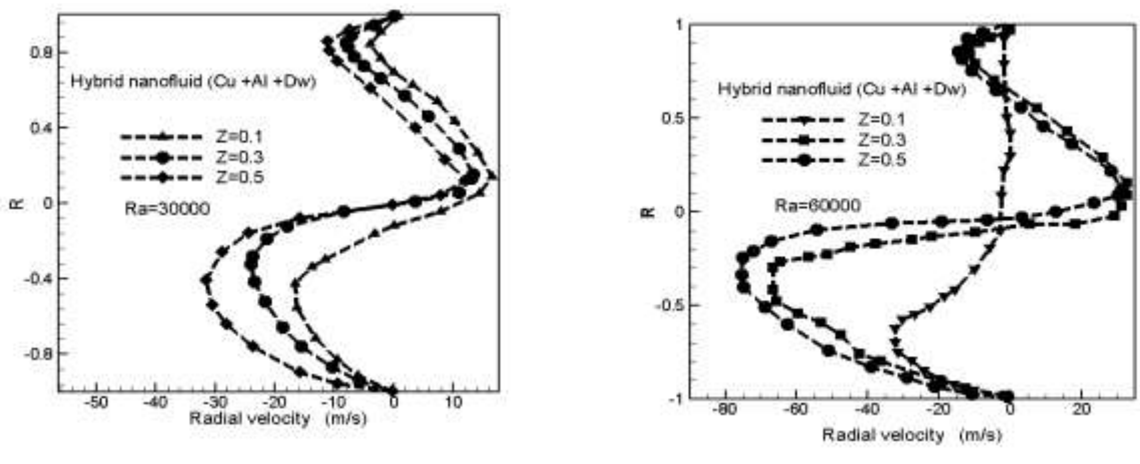


Fig. (12): variation the radial velocity **of the hybrid nanofluid (Cu+Al+Dw) with vertical Axis for Pe=20, Φ=5%vol ,(glass beads(dp=20mm)) at different Ra and position**

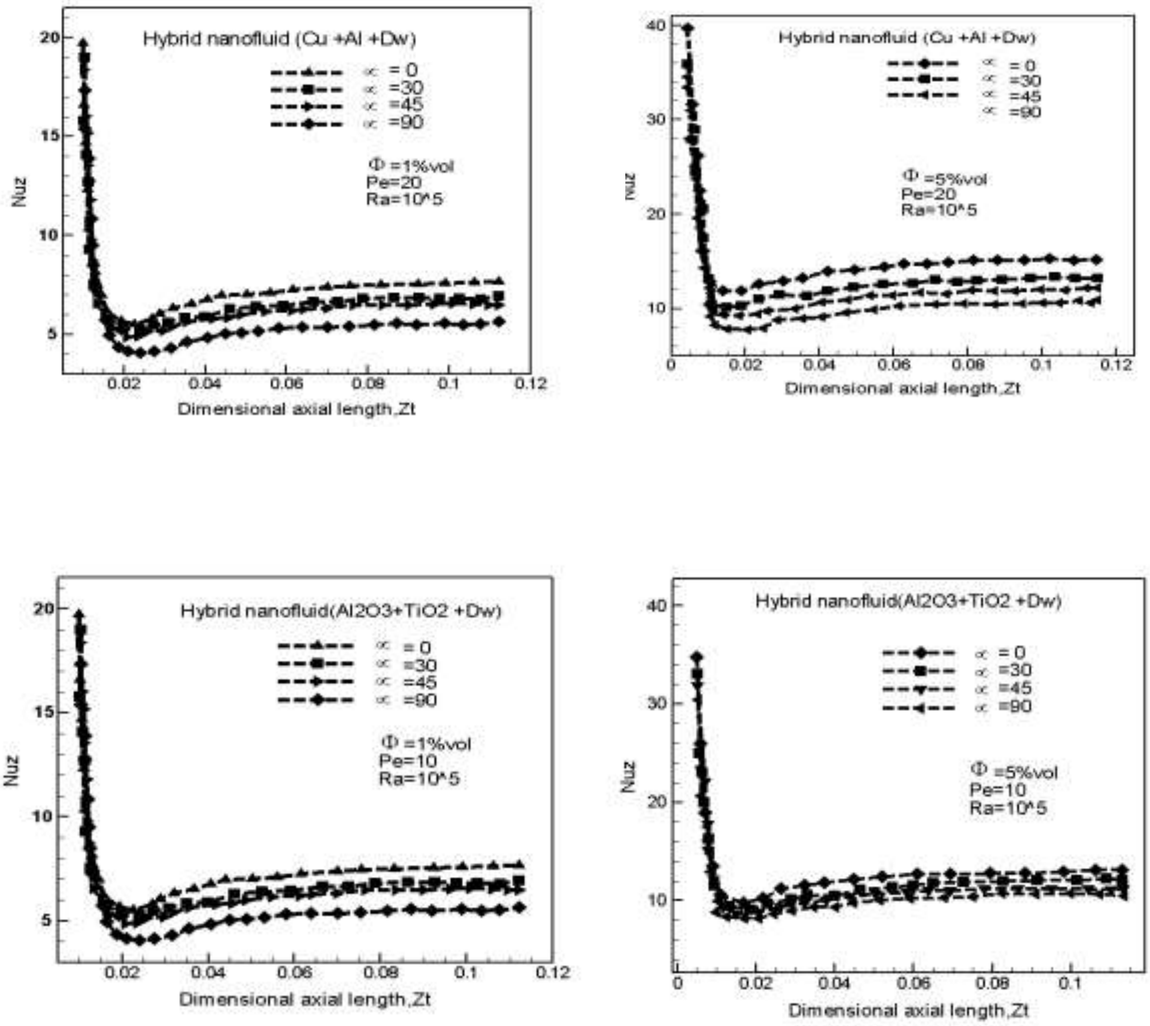


Fig. (13): The average Nusselt number to UHF of the hybrid nanofluid (Cu+Al+Dw) And (Al_2O_3+TiO_2 +Dw) nanofluids with different angles, Ra=10^5 , Pe=20, Φ=1% vol and 5% vol

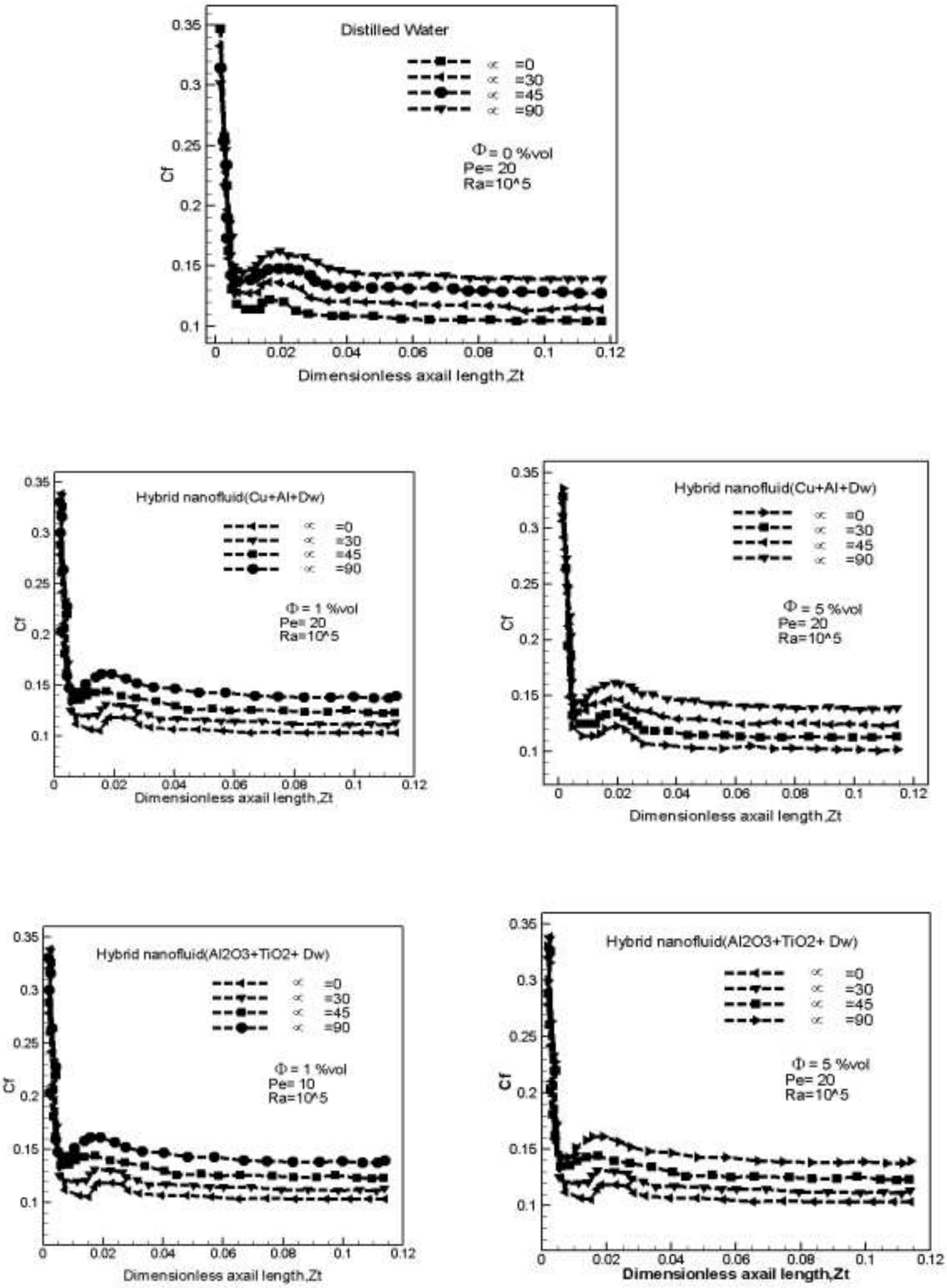


Fig. (14) : The average skin friction coefficient to UHF of the hybrid nanofluid (Cu+Al+Dw) and (Al_2O_3+TiO_2 +Dw) nanofluids with different angles, Ra, Pe=20, Φ=1% vol and 5% vol

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