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Numerical Investigation of Heat Transfer Characteristics of Nano-fluid Flowing Through a Circular Pipe Surrounded by Porous Medium

MD. Uzzal Hossain, Mohammad Ilias Inam*
Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
Porous medium and nano-fluid have become very eminent area of interest in heat transfer analysis nowadays because of its enhanced heat transfer capacity than normal fluid flow in solid pipe. With expanding technological advancement, porous medium have drawn attention of the researchers. The main advantage of using porous medium in recent years which have been accomplished from numerous research works is the enhancement of heat transfer rate than solid pipe. Porous medium and nano-fluids have gigantic impact in engineering sectors such as automobile cooling system, nuclear reactors, industrial applications, and biomedical applications. The objective of this study is to numerically investigate the convective heat transfer of water-based Al_2O_3 nano-fluids flowing through a circular pipe surrounded by porous medium at constant heat flux of 6000 W/m^2 under laminar flow conditions. The effects of nano-particle concentration, Reynolds number, Darcy Number and porosity on the heat transfer characteristics of Al_2O_3-water nano-fluids are investigated. Convective heat transfer co-efficient, Nusselt number and pressure drop have been estimated for porosity 0.1 to 0.5, Darcy number 10^{-2} to 10^{-6}, volume fraction 0.01 to 0.05 and Reynolds number 100 to 500. Effective thermal conductivity is also observed for different volume fraction of nano-particle .The simulation was performed with ANSYS Fluent 16.2 .The investigated result concluded that convective heat transfer co-efficient and Nusselt number increase with Darcy number, Reynolds number and volume fraction of particle but decrease with porosity of porous medium. Effective thermal conductivity is increased with volume fraction of nano-particle. Pressure drop is decreased with Darcy number but increased with Reynolds number.

Key Words: Nano-fluid, Darcy Number, Porosity & Nusselt Number.

1. Introduction

Heat transfer is a process that is related to numerous application all around us. It is a condition in which the energy transfer occurs between systems due to temperature differences. It is such a marvel in which redistribution of internal energy in the system happens at the boundary of the system. Fluid flow and heat transfer has become remarkable field of interest to engineering and scientific researchers. The abundance of applications incorporates a wide assortment of components and systems for energy devices, including general power systems, heat exchangers, high performance gas turbines and other power conversion devices.

Heat transfer in porous medium is a very complex and classical problem. The main purpose of using porous medium is to enhance heat transfer rate in different engineering applications, such as nuclear cooling, heat exchangers etc [1].

Nano-fluids, a modern heat transfer fluids, defined as liquid suspensions of nanometer leveled particles into base fluid. Nano-fluids have numerous important properties that make conceivably helpful in numerous applications of heat transfer, including micro-electronics, fuel cells, pharmaceutical process, and hybrid power engines, domestic etc. They upgrade thermal conductivity and the convective heat transfer co-efficient compared to the base fluid [2].

Bourantas et al.(2014) numerically explored heat transfer characteristics and natural convection of nano-fluid in porous media .They observed streamline and temperature contours for Da=10^{-4} and Pr =6.2 and for various Rayleigh number .They also observed average Nusselt number for Rayleigh number ranging from 10^3 to 10^7 [3]. Kefayati et al.(2016) investigated heat transfer rate and entropy change on laminar natural convection of non newtonian nanofluid in a permeable media. He used copper-oxide(CuO) as nano-particle and water(H_2O) as base-fluid . Different heat transfer characteristics have been watched for Rayleigh number ranging from Ra=10^4 to 10^5, Darcy number ranging from Da=0.001 to 0.1 and the volume fraction ranging from φ=0 to 0.04.They found heat transfer and entropy generations decline with Darcy number reduction and reasoned that average Nusselt number increment with expanding volume fraction [4].

S. Sivasankaran et al.(2016) inspected thermal and hydraulic characteristics of laminar progression of Al_2O_3 -water based nano-fluid coursing through a helical channel. Nusselt number evaluated for Reynolds number ranging from 500 to 1900 and effective thermal conductivity for porosity ranging from 0.1 to 0.5 [5].

Hashemi et al.(2017) investigated characteristic convection of Cu based water nanofluid with heat generated in both solid and liquid phases of the permeable medium. They found that the quality of fluid is inversely proportional with Darcy number [6]. Misirlioglu et al. [2005], explored numerically convection inside a cavity in which fluid coursing through permeable medium. The wavy walls were like cosine curve [7].

2 Problem Statement:

Setup Name	Setup type
Problem Type	2D
2D Space	Axisymmetric
Solver Type	Pressure Based
Nano-fluid	Water Based Al_2O_3
Inlet Temperature	298 K
Flow Type	Two dimensional, Laminar, Steady state, Incompressible
Heat Flux	6000 W/m^2
Reynolds Number	100 to 500

The problem is shown schematically in figure:

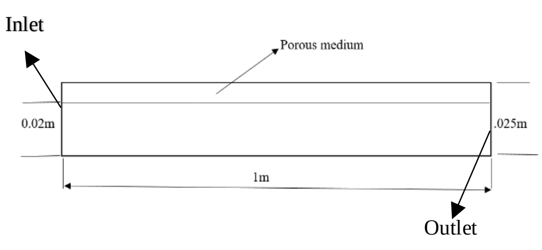

Fig. 2.1: Dimension of the porous pipe

2.1 Boundary Condition

At inlet, constant temperature is fixed at 298k. Both base fluid and Nano-particles are entering into inlet at an equal velocity. This velocity is depending on the Reynolds number. The boundary condition at the outlet section of the pipe is considered to be pressure outlet. The pressure outlet boundary condition defines an outflow condition based on the flow. The wall has given constant heat flux of 6000 W/m^2. Darcy Number ranges from 10^{-6} to 10^{-2} for porous medium. Diameter of of the nano-particles is 20 nm.

3. Governing equation

The three governing equation such as continuity, momentum and energy equations are solved to find out the solution of a heat transfer problem.

Continuity equation: The form of continuity equation or the conservation of mass equation are:

$$\frac{\partial \rho_{\mathrm{nf}}}{\partial t} + \frac{\partial}{\partial x}(\rho_{\mathrm{nf}} u) + \frac{\partial}{\partial y}(\rho_{\mathrm{nf}} v) + \frac{\partial}{\partial z}(\rho_{\mathrm{nf}} w) = 0 \qquad (1)$$

Momentum Equations: The whole space is comprehended with a solitary force condition and subsequent velocity field is s hared between the phases. The following momentum equation relies upon the volume fractions of all phases by the properties β and μ.

$$\frac{\partial}{\partial t}(\rho v) + \nabla(\rho \vec{v}\vec{v}) = -\Delta p + \Delta[\mu(\Delta \bar{v} + \Delta v^T)] + \rho \vec{g} + F \qquad (2)$$

Energy Equation: The energy conservation equation written as follows :-

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha_{n_f}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{q"}{\rho C_p} \qquad (3) \quad [8]$$

3.1 Effective properties of the nanofluid

Density of nano-fluid is calculated by using following equation :

$$\rho_{\mathrm{nf}} = \varphi \rho_{\mathrm{p}} + (1-\varphi)\rho_{\mathrm{bf}} \qquad (4)$$

Viscosity of nano-fluid is calculated by using flowing Brinkman equation:

$$\mu_{\mathrm{nf}} = \frac{\mu_{\mathrm{bf}}}{(1-\varphi)^{2.5}} \qquad (5)$$

Permeability is a property of the porous medium which measure the capacity and ability of transmission of fluid through porous medium. It is defined by K.

$$\text{Darcy Number, Da} = \frac{\mathrm{K}}{H^2} \qquad (6) \qquad [9]$$

3.2 Mesh Dependency Test

In order to check whether the result were mesh dependent or not, the grid sensitivity test had been performed to ensure that the obtained result does not fluctuate with the variation of mesh. Mesh dependency test is checked by increasing the number of elements. The result of mesh dependency is given below:

Table 3.2.1: Mesh Dependency test for Porous Pipe:

No. of Elements	Nusselt Number
12200	5.176
26600	5.164
50000	5.159
83200	5.148
140800	5.147

3.3 Model Validation

The present investigation is done for water flow through solid pipe, Porous pipe and nano-fluid flow through solid pipe and porous pipe. The values of Nusselt number are compared for the water flow through solid pipe for constant wall heat flux with [10].

Table 3.3.1: Table for Model Validation

Present investigation	Reference[10]
Nu = 4.38	Nu = 4.36

4. Result & Discussion

In Fig. 4.1 Velocity contour for different Darcy Number has been shown. It is clearly seen that fluid flow velocity into porous medium at inlet section is increasing with the increment of Darcy Number and it is also delayed the development of hydro-dynamically fully developed flow.

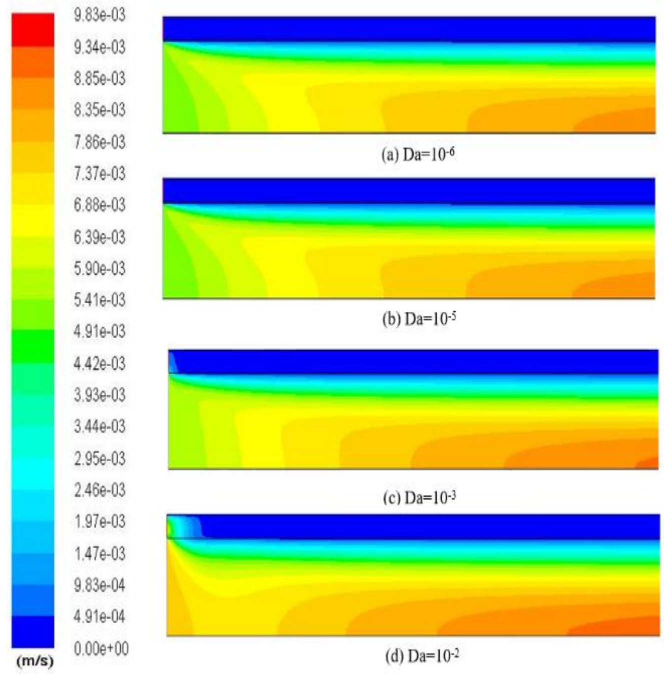

Fig. 4.1: Effect of Darcy Number on velocity contour

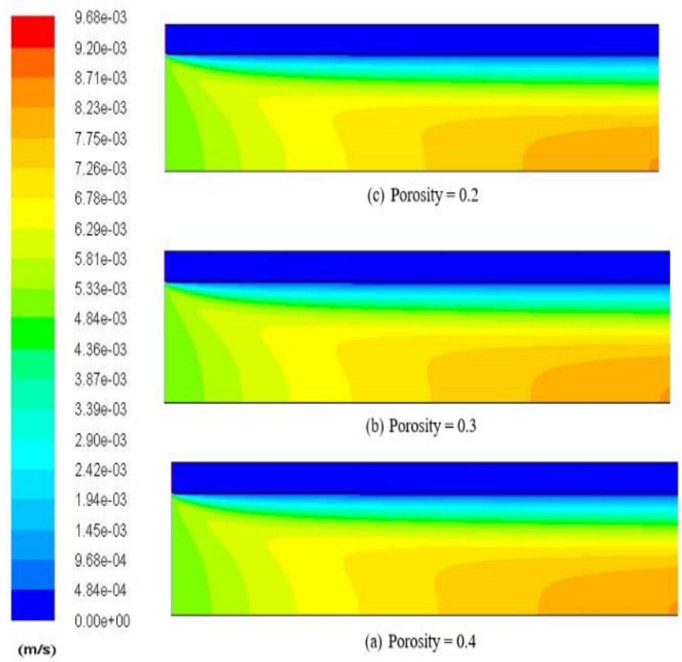

Fig. 4.2: Effect of porosity on velocity contour

In Fig. 4.2 Velocity contour for different porosity has been shown. There is no effect in fluid flow velocity into porous medium but it makes a little fast in the development of hydro-dynamically fully developed flow with increasing porosity.

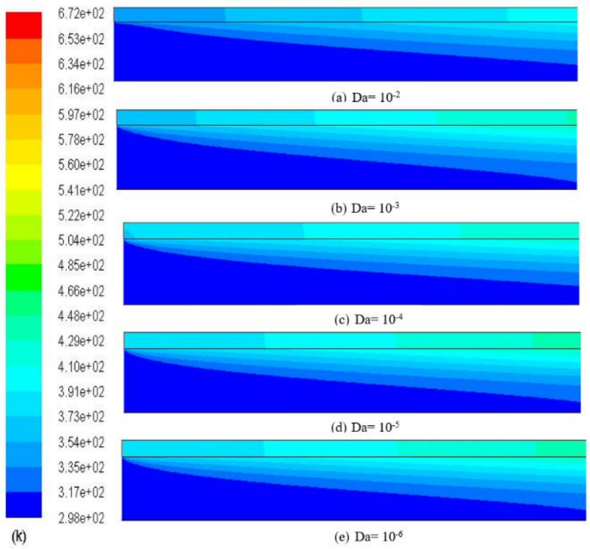

Fig. 4.3: Effect of Darcy Number on Temperature contour

In Fig. 4.3 Temperature contour for different Darcy Number has been shown. It is clearly seen that temperature of fluid inside porous medium is increasing with decreasing Darcy Number and it makes fast the development of thermally fully developed flow with increasing Darcy Number.

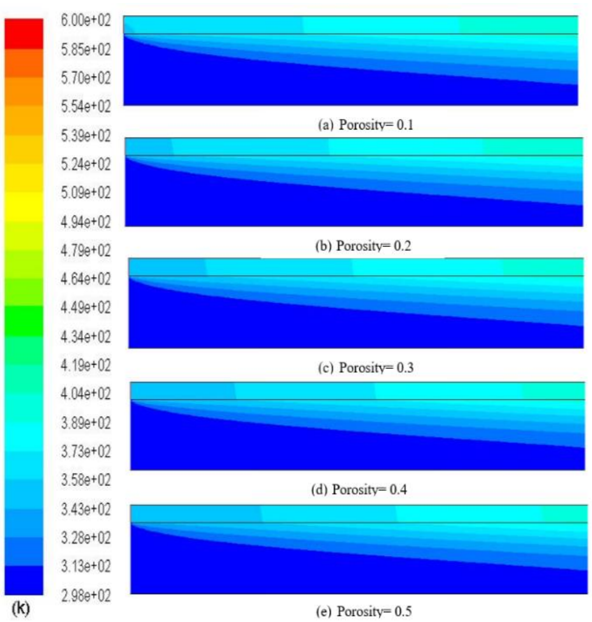

Fig.4.4: Effect of porosity on Temperature contour

In Fig.4.4 temperature contour for different porosity has been shown. It is clearly seen that temperature of fluid inside porous medium is increasing with decreasing porosity.

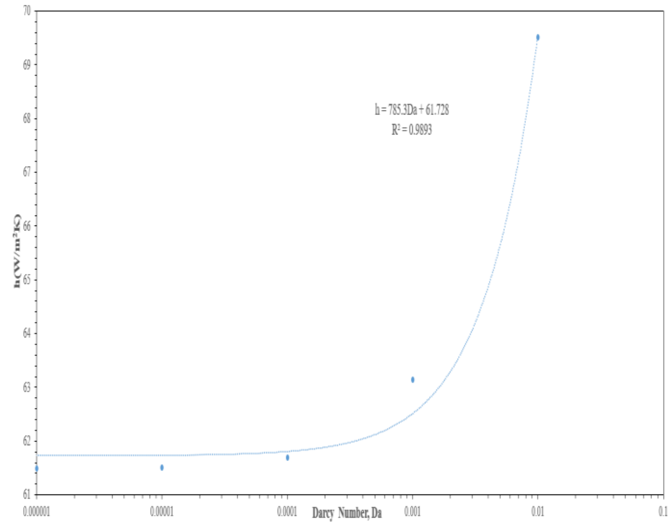

Fig. 4.5: Effect of Darcy Number on Convective Heat Transfer Co-efficient for only Porous pipe

Fig.4.5 shows graphical representation of convective heat transfer co-efficient vs Darcy Number Trend-line for only porous pipe at Reynolds number 200 and porosity 0.5. Heat transfer co-efficient is increased slightly with Darcy number but dramatic increament begin after reaching at Da=10^{-3}.

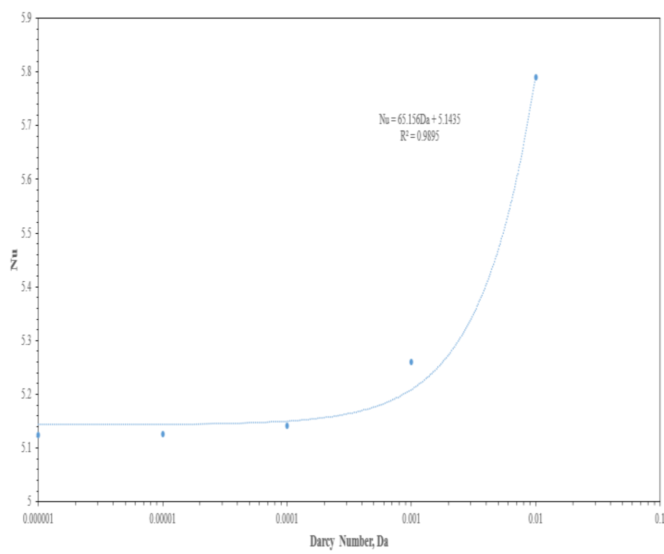

Fig. 4.6: Effect of Darcy Number on Average Nusselt Number for only Porous pipe

Fig.4.6 shows graphical representation of average Nusselt Number vs Darcy Number Trend-line for only porous pipe at Reynolds number 200 and porosity 0.5. Average Nusselt Number is increased slightly with Darcy number but dramatic increment begin after reaching Da=10^{-3}.

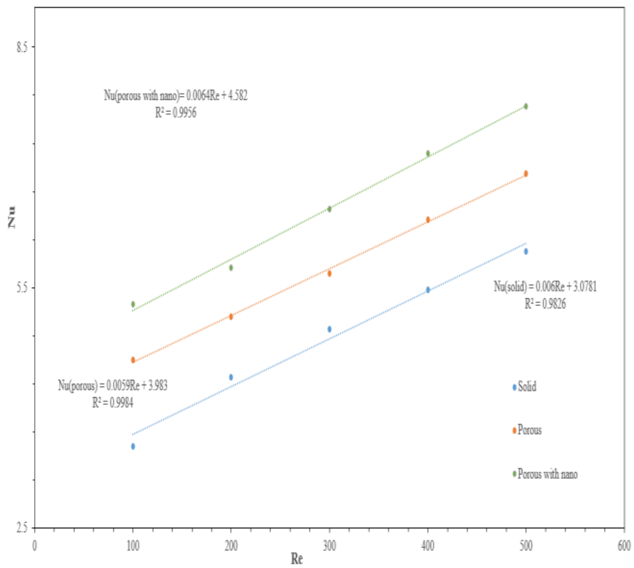

Fig.4.7: Comparative Effect of Reynolds Number on Average Nusselt Number between Solid, Porous and Porous with Nano-fluid

Fig. 4.7 shows graphical representation of average Nusselt Number vs Reynolds Number Trend-line for solid ,porous and porous with nano-fluid. Nusselt Number is proportional to Reynolds Number for all cases but maximum nusselt number is gotten from porous with nano-fluid.

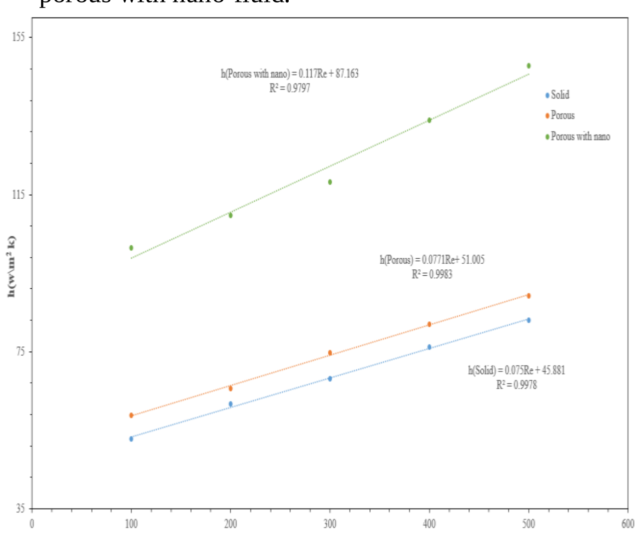

Fig. 4.8: Comparative Effect of Reynolds Number on Convective Heat Transfer Co-efficient between Solid, Porous and Porous with Nano-fluid

Fig.4.8 shows graphical representation of convective heat transfer co-efficient vs Reynolds Number Trend-line for solid ,porous and porous with nano-fluid. Heat transfer rate is proportional to Reynolds Number for all cases but maximum rate is gotten from porous with nano-fluid.

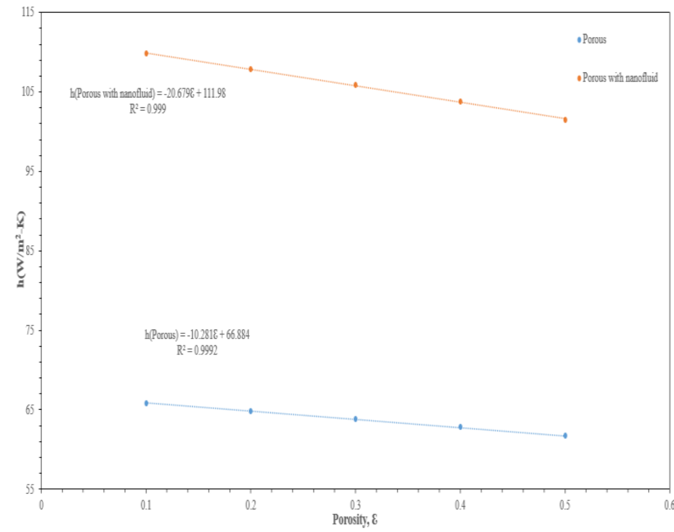

Fig.4.9: Comparative Effect of Porosity on Convective Heat Transfer Co-efficient between Porous and Porous with Nano-fluid

Fig.4.9 shows graphical representation of convective heat transfer co-efficient vs porosity Trend-line for only Porous pipe and porous with nano-fluid for Re= 200, Darcy Number = 10^{-4} and VF =0.01 and compare between them. Heat transfer rate is decreased with porosity and it is clearly seen that for prous with nano-fluid heat transfer rate is higher than only porous pipe.

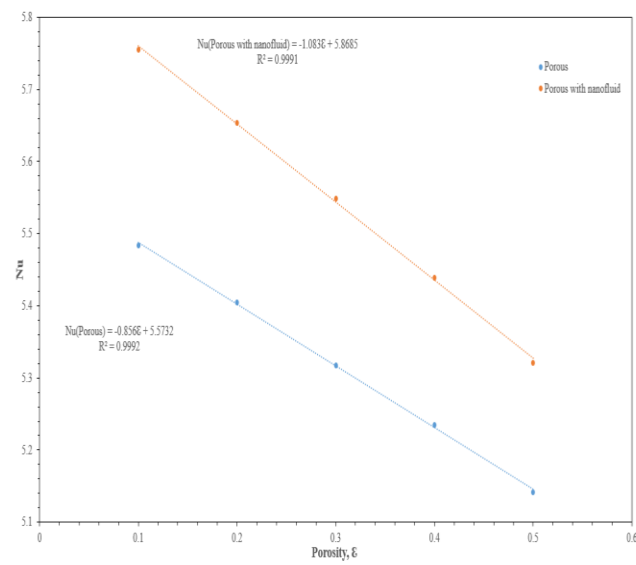

Fig.4.10: Comparative Effect of Porosity on Average Nussselt Number between Porous and Porous with Nano-fluid

Fig.4.10 shows graphical representation of average Nusselt Number vs porosity Trend-line for only Porous pipe and porous with nano-fluid for Re= 200, Darcy Number = 10^{-4} and VF =0.01 and compare between them. Averege Nusselt umber is inversely proportional to porosity and clearly seen that for prous with nano-fluid it has higher value than only porous pipe .

5. Conclusions

A comprehensive investigation on forced convection of water and nano-fluid through solid and porous pipe have been performed. The investigation is done to find out enhancement of heat transfer rate by using nano-fluid and porous medium for difreent Reynolds Number, Darcy Number, Porosity. The amount of heat transfer co-efficient and Nusselt Number both are increased remarkably with increasing Darcy Number. But The amount of heat transfer co-efficient and Nusselt Number Both are decreased with porosity.

6. References

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NOMENCLATURE

T	Temperature (K)
P	Pressure (pa)
Re	Reynolds Number
Nu	Nusselt Number
h	Convective heat transfer coefficient (W/m2-k)
q	Heat flux
μ	Dynamic viscosity
ρ	Density (kg/m3)
C_p	Specific heat (J/kg-K)
φ	Volume fraction
α	Kinetic energy correction factor
Ɛ	Porosity
Da	Darcy Number
V	Flow velocity (m/s)
nf	Nano-fluid
bf	base fluid
p	particle