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Heat Transfer Analysis in Radial Flow Cooling System Using Nanofluid

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Abstract

Nanofluids offer great opportunities for heat transfer enhancement rather than the normal water/glycol/oil based fluids in the field of microelectronics, fuel cells and hybrid power engines. They are colloidal suspensions of metals, oxides, carbon nanotubes in base fluid. This study investigates heat transfer of water-based nanofluid in a radial flow channel between two coaxial and parallel discs where the inlet tube wall is insulated and the parallel discs are maintained at constant temperature. Water based nanofluid contains Cu as nanoparticle. The numerical analysis has been done using finite volume method in ANSYS Fluent. Computations have been verified with the experimental data available in the literature. Results show that significant increase in heat transfer is possible in nanofluid even at smaller volume fraction. The flow behavior and the effect of volume fraction on thermal properties have also been shown in this experiment.

Keywords: Nanofluid, Nanoparticle, Heat transfer, Radial flow

1. Introduction

Nanofluids have various significant properties that make them potentially useful in many applications of heat transfer, including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines, domestic refrigerator, heat exchanger, in grinding, machining and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. Fluids such as water, oil and ethylene glycol, have low thermal conductivity which put limitation in increasing the performance of various electronic devices for various engineering applications. . As nanofluids possess a greater heat transfer rate than normal coolants and its convective thermal coefficient also increases with the proper volume concentration, this can be a better solution for reducing the cost of cooling performance in compact size electronic components and provide a greater heat transfer. The objectives of this investigation is to analyze the heat transfer capabilities of Cu nanofluid inside a radial flow channel and the effect of volume fraction on the thermal properties. The literature related to this topic investigates the fluid flow and heat transfer in typical radial flow cooling systems. A numerical study of laminar flow and heat transfer between a stationary and a rotating disk has been analyzed by Prakash in 1985. It shows that, in the presence of rotation, the flow is indeed quite complex and is characterized by recirculating zones near the inlet and the exit [1]. An experimental study is conducted to determine local heat-transfer performance and mechanisms in radial flow through two parallel heated discs [2]. Szeri analyzed the nature of the basic flow between parallel discs. Garimella and Nenaydykh [4] have completed a parametric examination of the impacts of different aspect ratios such as nozzle to plate spacings vs nozzle diameter and nozzle thickness vs nozzle diameter and Reynolds numbers ranging from 4000-23,000. They likewise have proposed connections for the stagnation point Nusselt number as far as jet Reynolds number, Prandtl number for fluid. Some results show that suspended metallic particles exhibit high thermal conductivities compared to those of currently used heat transfer fluids and one of the benefits of nanofluids will be dramatic reductions in heat exchanger pumping power [5]. Results have shown that metallic oxide nanoparticles (such as Al_20_3 and CuO) have excellent dispersion properties in water, oil and ethylene glycol and form stable suspensions. Some scientists propose that as a medium of heat transfer, the nanofluid behaves much more like as a single phase fluid than a mixture of solid and fluid [6]. Nanofluids are assumed to show advanced properties compared to traditional type of coolants that contain micrometer sized or millimeter sized particles. It has been shown that a nanofluid comprised of Cu particles dispersed in ethylene glycol possess a higher thermal conductivity compared to pure ethylene glycol or ethylene glycol containing the same amount of volume fraction of nanoparticles. [8]. Pak and Cho have achieved results from experiment inside a tube on convective type of heat transfer performances for both laminar flow and turbulent flow. It was seen that the Nusselt number rises with the increase of particle volume fraction and Reynolds number and decreases with increasing spacing of discs and the pumping power may try to put certain restrictions on the use of nanfluiid [10]. Recent studies show that the thermophysical properties vary with temperature and volumetric concentration of nanofluids [11]. Roy [12] considered the hydrodynamic and thermal fields of a water–γ Al_20_3 nanofluid in a radial laminar flow cooling system. Results show that considerable heat transfer enhancement is possible, even achieving a achieving a twofold increase in the case of a 10% nanoparticle volume fraction nanofluid. An increase in wall shear stress is also noticed with an increase in particle volume concentration.

2. Problem Description

Fig. 1. shows the schematic diagram of the problem which is to be analyzed. It consists of steady, laminar flow and heat transfer analysis of water based nanofluid containing Cu as nanoparticle that flows inside a radial channel which is comprised of two coaxial and parallel discs. The discs whose outer radius are R, separated by a gap “a”. The flow of nanofluid enters the radial channel through the inlet orifice whose radius is R_i.The parallel discs are heated to a high temperature, T_h. All the discs remain stationary.

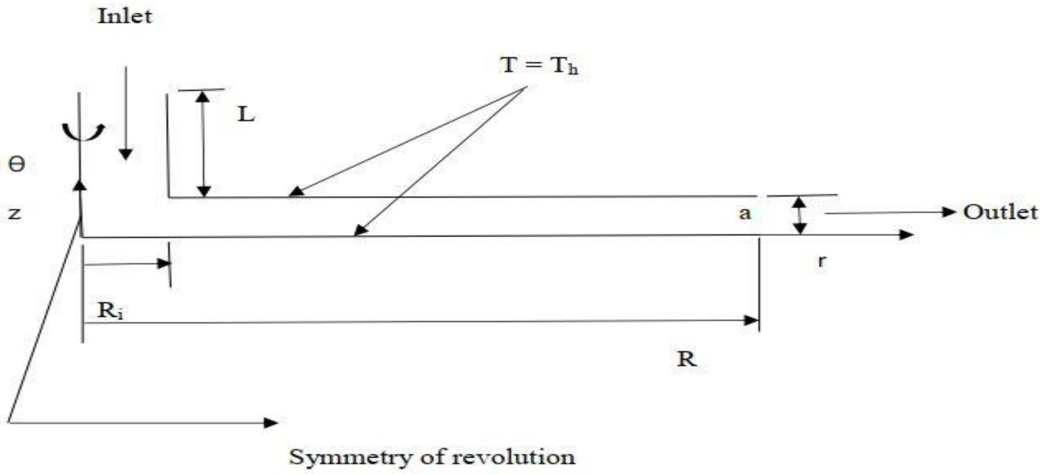


Fig.1. The problem configuration

3. Governing equations

According to various researches it is assumed that nanofluids behaves more like single-phase fluids. Though, because of the increased particle size, it seems logical to assume that such type of mixture can be easily made into fluid and it can be assumed that the motion slip between the phases would be negligible. The nanofluid is assumed to be in steady state. The flow is considered to be laminar. It is considered that the base fluid which is water and the nanoparticles are in thermal equilibrium and there is no slip between them. Here we assume that fluid velocity at all fluid–solid boundaries is equal to that of the solid boundary which is the no slip condition and fluid temperature at all fluid–solid boundaries is equal to that of the solid boundary wall temperature which is no jump condition. The thermo-physical properties of the nanofluid are assumed to be constant except for the density variation. It will be assumed that there is a symmetry of revolution with respect to the main axis. The general governing equations are written in the cylindrical coordinate *(r, z)* system considering symmetry of revolution are as follows [12]:

Continuity equation: $\nabla\cdot(\rho V) = 0$ (1)

Linear momentum equation: $\nabla\cdot(\rho V V_i) = -\nabla P + \nabla\cdot(\mu\nabla V_i) + S_i,\ i = 1,2$ (2)

Energy equation: $\nabla\cdot(\rho V C p T) = \nabla\cdot(k\nabla T)$ (3)

where $\boldsymbol{V} = (V_R, V_Z)$ is the velocity vector; S_1 and S_2 are the velocity-related stress terms given as follows:

For $i = 1$, the radial direction: $S_1 = -\mu\,\{V_R / R^2\}$ (4)

For $i = 2$, the axial direction: $S_2 = 0$ (5)

The effective properties of nanofluid are calculated as follows-

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s \quad (6)$$

The heat capacitance of the nanofluid is expressed as (Abu-Nadu (2007); Khanafer *et al.* (2003) [13]):

$$(\rho C_p)_{nf} = (1-\varphi)\,(\rho C_p)_f + \varphi(\rho C_p)_s \quad (7)$$

The effective thermal conductivity approximated by Hamilton model:

$$k_{nf} = k_{bf}(4.97\varphi^2 + 2.72\varphi + 1) \quad (8)$$

4. Boundary conditions and properties

Boundary conditions are:

(i) At the tube inlet section, a uniform axial velocity and temperature profile has been specified:

$$z = a + L \text{ and } 0 \le r \le R_i;\ V_R = 0;\ V_Z = V_0;\ T = T_0 \quad (9)$$

(ii) At the inlet tube wall, the no-slip condition and insulated type of wall are considered:

$$r = R_i \text{ and } a \le z \le a + L;\ V_R = V_Z = 0;\ \partial T / \partial r = 0 \quad (10)$$

(iii) On the vertical axis that pass through the center of the discs, the following conditions of symmetry prevail:

$$r = 0 \text{ and } 0 \le z \le a + L;\ V_R = 0;\ \partial V_Z / \partial r = \partial T / \partial r = 0 \quad (11)$$

(iv) On the upper disc and lower discs, the no-slip conditions are considered as well as a constant temperature:

$$z = 0;\ 0 \le r \le R;\ z = a;\ R_i \le r \le R;\ V_R = V_Z = 0;\ T = T_h = 80^0\ C \quad (12)$$

(v) At the outlet region:

$$r = R \text{ and } 0 \le z \le a \quad (13)$$

Table 1. Thermophysical properties of materials [14]

Property	**ρ (kg/m^3)**	**Cp (J/kgK)**	**K (W/mK)**	**α* 10^7 (m^2/s)**	**β (K^{-1})**
Water	997.1	4179	0.613	1.47	0.00021
Cu	8933	385	400	1163.1	0.000051

5. Process steps

There are there steps: pre-processing, solver, and post processing. Pre-processing consists of formation of geometry and meshing. Solver consists of physics setup and post processing consist of CFD post, which deals with different results. As part of pre-processing geometry of physical model is drawn in DESIGN MODELER of ANSYS Fluent 19.2. Then the geometry is imported to MESH and meshing is done in required degree. Named selection of the geometry is done in MESH section as inlet, outlet, wall 1, wall 2, and wall 3. For this model quadratic mesh has been used. In solver section meshed geometry is imported to the SETUP of ANSYS Fluent 19.2. Pressure based**,** steady and 2D analysis is selected**.** Multiphase-mixture and viscous laminar flow is taken with energy equation is on. Materials are water (base fluid) and nanoparticles and their properties are given in the material section. Base fluid (water) is set as primary phase and copper nanoparticle is set as secondary phase**.** Boundary conditions are setup. Then upon certain sub steps solution is initialized and finally run the calculation.

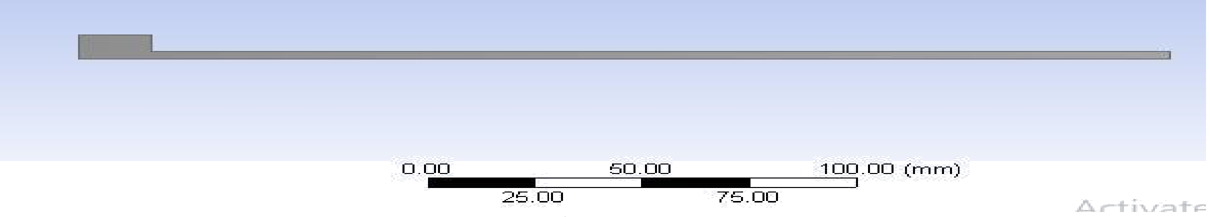


Fig. 2. Geometry formed in ANSYS 19.2

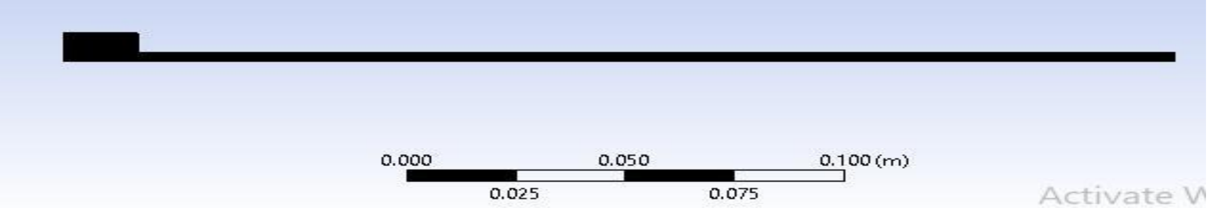
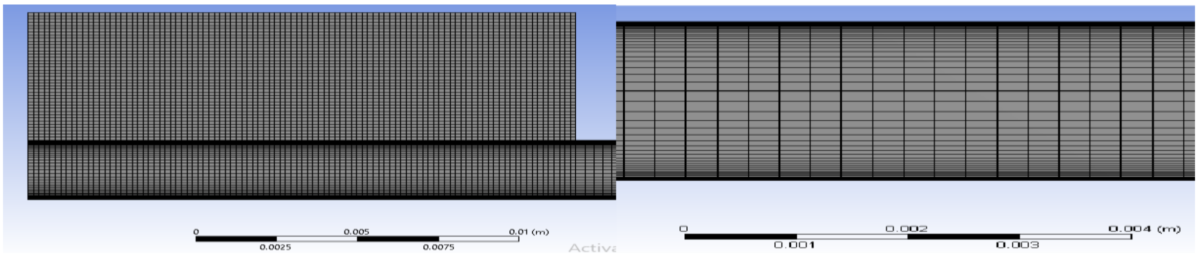


Fig. 3. Mesh of the full section formed in ANSYS 19

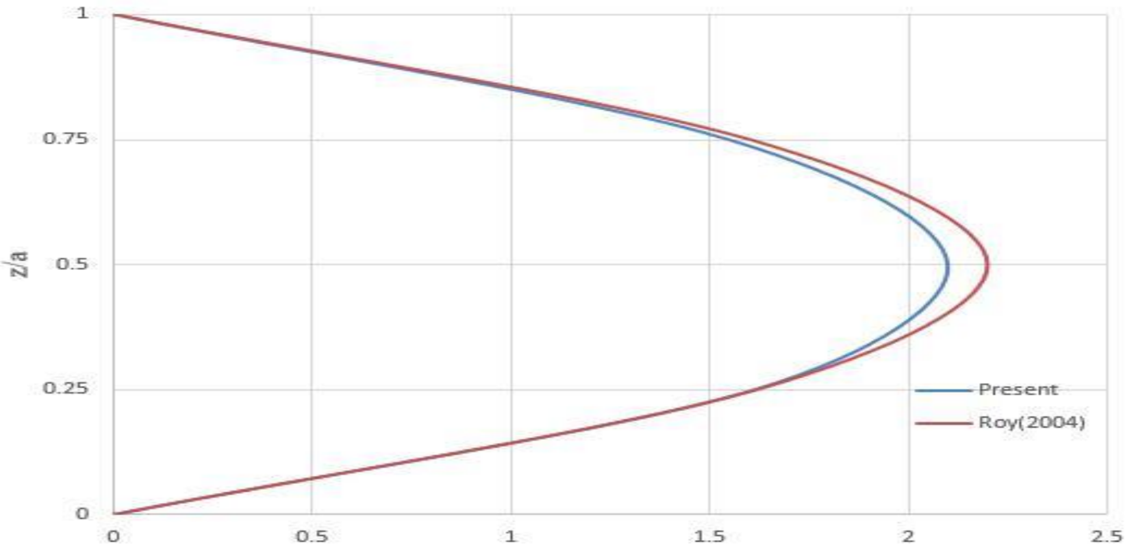


(a) Inlet region (b) Heated wall region

Fig. 4. Mesh of the Inlet and Heated wall region

6. Numerical model validation and mesh dependency test

The model is solved by ANSYS Fluent 19.2. Fig. 5. shows the graph of the present work and the work present in the literature. The result shows similar trend to the existent work with some error at the midsection of the channel at the given radial position of *r* = 135.47mm.



$V_{R*}\,2a/\upsilon\,(Re/\ \eta)^{.5}$

Fig. 5. Numerical model validation

Here, solution for different mesh size have been studied in order to determine independence of each solution. For various mesh sizes the outlet temperature have been studied to find the mesh independent result.

Table 2. Mesh description for outlet temperature

Number of nodes	Number of element	Outlet temperature
40981	40000	319.5033
62051	61000	319.0819
70151	69000	319.0863

7. Result analysis and discussion

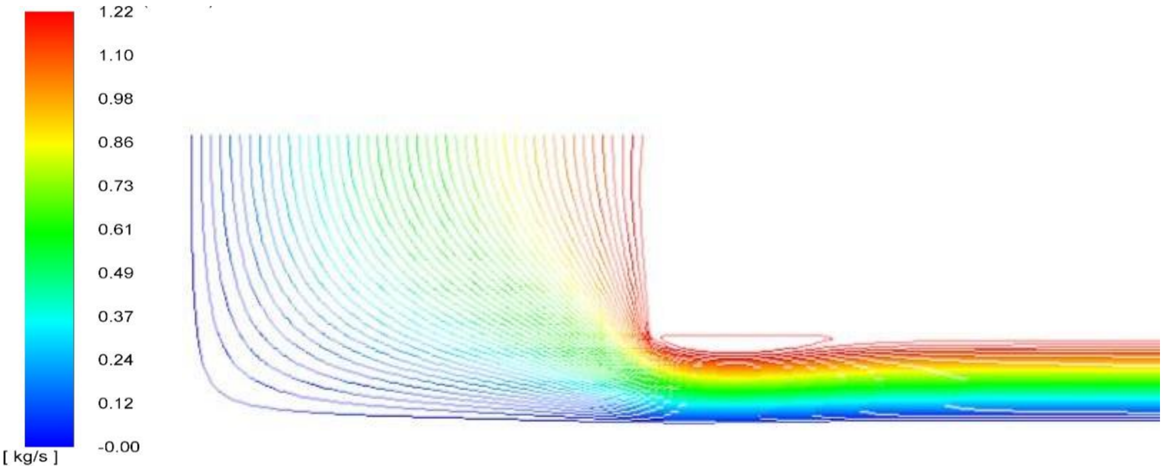


Fig. 6. Stream function (Stream line) contour for volume fraction 5%

Fig. 6. shows the stream function (Stream line) contour for volume fraction 5%. It shows that the magnitude of stream function is lower at the inlet and it is quite increasing along the outlet. A recirculation cell produces due to sudden change in flow direction from inlet to outlet. The Reynolds number here is 1200 and the sudden change is due to the flow separation causing a certain vena contracta effect. It is an expected result due to the flow characteristics of this model.

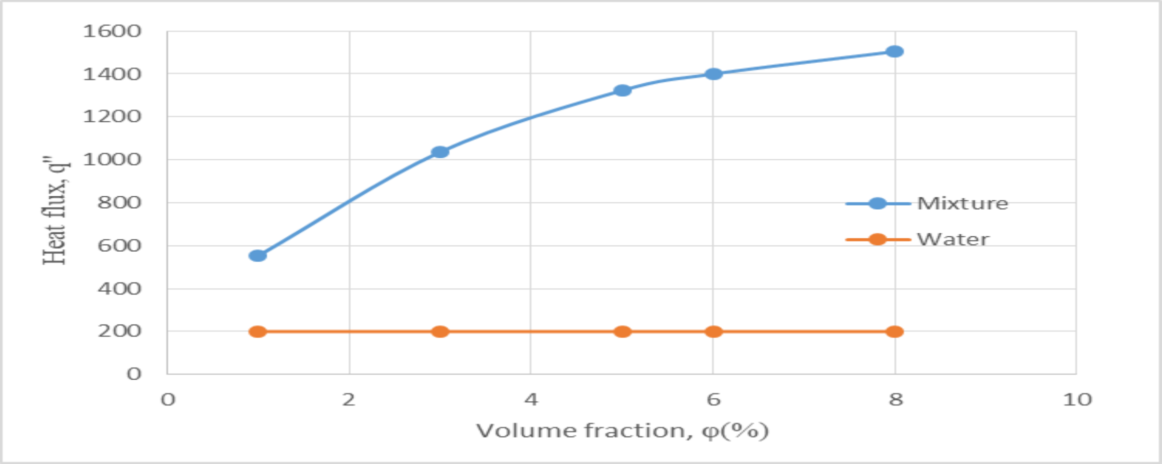


Fig. 7. Heat transfer enrichment at *r* = 85 mm

Fig.7. shows that the heat transfer increases at a very greater amount by using nanofluid than water. And with the increasing volume fraction from 1% to 8% the heat flux of the nanofluid also increases. The heat flux of water is constant irrespective of the volume fraction. In the figure the mixture denotes the nanofluid. This is the main observation of this study. The result proves that nanofluid is a great source of heat transfer than any normal fluid such as water. This result show significant possibilities of higher heat transfer rate in case of nanofluid. The Reynolds no is 1200 for this flow. This result fulfills the primary objective of this experiment.

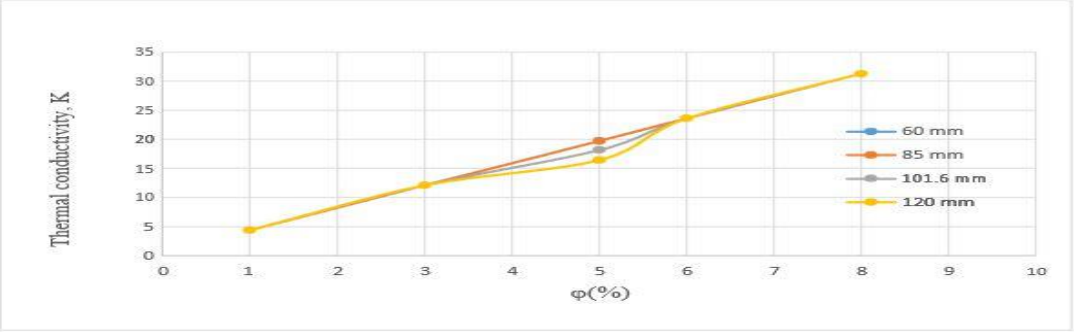


Fig. 8. Influence of volume fraction on thermal conductivity

Fig.8. shows the influence of volume fraction on thermal conductivity for *r* = 60 mm, 85 mm, 101.6 mm, 120 mm. It shows that the trend of the thermal conductivity is almost linear with the increasing volume fraction. At 5% volume fraction there is very small difference of value of thermal conductivity can be seen for different position due to the various positions of the mesh elements and nodes which can be negligible. It proves that with the increasing volume fraction the heat transfer capacity of nanofluid increases.

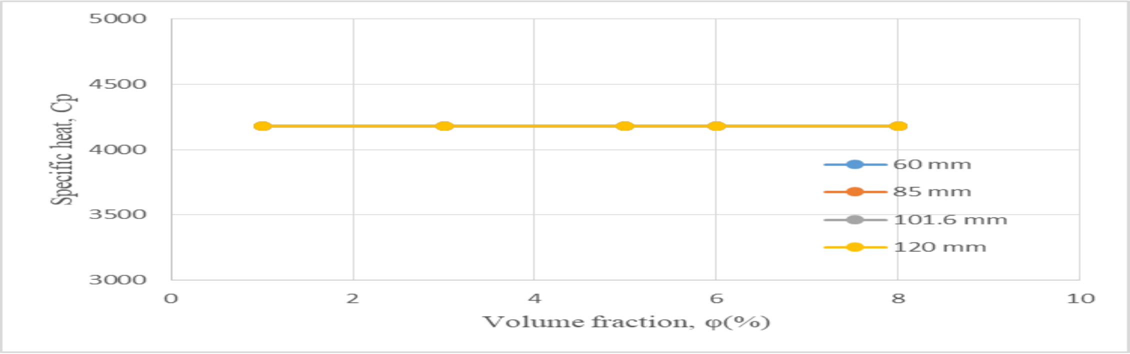


Fig.9. Influence of volume fraction on specific heat

Fig.9. shows the influence of volume fraction on thermal conductivity for *r* = 60 mm, 85 mm, 101.6 mm, 120 mm. It can be seen that the specific heat of the nanofluid remains constant irrespective of the volume fraction for different positions. With the increasing volume fraction the value of specific heat is constant. Thus volume fraction has no effect on specific heat.

8. Conclusion

A comprehensive investigation on forced convection in a radial cooling system filled with nanofluid is presented. Results have shown that nanoparticles provide a considerable increase in heat transfer rate than water even at small percentage of volume fraction. The flow behavior of the channel has been also seen and the effect of volume fraction on thermal properties has been discussed. This experiment shows significant proof of using nanofluid instead of base fluid. However research work will be necessary to evaluate the effect of particle size on the heat transfer rate as it is a factor that affect the heat transfer.

9. References

1. C. Prakash, U.S. Powle, N.V. Suryanarayana, Analysis of laminar flow and heat transfer between a stationary and a rotating disk, AIAA J. 23 (1985) 1666–1667.
2. S. Mochizuki, W.-J. Yang, Local heat-transfer performance and mechanisms in radial flow between parallel disks, J. Thermophys. 1 (2) (1986) 112–115.
3. A.Z. Szeri, S.J. Schneider, F. Labbe, H.N. Kaufman, Flow between rotating disks, part 1: basic flow, J. Fluid Mech. 134 (1983) 103–131.
4. S.V. Garimella, B. Nenaydykh, Nozzle-geometry effects in liquid jet impingement heat transfer, Int. J. Heat Mass Transfer 39 (14) (1996) 2915–2923.
5. S.U.-S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, ASME Publications, FEDVol. 231/MD-Vol. 66, 1995, pp. 99–105.
6. Y. Xuan, W. Roetzel, Conceptions for heat transfer correlation of nanofluids, Int. J. Heat Mass Transfer 43 (2000) 3701–3707.
7. S. Lee, S.U.-S. Choi, Application of metallic nanoparticle suspensions in advanced cooling systems, ASME Publications, PVP-Vol. 342/MD-Vol. 72, 1996, pp. 227–234.
8. J.A. Eastman, S.U.-S. Choi, S. Li, W. Yu, L.J. Thompson, Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles, Appl. Phys. Lett. 78 (6) (2001) 718–720.
9. B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Exp. Heat Transfer 11 (2) (1998) 151–170.
10. Iulian Gherasim, Gilles Roy, Cong Tam Nguyen, Dinh Vo-Ngoc, Heat transfer enhancement and pumping power in confined radial flows using nanoparticle suspensions (nanofluids), International Journal of Thermal Sciences 50 (2011) 369-377
11. Ravikanth S. Vajjha, Debendra K. Das, A review and analysis on influence of temperature and concentration of nanofluids on thermophysical properties, heat transfer and pumping power, International Journal of Heat and Mass Transfer 55 (2012) 4063–4078
12. Gilles Roy, Cong Tam Nguyen, Paul-Rene Lajoie, Numerical investigation of laminar flow and heat transfer in a radial flow cooling system with the use of nanofluids, Superlattices and Microstructures 35 (2004) 497–511
13. Khanafer, K., Vafai, K., Lightstone, M., 2003. Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids 46, 3639–3653.
14. Ogut E.B. Natural convection of water-based nanofluids in an inclined enclosure with a heat source. Int Journal of Thermal Sciences 4 8 (2009) 20 63–2073

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