INfIUENCE OF VOLUME FRACTION OF NANOPARTICLES ON THE LAMINAR FORCED CONVECTION flOW AROUND A CIRCULAR CYLINDER

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ABSTRACT

In this study, heat transfer due to forced convection of Al_2O_3-H_2O nanofluid flow over an isothermal cylinder has been nume rically investigated. Governing equations containing continuity, N–S equation and energy under steady state have been solved using finite volume method. Here, the Reynolds number (Re) are varying from 10 to 40 and the volume fractions (φ) are considered here are 0% to 5%. The effect of volume fraction of nanoparticles on fluid flow and heat transfer were investigated numerically. It was found that at a given Nusselt number, drag coefficient, re-circulation length, and pressure coefficient increases by increasing the volume fraction of nanoparticles

Keywords: *steady flow, nanofluid, volume fraction, Reynolds number, finite volume, circular cylinder.*

NOMENCLATURE

a – thermal diffusivity, [m^2/s]
C_D – coefficient of drag, [–]
D – cylinder diameter, [m]
k – thermal conductivity, [Wm^{-1} K^{-1}]
P – non-dimensional pressure, [–]
Pr – Prandtl number, $(= \nu/a)$, [–]
Re – Reynolds number, $(= \rho U_\infty D/\mu)$, [–]
t – non-dimensional time, [s]
T – temperature, [°K]
U,V – non-dimensional velocity components, [–]
x,y – non-dimensional coordinates, [-]

Greek symbols
μ – dynamic viscosity, [kg m-^{1}s^{-1}]
ρ – density, [kg m-^{3}]
θ – non-dimensional temperature, [–]
ν – kinematic viscosity, [m^{-2} s^{-1}]
α – separation angle [°]

Subscripts
∞ – inlet condition
w – wall
ave – average
f – fluid
p – solid
nf – nanofluid
s – separation of flo

1. INTRODUCTION

Forced convection heat transfer is an important phenomenon in engineering and industry with widespread application in diverse field, such as , microelectronics, transportation, nuclear power plants, cooling of microchips in computers, and heat exchangers and other industrial system in various sectors. Recently, a new class of heat transfer fluids, called nanofluids, has been developed by suspending nanocrystalline particles in fluids. Nanofluids are thought to be the next-generation heat transfer fluids, and they offer exciting possibilities due to their enhanced heat transfer performance compared to ordinary fluids.

2. MATHEMATICAL MODEL

Figure 1 shows the computational domain used in this investigation. The corresponding distance between the top and bottom boundaries is 100D.
At the inlet, a uniform flow was prescribed (U =1, V =0, $\theta_\infty = 0$). At the outlet, a homogeneous Neuman boundary condition for the velocity components (U and V) and temperature (θ) was used. No-slip conditions were prescribed on the cylinder. At the cylinder surface, uniform temperature (θ = 1) was prescribed.

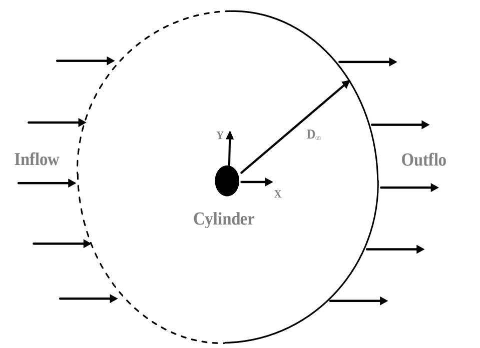


Fig. 1. Schematics of the unconfined flow around a circular cylinder

a. Properties of Nanofluids

The thermo physical properties of the nanofluids are mainly depend upon the properties of the base fluid and the solid particles, volume fraction of the solid particles in the suspension and particles shape. The properties of nanofluids can be calculated using the following relations
Density and heat capacity of nanofluid on the other hand, are estimated by using classical mixture models [14,15] as follows;

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_p \tag{1}$$

$$(\rho C_p)_{nf} = (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_p \tag{2}$$

Where,φ is the nanoparticle volume fraction and is given as:

$$\varphi = \frac{\text{Volume of nanoparticles}}{\text{Total volume of solution}} \tag{3}$$

In this study, for the homogeneous single-phase Al_2O_3 - water nanofluid model with constant properties, nanofluid thermal conductivity (k_{nf}) is determined by the correlation reported by Hamiltone Crosser [16]. The formulation can be given as;

$$\frac{k_{nf}}{k_f} = \frac{k_p + (n-1)k_f - (n-1)(k_f - k_p)\varphi}{k_p + (n-1)k_f + (k_f - k_p)\varphi} \tag{4}$$

where, n = 3 is the shape factor for spherical particles.
Maiga et al. [14] presented a 2nd degree polynomial curve fit to experimental data for Al_2O_3- water nanofluid viscosity as;

$$\frac{\mu_{nf}}{\mu_f} = 123\varphi^2 + 7.36\varphi + 1 \tag{5}$$

	k [W.m^{-1}.K^{-1}]	ρ [Kg.m^{-3}]	μ 10^{-3} [Kg.m^{-1}.s^{-1}]	Cp [J.kg^{-1}.K^{-1}]

Water	0.613	997.1	1.003	4179.0
Al_2O_3	40	3970	…..	765.0

TABLE 1. Thermophysical properties of nanoparticle and base fluids

b. Numerical Method

The fluid flow and heat transfer are solved by using commercial CFD solver FLUENT (6.3). FLUENT uses finite volume method, according to which, it is assumed that volume is made up of a large number of small control volumes, which are regular parallelepiped. The governing equations are valid over all such control volumes.

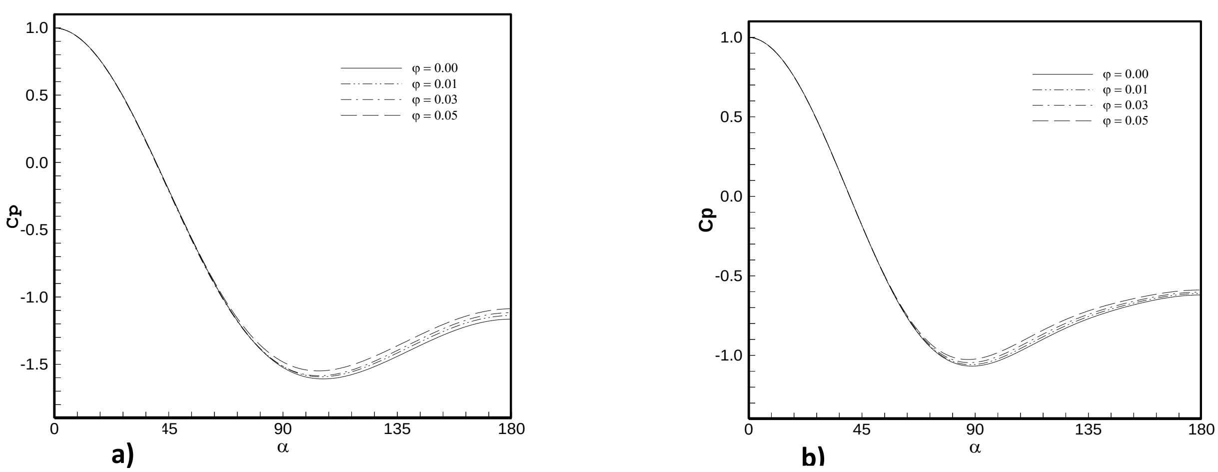
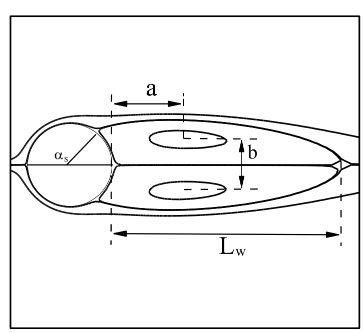


Fig 2. Distribution of pressure coefficient around surface of cylinder for various solid volume fractions φ at a) Re = 10, b) Re = 40

3. RESULTS AND DISCUSSION

a. Validation of Results.

The values obtained in current simulation are found to match closely with data published in literature.



.	Authors	C_D	α_s	L_w	a/D	b/D
Experime	Coutanceau and Bouard [7]	–	126.2	2.13	0.73	0.59
Numerical study	R. Gautier et al [12]	1.49	126.4	2.24	0.71	0.59
	Linnick and Fasel [16]	1.54	126.4	2.28	0.72	0.60
	Fornberg [13]	1.50	124.4	2.24	–	–
	Ding et al. [17]	1.58	127.2	2.35	–	–
	Present work	1.50	126.3	2.25	0.71	0.61

TABLE 2: Validation of present work results with literature values for Re = 40

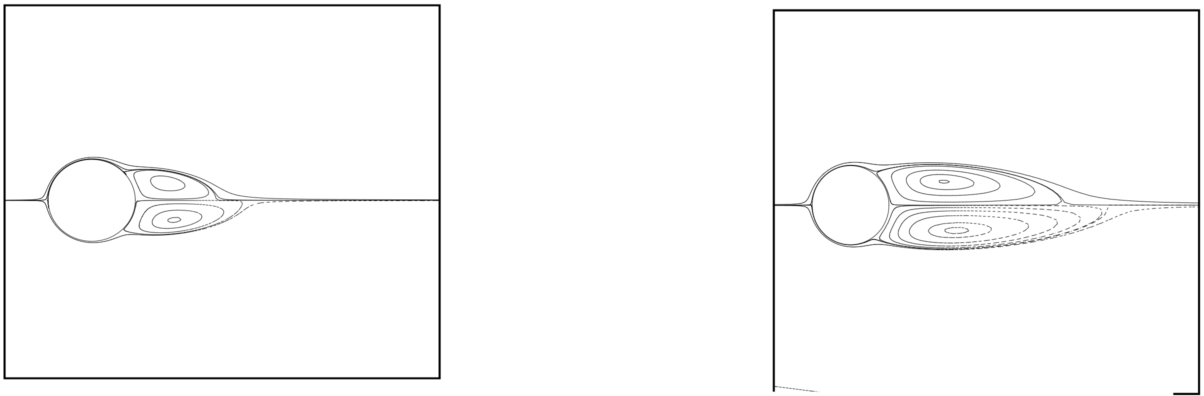
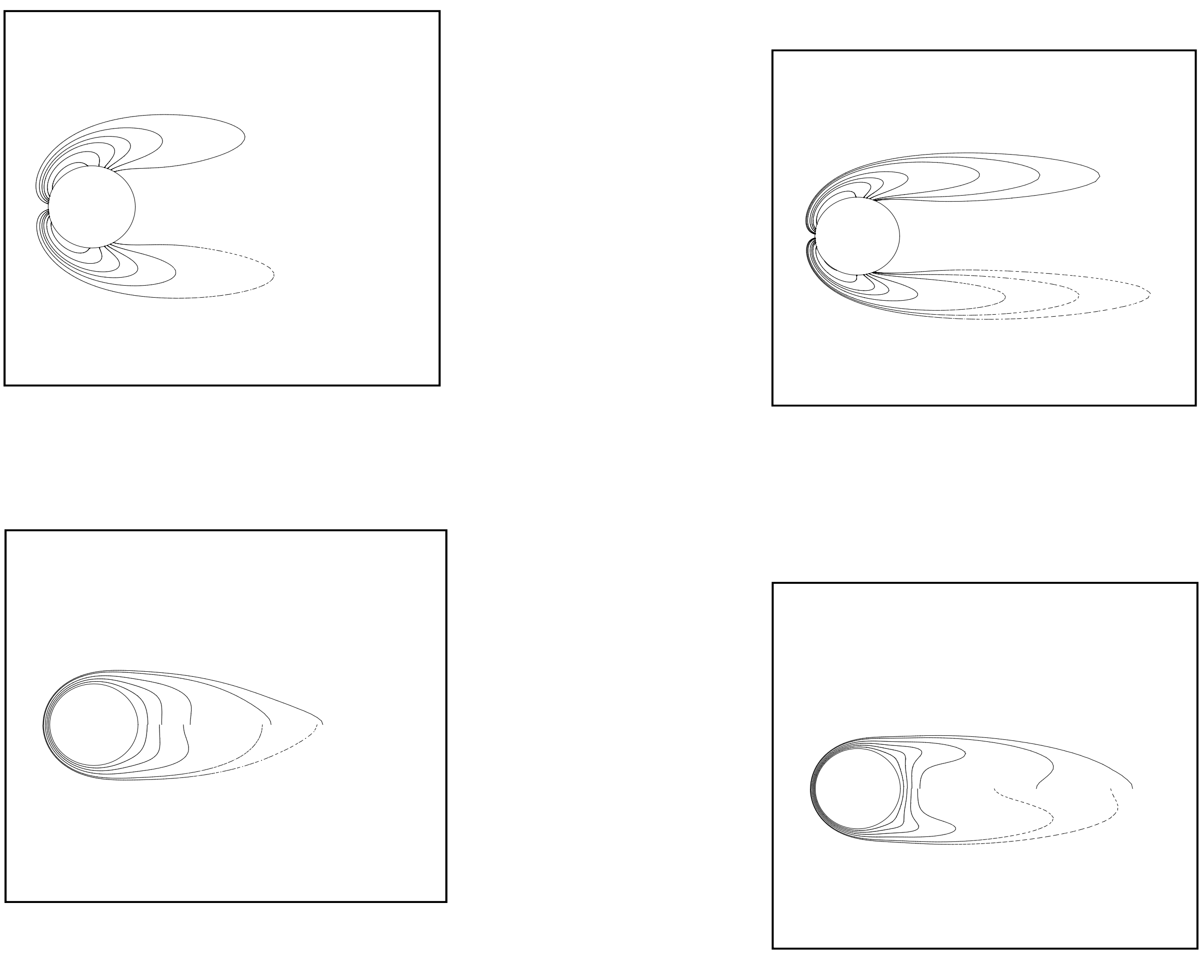


Fig 3. The streamlines, vorticity and isotherm contours around the cylinder, (clear fluid (upper half) and water/Al_2O_3 5% (lower half)) at a) Re = 20, b) Re = 40



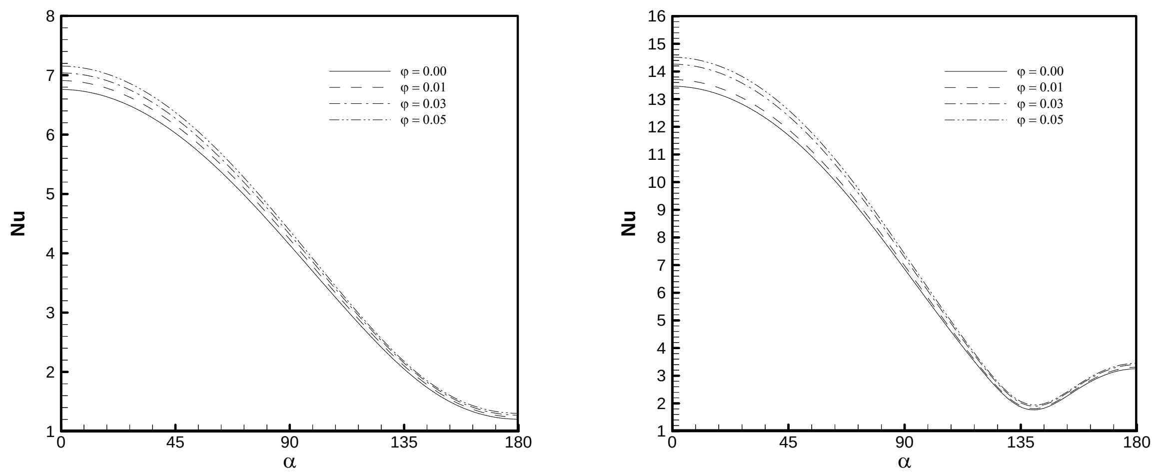
a)

b)

b. Effect of nanoparticle on flow characteristics

The streamlines, vorticity and isotherm contours around cylinder are compared between clear fluid and nanofluid (φ = 0.05) in Fig. 3 for Reynolds number of 10 and 40. It can be seen that the re-circulation length increases as Reynolds number increases in both clear and nanofluid. However, in nanofluid the center of wake is slightly shifted away from the surface of the cylinder comparing with clear fluid.

The strength of the vorticity is increased comparison with the nanofluid. For the temperature distribution contours, it can be concluded that the temperature contours are steeper in the near-wake region with increasing Reynolds number. This signifies that higher Reynolds number sets a higher temperature gradient. It can also be seen that the nanofluid show higher heat transfer rate from the cylinder than clear fluid.



a) Fig. 4 Variation of local Nusselt number on cylinder surface with various solid volume fraction φ at a) Re = 10, b) Re = 40 **b)**

c. Effect of nanoparticle on au

In this section, we investigate the effect of nanoparticle volume fraction on heat transfer performance of nanofluid. The quantification of heat transfer is characterized by local and average Nusselt number. For a nanofluid, the Nusselt number is a function of various factors such as heat capacitance and thermal conductivity of both the base fluid and the nanoparticles, the volume fraction of suspended particles, the viscosity of the nanofluid and the wake structur.

A comparison between local Nusselt numbers along the cylinder for various solid volume fractions and Reynolds number was show in Fig. 4. It can be seen that Nusselt number increase with increase in solid fraction as well as increase in Reynolds number. However, the reason for increase in the two cases is entirely different.

4. CONCLUSION

Single models have been investigated for the characterization of laminar forced convection of Al2O3 - water nanofluid with various concentrations around a circular cylinder. In this article, the point of investigation was to evaluate the effect of nano-particle on convective heat transfer and flow characteristics.

The significant observations made on the forced convection around a circular cylinder are summarized as follows:

1) The vorticity, pressure coefficient, recirculation length are increased by the addition of nanoparticles into clear fluid.

2) The Local Nusselt number, average Nusselt number and heat transfer coefficient of a nanofluid is augmented by increasing the volume fraction of nanoparticles.

3) Temperature gradient at the cylinder surface along normal direction drops with increase in nano particle concentration. However there is an increase in the thermal conductivity of nanofluid, thus leading to increase in Nusselt number.

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