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Numerical investigation of fluid flow and heat transfer around a solid circular cylinder utilizing nanofluid ☆

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ABSTRACT

In this study, flow-field and heat transfer through a copper–water nanofluid around circular cylinder has been numerically investigated. Governing equations containing continuity, N–S equation and energy equation have been developed in polar coordinate system. The equations have been numerically solved using a finite volume method over a staggered grid system. SIMPLE algorithm has been applied for solving the pressure linked equations. Reynolds and Peclet numbers (based on the cylinder diameter and the velocity of free stream) are within the range of 1 to 40. Furthermore, volume fraction of nanoparticles (φ) varies within the range of 0 to 0.05. Effective thermal conductivity and effective viscosity of nanofluid have been estimated by Hamilton–Crosser and Brinkman models, respectively. The effect of volume fraction of nanoparticles on the fluid flow and heat transfer characteristics are investigated. It is found that the vorticity, pressure coefficient, recirculation length are increased by the addition of nanoparticles into clear fluid. Moreover, the local and mean Nusselt numbers are enhanced due to adding nanoparticles into base fluid.

1. Introduction

The prediction of fluid flow and heat transfer past a circular cylinder has been the subject of significant research interests because of its relevance in many engineering applications. Fornberg [1], Deniss and Chang [2] and Braza et al. [3] studied the fluid flow past a circular cylinder. Sparrow and Lee [4], Badr [5], Bharti et al. [6] and Zhang et al. [7] presented convective heat transfer around a circular cylinder. Heat transfer characteristics have been enhanced around a circular cylinder by using a porous matrix [8,9]. Moreover, a new approach for enhancing heat transfer characteristics is adding the nanoparticles into base fluid [10,11]. However nanoparticles have extremely small size, wide specific surface area and high thermal conductivity [12]. Each nanofluid may have different rheological properties; therefore various correlations have been developed to estimate viscosity of nanofluids [13–15]. Since a nanofluid is usually contained some low concentration of nanoparticles, it is rational to consider nanofluid as a single phase flow [16]. The present work deals with the fluid motion and forced convective heat transfer around a circular cylinder using copper-water nanofluid. The effective thermal conductivity of nanofluid is estimated by Hamilton-Crosser model [17]. Furthermore Brinkman model [13] is applied for predicting the viscosity of nanofluid. However the main motivation of this study is to predict the effects of nanoparticles on heat transfer past a circular cylinder, the fluid flow parameters such as recirculation length, pressure coefficient etc are investigated as side-effects.

2. Mathematical modeling

2.1. Governing equations

Fig. 1 shows a schematic configuration of the computational domain and coordinate system used in the present study. A mathematical model of two dimensional, laminar and incompressible flow of a nanofluid past a long cylinder at cylindrical coordinate system can be expressed as the following:

- Continuity

$$\frac{1}{r^*}\frac{\partial(r^* u_r^*)}{\partial r^*} + \frac{1}{r^*}\frac{\partial u_\theta^*}{\partial \theta^*} = 0 \tag{1}$$

- θ — Momentum equation

$$\left(\frac{u_\theta^*}{r^*}\frac{\partial u_\theta^*}{\partial \theta^*} + u_r^*\frac{\partial u_\theta^*}{\partial r^*} + \frac{u_\theta^* u_r^*}{r^*}\right) = -\frac{1}{\rho_{nf}}\frac{1}{r^*}\frac{\partial p^*}{\partial \theta^*} + \nu_{nf}\left(\frac{1}{r^*}\frac{\partial}{\partial r^*}\left(r^*\frac{\partial u_\theta^*}{\partial r^*}\right) + \frac{1}{r^{*2}}\frac{\partial^2 u_\theta^*}{\partial \theta^{*2}} + \frac{2}{r^{*2}}\frac{\partial u_r^*}{\partial \theta} - \frac{u_\theta^*}{r^{*2}}\right) \tag{2}$$

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