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Flow of power-law fluids past an equilateral triangular cylinder: Momentum and heat transfer characteristics

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ABSTRACT

Extensive numerical simulations for the 2-D laminar flow of power-law fluids over an equilateral triangular cylinder are performed to elucidate the role of power-law index ($0.2 \leq n \leq 1.8$) on the critical Reynolds number denoting the onset of flow separation and of vortex shedding. Results are presented for both orientations of the triangular cylinder, namely, its apex facing in the upstream and the downstream directions. For shear-thinning fluids, the onset of wake formation and vortex shedding both are seen to be delayed than that in Newtonian and shear-thickening fluids. After delineating the limits of the steady flow regime, the effects of the Reynolds and Prandtl numbers and the power-law index on drag phenomena and heat transfer characteristics of triangular cylinder for shear-thinning fluids have been studied in the steady flow regime. The results reported herein embrace the following ranges of conditions: $0.2 \leq n \leq 1$; $1 \leq \mathrm{Re} \leq 30$ and $1 \leq \mathrm{Pr} \leq 100$. Detailed results on isotherm contours, local Nusselt number and its surface-averaged values are presented. Finally, the present numerical values of the critical Reynolds numbers and Nusselt number have been correlated using simple forms which are convenient for interpolating the present results for the intermediate values of the governing parameters in a new application.

1. Introduction

The flow of fluids over cylinders of different cross-sections constitutes an important class of problems within the field of fluid mechanics from both theoretical as well as pragmatic considerations. Such model flows are often used to gain useful insights into the nature of the underlying physical processes such as the detailed structure of the flow field, wake phenomenon, vortex shedding, etc. as well as the prediction of hydrodynamic forces acting on submerged objects (drag and lift), the rates of heat and mass transfer. In addition to such an overwhelming intrinsic importance, the flow past cylinders of various cross-sections is also encountered in numerous industrial settings. Typical examples include tubular and pin type heat exchangers, use of thin wires as measuring probes, support structures, cooling of electronic components, use of submerged obstacles to form weld lines in polymer processing applications, etc. Consequently, over the years, a vast body of knowledge has accrued on the flow of Newtonian fluids past cylinders of different cross-sectional shapes over wide ranges of conditions. A cursory inspection of the available information clearly shows that the bulk of the literature pertains to the case of a circular cylinder, followed by that relating to cylinders of elliptic and square cross-sections [1,2]. However, only very limited work has been reported on the flow over semi-circular cylinders [3–6], triangular [7,8], polygonal cylinders [9] and square cylinders (e.g., see [10,11]). In addition to the viscosity and density of the fluid and the diameter of the cylinder, the flow past a circular cylinder is influenced by a large number of parameters including its orientation with respect to the oncoming fluid, nature of the faraway flow field (oscillating, shear, uniform, angle of incidence, for instance), type of fluid (compressible or incompressible, Newtonian or non- Newtonian), confined or unconfined flow, aspect ratio of the cylinder, etc. Even for the simplest case of the parallel uniform cross-flow of an incompressible fluid past an unconfined circular cylinder, the flow exhibits a range of flow regimes. For instance, at very low Reynolds numbers, the flow remains attached to the surface of the cylinder thereby showing the complete fore and aft symmetry. Under these conditions, the flow is two-dimensional and steady provided the length to diameter ratio of the cylinder is large to avoid the end effects. This flow regime occurs up to about Re ~ 4–5. As the Reynolds number is progressively increased, the flow begins to separate in the rear part of the cylinder leading to the formation of two symmetric vortices. Both the length and width of the separated flow region increase

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