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Hydrodynamic and Rheological Behaviour of a Dilatant Fluid through a Rotating Cylinder

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ABSTRACT

The present study investigates numerically a fully developed turbulent flow of shear-thickening $(n=1.25)$ fluids through an isothermal axially rotating pipe by means of the large eddy simulation (LES) approach with an extended Smagorinsky model at simulation Reynolds numbers of 4500 and simulation Prandtl number (Pr_s) of 1 over a rotation rate range $(0 \le N \le 3)$. The emerging results suggest that the centrifugal force induced by the swirl driven by the rotating pipe wall causes a pronounced decrease in the shear rate profile of the dilatant fluid along the pipe radius, resulting in a marked increase in the axial velocity profile in the logarithmic region; this trend is more pronounced as the rotation rate increases.

Keywords: LES, fully developed, turbulent flow, shear-thickening.

1. Introduction

Non-Newtonian fluids play a vital role in mechanical, technical applications and engineering fields nowadays, as well as in petroleum, cement, pharmaceutical, polymer and food processing, and an extensive range of applications. According to the last literature survey, non-Newtonian fluids through axial pipes have attracted much attention recently. These investigations focused on studying the rheological and hydrodynamic behaviours of this type of fluids either experimentally [1], [2], [3]. The research of Metzner and co-workers (1955-1959) [1],[2],[3] remains to understand the rheological and hydrodynamic behaviour and flow of non-Newtonian fluids through a smooth pipe, they predicted the turbulent velocity profiles of non-Newtonian fluids, and they also derived a correlation for friction factor as a function of the generalised Reynolds number. More recently, Abdi and co-workers [4] offered extensive investigations of the turbulent flow of non-Newtonian fluids using the LES approach with an extended Smagorinsky model to investigate numerically the fully developed turbulent flow of Ostwald de Waele fluid through a straight cylindrical pipe with a length of the domain of 20R in the axial direction. Their predicted findings results were in excellent agreement with those of experimental and DNS data available in the literature. The present study investigates numerically a fully developed turbulent flow of shear-thickening $(n=1.25)$ fluids. through an isothermal axially rotating pipe by means of the large eddy simulation (LES) approach with an extended Smagorinsky model at simulation Reynolds numbers of 4500 and simulation Prandtl number (Pr_s) of 1 over a rotation rate range $(0 \le N \le 3)$.

2. Problem Description

The numerical integration has been performed by the finite difference scheme, second-order accurate in space and time with a numerical resolution of 65^3 grid-points in axial, radial and circumferential directions, respectively. The governing equations have been discretised on a staggered grid using cylindrical coordinates with a computational domain length of 20R in the axial direction.

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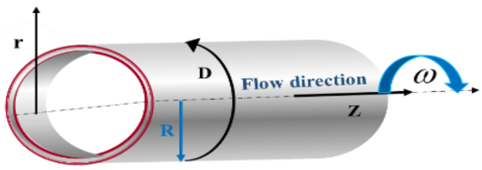

Figure 1: Computational Domain.

3. Results and Discussion

The figures 2 and 3, illustrate and depict the turbulent axial velocity profiles and the root mean square (RMS) distribution of the axial velocity fluctuations, respectively, of dilatant $(n=1.25)$ fluids, scaled by the friction velocity $U_\tau = \sqrt{\tau_w / \rho}$ along the pipe radius (R), versus the distance from the wall in wall units (Y^+) at a simulation's Reynolds number of 4500 and over a rotation rate range of $(0 \le N \le 3)$.It can be said that the centrifugal force induced by the swirl-driven results in a marked increase in the axial velocity profile in the core region, where which is known as the laminarisation phenomenon, and the swirl caused by the rotating pipe wall results in a noticeable attenuation in the generation and transport mechanism of turbulence intensities of the axial velocity fluctuation from the wall vicinity towards the core region for the dilatant fluid.

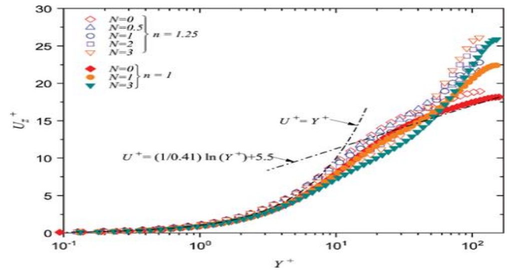

Figure 2: Turbulent axial velocity profiles.

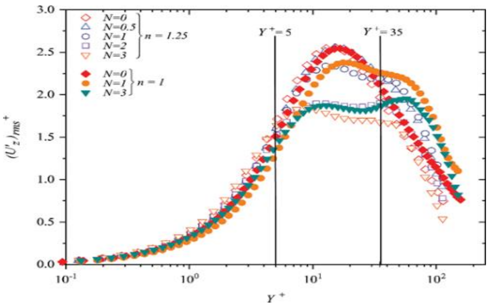

Figure 3: RMS of the fluctuating axial velocity profiles.

4. Conclusions

A critical examination of the effects of the centrifugal force induced by the swirl driven by the rotating pipe wall on rheological, hydrodynamic was the goal of the present study to shed further light on the laminarisation phenomenon of power-law fluids. The major conclusions of this research will be summarised:

- The streamwise velocity profiles of the dilatant were affected strongly by the centrifugal force induced by the swirl driven by the rotating pipe wall.
- In dilatant fluid, swirl generated by rotating pipe walls attenuated the generation and transport mechanism of turbulence intensities of the velocity fluctuations from the wall vicinity to the core region.

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