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LES of Turbulence Features of Turbulent Forced Convection of Dilatant Fluid in an Axially Rotating Pipe

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ABSTRACT

The present study seeks to shed further light on the laminarisation phenomena of the dilatant fluid by critically analysing the effect of the centrifugal force induced by the swirl driven by the rotating pipe wall on the thermal quantities. The present investigation also aims to ascertain the accuracy and the reliability of the laboratory code predicted findings and to examine the large eddy simulation approach effectiveness for predicting the turbulent flow of this kind of fluids. In addition to knowing to what extent the extended Smagorinsky model can characterise the scale's motions, especially in the wall vicinity. The emerged findings suggest that the centrifugal force induced by the rotating pipe wall results in a noticeable amelioration of the temperature fluctuations out of the viscous sub-layer. In other words, the swirl driven by the rotating pipe wall results in a pronounced enhancement in the generation and transport of the turbulence intensities of the temperature fluctuations. This trend is more pronounced as the rotation rate increases.

Keywords : LES, laminarisation, centrifugal force, dilatant.

1. Introduction

The turbulence state of a fluid is one of the most challenging problems in fluid dynamics due to its importance in mechanical and engineering fields. The 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. The flow through rotating pipes is of great practical interest because of the various industrial applications. Several computational and experimental experiments have been carried out in recent years to understand the laminarisation phenomenon better and examine the impact of the rotating pipe wall on the mean flow characteristics and turbulence statistics. According to the last literature survey, non-Newtonian fluids through axial pipes have attracted much attention recently. In 2019 Abdi et al. [1] studied the forced convection of a fully developed turbulent flow of the pseudoplastic ($n = 0.75$) and Newtonian fluids through a heated axially rotating pipe using LES with an extended Smagorinsky model. This investigation aimed to explore the effects of the flow behaviour index of the shear-thinning fluids on the rheological properties and the thermal quantities. More recently, Abdi and co-workers [2] performed extensive investigations of pseudoplastic and dilatant fluids through a heat-stationary cylindrical pipe to provide more details about the rheological and hydrodynamic behaviour in addition to the turbulence feature via analysing and discussing the effects of the flow behaviour index and Reynolds number on the mean flow, thermal quantities, and statistical turbulence quantities, especially in the vicinity of the wall. In recent decades, increasing attention and no study has been carried out on the turbulent flows of non-Newtonian fluids with related heat transfers through rotating cylindrical pipes. The current research aims to investigate the effects of turbulent and thermal properties using LES approach.

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2. Problem Description

The present study investigates numerically a fully developed turbulent flow forced convection of thermally independent dilatant fluid (n=1.25) through a heated axially rotating pipe using a large eddy simulation (*LES*) approach with an extended Smagorinsky model over a wide range of rotation rates ($0 \leq N \leq 3$) at the simulation's Reynolds and Prandtl numbers of 4500 and 1, respectively. With an adequate grid resolution of 65^3 gridpoints in r, θ and z direction, respectively, and a domain length of $20R$ in the streamwise direction. A Uniform heat flux (q_w) is imposed on the wall as a thermal boundary condition.

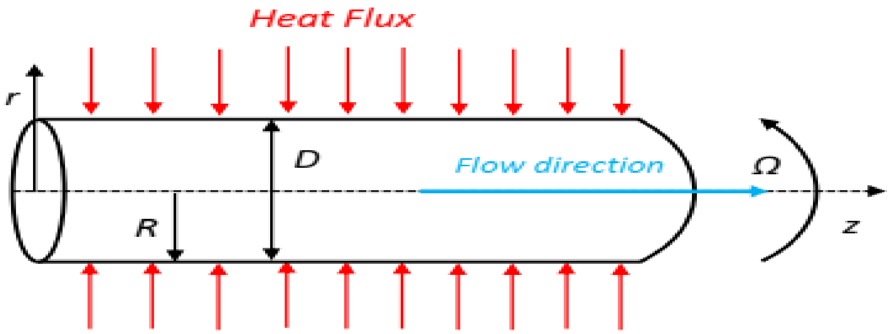

Figure 1: *Computational Domain*

3. Results and Discussion

The present subsection aims to shed light on the influence of the centrifugal force induced by the swirl driven by the rotating pipe wall on the fluid temperature by analysing and discussing the effect of the rotation rates. Figures 1 and 2 illustrate the temperature profiles and the *RMS* of the temperature profiles respectively.

Figure 2 shows the dimensionless temperature distributions (θ^+) of the dilatant ($n = 1.25$) fluid. There is a clear trend of increase in the temperature profile (θ^+) along the radial direction, where the temperature profile (θ^+) begins to enhance gradually wall with the wall distance far away from the pipe wall, for all cases. It can be seen from **Figure 2** that the profiles of the dilatant fluid begin to deviate slightly from each other with the wall distance (Y^+) further away from the pipe wall towards the core region. It is interesting to note that this reduction is due to the smaller residence time of the fluid particles away from the pipe wall. The fluid flow is more accelerated due to the centrifugal force induced by the pipe wall rotation; this trend is more pronounced as the rotation rate increases.

Moreover, it can be seen from **Figure 3** that the effect of the flow behaviour index (n) is almost limited in the vicinity of the pipe wall where the RMS profiles have the same tendency along the pipe radius; these profiles coincide with each other near the wall region ($Y^+ < 1$). At around ($Y^+ = 1$) these profiles differ considerably in the buffer and logarithmic regions with the distance from the pipe wall (Y^+). These profiles drop rapidly after reaching the peak locations, indicating that the temperature fluctuations are generated in the vicinity of the wall and propagated progressively towards the core region. It should be noted that beyond ($Y^+ \approx 7$), the temperature fluctuations intensities ultimately fall off to lower values, indicating that the temperature fluctuations vanish gradually far away from the wall for all rotation rates.

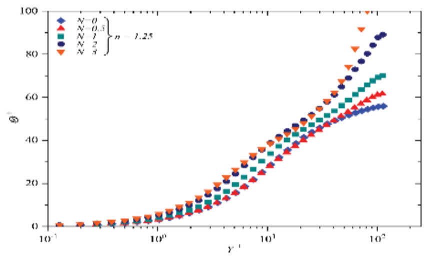

Figure 2: *Temperature Profiles*

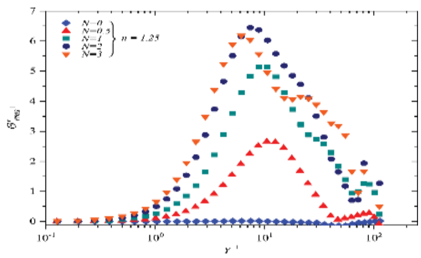

Figure 3: *Root Mean Square of Temperature Profiles*

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4. Conclusions

The major conclusions of this research will be summarised as follows:

- The increased rotation rate induced a noticeable reduction in the temperature profile along the radial coordinates, especially in the logarithmic region for the dilatant fluid.
- The increased rotation rate results in a pronounced increase in the turbulent transfer mechanism of the temperature fluctuations between the flow layers; this deviation is related to the smaller relative apparent fluid viscosity towards the pipe centre with an increasing rotation rate (N).

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