Transition to turbulence in pipe flow of shear-thinning fluid: Influence of the nonlinear viscous terms.

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Nicolas Lopez Carranza*, **Mathieu Jenny***, **Chérif Nouar***

* Laboratoire d'Énergétique et de Mécanique Théorique et Appliquée (UMR 7563 CNRS)
Nancy Université, 2 Avenue de la Forêt de Haye BP160, 54504 Vandoeuvre-lès-Nancy, France
e-mail: cherif.nouar@ensem.inpl-nancy.fr, web page: http://www.lemta.fr

ABSTRACT

Comparatively to the newtonian case, very few studies have been devoted to the transition to turbulence in a pipe for non-newtonian fluids, despite the importance of this problem in the design and the control in several industrial processes such as in oil-well cementing, extrusion of molten polymers, paper coating, *etc*. The existing literature reveals two interesting and yet unexplained effects: (i) delay of transition to turbulence [1] and (ii) an asymmetry of the mean axial velocity profiles [2]. The present work deals with the transition to turbulence in a pipe for a purely shear-thinning fluid. These linearly stable flows are mainly characterized by, on one hand, a stratification of the viscosity between the wall and the pipe axis and on the other hand, by a nonlinear variation of the viscosity with the shear rate. The rheological behavior of the fluid is assumed to be described by the Carreau-Yasuda's model: $\mu = [1 + (\lambda\dot{\gamma})^a]^{(n-1)/a}$, where $0 < n < 1$ is the shear-thinning index, λ is a dimensionless constant time of the fluid and $\dot{\gamma}$ is the second invariant of the strain rate tensor. It is worthy to note that the degree of nonlinearity in $\mu\,(\dot{\gamma})$ is much stronger than the quadratic nonlinearity of the inertial terms. The aim of the present work is to analyze the influence of this nonlinearity on the typology of the mechanisms of transition to turbulence. The governing equations are solved numerically using a solenoidal pseudo-spectral Petrov-Galerkin method similar to that proposed by Meseguer and his co-workers [3], [4]. The time discretization uses a semi-implicit fourth-order scheme. The nonlinear viscous and convective terms are calculated in the physical space and integrated via the Adams-Bashforth explicit formula, while the linear terms are calculated via an implicit scheme. At time $t = 0$, the flow is assumed fully developed and a perturbation in the form of streamwise rolls is added. Numerical results show that the nonlinear dependency $\mu(\dot{\gamma})$ leads to: (i) reduction of viscous dissipation, which is related to a new term in the Reynolds-Orr equation, denoted "non-newtonian Reynolds-stress tensor" and (ii) the formation of a broad spectrum of azimuthal modes which affects significantly the mechanisms of transition to turbulence.

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