DIRECT NUMERICAL SIMULATION OF VISCOPLASTIC-TYPE NON-NEWTONIAN FLUID FLOWS IN STENOSED ARTERIES

A Carmona[1], O Lehmkuhl[1,2], C D Pérez-Segarra[1] and A Oliva[1]
[1]*Heat and Mass Transfer Technological Center, Technical University of Catalonia, Colom 11, 08222 Terrassa (Barcelona), Spain.*
[2]*Termo Fluids, S.L., Avda. Jaquard, 97 1-E, 08222 Terrassa (Barcelona), Spain.*
E-mail: 1 cttc@cttc.upc.edu, 2 termofluids@termofluids.com

Abstract
The aim of this work is to provide DNS solutions for turbulence flows of viscoplastic-type non-Newtonian fluids and thus contribute to gain insight into the underlying physics of the non-Newtonian turbulent flows. This knowledge may be useful, among many other things, for developing more accurate turbulence models which describe better the implicit physics of this subject. Nevertheless, from our point of view, few DNS solutions of viscoplastic-type non-Newtonian fluid flows have been provided with this objective, despite the growing presence of these kind of fluids in the field of CFD simulations.

INTRODUCTION

CFD simulations for turbulent flows of viscoplastic-type non-Newtonian fluids are of special interest due to the increase of their applications on the biomedical field, among many others. For example, cardiovascular diseases, such as stenosis [9, 10] and aneurysm [14, 13, 12], begin to be more often dealt with this kind of computational techniques. The reason is that, on the one hand, these computational techniques allow to analyse isolatedly the fluid dynamics from the rest of factors with which it interacts in a non-linear way to jointly contribute to the disease evolution. On the other hand, these numerical solutions can also complement the standard diagnoses of these diseases with a more accurate quantitative information.

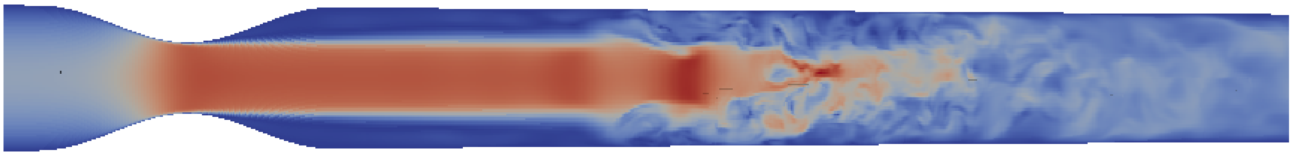
DISCUSSION

Several authors have used specific rheological laws together with the generalized Newtonian model to analyse the flow of non-Newtonian fluids which exhibit stresses exclusively viscous with plastic effects (viscoplastic fluids). Brent C. Bell and Karan S. Surana [2] used a power-type rheological law to analyse the flow of some non-Newtonian fluids in different geometrical configurations. K.A. Pericleous [8] studied the fluid flow and the heat transfer in a differentially heated cavity using a power-type rheological law, in order to characterize the pseudoplastic and dilatant behaviour of certain non-Newtonian fluids. M. M. Molla et al. [7] analysed the characteristics needed for a LES model in order to be conceptually consistent with the behaviour of non-Newtonian fluids, using a Cross rheological law to describe the behaviour of a specific non-Newtonian fluid. M. Rudman et al. [11, 6] used direct numerical simulation for turbulent flow of shear-thinning non-Newtonian fluids in a pipe to understand the transition and turbulence flow of this kind of fluids. Nevertheless, from our point of view, few DNS solutions of viscoplastic-type non-Newtonian fluid flows have been provided, despite the growing presence of this kind of fluids in the field of CFD simulations.

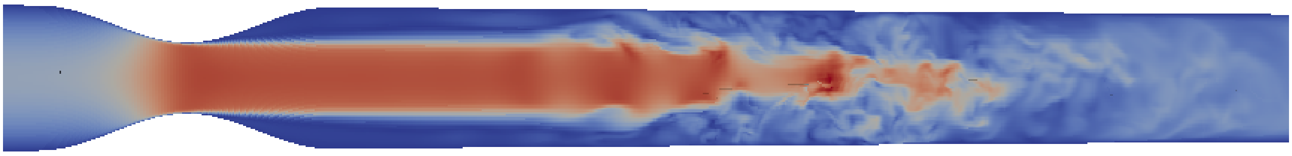
Therefore, the aim of this work is to provide DNS solutions for turbulence flows of viscoplastic-type non-Newtonian fluids. A sudden expansion channel (SEC) [4] and a constricted rigid pipe (CRP) [1] are used as test cases, the latter being the main test problem in which this work will focus. It is expected DNS solutions to contribute to gain insight into the underlying physics of the non-Newtonian turbulent flows. This knowledge may be useful, among many other things, for developing turbulence models which describe better the implicit physics of this subject. In order to achieve this objective, manufactured solutions [3], benchmark solutions [2] and experimental results [1] are being used to verify and validate the numerical models developed [5, 3] to deal with this kind of non-Newtonian fluids.

CONCLUSIONS

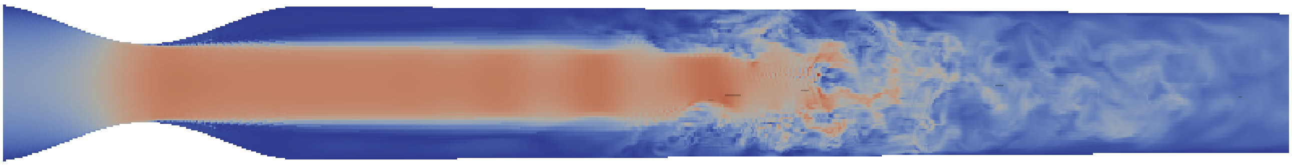
The viscoplastic behaviour of certain non-Newtonian fluids is generated from a viscous stress which has been defined by a potential-type rheological law. In the present work, the pseudoplastic and dilatant behaviours are being studied. On this matter, the influence of different physical aspects on the numerical simulations are being analysed, e.g. different exponent values in the potential-type rheological law and different values of the non-dimensional numbers. Moreover, the influence of different numerical aspects on the numerical simulations are also being analysed, e.g. mesh generation algorithms, conservative numerical schemes and more efficient and parallel algorithms and solvers. More details about this work will be included in the future paper.



(a) Dilatant fluid, n=1.25



(b) Newtonian fluid, n=1.0



(c) Pseudoplastic fluid, n=0.95

Figure 1: Preliminary instantaneous snapshots of the velocity field, Re=1000;

References

[1] S. A. Ahmed and D. P. Giddens. Velocity measurements in steady flow through axisymmetric stenoses at moderate reynolds numbers. *Journal of Biomechanics*, **16**:505–516, 1983.

[2] B.C. Bell and K.S. Surana. Surana. p-version least squares finite element formulation for two-dimensional, incompressible, non-newtonian isothermal and non-isothermal fluid flow. *International Journal for Numerical Methods in Fluids*, **18**:127–162, 1994.

[3] A. Carmona. *Numerical simulation of the fluid dynamics and the thermal behaviour of non-newtonian fluids of pseudoplastic and dilatant type*. PhD thesis, Technical University of Catalonia, UPC, 2011.

[4] R. M. Fearn, T. Mullin, and K. A. Cliffe. Nonlinear flow phenomena in a symmetric sudden expansion. *Journal of Fluid Mechanics*, **211**:595–608, 1990.

[5] O. Lehmkuhl, C.D. Perez-Segarra, R. Borrell, M. Soria, and A. Oliva. Termofluids: A new parallel unstructured cfd code for the simulation of turbulent industrial problems on low cost pc cluster. **67**:275–282, 2009.

[6] H.M. Blackburn M. Rudman. Direct numerical simulation of turbulent non-newtonian flow using a spectral element method. *Applied Mathematical Modelling*, **30**:1229–1248, 2006.

[7] M. M. Molla, A. Hossain, B.-C. Wang, and D. C. S. Kuhn. Large-eddy simulation of pulsatile non-newtonian flow in a constricted channel. *Progress in Computational Fluid Dynamics*, **12**:231–242, 2012.

[8] K.A. Pericleous. Heat transfer in differentially heated non-newtonian cavities. *International Journal of Numerical Methods for Heat & Fluid Flow*, **4**:229–248, 1994.

[9] M. Rosenfeld. Validation of numerical simulation of incompressible pulsatile flow in a constricted channel. *Computers and Fluids*, **22**:139–156, 1993.

[10] M. Rosenfeld. A numerical study of pulsating flow behind a constriction. *Journal of Fluid Mechanics*, **30**:203–223, 1995.

[11] M. Rudman, H.M. Blackburn, L.J.W. Graham, and L. Pullum. Turbulent pipe flow of shear-thinning fluids. *Journal Non-Newtonian Fluid Mechanics*, **118**:33–48, 2004.

[12] T.H. Yip and S.C.M. Yu. Oscillatory flows in straight tubes with an axisymmetric bulge. *Experimental Thermal and Fluid Science*, **26**:947–961, 2002.

[13] S. C. M. Yu. Steady and pulsatile flow studies in abdominal aortic aneurysm models using particle image velocimetry. *International Journal of Heat and Fluid Flow*, **21**:74–83, 2000.

[14] S. C. M. Yu, W. K. Chan, B. T. H. Ng, and L. P. Chua. A numerical investigation on the steady and pulsatile flow characteristics in axi-symmetric abdominal aortic aneurysm models with some experimental evaluation. *Journal of Medical Engineering & Technology*, **23**:228–239, 1999.