Implementation of a Viscoelastic Model to Generate a Shear Stress Test Using the DEVSS/SUPG Method

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INTRODUCTION: The viscoelastic flow of polymer based energetic materials exiting an extrusion die is one of the most complex problems to tackle by CFD owing to the hyperbolic nature of the equation of state describing the extra stress tensor. The only way to solve the problem is to simulate it using a stabilized numerical method. This project aims at developing a simulation model that will facilitate die design process for new formulations. [1]

$$\boldsymbol{\tau}+\lambda\left(\frac{\partial \boldsymbol{\tau}}{\partial t}+\mathrm{u}\cdot\nabla\boldsymbol{\tau}-\boldsymbol{\tau}\cdot\nabla\mathrm{u}-\nabla\mathrm{u}^{\mathrm{T}}\cdot\boldsymbol{\tau}\right)=\eta_p\left(\nabla\mathrm{u}+\nabla\mathrm{u}^{\mathrm{T}}\right)$$

Equation 1. Upper-convected Maxwell equation

COMPUTATIONAL METHODS: Dozens of numerical methods were created to solve this type of equation with more or less success. However the most widespread and reliable approach, as demonstrated with a variety of flow configurations, remains the discrete elastic viscous split stress. This technique consists in adding an equation with its test function in order to define the velocity gradient and make the problem more elliptical. It is generally coupled with a streamline upwind Petrov-Galerkin to avoid oscillation due to convective terms. In this study an unsteady viscoelastic flow inside a slot geometry is considered.[2]

$$(\boldsymbol{S}+\alpha\boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{S},\lambda\overset{\nabla}{\boldsymbol{\tau}}+\boldsymbol{\tau}-2\eta\boldsymbol{D})=0, \quad (1)$$

$$((\boldsymbol{\nabla}\boldsymbol{v})^T,2\eta(\boldsymbol{D}-\bar{\boldsymbol{D}})+\boldsymbol{\tau})-(\boldsymbol{\nabla}\cdot\boldsymbol{v},p)=0 \quad (2)$$

$$(\boldsymbol{E},\boldsymbol{D}-\bar{\boldsymbol{D}})=0. \quad (3)$$

Equation 2. stabilized week formulation of UCM coupled to momentum equations

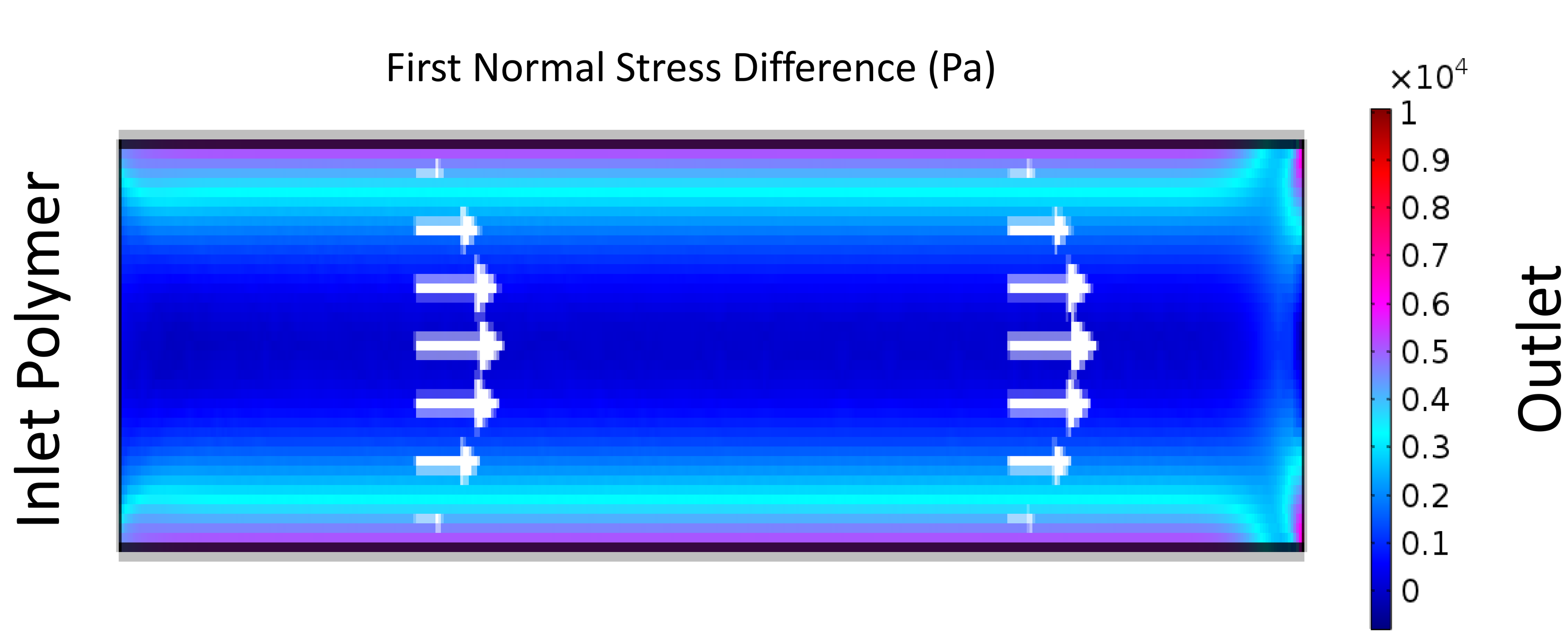

Figure 2. Laminar Flow of Polymers Inside a Slot Geometry during steady state for Re=0.01 and Wi=0.35

RESULTS: In this study, the DEVSS/SUPG has been applied to simulate the behavior obtained with Oldroyd-B and PTT models. The following figures show the results obtained during a step shear stress test, and the difference between the numerical predictions and the analytical solutions. In both cases, the discrepancy between two curves never exceeded 2%.

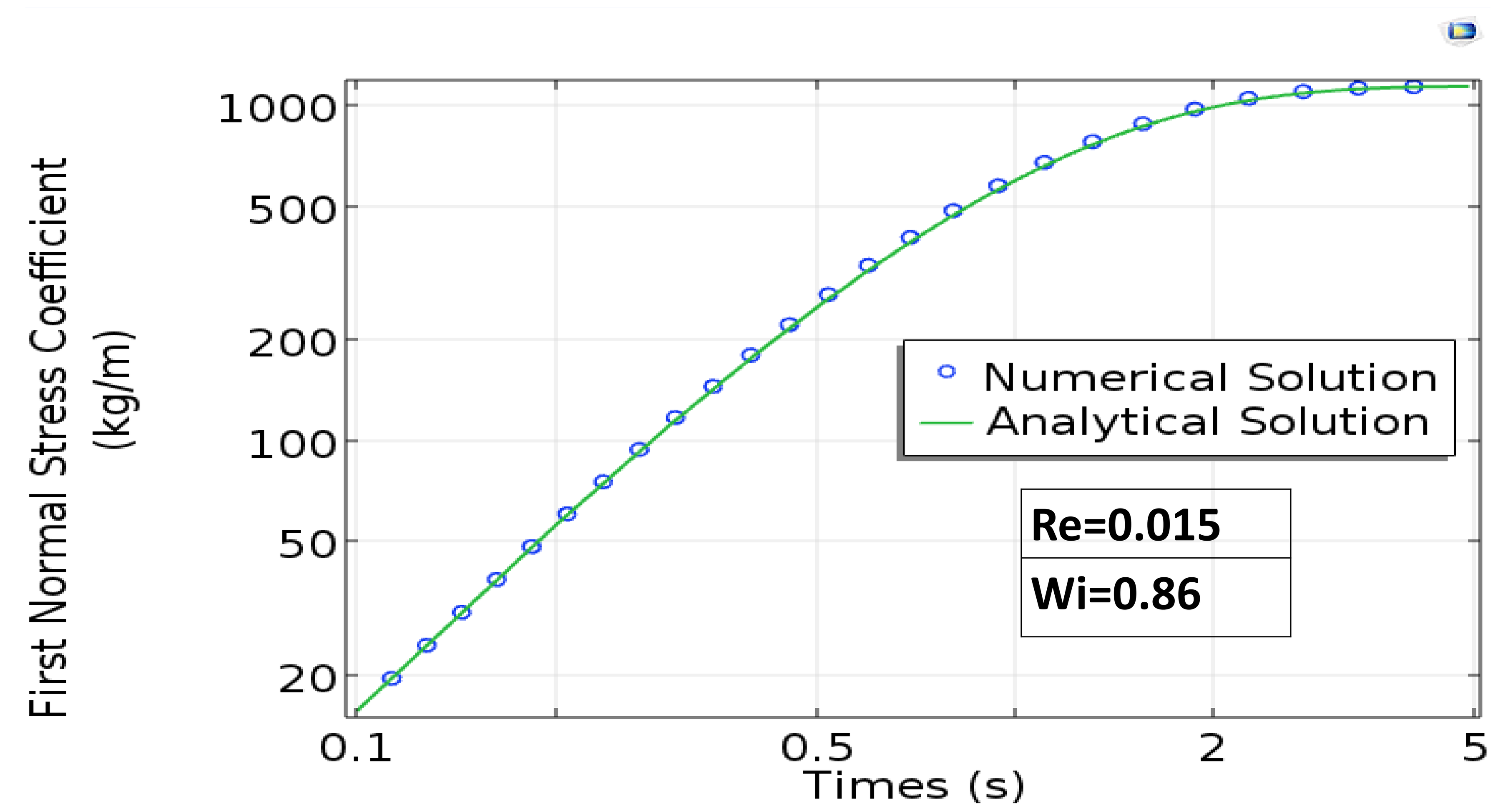

Figure 3.
Evolution of the first normal stress difference during a step shear stress for an Oldroyd-B Model

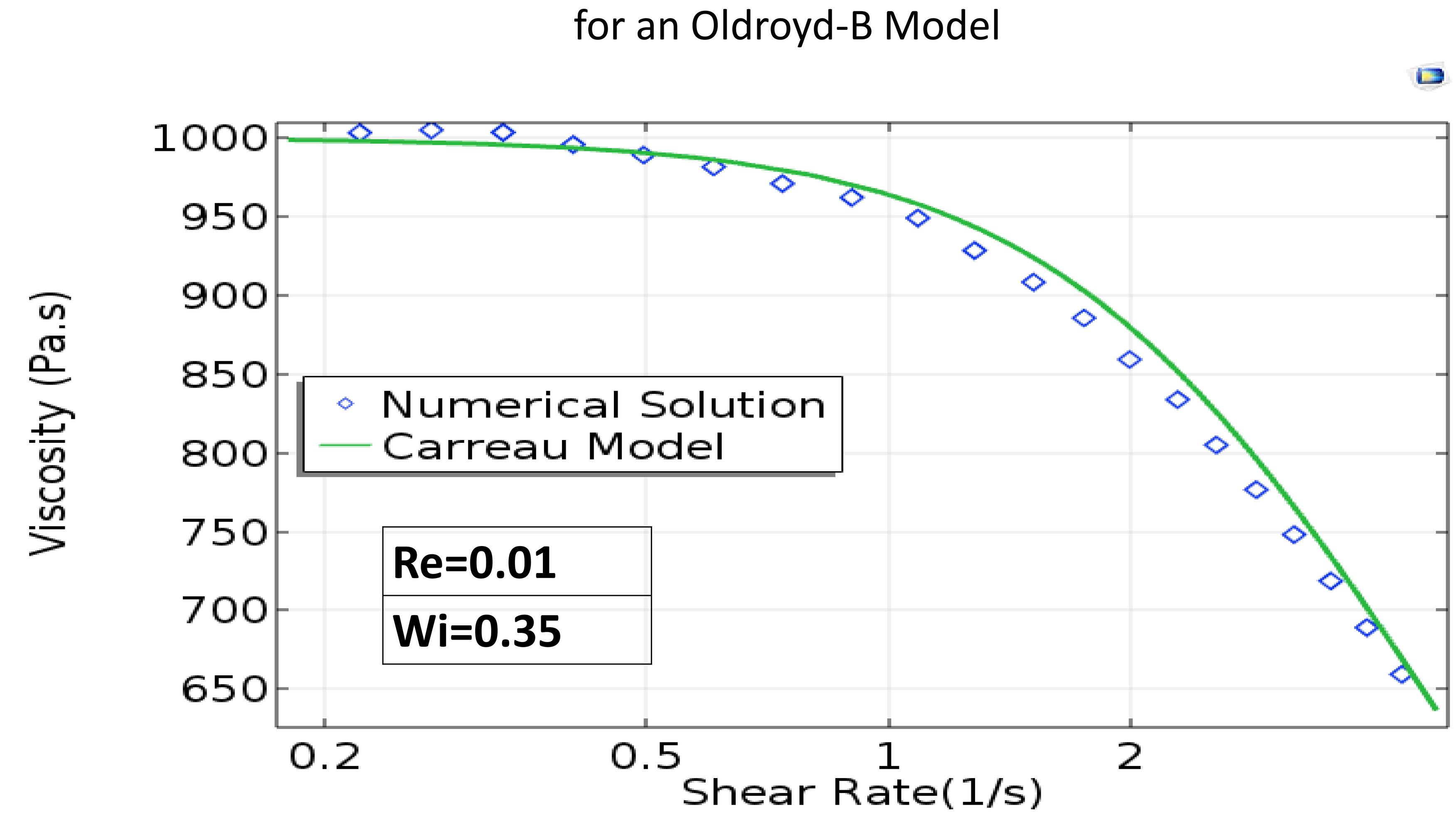

Figure 4.
Evolution of viscosity as a function of shear rate for a shear thinning polymer (PTT Model)

CONCLUSIONS: It is possible to satisfactorily depict the behavior of a viscoelastic fluid Couette flow. The next steps will consist in simulating a flow inside a 4:1 contraction, which is analog to a converging die before the free surface flow at its exit. The final aim of this project is to develop a robust design technique for the sheet die extrusion of viscoelastic energetic materials.

REFERENCES:

1. Pimenta, F., & Alves, M. A.. Stabilization of an open-source finite-volume solver for viscoelastic fluid flows. Journal of Non-Newtonian Fluid Mechanics, 239, 85-104.)(2017)
2. Owens, R. G., & Phillips, T. N.. Computational rheology (Vol. 14). London: Imperial College Press.(2002)

Acknowledgments: The financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) is gratefully acknowledged.