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J.E. López-Aguilar, M.F. Webster, H.R. Tamaddon-Jahromi, O. Manero

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High-Weissenberg predictions for micellar fluids in contraction-expansion flows[1]

J. E. López-Aguilar[a], M.F. Webster[a,2], H.R. Tamaddon-Jahromi[a], O. Manero[b]

[a]Institute of Non-Newtonian Fluid Mechanics, College of Engineering, Swansea University, SA2 8PP, United Kingdom; [b]Instituto de Investigaciones en Materiales, UNAM, 04510, Mexico.

Abstract

This study is concerned with the numerical modelling of thixotropic and non-thixotropic materials in contraction-expansion flows at high Weissenberg number (*We*). Thixotropy is represented via a new micellar time-dependent constitutive model for worm-like micellar systems and contrasted against network-based time-independent PTT forms. The work focuses on steady-state solutions in axisymmetric rounded-corner 4:1:4 contraction-expansion flows for the benchmark solvent-fraction of β=1/9 and moderate hardening characteristics (ε=0.25). In practice, this work has relevance to industrial and healthcare applications, such as enhanced oil-reservoir recovery and microfluidics. Simulations have been performed via a hybrid finite element/finite volume algorithm, based around an incremental pressure-correction time-stepping structure. To obtain high-*We* solutions, both micellar and PTT constitutive equation *f*-functionals have been amended by (i) adopting their absolute values appealing to physical arguments (ABS-correction); (ii) through a change of stress variable, $\boldsymbol{\Pi}=\boldsymbol{\tau}_p+(\eta_{p0}/\lambda_1)\boldsymbol{I}$, that aims to prevent the loss of evolution in the underlying initial value problem; and finally, (iii) through an improved realisation of velocity gradient boundary conditions imposed at the centreline (VGR-correction). On the centreline, the eigenvalues of $\boldsymbol{\Pi}$ are identified with its $\boldsymbol{\Pi}$–stress-components, and discontinuities in $\boldsymbol{\Pi}$–components are located and associated with the *f*-functional-poles in simple uniaxial extension. Quality of solution is described through τ_{rz}, N_1 and N_2 (signature of vortex dynamics) stress fields, and $\boldsymbol{\Pi}$-eigenvalues. With {micellar, EPTT} fluids, the critical Weissenberg number is shifted from critical states of We_{crit}={4.9, 220} without correction, to We_{crit}={O(10^2), O(10^3)} with ABS-VGR-correction. Furthermore, such constitutive equation correction has been found to have general applicability.

Keywords: high-elasticity solutions, positive definiteness, wormlike micelles, Bautista-Manero models, numerical simulation, hybrid finite element/volume method, enhanced oil-recovery

1. Introduction

This study addresses the topic of high Weissenberg (*We*) number solutions for worm-like micellar systems using the class of Bautista-Manero models [1-4]. The work concentrates on the rounded 4:1:4 contraction/expansion benchmark flow problem, and various alternative procedural and constitutive approaches are introduced. Herein, high-elasticity levels are accessible through two routes: (i) a correction to the constitutive model based on physical arguments, in which absolute values of the dissipation-function components are considered in complex flow; and (ii) the imposition of consistent boundary conditions at the axisymmetric geometry centre flow-line. There, in complex flow, the

[1] Dedicated to Professor Ken Walters on the occasion of his 80th birthday

[2] Author for correspondence, email: M.F.Webster@swansea.ac.uk