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The fully-implicit log-conformation formulation and its application to three-dimensional flows

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Abstract

The stable and efficient numerical simulation of viscoelastic flows has been a constant struggle due to the High Weissenberg Number Problem. While the stability for macroscopic descriptions could be greatly enhanced by the log-conformation method as proposed by Fattal and Kupferman, the application of the efficient Newton–Raphson algorithm to the full monolithic system of governing equations, consisting of the log-conformation equations and the Navier–Stokes equations, has always posed a problem. In particular, it is the formulation of the constitutive equations by means of the spectral decomposition that hinders the application of further analytical tools. Therefore, up to now, a fully monolithic approach could only be achieved in two dimensions, as, e.g., recently shown in [P. Knechtges, M. Behr, S. Elgeti, Fully-implicit log-conformation formulation of constitutive laws, J. Non-Newtonian Fluid Mech. 214 (2014) 78–87].

The aim of this paper is to find a generalization of the previously made considerations to three dimensions, such that a monolithic Newton–Raphson solver based on the log-conformation formulation can be implemented also in this case. The underlying idea is analogous to the two-dimensional case, to replace the eigenvalue decomposition in the constitutive equation by an analytically more "well-behaved" term and to rely on the eigenvalue decomposition only for the actual computation. Furthermore, in order to demonstrate the practicality of the proposed method, numerical results of the newly derived formulation are presented in the case of the sedimenting sphere and ellipsoid benchmarks for the Oldroyd-B and Giesekus models. It is found that the expected quadratic convergence of Newton's method can be achieved.

Keywords: Log-conformation, Oldroyd-B model, Giesekus model, Finite element method
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1. Introduction

Viscoelastic flows are ubiquitous in modern industrial applications. They are essential for the correct description of the flow properties of blood, as well as polymer melts, which makes a good understanding of the used models necessary

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