Viscoelastic flow simulations in random porous media

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between the horizontal nozzles, the meniscus interface exhibits periodic oscillations due to the downstream drop detachment. Increasing the elasticity of the injected fluid has a stabilizing effect on the meniscus, the flow dynamics between the nozzles subsequently reaching a quasi-steady state. The maximum distance between the nozzles which keeps the meniscus out of breaking was also investigated; that distance increases with the relaxation time of the polymer solution. A "taut spring" model is proposed to characterize the dynamics of the phenomena, the measured time evolution of the upper-meniscus shape being compared with the numerical solutions of the obtained equation.

Wednesday 13:20 Amalienborg NF25

Exchange flows of viscoplastic liquids in vertical tubes

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Well plugging for abandonment is an essential operation performed under a variety of conditions. The success of the operation is related to the capability of the cement plug to remain on the top of the drilling fluid while it sets, which can take several hours. However, gravity tends to move cement plugs downwards, due to their larger density relative to the drilling fluid underneath. The aim of the research is to better understand cement plug stability. To this end, we performed an experimental study with two immiscible liquids in a vertical tube considering viscoplastic and interfacial effects. The elasto-viscoplastic fluids are Carbopol® 980 aqueous solutions at different concentrations, and the lighter fluids are either Soya soybean oil or Shell Tellus Premium Oil 46. The influence of interfacial tension was studied through the use of surfactants. The test section consists of a Plexiglas tube, 44mm internal diameter and 660mm length, with a Mylar® sliding gate to ensure an initially flat interface. Flow visualization was performed with a digital camera, and the terminal velocities of the heavier fluid were obtained through image analysis. The influence of the governing parameters on the interface stability, front velocity at terminal motion, and morphology was investigated. Three different equilibrium regimes were observed, namely unstable, metastable, and stable (no flow). The unstable regime is a wavy core-annular flow with the denser fluid in the core that begins instantaneously after gate removal. In metastable equilibrium a plug flow develops after a delay time. For the limiting cases of unstable equilibrium regime, the presence of surfactant changes the force balance by reducing the interfacial tension contribution, thus favoring the onset of flow. It was observed that interfacial tension does not affect significantly terminal velocity. Moreover, the denser fluid velocity (zero or finite) can be estimated from the state of equilibrium analysis through dimensionless parameters.

Wednesday 13:40 Amalienborg NF26

Flow of a second order oluid through a porous medium: Rheological validation of a generalized Darcy’s equation

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The flow of a non-Newtonian fluid through and over a porous medium occurs in a variety of industrial, biological and environmental applications as resin transfer moulding, propagation of blood through kidney, environmental clean-up technologies, and injection of drilling fluids in rocks either for wells reinforcement or for enhancing oil recovery. Finally, important is the flow through and over a roughened geometry that is encountered in rheometry. Roughened geometries are indeed used to prevent, or reduce, the apparent wall slip often observed with, e.g., multiphase fluids and/or highly non-Newtonian fluids. A convenient way to study such problems is with homogenized equations like those of Darcy, or Brinkman, valid for Newtonian fluids. Phenomenological modifications of Darcy's law to account for the fluid non-Newtonianess are available in the literature for shear thinning fluid. Recently, Minale (2016a,b) developed a generalization of Brikman's equation for second order fluids, in the sense of Coleman and Noll, and the corresponding boundary condition to be applied at the interface between a porous medium and a homogeneous fluid. The second order fluids have a general behaviour to which each real fluid must tend in the limit of slow flows.
We here experimentally validate the theory proposed by Minale (2016a,b) by choosing a cross-hatched geometry as an ideal brush-like porous medium and two Boger fluids, with different elasticity, as the model fluids obeying the second order constitutive equation. We used an ARES-G2 (TA Instruments) equipped with a cross-hatched geometry on a single plate and we measured both the velocity at the interface and the first normal stress difference. We compared the experimental results with the model predictions and we validated the important theoretical results that the new non-Newtonian permeability depends on the porous medium characteristics, only.

References: Minale M., Phys. Fluids, 28, 023102, 2016a; Minale M., Phys. Fluids, 28, 023103 2016b.

Wednesday 14:00 Amalienborg NF27

Viscoelastic Flow Simulations in Random Porous Media

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Polymer liquids are used in the oil industry to improve the volumetric sweep efficiency and displacement efficiency of the oil from a reservoir. Surprisingly, it is not only the viscosity but also the elastic properties of the displacing fluid that determine the displacement efficiency. This may be caused by the ability of a viscoelastic fluid to pull oil out of dead-ends. The aim of our work is to obtain a fundamental understanding of the effect of fluid elasticity, by developing an advanced computer simulation methodology for the flow of non-Newtonian fluids through porous media.We simulate a 3D unsteady viscoelastic flow through a model porous medium using computational fluid dynamics. The primitive variables velocity, pressure and stresses are used in the formulation. The physical and rheological properties of actual polymer solutions used in polymer flooding have been incorporated, where the viscoelastic stress part is formulated using a FENE-P type of constitutive equation. The simulations are performed using a finite volume methodology with a

staggered grid. The solid-fluid interfaces of the porous structure are modeled with a second ordered immersed boundary method.The porous medium is generated by placing stationary spherical particles of equal size in random positions using a Monte Carlo method. By means of 3D periodic boundary conditions we model the flow behavior for Newtonian and viscoelastic fluids through such a porous structure. The effect of porosity and different Deborah numbers (De) is studied in detail. The simulations provide insight on how flow structure and viscoelastic stresses change with increasing De number. To our surprise we observe completely different flow structures at high De through various pore configurations. The simulations provide a detailed understanding of the strong interplay between fluid rheology and flow topology in a random porous medium. This work has a significant importance for applications in oil recovery, polymer and food processing, and other industries.

Wednesday 15:50 Amalienborg NF28

Making a hole in a viscoelastic film: the role of deformation history

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The main feature of a viscoelastic fluid is the presence of a fading memory. As a consequence, the fluid remembers the past deformation history over times of the order of the material relaxation time. Such a feature is of particular interest when a hole is made through a liquid thin film and the subsequent hole opening dynamics are considered. For a purely viscous fluid (and if inertia can be neglected) the opening speed depends solely upon the balance between surface tension and viscous forces. On the contrary, when elasticity comes into the game, it plays a complex and relevant role. In this case, the elastic energy possibly stored in the fluid during film formation can make the initial film retraction faster (possibly much faster) than in the purely viscous case. The practical consequences of this concept are investigated in the present contribution. In particular, a home-made apparatus is used to generate a viscoelastic bubble by inflating a thin viscoelastic film. Immediately following inflation, a hot needle creates a small hole in the film, and its opening dynamics are quantitatively measured by image processing of a high-speed camera movie. The experimental results show that the initial hole opening speed increases as the film inflation rate increases, thus proving the role of the elastic energy stored during the film inflation. We also show that a simple, yet physically sound mathematical model is able to capture the essence of the observed behaviour without the need of adjustable parameters.

Wednesday 16:10 Amalienborg NF29

Dewetting of freely suspended films of polymer solution

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We study the dewetting of freely suspended films of polymer solution, where viscous effect are dominant. This problem is interested in many industrial process such as curtain coating. We develop a one-dimensional model that takes into account the rheological properties of polymer solutions. We numerically solve the evolution equation and compare to the scaling results.

Wednesday 16:30 Amalienborg NF30

Displacing difficult yield stress fluids from pipes

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Having yield stress fluids (YSFs) stuck in ducts is a common occurrence in industrial and natural settings that range from flow assurance in pipelines, through mucus-blocked aioli in pneumonia to the cleaning of dairy products in food processing. Here we give an overview of recent experimental studies in which pipes filled with YSFs (Carbopol) are cleaned by displacing with a Newtonian fluid (water). In these experiments we focus on regimes where the yield stress is the dominant stress in the system and hence removal is ``difficult''. We explore these flows by varying rheology, flow rates, pipe inclination and density differences. Dimensionlessly we vary the Reynolds number, inclination, Atwood number, viscosity ratio and Froude number, all at very large Bingham numbers. Broadly, 3 types of displacement flow are observed: central flows, slump flows and mixed flows. The transition between central and slump flows appears to be governed by the ratio of Reynolds and Froude number (equivalent to the Archimedes number). For any flow parameters, a sufficiently large Reynolds number results in mixed displacements, i.e. via turbulence, but mixing may be instigated at lower Reynolds numbers by viscosity or buoyancy-driven instabilities. Without any buoyancy increasing the Reynolds number results in progressively smooth interfaces between fluids: low Reynolds numbers counter-intuitively lead to progressively wavy and irregular interface. In vertical displacements varying the density difference (Atwood number) from positive to negative has 2 main effects. First the overall effectiveness of the displacement increases, aided by buoyancy. Secondly at sufficiently large viscosity ratios, viscous fingering occurs ahead of the main displacement front. These fingers can propagate either initially in the centre, or near the wall, often adopting helical patterns as they destabilize and mix. In between these parameters a whole zoo of interesting flow types are observed, as we review.