4th Workshop on

Viscoplastic Fluids: From Theory to Application

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Organizers

Pontifícia Universidade Católica do Rio de Janeiro
University of British Columbia

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FOREWORD

These proceedings contain the abstracts of the presentations of the Fourth Workshop "Viscoplastic Fluid: From Theory to Application," held at Marina Palace Hotel in Rio de Janeiro, RJ, Brazil, on November 6-10, 2011.

The Workshop has the support of the Brazilian Society of Rheology (SBR). It is organized by Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio, Local Organizers and Scientific Committee) and the University of British Columbia (UBC, Scientific Committee). Its objective is to bring together the leading researchers in the field of viscoplastic fluids, across several disciplines, to foster awareness and the cross-disciplinary transfer of ideas.

The first Workshop of this series was held in 2005 at BIRS, in the city of Banff, Alberta, Canada. The next ones took place in Monte Veritá, Switzerland (2007), and in Limassol, Cyprus (2009).

The Organizing Committee is thankful for the financial support of CNPq, CAPES, FAPERJ, and the Brazilian Society of Rheology. Thanks are also due to the Department of Mechanical engineering of PUC-Rio. The Committee also wishes to express its gratitude to the technical staff for their valuable help.

Finally, the organizers extend a warm welcome to all participants, wishing them a very pleasant stay in Rio de Janeiro.

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Length-scale dependence of the gel transition

John R. de Bruyn
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Abstract
We have studied gelation in a Laponite clay suspension and in polymer blends using shear rheometry and microrheological techniques. Both types of materials undergo a gel transition as the material ages, and this transition is visible in both the micro and the bulk measurements of the viscous and elastic moduli. The gel transition occurs later on the microscopic scale than on the bulk scale, however. The reasons for and the generality of this scale-dependence will be discussed.
Rheo-PIV and Large Amplitude Oscillatory Shear Flow For Probing Visco-Elasto-Plastic Behavior in Yielding Materials

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Abstract
Waxes, clay dispersions and micellar solutions are examples of complex rheological systems that all display dramatic shear-thinning, viscoplastic responses, wall-slip and thixotropy beyond a critical imposed stress. To explore the dynamics of these transitions we use a Rheo-PIV system that enables simultaneous measurements of the bulk flow behavior using rheometry and of the local shearing deformation using Particle Image Velocimetry. The bulk rheological measurements are correlated to deviations from the linear velocity profile anticipated for a homogenous sample undergoing simple shear - this provides new insights into the structural and rheological evolution of these complex fluid systems under representative shearing conditions. Large Amplitude Oscillatory Shear (LAOS) is used in order to map out the progressive development in the non-linear behavior in the material. The capabilities of the Rheo-PIV apparatus allow deviations from a linear velocity profile to be determined within a single cycle of oscillatory shear and continuously monitored over several cycles of aging, or internal yielding. These deviations can also be correlated to simultaneous measurements of the oscillating stress-strain response of the fluid.

As a specific example we consider the formation of hydrocarbon wax mixtures; a commonly encountered precipitate that can result in gelation of crude oils and cessation of flow in pipelines. We develop a model wax-oil system that exhibits rheological behavior similar to waxy crude oils encountered in production scenarios. The restart of flow and breakdown of the gelled wax-oil structure is observed in the RheoPIV system under two scenarios - a constant applied stress, and a constant applied strain rate. In addition, the effect of varying surface roughness on flow restart is investigated by comparing the temporal evolution of the velocity fields for an initially gelled fluid in contact with both a roughened and smooth surface. The material response in each case indicates that some classes of surface act as slip inhibitors and prevent the gelled wax-oil system from slipping against them. This promotes bulk deformation and the more rapid breakdown of the gel structure. These results are consistent with recent observations in other jammed/yielding systems and have an immediate bearing on pipeline restart strategies.
Viscoplastic fluids in forming processes

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Abstract
Many industrial applications of viscoplastic fluids are to be found in forming processes, wherein the ability of the material to retain its shape following processing makes it possible to manufacture products of complex shape. Examples include the clays which led Eugene Bingham to coin the simplest model for viscoplastic flow. These materials may be categorised as 'stiff' pastes as the critical stress for yielding will often be of the order of 1 kPa or greater. Clays and dense particulate pastes also offer the opportunity to manufacture products with particular microstructures. The challenge in this area of viscoplastic fluid flows is to tie together the knowledge of how to formulate a paste, e.g. selecting the solid and liquid phases, to give the rheological behaviour suited to the forming process, which in turn requires a reliable understanding of how the fluid is flowing in the forming machine. This presentation will review how far we have come along the path to a priori forming processes being designed in silico, with particular focus on extrusion, illustrated by examples from a range of industrial processes.
Osmotic interactions and solid-liquid transitions in soft colloid-polymer mixtures

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Abstract
Colloid-polymer mixtures are established as an ideal model system for studying the effects of depletion interactions on colloidal phase/state behavior and tailoring the viscosity of suspensions. In the last decade, the role of particle softness was revealed. This additional parameter is responsible for an unprecedented richness in the behavior of the mixtures. In this work, we build-up on this background and examine in detail the state behavior of entropic mixtures involving star and linear polymers. We show how to quantify individual component contributions based on the osmotic effect of the linear chains. We also take advantage of this effect in tuning yielding and re-entrance transitions, hence providing design criteria for controlling the rheological character of the mixture at molecular scale. The choice of the particular soft colloidal system is also discussed in terms of its yielding and time-dependent rheology which reflects the behavior of a large class of particulate systems.
Rheology and the Resource Industries

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Abstract
The world’s resource industries, which include minerals, coal, and the sand mining of oil, are the world’s largest producers of waste. Much of this waste is produced as a fine particle suspension which is pumped to a storage area generally at a low concentration where it behaves like a Newtonian fluid. Simply by removing water from the suspension and reusing and recycling water represents a step towards a more sustainable practice in this industry. As the concentration of such a suspension is increased as a result of dewatering, the materials exhibit non-Newtonian behaviour, characterized by shear thinning, a yield stress, and in some instances, by thixotropic behaviour. Such high concentration, non-ideal (dirty) suspensions in the resource industries has meant that new rheological methods and techniques were needed for both shear and compression rheology to measure and interpret the basic flow properties. Also, some older empirical techniques needed to be modified and interpreted in a more fundamental way so that the results could be used in design. The paper reviews these techniques and illustrates how the industry itself has motivated their development. Understanding and exploiting this rheology has resulted in dramatic improvement in the waste disposal strategy for some industries, but many have failed to embrace the available technology. Why? Is regulation the answer? Probably not. The paper concludes that a greater positive change in the waste management practice will occur in the future, motivated by a number of factors, including public perception and perhaps even by common sense accounting.

The paper is an overview of thirty years of work with the resource industries on environmental waste minimisation. Aspects have been published in the Proceedings of Paste and Thickened Tailings Conferences held annually since 19991,2

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1 Conference Proceedings are available from The Australian Centre for Geomechanics, Nedlands, Western Australia.
2 The complete version of this paper is available in Chemical Engineering Science.
Restart of Waxy Crude Oil: a new approach to determine the initial gel structure

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From an operational viewpoint, transporting waxy crude oil in pipeline under steady state flowing conditions is not a too complex operation. However, during shutdown process when the pipeline is submitted to severe external temperatures, the large wax content of waxy crude oils leads to many rheological problems related to the interlocking gel-like structure build-up ([1]-[2]-[3]-[4]). The primary interest with waxy crude oils transportation is the issue of restarting. In particular, the operating conditions required to restart the flow strongly depend on the properties of the gel structure, and so on the shutdown conditions in terms of temperature and flow rate under which the gel has been formed. For all these reasons, it is essential to have a fairly accurate description of the gel structure at the initial restart time.

In this paper, we propose a new approach combining numerical calculations and experimental characterisations in order to determinate the initial state of the gel structure and to estimate the restart conditions of the flow (restart pressure, restart time...).

The gel structure determination is based on dynamic rheometer tests by taking into account the thermal and mechanical history, i.e. temperature and flowing conditions at which the oil has been transported, cooled down and stopped.

A 1.5D restart numerical model is used to tackle the whole restart process given the initial state of the gelled waxy crude oil established with dynamic rheometer tests. The 1.5D model is able to simulate the restart of a weakly compressible viscoplastic and thixotropic fluid flushed by another fluid. The rheological model is the Houska model [5]. In this 1.5D model, only the velocity component in the direction of the pipe axis is assumed non-zero but it is allowed to vary both in axial and radial directions [6].


Startup tube flow of thixotropic yield-stress fluids

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Abstract
The startup flow of thixotropic yield stress fluids in tubes is studied numerically. In the situation of interest, the structured fluid is displaced by another fluid, under the application of a constant inlet pressure. The fluid is assumed to obey a recently pro- posed model for thixotropic yield-stress fluids that relies on a structure parameter. The momentum conservation principle is employed in a simplified form that arises by assuming quasi-steady flow, i.e. the shear stress radial distribution is assumed to be linear as it is in steady flow. Inertial effects are also included in the analysis. A numerical procedure was developed to integrate the differential equations that arise, and the average velocity and structure parameter radial distribution are obtained for different combinations of the rheological and flow parameters, allowing the determination of the necessary conditions for a successful restart. Among other features, the approach is capable of predicting the “avalanche effect,” i.e. situations of no flow for long time periods and then the sudden onset of motion.

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Numerical Model To Predict the start-up of weakly compressible flows of thixotropic drilling fluids

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Abstract
This work presents a mathematical model to simulate the start-up flow of drilling fluids in drillpipes. The compressible transient flow approach is build upon the one-dimensional mass and momentum conservation equations, an equation of state and a thixotropic fluid model. On the contrary to prior works that deals with the gel breaking by employing a viscous-plastic model together with a structure parameter model, the current work uses an approach that also accounts for the material elasticity. Such thixotropy model is fitted to rheometer data with reasonable agreement. The start-up flow is then simulated and the results are compared to Newtonian and Bingham fluid flow models. It can be anticipated that the pressure overshoots observed in start-up flows depend not only on the thixotropy properties of the fluid but also on the flow compressibility and Reynolds number. Besides, the thixotropic pressure overshoots are not always larger than the Bingham and Newtonian counterparts as one would expect.
Rheology of waxy crude oils

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Abstract
Along the last decades, significant research effort has been directed into developing procedures for obtaining reliable rheological measurements of waxy crude oils. The challenge has been to understand the effects of thermal and shear histories on rheological properties such as viscosity, yield stress, storage modulus, and loss modulus. In this talk we start by exemplifying that the complex rheological behavior of waxy oils gives rise to significant lack of consensus in the related literature. We then proceed to present a broad-range set of rheometric experiments for a waxy crude oil, including temperature ramps, flow curves, creep tests, and stress-amplitude-sweep tests, and compare the results obtained with the ones found in the literature. We demonstrate that precautions must be taken—in addition to the ones recommended in the established literature—in order to obtain reliable data from rotational rheometry. We also investigate the effects of the holding time and of the temperature and shear histories on the microstructure, through the postcooling rheological properties of these oils. Finally, we discuss the use of a recently proposed elasto-viscoplastic thixotropic fluid model as an attempt to mimic the rheological behavior of these materials.

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Partial displacement of visco-plastic fluids with large yield stress in slightly inclined pipes

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Abstract
We study experimentally and analytically the buoyant miscible displacement flow of a visco-plastic fluid by a Newtonian fluid along a long pipe, inclined at angles close to horizontal. We focus on the industrially interesting case where the yield stress is significantly larger than a typical viscous stress in the displacing fluid, but where buoyancy forces may be significant. We identify two distinct flow regimes: a central-type regime usually found for small density ratios or at steeper angles of inclination, and a slump-type regime for higher density ratios. In the central-type displacement flows, we find non-uniform static residual layers around the pipe wall. We show that the non-uniformity is actually a long-wave variation along the pipe. In the slump-type displacement we generally detect two propagating displacement fronts. A fast front propagates in a thin layer near the bottom of the pipe. A much slower second front follows, displacing a thicker layer of the pipe, but sometimes stopping altogether. The second front appears to be affected by buoyancy and when it stops this is associated with relaxation/spreading of the front shape. In the thin lower layer the flow rate is focused and can result in large Reynolds numbers, in the transitional regime. These flows can be unsteady and unpredictable.

We show that the two regimes are delineated by the value of the Archimedes numbers, a parameter which is interestingly independent of the imposed flow rate. We present the phenomenology of the two flow regimes. Our experiments use Carbopol as the yield stress fluid, displaced with water. We use flow visualisation and an ultrasound Doppler velocimetry technique to measure velocities and the thickness of the static residual layer. For simplified configurations, we compare computational and analytical predictions of the flow behaviour (e.g. static layer thickness) with our experimental observations.

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Displacement of two viscoplastic materials in a capillary plane channel

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Abstract
The immiscible displacement in a capillary plane channel of two viscoplastic materials that obey a Papanastasiou's constitutive equation is numerically analyzed. An elliptic mesh generation technique, coupled with the Galerkin Finite Element Method is used to determine the velocity field and the configuration of the interface between the two materials. We investigate the displacement efficiency and the flow patterns of the problem as functions of the dimensionless parameters that govern the problem: the capillary number (Ca), the viscosity ratio of the two fluids (Nh) and the yield numbers associated to the displacing and displaced materials. We constructed maps of streamlines in the Cartesian space defined by the different dimensionless numbers in order to capture the rough location of the transition between bypass and recirculating flow regimes. Higher yield number values induce bypass flow regimes, especially for high Ca.

The dimensionless forms of the momentum conservation equation and the force balance at the interface were essential for the understanding of the role played by the dimensionless numbers that govern the problem. Flow patterns were sometimes markedly different from other pairs of fluid--fluid displacement investigated in the literature.
Injection of yield stress fluid through porous medium

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Keywords: yield stress fluid, porous media, injection

Abstract
The flow of non-Newtonian fluids through porous media is of interest for various applications: injection of cements slurries to reinforce soil, propagation of blood through kidney and, likely the most economically important application, injection of drilling fluids in rocks. The basic knowledge of the pressure drop needed to induce a steady inertia-less flow of a yield stress fluid through a porous medium is as yet not well developed. The ultimate goal is to be able to predict the pressure vs flow rate relation from independent measurements of the fluid properties and porous systems characteristics. Several approaches based on network model [Chen et al. (2005), Chase and Dachavijit (2005)] provide more accurate description of the reality but no generic relation. All the different numerical or theoretical models have to be validated by some macroscopical experiment. Some experimental studies with flow of yield stress fluid through porous media have been done [Park (1972), Al-Fariss and Pinder (1987), Mendes et al. (2002), Chase and Dachavijit (2005)] but they are still scarce. However, existing data rely on a limited range of mean flow velocity, typically slightly more than one decade, and parameter variations (pore size and rheological parameters). This implies that the comparison with a model can hardly be discriminatory. Actually a major difficulty in experiments of non-Newtonian fluid through porous media is to control both the fluid properties and the characteristics of its transport through the porous medium, in particular the measurement of the pressure drop is one of the main problems. Here we present a set of data obtained for two types of test (rheometry and flow transport through porous media) in a wide range of shear rates and varying sample size, pore size, material type (emulsion, gel) and the rheological characteristics of the fluid. First we show that the pressure vs flow rate data may be very well represented by a Herschel-Bulkley model. In addition, for a material type, the parameters of this model are simply proportional to those of the flow curve of the fluid. However, an unexpected effect appears: these parameters depend on the material type (emulsion or gel). We then discuss the possible physical origin of these results. An asymptotic approach forecast well the general form (HB) of the pressure vs flow rate relation. A complementary study concerning flows through simple geometries allows to estimate the values of the parameters and suggests that the origin of the observed difference is a confinement effect, an overestimation of the yield stress for small gaps.
The Stability of Yield Stress Fluids: Paradoxes and Opportunities

I.A. Frigaard\textsuperscript{1,2}

Abstract: Although the study of hydrodynamic stability dates back to the late 1800’s, the study of analogous problems with yield stress fluids is much more recent. We give an outline of this interesting area, explaining which techniques have been used and where the limitations lie in the analysis performed to date. We take a look at classical parallel shear flows and explain the stability paradox of a vanishing yield stress and discuss some experimental anomalies. We then highlight some of the unique features of flow stability in yield stress fluid flows and give examples of how these features might be exploited practically.

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Stratified flows of Herschel-Bulkley fluids in pipes: Closure Approximations.

Ian Frigaard and Miguel Moyers-Gonzalez

Abstract
In this work we consider a two-fluid laminar stratified flow of shear-thinning viscoplastic liquids. For rheological description of the materials we choose the Herschel-Bulkley model. We propose an approximation of the mathematical description of the closure problem. This approach uses an analytical approximation of the closure that retains the fluid constitutive laws and satisfies the stress conditions, but approximates the flow rates in a way that mimics the behaviour of the full system. This way we expect to effectively model rheological behaviour of the approximation, i.e. retaining a fairly uniform error over a broad range of parameters.
Thermal plumes in a yield-stress fluid: comparison of laboratory and numerical experiments

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Abstract
Thermal convection in non-Newtonian fluids occurs in many different fields, from engineering (glass-production, food industry) to geoscience (planetary mantles, lava lakes, icy satellites), but is still not very well understood. From a theoretical point of view, the difficulty is that the viscosity of these fluids approaches infinity when the motion amplitude vanishes. Therefore convective instabilities cannot grow from a static conductive state submitted to infinitesimal perturbations (as in the classical Rayleigh-Bénard configuration). For this reason, we study the development of thermal plumes out of a localized heat source (peltier element) in Carbopol. Rheometry shows that this fluid presents a yield stress, is shear thinning and can be described by the Herschel-Bulkley model. Thermochromic-liquid-crystals and PIV allow us to measure simultaneously temperature and velocity fields. The results show that depending on the yield parameter $Y_0$, defined as the ratio of the thermally induced stress and the yield stress, three different regimes can develop. For very low $Y_0$, no motion is observed. For intermediate $Y_0$, a slow convection cell develops around the heater. At high $Y_0$, a finger-shape instability develops from the slowly convecting cell. The finger morphology is associated with a deformation very localized on the edges of the thermal anomaly, while the material inside the plume rises as a plug. Furthermore, depending on the experimental parameters, the instability motion can show episodicity. We have systematically studied the influence of the yield stress, the thermal power of the heat source and the fluid height on development and behavior of the instability.
In parallel, we have conducted a numerical study to compare to the experimental results. In a first step, we solve only the "liquid" problem: since a Herschel-Bulkley rheology implies infinite viscosity at zero-shear-rate, we regularize the viscosity by imposing a high cut-off value at low shear rate. Despite this regularization, the numerical simulations reproduce well a number of features observed in the laboratory experiments, such as the morphology and some episodicity. However, the plume onset time is controlled by the cut-off viscosity value and remains far from the laboratory systematics.
New possibilities in multi-layer and multi-fluid flows

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Abstract

Multi-layer shear flows have a broad range of application in industry such as co-extrusion processes, film coating processes and lubricated pipelining. In all 3 processes the rate of production is limited by flow instabilities and especially by instabilities at the interface between adjacent layers. Use of a yield stress fluid as the lubricating fluid and controlling the individual flow rates to maintain a plug region at the interface can lead to multi-layer flows that are hydro-dynamically stable: linearly and nonlinearly, both theoretically and in laboratory experimental studies; see Frigaard (2001), Moyers-Gonzalez et al. (2004), Huen et al. (2007). Recently, we have studied these flows computationally in the setting of a Newtonian core fluid surrounded by a Bingham lubricated fluid, within pipe and channel configurations; see Hormozi et al. (2011a) and Hormozi et al. (2011b). Ongoing studies consider experimental aspects of the same flows. Our computational studies have shown that interesting convective effects may be frozen into the interface. These studies open up new potential areas for application such as drop encapsulation and near net shape production of multi-layered products with axial variations. We give an overview of these studies and our ongoing work.

References:


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Rheologic characteristics and long term stability of bitumen and brittle failure estimation

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Abstract
Bitumen is one major addition in asphalt production. Due to raising requirements on asphalt in term of higher load on roads, longer lifetime and form stability regular bitumen can not satisfy the demands any more. Bitumen is a colloidal suspension, mostly viscoplastic on low temperatures it changes its behavior to viscoelastic at higher temperatures and above a certain temperature it is save to suppose a newton fluid. It seems interesting to gain information about low temperature characteristics (beyond 10 °C) through rheological characterization between 15 °C and 90 °C as this is can be measured with low cost equipment. Our measurement results suggest that it is possible to extrapolate the brittle failure for standardized loads on bitumen without actually performing brittle failure tests using an adequate rheological model.

Asphalt industries are using polymer modified bitumen. The combination of bitumen with synthetic polymers results in better properties, especially in reducing viscoplastic effects at low temperature and raising softening points. Nevertheless it seems that quality of those bitumen brands still got worse in the last years. Common tests standardized in DIN (German industrial standards) were not sufficient to show the changes. Bitumen with the same standardization was taken from different production years and within rheologic test series derived characteristic numbers it is now possible attest changes. We suppose the source can be found in changed oxidation processes for higher yields in bitumen refining.

These rheological measurement cycles do take a certain amount of time and the number of devices is limited, therefore it was often not possible to carry out a large set of test series. To raise the amount of control samples, research on a new automated low cost rheologic device was conducted and some of the scientific findings in the suggested paper are already acquired with the new device.
Free Convection around a cylinder immersed in viscoplastic fluid Media – a numerical study

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Abstract

Viscoplastic fluids are viewed nowadays as a class of non-Newtonian materials that present deep changes in their mechanical properties within a small stress range. At lower limits, the behavior is either highly viscous or non-flowing while at higher limits the behavior is essentially fluidic. Considerable efforts have been employed in mathematical modeling and numerical simulation of such flows. Of practical interest are the cases which also include heat transfer effects which add more dependent variables to the problems and present even more challenges. The objective of this paper is to present a detailed numerical study of free convection flow around a circular cylinder immersed in an infinite domain. Several fluid media are modeled as viscoplastic fluids, using the Bingham-Papanastasiou viscosity function. The partial differential equations solved were the mass, thermal energy and momentum balances for incompressible flows with the Boussinesq approximation for the buoyancy term. These equations are approximated on ANSYS CFX, which employs a finite volume methodology. An extensive numerical study was performed to define appropriate boundary conditions, boundary distances to the cylinder in order to reliably reproduce the far field and mesh refinement. A Newtonian fluid study for the range of Rayleigh number from 10\textsuperscript{3} to 10\textsuperscript{6} and Prandtl number from 1 to 10 was conducted and compared to existing empirical correlations of Morgan and Churchill and Chu. Similarly, a viscoplastic model study was conducted and compared with results from the literature. Finally, the free convection flow around a cylinder with viscoplastic fluids was conducted with ranges of Rayleigh number from 10\textsuperscript{3} to 10\textsuperscript{6}, Bingham number from 0.5 to 20 and Prandtl number from 1 to 10. A correlation for the Nusselt number for Bingham fluids in free convection around a cylinder was introduced.

Keywords: viscoplastic, Bingham-Papanastasiou, free/natural convection, cylinder, heat transfer, non-Newtonian.
Combined effects of compressibility and slip on flows of a Herschel–Bulkley fluid

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Abstract
In this work we investigate numerically the combined effects of pressure-dependent parameters, such as the density and the slip coefficient, on Poiseuille and extrudate-swell flows of a Herschel-Bulkley fluids. Approximate semi-analytical solutions of the steady, creeping, weakly compressible plane and axisymmetric Poiseuille flows of a Herschel–Bulkley fluid are also derived and discussed.
Shallow flow of a viscoplastic fluid with topography

Ioan R. Ionescu

Abstract
The shallow flow of a viscoplastic fluid over a general basal topography is investigated. The material constitutive law may include two plasticity (flow/no flow) criteria: Von-Mises (Bingham fluid) and Drucker-Prager (Mohr-Coulomb). Coulomb frictional conditions on the bottom are included. Supposing that the shear stresses are small with respect to the extensional and in-plane shear stresses a stress analysis is developed for small thickness aspect ratio. A Saint-Venant type asymptotic model and a new depth integrated theory is deduced. The main advantage is the fact the resulting shallow equations have the same structure as the three dimensional ones. The 2-D (tangent) momentum balance law is completed with a "shallow constitutive equation" which links the in-plane (tangent) averaged stresses to the in-plane (tangent) rate of deformations. The shallow flow/no flow (yield) condition and the shallow viscosity are not the same as in the three dimensional case but the constitutive law has the same structure. The curvature of the bottom surface is involved in the model in the expression of the differential operators as well as in the frictional terms. Using the shallow yield criterion a "safety factor" (limit load) was introduced to study whenever the fluid/solid flows or not from a rest configuration. To illustrate the capabilities of the shallow model to reproduce the flow the sheet flow is analyzed. Two comparisons between the (2-D) in-plane flow and the asymptotic (1-D) flow for the Drucker-Prager fluids are considered. One comparison involves the experimental data and the other one two dimensional ALE computations. A mixed finite-element and finite-volume strategy is developed. Specifically, the variational inequality for the velocity field is discretized using the finite element method while a finite volume method is adopted for the hyperbolic equation related to the thickness variable. To solve the velocity problem, a decomposition-coordination formulation coupled with the augmented Lagrangian method. The finite volume method makes use of an upwind strategy in the choice of the flux. Several boundary value problems, modeling shallow dense avalanches, for different viscoplastic laws are selected to illustrate the predictive capabilities of the model: spreading a Drucker-Prager dome on a talweg, the role of barriers in stopping a viscoplastic avalanche and the flow of a Bingham fluid from a reservoir.
A finite element investigation of inertia and viscous effects on axisymmetric flows of purely-viscous fluids with yield stress

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Abstract
In the present work the modeling of the behavior of viscoplastic materials is addressed by a recently proposed equation by de Souza Mendes and Dutra (2004), from now on denoted by SMD model. The mechanical model, made up by usual continuity and motion equations for incompressible fluids coupled with the SMD equation, is approximated by a Galerkin least-squares (GLS) formulation in terms of pressure and velocity. Taking advantage of the good stability features of such a formulation, SMD flows through an axisymmetric channel, subjected to a sudden expansion and contraction, are approximated by standard bi-linear finite elements. According to the sensitivity analysis, aiming at investigating the influence inertia and viscous effect on a viscoplastic fluid dynamics, the topology of yield surfaces proved to be strongly related to inertia and yield stress amounts considered in the flow.

Keywords: Inertia flows; axisymmetric geometry; viscoplasticity; SMD fluid; GLS method.
Boundary Integral simulations of motion and deformation of single phase and two-phase viscoplastic drops in a viscous flow

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Abstract
The slow sedimentation of deformable viscoplastic drops and shells in a Newtonian fluid is simulated making use of a variation of boundary integral equation (BIE) method. The Green function for the Stokes equation is used and the non-Newtonian stress is treated as a source term. Integration over the outer unbounded domain, occupied by the Newtonian liquid, is eliminated by satisfying the boundary condition and using the integral expressions for the adjoined domains. Thus, the problem is reduced to an integral equation in a bounded domain, thus providing a main advantage of this method. We studied sedimentation of single phase drops and two-phase compound drops in which the outer shell is viscoplastic and the core is Newtonian. The focus of the study is on the dynamics of the deformation of the interfaces and the evolution of the unyielded zones inside the shell, and on the effect of the yield stress on the stationary states.

For single-phase viscoplastic drops, the computations are carried out for a range of physical parameters of the system. It is revealed that an increase in the yield stress magnitude (e.g., the Bingham number, $Bn$) stabilizes the shape of both oblate and prolate drops. This is in contrast to the effect of a viscosity increase of a Newtonian drop that is known to destabilize oblate drops. This strong stabilization effect can be explained by the presence of unyielded zones inside the falling viscoplastic drops. An interesting observation is that the growth of the plastic viscosity of the Bingham fluid destabilizes oblate deformations at low $Bn$, similar to the Newtonian drop case, and has a stabilizing effect at higher $Bn$.

The study of the two-phase compound drops was performed for the special case of a viscoplastic shell filled with a Newtonian fluid having a viscosity equal to that of the ambient medium. In this particular case the BIE computations are considerably facilitated. We report on series of simulations of initially concentric spherical double emulsion drops settling in the gravity field for various values of volume and viscosity ratios of the phases, and of the Bingham, Bond and Capillary numbers. Special attention is given to the case of a light core fluid embedded in a heavy shell, and the downward motion of such compound drops. The behavior of the opposite case of a light shell and a heavy core is discussed as well. The computations, carried out for a range of physical parameters of the system, revealed that the unyielded zones are more extended in the cases of thinner shells and weaker deformability of the interfaces. We anticipate a more pronounced stabilizing effect of the yield stress in these cases.
A study of the yielded region around Newtonian drops slowly settling in viscoplastic fluids in unbounded and bounded domains

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Abstract
Understanding the dynamics of Newtonian drops in viscoplastic media is of great importance in multiphase systems such as in pharmaceutics, foodstuff and cosmetics. We report on a study of the motion of viscous drops in a yield stress material in which the yielded region size and shape are investigated using flow visualization techniques (PIV). The drops move either as isolated in an unbounded domain or in the presence of a disturbance such as an adjacent vertical wall or a neighbor drop.

Low concentrated aqueous gel of Carbopol 940 (0.07% w/w) was used as the yield stress material. Rheological characterization combined with a direct visualization suggest a behavior of an almost ideal Herschel–Bulkley fluid having a relatively high yield stress, in the range reported in the literature for viscometric flows, and with only minor thixotropic and elastic effects. The rheological study provide the dynamic values of $G'$ and $G''$ as well as a demonstration that the viscoplastic layer slides near certain solid boundaries when the yield stress was not exceeded. 100$\mu$L Newtonian drops ($R \sim 2.8$mm) of various densities having similar viscosity and interfacial tensions were used. The sedimentation velocity of heavier and lighter drops differ by an order of magnitude where the former typical velocity was of $O(0.1$ mm/s) and the latter of $O(0.01$ mm/s). All drops move under creeping flow regime with $Re < 10^{-5}$.

The PIV measurements provided the velocity field around the moving drop from which three kind of maps were calculated: absolute values of velocity, effective viscosity and second invariant of velocity gradient tensor. For a drop moving in an unbounded domain it is evident that the shape of the yielded region extends more vertically than horizontally. The vertical extent does not significantly change with the drop speed, but the horizontal dimension at the equator shrinks considerably for drops with higher velocity. Yet, the outer contour of the yielded region (if it exists) is not well defined by the PIV technique. Far field velocity values are always detected and they seem to vary from case to case in which the drop speed change. It is demonstrated by the above maps that this technique cannot uniquely define a sharp boundary.

A curious phenomenon that is evident when the drops settle in proximity to a vertical solid wall is that their settling speed is augmented. This is contrary to what is known with Newtonian or viscoelastic domains. In addition, it is demonstrated that, when close to the wall, the drops drift slowly toward it, again opposite to what is anticipated for Newtonian systems. The increase in settling speed can be attributed to the dynamic formation of a thin clear layer providing effective wall slip, similar to what was evident in the rheological studies. This model is corroborated with computations using the commercial software FLUENT where introduction of slip at the adjacent wall indeed augmented the drop settling velocity.
A unified approach to model elasto-viscoplastic thixotropic yield-stress materials and apparent-yield-stress fluids

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Abstract
A constitutive model for elasto-viscoplastic thixotropic materials is proposed. It consists of two differential equations, one for the stress and the other for the structure parameter, a scalar quantity that indicates the structuring level of the microstructure. In contrast to previous models of this kind, the structure parameter varies from zero to a positive and typically large number. The lower limit corresponds to a fully unstructured material, whereas the upper limit corresponds to a fully structured material. When the upper limit is finite, the model represents a highly shear thinning, thixotropic, and viscoelastic fluid that possesses an apparent yield stress. When it tends to infinity, the behavior of a true yield-stress material is achieved. The model is employed in different rheometric flows, and an excellent predictive capability is observed.

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What causes changes in the microstructure, strain rate or stress?

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Abstract
Modeling the mechanical behavior of thixotropic fluids is a very difficult task that has
received a fair amount of attention in the last few years. Many thixotropy models have been
proposed so far, but information still lacks in the literature regarding the behavior and usage
of these models. Many of the existing models describe the material behavior using the
structure parameter, which is governed by an evolution equation. It indicates the structuring
level of the material, which is in fact a function of the stress level applied to the material.
However, it is customary to assume that the structure parameter is a function of the strain
rate level. In this work we performed a numerical investigation of the flow of a thixotropic
fluid past a cylinder between two parallel plates, using the constitutive equation recently
proposed by de Souza Mendes (2009). This equation is based on the upper-convected
Maxwell model, modified to accommodate a relaxation time and a shear-thinning viscosity,
both dependent on the structure parameter, which is governed by its evolution equation.
Results are obtained considering the structure parameter both as a function of strain rate
level, and also as a function of the stress level. We compared the results obtained with these
two different approaches, and observed an interesting behavior. Indeed, the approach
obtained using the stress-level-dependent structure parameter leads to a physically realistic
flow pattern, whereas when a strain-rate-level-dependent structure parameter is employed,
the flow pattern obtained is not plausible.
**A combined BDF-semismooth Newton approach for time-dependent Bingham flow**

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**Abstract**

This work is devoted to the numerical simulation of time-dependent convective Bingham flow in cavities. Motivated by a primal-dual regularization of the stationary model, a family of regularized time-dependent problems is introduced. Well posedness of the regularized problems is proved, and convergence of the regularized solutions to a solution of the original multiplier system is verified. For the numerical solution of each regularized multiplier system, a fully discrete approach is studied. A stable finite element approximation in space together with a second-order backward differentiation formula for the time discretization are proposed. The discretization scheme yields a system of Newton differentiable nonlinear equations in each time step, for which a semismooth Newton algorithm is used. We present two numerical experiments to verify the main properties of the proposed approach.

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Squeezing of a Finite Amount of Viscoplastic Material Exhibiting Thixotropy

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Abstract
The flow and shape evolution during the compression of a finite amount of a viscoplastic material exhibiting thixotropic effects is investigated by means of numerical simulations. The problem relates to the popular compression test used for the rheological characterization of non-Newtonian fluids. The flow is modelled in Lagrangian coordinates using the Papanastasiou regularization for the Bingham plastic and a mixed-Galerkin finite element method. Simulations have been performed for compression under both constant load and constant velocity. Results for various Reynolds and Bingham numbers are presented and discussed.
Evaluation from thixotropic behavior of acrylic paints and polyaniline blends dispersed by ultrasonic

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Abstract
The thixotropic behavior of acrylic paints and Polyaniline (PAni) blends, with different contents of PAni dopped by dodecylbenzene sulphonic acid (DBSA), dispersed by ultrasonic device, were investigated by controlled shear rate testing ramps. The results showed that the apparent viscosity decreased on the samples with 5wt% PAni content and increased on the samples with 10 wt% content. All samples exhibited non-newtonian flow behavior (shear thinning) and time dependant (thixotropic). The results showed that the addition of PAni-DBSA affects the rheological behavior of the mixtures due to the interactions between the components in the mixture. The best properties were obtained for samples 90/10 wt% indicating the feasibility of the usage as a conducting paint.

Polyaniline (PAni) is one of the important conducting polymers, although, it is well known that insoluble and infusible nature of Inherently Conducting Polymers (ICP) have kept them away from formation of solutions/melt [1]. The mechanical properties of conducting PAni have been investigated in the literature only with respect to its blends, polyaniline usually acted as a particulated conducting filler in a suitable matrix that provided the required mechanical properties [2].

The aim of this work is to use rheology as an efficient tool for exploring structural properties and molecular interactions of acrylic paints and polyaniline blends, because it determines the performance of the paint during the whole handling cycle, from storage to application and drying [3].

The mixtures were prepared on different contents of PAni, 95/5, 90/10 and 85/15 wt% (Acrylic Paint/PAni- DBSA), all samples were dispersed by an ultrasonic device with constant frequency at 30Hz, 100W power and constant amplitude of 50%, over five minutes. The rheological measurements of the samples, except for 85/15wt%, due to an overload torque from the instrument, have been carried out on a dynamic rheometer RheoStress 1 (Haake-Germany) with low inertia PP35 Ti parallel plate geometry.

The controlled shear rate testing ramps were performed from 0 up to 500 1/s, at constant temperature 30 degrees Celsius, to obtain the viscosity profile as a function of the shear rate, in addition, ramp with linear shear rate increasing from 0 up to 500 1/s (ramp up) and ramp with linear shear rate decreasing from 500 up to 0 1/s (ramp down), in order to evaluate the thixotropic behavior from the samples, the experimental data were fitted by Ostwald-Waele Model Equation (1), with high determination coefficients (R² = 0,90-0,99), the flow behavior index (n) decreased as the PAni content increased (0,41-0,23), on the other hand, the apparent viscosity at 100 1/s (ηa,100) increased as the PAni content increased, except for 5wt%, which results in a macroscopic entanglement of polymers chains, leading to a weak or strong gel depending on the physical and chemical nature of the
interactions \[4\]. \( \tau = K \gamma \cdot n \) (1)

Where, \( \tau \) is the shear stress (Pa), \( \gamma \) is the shear rate (1/s), \( K \) is the consistency index (Pa.s) and \( n \) is the flow behavior index (dimensionless). All samples exhibited a shear rate and time dependent (shear thinning and thixotropic) behavior, thixotropy describes the time dependence of the transient state viscosity at a given shear rate and the reversible and relatively slow breakdown of internal structure under shear, usually evaluated by measuring the enclosed area between the up-and down curve obtained in a linear increasing and decreasing shear rate over time, named hysteresis loop test, Green and Weltmann developed this method in 1946 \[3\]. The thixotropy increased as the PAni content increased, indicating a strong influence from the addition of the PAni on the acrylic paints, due to the interactions established between the acrylic matrix and the PAni.

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Study of toothpaste as a thixotropic material

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Abstract
A commercial toothpaste is investigated in this work as a model paste system to study its rheology and processing characteristics in capillary flow using various dies. Its rheological behaviour has been determined as that of a yield-stress, thixotropic material with a time-dependent behaviour. The rheological data obtained from a parallel plate rheometer were used to formulate a constitutive equation that is a viscoplastic model with a structural parameter which obeys a kinetic equation, typically used to model thixotropy. The predictive capabilities of this model is tested against capillary data for a variety of capillary dies having different length-to- diameter ratios ($L/D$), contraction angles ($2a$), and contraction ratios ($Db/D$)\textsuperscript{2}, where $Db$ is the diameter of the barrel of the capillary rheometer.
Rheological behavior of synthetic enamel and polyaniline: effect of concentration and blending

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Abstract
The rheological properties of synthetic enamel and polyaniline blends, with different contents of Polyaniline (PAni) dopped by dodecylbenzene sulphonate acid (DBSA), dispersed by ultrasonic device, were investigated by controlled shear rate testing ramps, all samples exhibited non-newtonian flow behavior (shear thinning). The creep and recovery test indicated an increase in the viscosity-zero-shear-rate and elasticity as the PAni content increased. The results showed that the addition of PAni-DBSA affects the viscoelastic behavior of the mixtures due to the interactions between the components in the mixture.

Polyaniline (PAni) is usually obtained as an intractable powder, although, it is also found as blends when the polymerization is taken place in the presence of various substrates. Blends have also been made by combining PAni with others polymers, in order to improve the processibility of this conductng polymer [1]. In this paper, we succeeded on preparing blends of PAni and synthetic enamel (alkyd resin) with low content of silikon on its formulation, in order to combine the good mechanical properties of the synthetic enamel while retaining the inherent conductivity oh the PAni.

The mixtures were prepared on different contents of PAni, 98/2, 95/5 and 90/10 wt\% (Synthetic Enamel/PAni-DBSA), all samples were dispersed by an ultrasonic device with constant frequency at 30Hz, 100W power and constant amplitude of 50\%, over ten minutes. The rheological measurements of the samples, have been carried out on a dynamic rheometer RheoStress 1 (Haake-Germany) with low inertia PP35 Ti parallel plate geometry. The controlled shear rate testing ramps were performed from 0 up to 500 1/s, at constant temperature 30 degrees Celsius, to obtain the viscosity profile as a function of the shear rate, the experimental data were fitted by Ostwald-Waele Model Equation (1), with high determination coefficients (R\textsuperscript{2} = 0,90-0,99). The viscosity-zero-shear-rate and response time were determined through the creep and recovery test, which allows one to differentiate well between the viscous and elastic response from the samples, introducing the stress-dependency of both the viscous and the elastic behavior of solids and fluids [2] The creep and recovery tests were performed at constant shear stress (5Pa) over 180 s, afterwards, the samples are kept under no shear stress (0Pa), in order to follow up the structures recovery.

\[ \tau = K \gamma^n \] (1) Where, \( \tau \) is the shear stress (Pa), \( \gamma \) is the shear rate (1/s), \( K \) is the consistency index (Pa.s) and \( n \) is the flow behavior index (dimensionless).

All samples showed a progressive increase of viscosity-zero-shear-rate and elasticity with increasing concentration of PAni, the rheology of paints depends mainly on the nature and concentration of the polymer matrix [3] and determines the performance of the paint during
the whole handling cycle, from storage to application and drying [4], creep and recovery test made on the linear viscoelasticity region, indicates the required physical stability by a paint to allow its storage avoiding sedimentation process of the dispersion, on the other hand, applicability of paints should be also evaluated through controlled shear rate testing ramps, as viscosity of these sytems, is a function of shear rate and time.

Results showed that the presence of Pani-DBSA on the synthetic enamel, tends to deliver the required stability on the mixtures, in order to avoid sedimentation process, due to all the samples showed a progressive decrease of relaxation time with increase concentration of PANi, which are in a good agreement with the results described previously on creep and recovery tests.

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A Weighted Residual Method for 2-Layer Flows with Yield Stress Fluids

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Abstract
Buoyancy dominated displacement flows are important in many industrial processes. In operations such as oilfield cementing, fracturing and drilling the fluids involved are non-Newtonian. An industrially relevant regime is that in which weak inertial effects are present. Density differences during displacement often lead to stratification and thereafter to instability and mixing. An appropriate model for this type of flow is a lubrication/thin-film displacement model, which models the evolving stratification. However, the neglect of inertial effects in such models limits their suitability.

Rather than use 2D or 3D simulation for these flows, which is particularly costly for yield stress fluids, it is of interest to model these flows using reduced models. On the other hand, we would like to predict the stability and displacement characteristics of the flow correctly (but at reduced computational cost). Here we present our recent work on modelling these flows. A recent approach to modelling weak inertial effects is the weighted residual method of Ruyer-Quil & Manneville (2000). This has been extended to two-layer Newtonian fluid flows by Amaouche et al. (2007). The basic approach is gives a 2nd order accurate approximation to the interface height and volumetric fluxes, while reducing the model complexity to two coupled 1D conservation laws, and also reproducing the stability characteristics of the full 2D flow. We show how this approach is extended to two-layer flows in which both fluids are of Herschel-Bulkley type. Although the derivation is complex, the resulting equations have the same structure as the Newtonian fluid model. We present examples from the analysis of these equations and discuss possible generalisations.

References:
On the existence of a simple yield stress fluid behavior

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Abstract

Materials such as foams, concentrated emulsions, dense suspensions and colloidal gels, are yield stress fluids. Their steady flow behavior, characterized by standard rheometric techniques, is usually modeled by a Herschel-Bulkley law.

The emergence of techniques that allow the measurement of the local flow properties (velocity and volume fraction fields) of yield stress fluids has led to observe new complex behaviors. It was shown that many of these materials exhibit shear banding in a homogeneous shear stress field, which cannot be accounted for by the classical steady-state constitutive laws of simple yield stress fluids. In some cases, it was also observed that the velocity fields are not consistent with a single constitutive law and that non-local models are needed to describe the flows. Doubt may then a priori be cast on any macroscopic characterization of such systems, and one may wonder if any material behaves in some conditions as a Herschel-Bulkley material.

In this presentation, we will first review the phenomena observed in yield stress fluids, and discuss the conditions in which they appear. We will then present an experimental investigation of the flow behavior of several yield stress fluids (foams, concentrated emulsions, Carbopol gels) with MRI techniques. We will show that, as long as they are studied in a wide (as compared to the size of the material mesoscopic elements) gap geometry, they behave as 'simple yield stress fluids': they are homogeneous, they do not exhibit steady-state shear banding, and their behavior can be modeled by a simple local constitutive law which accounts for all flows and matches the macroscopic response. We will discuss the conditions in which transient shear banding and nonlocal behavior are observed. We will also discuss in detail the shear banding issue: we will show that a simple change in their physical properties can turn these simple yield stress fluids into shear-banding materials.

References

Understanding Yield Stress Fluids: Two Types of Yield Stress Fluids – Three types of Shear Banding

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Abstract

Yield stress fluids are considered to be those materials that do not flow unless a certain threshold stress is overcome; this threshold is the so called yield stress. It has been reported that the yield stress can be hard to determine and variations of more than one order of magnitude can be obtained depending on the way it is measured\textsuperscript{1,2}. Additionally when yield stress materials are made to flow, most of the time shear banding occurs, i.e. part of the material flows, while another part remains quiescent, which can also interfere with the determination of the yield stress\textsuperscript{3}. We developed a model system, concentrated oil-in- water emulsions and show that in order to understand the difficulties in determining the yield stress, one must distinguish between two types of yield stress fluids: thixotropic and nonthixotropic (or simple) materials\textsuperscript{4}. A simple emulsion is also a ‘simple’ yield stress fluid. However it is possible to prepare emulsions with thixotropic behaviour, by means of clay addition to the formulation. When considering shear banding we show that three types of shear localization can occur for yield stress materials. We do this by measuring the
velocity profiles in rheometric flows using a rheometer coupled to a confocal microscope. On one hand both the simple and thixotropic emulsions exhibit shear localization when either wall slip or stress heterogeneities are present. On the other hand, the thixotropic emulsion exhibits a critical shear rate, below which, shear banding occurs. We perform a detailed study of the wall slip, which shows that the slip disappears when the emulsion droplets stick to the surface of the rheology cell, creating an effect similar to having a rough surface.

3 - Paredes, J.; Shahidzadeh – Bonn, N. And Bonn, D. Accepted JPCM 2011.
Boundary layer in yield stress fluids

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Abstract
Many practical situations involve the interaction of a yield stress fluid and a solid surface: cleaning of tools in food industry or civil engineering, coating of cosmetic creams or gels, adhesion of pastes over solid surfaces, etc… Various physical phenomena may be involved in these situations: flow, wall slip, adhesion, etc.

We studied the problem of moving a mass of a yield stress fluid along a solid surface in the absence of other effects than the fluid flow. Previous studies concerned the motion of objects of various shapes (sphere, cylinder) through a yield stress fluid and showed that this motion induces, around the solid object, a flow of a fluid volume which depends only on the rheological properties of the fluid and the object shape. Here we focused on the vertical displacement of a thin rectangular plate through a wide volume of fluid macroscopically at rest. The force exerted by the fluid on the plate when it moves at constant speed was followed according to the immersed depth. In parallel, measurements of the velocity field by PIV (Particle Imaging Velocimetry) provided detailed information on the flow characteristics around the plate.

First we show that the critical force per unit surface for moving the plate through the fluid corresponds to the yield stress of the material. For simple yield stress fluids such as emulsions or gels, this is valid both when using the critical force below which the plate stops, and the residual force during relaxation after a sudden stoppage of the motion. This experiment thus provides a very robust technique for measuring the yield stress.

Then we focus on the solid-liquid transition and the characteristics of the flow around the plate. We show that during the plate motion, the solid-liquid transition is localized in a small region at the plate tip and then a liquid boundary layer of uniform thickness forms along the plate while the rest of the material remains solid. Surprisingly, in this layer the velocity profiles are self-similar. Moreover the thickness of this layer is independent of the plate velocity and of the basic rheological characteristics of the material in its liquid regime but varies in a wide range depending on the material. Finally the force vs velocity curve may be deduced directly from the constitutive equation of the fluid by using for the shear rate the ratio of the plate velocity to the boundary layer thickness.
Designing a simple rheometer: Dam-break flows of power-law fluids

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Abstract

Many geophysical flows, such as mud slides, debris flows, and avalanches, are non-Newtonian, and consequently exhibit complex flow behaviour. This is often due to an underlying microstructure within the flow – for example, a suspension of particles within an interstitial fluid. It is of interest, as well as importance, to study the rheology of such flows in order to gain a greater understanding of various non-linear physical processes that take place within the environment.

We put forward a method for determining the rheological parameters of a power-law fluid through the utilisation of both numerical results and data from simple laboratory experiments. This, in effect, acts as a simple rheometer.

The model employed describes a dam-break flow of a highly viscous material within a rectangular channel, which can be considered to be analogous to the flow of a muddy river. A relatively novel feature of this work is that it allows for the effect of the containing side walls of a channel of any specified dimensions. Much of the previous work in this area has neglected this aspect of the physics, but here it can be shown that the side walls have an appreciable influence on the flow.

The method relies on the numerical calculation of the flux through a cross-section of the channel, which has been done using both COMSOL finite element solver software and a pseudo-spectral method. For certain parameter values, unusual flow behaviour has been identified, with multiple solutions arising for the flux of an identical fluid through the same channel.

Laboratory results from experiments with Xanthan gum carried out by Angelo Castruccio and Dr Alison Rust in the School of Earth Sciences at Bristol will be shown in order to demonstrate the application, and effectiveness, of the method.
Oscillating-cup technique for simultaneous measurement of yield stress and electroconductivity

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Abstract
The recently developed theory of nonlinear oscillating-cup viscometry is extended on account of external magnetic field and on measurement of electroconductivity of fluids. Oscillating-cup technique is the main one for high-temperature melts and, in particular, liquid metals. In present work, viscometer is right circular cylinder filled with conducting fluid, suspended from thin wire so that it performs the damped torsional oscillations about vertical axis and placed in homogeneous static axial magnetic field. The mathematical model includes unsteady nonlinear conjugate differential equations of oscillation of cylinder and of magnetic hydrodynamics, e.g., ones of mass and momentum conservation, rheological constitutive equation, Ohm's law. Visco-plastic behavior is numerically described by regularized models of bi-viscosity, Papanastasiou or Bercovier and Engelman. By modeling of experiments, the features of nonlinear oscillations of viscometer filled with non-Newtonian fluids, including Bingham ones, are considered and interpreted on the basis of Newtonian behavior and effective viscosity. Influence of magnetic field on experiment parameters are also treated in detail.

One of the model cases corresponds to the following traditional assumptions of oscillating-cup method: fluid is incompressible, wall slip is absent, oscillation amplitudes are small, steady-state oscillations are considered. Induced magnetic field is neglected in comparison with the applied magnetic field by assuming that the magnetic Reynolds number much less than unity. For this case, we obtain exact solutions for description of oscillating flows of viscoplastic fluids in the presence of magnetic field that are of interest to use in the practice. Computation results coincide with ones from numerical modeling within measurement accuracy and numerical schemes. Such viscometric equations contain parameters of oscillator and oscillations and also fluid properties. Besides rheological constants: yield stress and kinematic viscosity after yielding, the last ones include density and electroconductivity that allows defining theirs too.

Possibilities of simultaneous estimation of all these properties from the same viscometric experiment are studied in terms of the sensitivity theory. Obtained estimations can be incorrect because of strong influence and correlation of errors in experimental data even using simplified formulas. So, errors of simultaneous measurement of density and viscosity of linear viscous fluid run up to thousand percents at working experimental conditions. In view of this, we develop the parametric identification methods to determine rheological parameters, density and electroconductivity. They include analysis of observability and identifiability of model in term of Jacobian, of its accuracy and adequacy and experimental design. Errors in estimations of fluid properties are found for their independent and combined measurements at conditions responding to high-temperature systems. The approach also allows check the consistency of viscometric data and investigate influence of magnetic field on rheology of magnetorheological suspensions.

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A sequence of physical processes determined and quantified in LAOS: Application to theoretical nonlinear yielding models

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Abstract
The nonlinear yielding responses of three theoretical models, including the Bingham, a modified Bingham, and Giesekus models, to large-amplitude oscillatory shear (LAOS) are investigated under the framework proposed recently by Rogers et al (2011). Under this framework, basis states are allowed to wax and wane throughout an oscillation, an approach that conflicts directly with the assumptions of all Fourier-like linear algebraic approaches. Full yielding descriptions of the nonlinear waveforms are attained by viewing the responses as representing sequences of physical processes. These interpretations are compared to, and contrasted with, results obtained from linear algebraic analysis methods: Fourier-transform rheology [Wilhelm (2002)]; and the Chebyshev description [Ewoldt et al (2008)] of the geometrical constructions σ′ and σ′′ [Cho et al (2005)]. Further, we show that the discrepancies between the built-in model responses and parameters, and the interpretations of the Chebyshev and Fourier coefficients are directly related to misinterpretations of σ′ and σ′′ as being the elastic and viscous stress contributions. We extend this idea to show how any linear algebraic analysis is incapable of producing physically meaningful information when a material yields.

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On the Sorting of non-Brownian Particle Suspensions in a Viscoplastic Fluid

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Abstract
In this work we explore the sorting of non-Brownian rod-like particle suspensions based upon the control of the threshold for motion in a yield stress fluid. The principle is demonstrated by observing the motion of particles under the influence of a centrifugal force in a weak gel. Here we develop calibration curves of the force required to initiate motion in a gel under numerous configurations of the particles. Demonstration separations of bidisperse suspensions are reported in which we achieve perfect separation based upon length, diameter, or density. The method is then applied to an industrial suspension, a papermaking fibre suspension, in which a length-based as well as fibre-wall thickness fractionation is reported. The efficiency of this process is demonstrated by comparison to the performance of traditionally used, industrial unit operations, i.e. pressure screens and hydrocyclones.
Rheological properties of suspensions of bubbles in yield stress fluids

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Abstract

Air bubbles are incorporated into yield stress fluids in many situations of practical interest (plaster board and cellular lightweight concrete manufacturing processes, lightweight thermal insulation mortars, food foams and mousses, ...). Even if primary goal for adding air to a material is to modify its properties in the hardened state, fluid material workability also depends upon gaseous phase properties as bubble size, air-paste surface tension, bubble volume fraction. Then, one needs to study the air effects on the fluid overall rheological properties in order to analyze and to improve handling and placing processes.

Whereas a lot of work has been focusing on the situation in which gas bubbles are added to a Newtonian fluid, much less attention has been given to the effects of air on non-Newtonian fluids overall properties. In this work we study the behavior of suspensions of bubbles in yield stress (Herschel-Bulkley) fluids in the framework of a nonlinear upcaling approach.

To begin with, the problem of a single spherical bubble embedded in an isotropic incompressible matrix sheared far from the bubble is addressed. It is recalled that the solution of this problem depends upon a capillary number $Ca$ defined as the ratio of the product of the matrix shear modulus and the bubble size to the surface tension in the air-matrix interface. This capillary number accounts for the relative stiffness of the bubble compared to that of the matrix. When the capillary number is naught, the bubble remains spherical while the air bubble does not resist to shear straining when the capillary number tends toward infinity: bubble deformability is a decreasing function of the capillary number.

The overall elastic shear modulus of a monodisperse suspension of bubbles is estimated using a pattern based self consistent scheme. Predicted trends are consistent with the results obtained for an isolated bubble: the overall elastic modulus of the suspension is an increasing function of the gas volume fraction when the capillary number is small whereas the opposite trend is predicted for large values of the capillary number.

Then, the behavior of suspensions of bubbles in a Herschel Bulkley fluid is studied in the framework of a nonlinear homogenization method. Estimates for the overall properties of the composite material are obtained. Estimates for both elastic shear modulus and yield stress are proposed and compared to experimental data obtained in our lab.
The effect of wall slip on the stability of the Rayleigh-Bénard Poiseuille flow of viscoplastic fluids

Christel Métivier, Albert Magnin

Abstract
This work investigates the effect of wall slip on the stability of the Bingham Rayleigh-Bénard Poiseuille flow. The steady state of the Bingham plane Poiseuille flow is characterized by an unyielded region of $2y_b$ width and two sheared regions close to the walls with both no-slip and slip conditions at the walls. A linear stability analysis of this flow with slip conditions is proposed in this paper. The slip boundary conditions case leads to flow destabilization compared with the results obtained in the no-slip case. Critical conditions are modified by varying $C_f$, the friction number. For $C_f < O(1)$, critical Rayleigh values $Ra_c$ tend to that obtained with a free-free case. For $10 < C_f < 30$, $Ra_c$ values decrease and reach a minimum in this zone. The value of $C_f$, for which $Ra_c$ is minimal, varies slowly with the Bingham number $B$. For $C_f > 30$ the flow is stabilized, i.e. $Ra_c$ values increase and finally tend to that of the no-slip case when $C_f > 1000$. Furthermore, for $1 < C_f < 10^4$, asymmetric modes were obtained. They are due to the slip boundary conditions at the walls.
Rayleigh-Bénard convection for viscoplastic fluids

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Abstract
The influence of rheological properties of yield stress fluids is investigated on the onset of the Rayleigh-Bénard convection. Different concentrations of Carbopol 940 are used in an experimental setup. The onset of thermoconvection is shown by measuring temperature differences and also by using shadowgraph flow visualization. The influence of the yield stress is shown through the yield number $Y = \frac{\tau_y}{\rho g \beta \Delta T}$, which represents the importance of the yield stress value against the buoyancy forces. The onset of instability occurs when $Y_c = 0.01$. 