Viscoplastic Fluids: From Theory to Application

Abstract volume

Under the auspice sof the French Academy of Sciences

With the support of

LABEX MMCD
The Chair Lafarge ENPC “Materials Science for Sustainable Construction” supported by...

UNIVERSITÉ PARIS-EST

Organized by

IFP Energies nouvelles, Rueil-Malmaison (France) ■ 18-21 November 2013

www.rs-viscoplastic2013.com
**Context and objectives**

IFP Energies nouvelles in the framework of its Rencontres Scientifiques, and Université Paris-Est organize the 5th Workshop on Viscoplastic Fluids: From Theory to Application to be held at IFP Energies nouvelles, Rueil-Malmaison (near Paris), France, from 18 to 21 November 2013.

The objective of the workshop is to bring together the leading researchers in the domain of viscoplastic fluids across several disciplines to foster awareness and the cross-disciplinary transfer of ideas.

As in the previous editions (Banff in 2005, Monte Verita in 2007, Cyprus in 2009 and Rio de Janeiro in 2011), the program will consist in a single technical session.

Main topics of the workshop:

- Phenomenology of yielding
- Mathematical modeling
- Numerical simulation
- Time-dependent fluids
- Fluid mechanics
- Rheological characterization
- Industrial applications: concrete, slurries, crude oil, cosmetics, food, geophysical flows, bio-fluid flows, etc.
Organizing Committee

Benjamin Herzhaft (IFPEN, France)
Guillaume Vinay (IFPEN, France)
Anthony Wachs (IFPEN, France)
Xavier Chateau (Laboratoire Navier, Université Paris-Est, France)
Philippe Coussot (Laboratoire Navier, Université Paris-Est, France)

Scientific Committee

Neil Balmforth (University of British Columbia, Canada)
Philippe Coussot (Laboratoire Navier, Université Paris-Est, France)
Iann Frigaard (University of British Columbia, Canada)
Anthony Wachs (IFPEN, France)
Oral presentations

Monday 18 November

8.15  Registration

9.00  Opening Address
Anthony Wachs (IFP Energies nouvelles)

9.15  Keynote address: Effects of elasticity and pressure oscillations on simulations of yield stress fluids: the case of a rising bubble
John Tsamopoulos (University of Patras, Greece)

10.15 Mixed convection from a heated circular cylinder in bingham plastic fluids
A. Bose, N. Nirmalkar, R. P. Chhabra (IIT Kanpur, India)

10.35 Residual deposits of yield stress fluids at the wall in poiseuille flows along uneven channel
A. Roustaei, I. Frigaard (University of British Columbia, Canada)

10.55 Break

11.25 Natural convection problem for a bingham fluid using the operator-splitting method
R. Huilgol, G. Kefayati (School of Computer Science, Engineering & Mathematics, Flinders University of South Australia, Australia)

11.45 Viscoplastic flow: transition to turbulence
N. Kanaris, P. Stylianou, S. Kassinos, A. Alexandrou (Department of Mechanical and Manufacturing Engineering, University of Cyprus, Cyprus)

12.05 Parameter identification: an application of inverse analysis to cement-based suspensions
C. Anglade, A. Papon, M. Mouret (Université de Toulouse, UPS, INSA, LMDC, France)

12.25 Lunch

13.55 Stopping times in cessation flows of Bingham plastics with slip at the wall
Y. Damianou, M. Philippou, G. Kaoullas, G. C. Georgiou (Department of Mathematics and Statistics, University of Cyprus, Cyprus)

14.15 Return to rest in finite time for a solid body settling in a yield stress fluid
A. Wachs², B. Herzhaft¹, G. Vinay¹, P. de Souza Mendes³, I. Firgaard⁴, R. P. Chhabra², X. Chateau⁵, P. Coussot⁶ (²IFPEN-Rueil, France, ¹IFPEN-Lyon, France, ³Pontificia Universidade Católica-Rio de Janeiro, Brazil, ⁴University of British Columbia, Canada, ⁵IIT Kanpur, India, ⁶Université Paris-Est, Laboratoire Navier, France)
<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.35</td>
<td>Numerical modeling of volcanic lava flows</td>
<td>N. Bernabeu(^1,2), C. Smutek(^2), P. Saramito(^1) ((^1) Laboratoire J. Kuntzmann, Université de Grenoble, France, (^2) Laboratoire Géosciences / IPG, Université de La Réunion, France)</td>
</tr>
<tr>
<td>14.55</td>
<td>3D computer simulation of the flow of yield stress suspension</td>
<td>H. Fahs, N. Roquet, X. Chateau ((^1)IFSTTAR Nantes, Université Nantes Angers Le Mans, France (^2)Université Paris-Est, Laboratoire Navier, France.)</td>
</tr>
<tr>
<td>15.15</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>15.45</td>
<td>Uzawa-like methods for numerical modeling of unsteady viscoplastic bingham medium flows</td>
<td>L. Muravleva, E. Muravleva (Lomonosov Moscow State University, Russia)</td>
</tr>
<tr>
<td>16.05</td>
<td>Numerical simulation of multiple viscoplastic fluids</td>
<td>S. Gonzalez-Andrade (Centro de Modelizacion Matematica, Escuela Politécnica Nacional de Quito, Ecuador)</td>
</tr>
<tr>
<td>16.25</td>
<td>Modeling granular collapse with pressure dependent viscoplastic fluids</td>
<td>I. R. Ionescu(^1), A. Mangeney(^2), F. Bouchut(^3) ((^1)LSPM Université Paris Sorbonne 13, France, (^2)Institut Physique du Globe, France, (^3)LAMA, Université Paris-Est, France)</td>
</tr>
<tr>
<td>16.45</td>
<td>Numerical modeling of elastoviscoplastic fluid flows</td>
<td>P. Saramito(^1), I. Cheddadi(^2), F. Graner(^3) ((^1) Laboratoire J. Kuntzmann, Université de Grenoble, France, (^2)Laboratoire J. L. Lions, Université Pierre et Marie Curie, France (^3) Laboratoire matériaux &amp; systèmes complexes, Université Diderot, France)</td>
</tr>
<tr>
<td>17.05</td>
<td>poster session</td>
<td></td>
</tr>
<tr>
<td>17.35</td>
<td>End of the poster session</td>
<td></td>
</tr>
<tr>
<td>18.00</td>
<td>Happy Hours – Café de Leffe in Rueil-Malmaison</td>
<td></td>
</tr>
</tbody>
</table>

**Tuesday 19 November**

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.00</td>
<td>Keynotes address: Suspensions of particles and bubbles in yield stress fluids</td>
<td>Guillaume Olvarez (Laboratoire Navier, Université Paris-Est, France)</td>
</tr>
<tr>
<td>10.00</td>
<td>Shear thinning and yield stress behaviour of suspensions of chlorella vulgaris microalgae</td>
<td>A. Soulies(^1), J. Proust(^1), J. Legrand(^1), C. Castelain(^2), T. I. Burgheliea(^3) ((^1)GEPEA, UMR-6144, LUNAM Université, Université de Nantes et CNRS, France, (^2)UMR-660 Laboratoire de thermocinétique, LUNAM Université, Université de Nantes et CNRS, France)</td>
</tr>
<tr>
<td>10.20</td>
<td>Influence of surface properties on the creeping flow of a yield stress fluid around spheres</td>
<td>L. Jossic, F. Ahouguio, A. Magnin ( Laboratoire Rhéologie et Procédés, France)</td>
</tr>
<tr>
<td>10.40</td>
<td>Break</td>
<td></td>
</tr>
<tr>
<td>11.10</td>
<td>Viscoplastic Dip-coating on a plate</td>
<td></td>
</tr>
</tbody>
</table>
11.30 Flow of liquid foams in two-dimensional porous media
B. Dollet¹, S. A. Jones¹, B. Geraud¹, Y. Meheust², I. Cantat¹ (¹Institut de Physique de Rennes, UMR 6251, CNRS/Université de Rennes, France, ²Géosciences, UMR 6118, CNRS/Université de Rennes, France)

11.50 The specificity of yield stress fluid flows through porous media
T. Chevalier, S. Rodts, C. Chevalier, P. Coussot (Laboratoire Navier, Université Paris-Est, France)

12.10 Lunch

13.40 Confined flows of polymer microgel
B. Geraud, L. Boquet, C. Barentin (Institut Lumière Matière, Université Lyon 1-CNRS, France)

14.00 A Jeffreys rheology framework for gels under Laos
P. De Souza Mendes¹, R. L. Thompson², A. Alicke¹, R. Leite¹ (¹Pontificia Universidade Católica-Rio de Janeiro, Brazil, ²LMTA-PGMEC, Universidade Federal Fluminense, Brazil)

14.20 The surface tension of yield stress fluids
J. Boujlel, P. Coussot (Laboratoire Navier, Université Paris-Est, France)

14.40 Break

15.10 Experimental investigation of viscoplastic free-surface flows in steady uniform regime
G. Chambon, A. Ghemmour, M. Naaim (IRSTEA, ETNA Research Unit, France)

15.30 Oscillating couette flow of a carbopol fluid
L. Lacaze, O. Thual, A. Filella, A. Harang (Institut de Mécanique des Fluides de Toulouse, France)

15.50 Experimental investigation of the rayleigh- bénard convection in a yield stress fluid
Z. Kebiche, C. Castelain, T. I. Burghelea (UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes et CNRS, France)

16.10 End of the presentations

Wednesday 20 November

9.30 Keynote address: A multiscale approach in concrete rheometry
Fabrice Toussaint (Lafarge, France)

10.30 The effect of initial temperature of cooling on the gel strength of waxy crude oil
D. E. V. Andrade, A. C. B. Da Cruz, A.T Franco, C.O.R Negrao (Thermal Science Laboratory (LACIT), Post-graduate Program in Mechanical and Materials Engineering (PPGEM), Federal University of Technology-Paraná (UTFPR), Brazil)
10.50 Local rheology analysis of waxy crude oils
R. Mendes¹, G. Vinay², G. Ovarlez³, P. Coussot³ (¹Petrobras, Brazil; ²IFPEN, France; ³Université Paris-Est, France)

11.10 Break

11.40 Yield stress of a waxy crude oil considered either as a gel or a suspension
T. Palermo¹, I. Henaut² (¹TOTAL, ²IFPEN, France)

12.00 Pilot plant handling and rheological behavior of colloidal petroleum coke-in water fuel suspensions
G. Nunez, H. Olmedo, N. Rojas, S. Torres, M. Briceno (Nano Dispersions Technology, Inc., Panama)

12.20 Lunch

13.50 Screen extrusion – a challenge for VPF simulation
I. Wilson (Department of Chemical Engineering and Biotechnology, University of Cambridge, United Kingdom)

14.10 Numerical and experimental investigation of drilling fluid flow start-up
C. O. R. Negrao, G. M. De Oliveira, T. J. Cogo, A. T. Franco (Thermal Science Laboratory (LACIT), Post-graduate Program in Mechanical and Materials Engineering (PPGEM), Federal University of Technology-Paraná (UTFPR), Brazil)

14.30 Iso-dense displacement and start-up flows of yield stress fluids
G. Moises¹, I. Frigaard ², M. Naccache³ (¹Petrobras, Brazil; ²University of British Columbia, Canada; ³Pontificia Universidade Catolica do Rio de Janeiro, Brazil)

14.50 Chaotic mixing experiment in complex fluids
E. Gouillard, J. Boujlel, D. Wendell (Surface du verre et interfaces, UMR 125, CNRS/Saint-Gobin, France)

15.10 Break

15.40 Polymer gels as phantoms for MRI device testing
J. R. De Bruyn¹, C. R. Mcrae², L. Fleury¹, W. B. Handler¹, B. A. Chronik¹ (¹Department of Physics and Astronomy, University of Western Ontario, Canada, ²Institute of Quantum Computing, University of Waterloo, Canada)

16.00 Applied rheology on sludge suspension in water treatment systems
R. Holm¹, R. Haldenwang², R. Chhabra³ (¹RH Consult, Stockholm Sweden, ²CPUT, Cape Town, South Africa, ³IIIT, Kanpur, India)

16.20 Impact of wall-slip effects on yield stress measurements in cyclopentane hydrate slurry
A. Ahuja, J. F. Morris (Levich Institute and Department of Chemical Engineering, the City College of New York, USA)

16.40 Boundary integral simulations of deformation of viscoplastic drops in compressional flows
O. M Lavrenteva, I. Smagin, A. Nir (Israel Institute of Technology, Israel)

17.00 Poster session
18.15  Departure for the cocktail reception

Thursday 21 November

8.30  Natural convection of a bingham fluid in a vertical channel
      I. Karimfazli, I. Frigaard (University of British Colombia, Canada)

8.50  The planar squeeze flow of bingham plastics
      L. Muravleva (Lomonosov Moscow State University, Russia)

9.10  On the landau-levich problem for a viscoplastic fluid
      M. Moyers-Gonzalez\(^1\), P. L. Wilson\(^1\), M. Sweid\(^2\), C. Castelain\(^2\), T. Burghelea\(^2\)
      (\(^1\)Department of Mathematics and Statistics, University of Canterbury, New
      Zealand, \(^2\)UMR 6607, Laboratoire de Thermocinétique, LUNAM Université -
      Université de Nantes et CNRS, France)

9.30  On the modelling of yield stress due to tube-tube interactions in carbon
      nanotube
      N. Giovanniantonio\(^1\), G. Ausias\(^2\), M-C. Heuzey\(^1\), P. Carreau\(^1\), J. Ferrec\(^2\)
      (\(^1\)Center for Applied Research on Polymer and Composites (CREPEC), Chemical
      Engineering Department, École Polytechnique de Montréal, Canada,
      \(^2\)Laboratoire d'Ingénierie des Matériaux de Bretagne, Université européenne de Bretagne,
      France)

9.50  Cosserat-bingham fluids
      V. Shelukhin (Lavrentyev Institute of Hydrodynamics, Russia)

10.10 Break

10.40 Vibration and "jammed" systems
      R. Phillips (Department of Chemical Engineering and Materials Science, University
      of California, USA)

11.00 Freezing in shapes in multilayer flows
      S. Hormozi, G. Dunbrack, A. Malekizamenjani, I. Frigaard (University of British
      Columbia, Canada)

11.20 Upscaling approach to the behavior of viscoplastic suspensions
      X. Chateau (Université Paris-Est, Laboratoire Navier, France)

11.40 Thixotropic flow past a cylinder
      A. Syrakos\(^1\), A. Alexandrou\(^2\), G. Georgiou\(^1\)
      (\(^1\)Department of Mathematics and Statistics, University of Cyprus, Cyprus,
      \(^2\)Department of Mechanical and Manufacturing Engineering, University of Cyprus, Cyprus)

12.00 Lunch

13.30 Elastic and inertia effects in viscoplastic fluid flows through an abrupt
      expansion-contraction
      D. D. Dos santos\(^1\), F. BICHET-LINK\(^1\), S. Frey\(^1\), M. F. Naccache\(^2\), P. R. De Souza\(^2\)
      (\(^1\)Federal University of Rio Grande do Sul, Brazil, \(^2\)Pontifical Catholic University of
      Rio de Janeiro, Brazil)
13.50 Flow of a yield-stress fluid above an obstacle: solid/liquid interface
   L.-H. Luu, P. Philippe, G. Chambon (IRSTEA, France)

14.10 Laminar unsteady pipe flow of a carbopol gel
   A. Poumaere¹, M. Moyers-Gonzalez², C. Castelain¹, T. I. Burghelea¹ (¹UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes et CNRS, France, ²Department of Mathematics and Statistics, University of Canterbury, New Zealand)

14.30 On the slow settling of rough and smooth solid spheres in a yield-stress fluid
   Y. Holenberg, O. M. Lavrenteva, U. Shavit, A. Nir (Chemical Engineering Department, Technion – Israel Institute of Technology, Israel)

14.50 Closing Address
ABSTRACTS

Abstracts are listed following program order

The abstracts are published in their original format as they were sent to Organizing Committee
Monday 18 November 2013
MIXED CONVECTION FROM A HEATED CIRCULAR CYLINDER IN BINGHAM PLASTIC FLUIDS

A. Bose, N. Nirmalkar and R. P. Chhabra

IIT Kanpur, India

Abstract

Within the framework of generalized Newtonian fluids, the phenomenon of convective heat transport in the boundary layer flows of viscoplastic fluids have received very little attention, though reliable results on heat transfer in unconfined power-law fluids from a heated circular cylinder based on the solution of the complete field equations in the forced-, free- and mixed-convection regimes have been reported only during past 10 years or so [1-4]. Broadly, all else being equal, shear-thinning behaviour can augment the rate of heat transfer by varying amounts depending upon the value of the power-law index and the strength of convective flow.

In contrast, the flow of visco-plastic fluids is characterized by the simultaneous existence of the so-called yielded and unyielded regions in the flow domain and this suggests that heat transfer occurs mainly by convection in the yielded regions and by conduction in the unyielded region. Therefore, the overall rate of heat transfer from a cylinder in such media is thus determined by the relative contributions of these two mechanisms. The size and shape of the yielded regions are, in turn, determined by the values of the Reynolds number and Bingham number; while the former tends to enlarge the fluid-like regions while the latter tends to suppress them [5]. This situation is further accentuated if the buoyancy-induced flow is superimposed on the external flow thereby resulting in the so-called mixed-convection regime.

In this work, the heat transfer characteristics of a heated circular cylinder in unconfined Bingham plastic fluids have been studied by numerically solving the governing differential equations. Scaling arguments suggest that this flow is governed by four dimensionless groups, namely, Reynolds number ($Re$), Richardson number ($Ri$), Prandtl number ($Pr$) and Bingham number ($Bn$). In order to elucidate the effect of each of these parameters, the present work spans the following ranges of conditions: $0.1 \leq Re \leq 40; 1 \leq Pr \leq 100; 0 \leq Bn \leq 10$ and $0 \leq Ri \leq 2$. Detailed results are presented and discussed in terms of the streamline and isotherm contours, yielded/unyielded regions, distribution of the local Nusselt number, etc. Interesting shapes not observed hitherto of the fluid-like and solid-like zones are observed depending upon the relative strengths of buoyancy-induced and external velocities. Indeed, the overall rate of heat transfer is determined by an intricate interplay between the viscous, inertial, buoyancy and yield-stress induced forces prevailing in flow domain.

References


R.P. Chhabra, Professor, Indian Institute of Technology Kanpur, India, Phone: 0091 512 2597393, Fax: 0091 512 2590104, Chhabra@iitk.ac.in
Residual deposits of yield stress fluids at the wall in Poiseuille flows along uneven channel

author's Name SURNAME (11-point Arial bold, centered)
Ali Roustaei, Ian Frigaard
Affiliation, Country (11-point Arial, centered)
University of British Columbia, Vancouver, Canada

First-level headings (11-point Arial bold, left-justified)
Normal text (11-point Arial, justified, single spaced)

A slow channel flow of a yield stress fluid along a wavy walled channel undergoes a number of interesting qualitative transitions as the amplitude of the wave is increased. For small amplitude long wavelength wall perturbations the characteristic central unyielded plug remains intact, but perturbs in shape so that the plug is widest in the narrowest part of the channel; see [1]. At a first critical amplitude the central plug breaks [1,2]. After breaking, in the central part of the channel we find unyielded plugs around the symmetry points connected by pseudo-plug regions in which extensional stresses are sufficient large to yield the fluid. Here we study a second critical amplitude beyond which there appears a region of unyielded fluid that is attached to the wall in the widest part of the channel, i.e. a fouling layer of static fluid. We explore the characteristics of this fouling layer numerically for a range of different channel wall geometries, showing how the amplitude, channel aspect ratio and Bingham number interact to influence the size of the residual deposit. We offer some analytical insights into formation of the residual deposits and predictions of their size. This represents the first stages [3] in a longer study to understand the effects of uneven wellbore geometry on drilling and primary cementing processes in oil and gas well construction.

References

Name of paper presenter, title, address, phone, fax, e-mail (10-point Arial, left-justified)

Uncertain who would present – correspond with:
Ian Frigaard
Departments of Mathematics & Mechanical Engineering,
University of British Columbia
frigaard@math.ubc.ca
1-604-822-3043 / 1-604-822-1316
Natural Convection Problem for a Bingham Fluid using the Operator-Splitting Method

Raja Huilgol & Gholamreza Kefayati
School of Computer Science, Engineering & Mathematics
Flinders University of South Australia
Adelaide
Australia


Name of paper presenter, title, address, phone, fax, e-mail:

Professor Raja R. Huilgol
School of Computer Science, Engineering & Mathematics
Flinders University of South Australia
GPO Box 2100
Adelaide, SA 5051
Australia

Phone: 61-8-8201-2938
Fax: 61-8-8201-2904
Email: Raj.Huilgol@flinders.edu.au
Viscoplastic Flow: Transition to Turbulence

Nicolas Kanaris, Photos Stylianou, Stavros Kassinos, Andreas Alexandrou
Department of Mechanical and Manufacturing Engineering
University of Cyprus, Nicosia Cyprus

Due to their characteristic flow behavior viscoplastic flows are generally considered laminar. Therefore almost all studies in the literature of viscoplastic flows are focused on laminar flow. However it is possible that the flow could be turbulent. In this work we performed DNS simulations for the classical flow past a circular cylinder in order to understand the flow when it undergoes a transition from laminar to turbulent flow. Results will be shown for the general flow, the structure of the yielded and unyielded regions are well as the global flow characteristics such as the drag coefficient.

Presenter: Prof. Andreas Alexandrou, Mechanical and Manufacturing Engineering Department,
University of Cyprus, Tel. +357 22892258, Fax: +357 22895384
PARAMETER IDENTIFICATION: AN APPLICATION OF INVERSE ANALYSIS TO CEMENT-BASED SUSPENSIONS

Célimène ANGLADE, Aurélie PAPON, Michel MOURET

Université de Toulouse, UPS, INSA, LMDC (Laboratoire Matériaux et Durabilité des Constructions), 135 Avenue de Rangueil, F-31 077 Toulouse Cedex 04, France.

Numerical prediction of viscoplastic fluid flow such as the placing of fresh concrete may be affected by the quality of the constitutive parameter identification procedure. In this study, the authors propose to develop a method to determine the constitutive parameters of cement-based suspensions. There are two main methods for identifying parameters: direct method and indirect method.

Specific experimental device devoted to the rheological testing of fresh cementitious materials is employed by the LMDC. It involves specific stirrers limiting sedimentation and segregation during the test. In fact helical or anchor stirrers produce axial flow which preserves the homogeneity of the sheared material. For a given suspension, experimental data consist in a set of pairs including the controlled rotational speed and the corresponding torque at steady-state flow. Given the geometry of the stirrers and the constitutive models used to represent the cement-based suspension, the direct method of parameter identification is not possible. Therefore the authors propose to by-pass this problem by carrying out an inverse analysis based on the FEM-simulation of the rheological experiments.

Inverse analysis consists in minimizing an error function which represents the difference between experimental and numerical data. The solution of this minimization corresponds to the unknown constitutive parameters. In this paper, the inverse analysis is performed by considering Herschel-Bulkley and Bingham models and by using deterministic and stochastic optimization algorithms. The results with respect to both the constitutive models and the algorithms are discussed.

ANGLADE Célimène, Postgraduate Student, LMDC – INSA/UPS- Génie Civil – 135, av Rangueil, 31077 Toulouse cedex4, +33(5)61559909, +33(5)61559949, anglade.celimene@gmail.com
STOPPING TIMES IN CESSION FLOWS OF VISCOPLASTIC FLUIDS WITH WALL SLIP

Yiolanda DAMIANOU, Maria PHILIPPOU, George KAOULLAS, Georgios C. GEORGIOU

Department of Mathematics and Statistics, University of Cyprus, Cyprus

Abstract
We solve numerically the cessation of axisymmetric Poiseuille flow of a Bingham plastic under the assumption that slip occurs along the wall. The Papanastasiou regularization of the constitutive equation is employed. As for the slip equation, a power-law expression is used to relate the wall shear stress to the slip velocity, assuming, however, that slip occurs only beyond a critical wall shear stress, known as the slip yield stress. It is shown that, when the latter is zero, the velocity becomes and remains uniform before complete cessation and that the stopping time is finite only when the slip exponent \( s < 1 \). In the case of Navier slip \( (s=1) \), the stopping time is infinite for any non-zero Bingham number and the volumetric flow rate decays exponentially. When \( s > 1 \), the decay is much slower, i.e. polynomial. The asymptotic expressions for the volumetric flow rate in the case of full-slip are also derived. When slip yield stress is non-zero, the velocity cannot become flat in cessation and the stopping times are finite in all cases.
Numerical modeling of volcanic lava flows

Noé Bernabeu (1,2), Claude Smutek (2), Pierre Saramito (1)

(1) Lab. J. Kuntzmann, U. Grenoble, France
(2) Lab. Géosciences / IPG, U. La Réunion, France

The Herschel-Bulkley viscoplastic model is commonly used to describe the dynamic of volcanic lava flows on slope. The small aspect ratio of such flows allows a depth averaged equation: it leads to a reduced model that decreases dramatically the computation time. A new viscoplastic reduced model is presented for 3D flow problems on arbitrarily topography. In order to solve the reduced 2D shallow nonlinear problem, a robust and efficient numerical method is developed, based on an adaptive mesh approach. The numerical results are compared with two experimental measurements on slopes. These comparisons validate the present approach and also shows the limits when the aspect ratio do not permits the depth averaged approximation. In conclusion we explore several possibilities to circumvent this limitation.
3D COMPUTER SIMULATION OF THE FLOW OF YIELD STRESS SUSPENSION

Hassan FAHS¹, Nicolas ROQUET¹, Xavier Chateau²

¹IFSTTAR Nantes, Université Nantes Angers Le Mans, France.
²Université Paris-Est, Laboratoire Navier (UMR 8205), Champs sur Marne, France.

Keywords: Suspension, Viscoplastic fluid, Fictitious domain method.

Particles suspended in a fluid medium make up a wide variety of materials both natural or human made. Despite their strong interest, these materials have so far been the subjects of specific studies in specific application areas. Comprehensive understanding of their behavior and more particularly of the link between their overall rheological properties and their composition remains to be built. For this purpose, characterization of the microstructure at the particle scale and elucidation of particle distribution impact on the suspension overall properties are needed; indeed spatial distribution of particles in a volume of suspension depends on the history of deformation experienced by the material and particles distribution changes induce changes of the overall material rheological properties. As experimental characterizations of the microstructure of flowing suspension are rather difficult, available results on this point are extremely few. Then we propose to address this question using numerical simulations.

Numerical simulations of the flow of a suspension of monodisperse spherical particles suspended in a Bingham fluid using the fictitious domain method with distributed Lagrange multipliers are presented. In the initial state, the particles are randomly distributed within the considered volume of suspension. Several deformation histories were simulated. The relevance of a particle distribution characterization by means of a small number of state variables (like texture tensor) in the framework of a continuous modeling of the overall behavior of the suspension is discussed in detail.

Hassan Fahs, Ph.D., IFSTTAR Nantes, phone: 06 60 38 31 93, e-mail: hassan.fahs@ifsttar.fr
UZAWA-LIKE METHODS FOR NUMERICAL MODELING OF UNSTEADY VISCOPLASTIC BINGHAM MEDIUM FLOWS

Larisa MURAVLEVA and Ekaterina MURAVLEVA

Lomonosov Moscow State University, Russia

The numerical simulation of viscoplastic fluid flow is difficult due to the non-differentiable form of the constitutive law and the inability to evaluate the stresses in regions where the material has not yielded. In case of creeping flows, we used the standard backward-Euler scheme for the time-discretization. At each time step, we use the augmented Lagrange method proposed by R. Glowinski and co-authors. Numerical simulation of Bingham plasticity traditionally uses the FEM for discretization. We propose two finite-difference schemes which are generalizations of schemes on staggered (MAC-scheme) and semi-staggered grids. We introduce auxiliary grids for discretization of the strain and stress tensors. If we consider flows with medium and high Reynolds numbers, we have employed operator splitting to simplify the computation. Earlier, a fractional-step time scheme was proposed in [1-3]. Our temporal discretization scheme is different from theirs. The system is decoupled into two subsystems by fractional step method: a Navier-Stokes problem and plasticity problem. The Navier-Stokes problem is solved by the second order scheme proposed by Van Kan and slightly modified later. The numerical simulation of high Reynolds numbers flow requires in particular a good approximation of the convective terms. They are treated explicitly and approximated by third-order upwind scheme. The numerical modeling of the unsteady cavity flows (start-up and cessation) [4], flows in pipes of different cross-sections [5,6], flow in wavy-walled channels [7] were held using our schemes.

This work is partially supported by Rus. Gov. Program "Kadry" contract №8226 and RFBR through project 12-01-31242-mol_a.


Ekaterina Muravleva, Dr.,
Leninskie gory, Main Building,
Department of Mechanics and Mathematics,
Lomonosov Moscow State University,
127006, Moscow, Russia,
+7 916 622 53 16 (cell),
+7 499 126 58 74 (home),
+7 495 939 55 39 (work),
+7 495 939 20 90 (fax)
catmurav@gmail.com
NUMERICAL SIMULATION OF TWO-PHASE VISCOPLASTIC FLOW BY LEVEL-SET AND SEMISMOOTH METHODS

Sergio GONZÁLEZ-ANDRADE

Centro de Modelización Matemática, Escuela Politécnica Nacional de Quito, Ecuador

This talk is devoted to the mathematical modelization and numerical simulation of the non-stationary two-phase flow of viscoplastic fluids. One of the most challenging issues in this field is to correctly represent the movement of the interface, which separates the two materials. When simulating this kind of flow with Newtonian viscous fluids, the level-set methods performed efficiently [2]. On the other hand, the semismooth Newton methods proved to be a numerically fast approach to the numerical simulation of viscoplastic fluids [1]. Therefore, we propose to combine these two methods in order to simulate the two-phase flow of viscoplastic fluids. After presenting the equations modelling this flow, we discuss existence and uniqueness results for the resulting system of differential equations. Due to instability issues, we discuss a regularization of the model by a bi-viscosity approach. Next, we construct an algorithm based on the combination of level-set and semismooth Newton methods, and we discuss the use of a multigrid method for the solution of the resulting large-scale finite dimensional problem. Finally, several numerical experiments are presented.

References


Modeling granular collapse with pressure dependent viscoplastic fluids

Ioan R. IONESCU
LSPM, University Paris 13, Sorbonne-Paris-Cité, France
Anne Mangeney
Institut Physique du Globe, Sorbonne-Paris-Cité, France
François Bouchut
LAMA, University Paris-Est, France

The goal of this paper is to propose a numerical and mechanical model for the flow of granular material over sloping planes. The numerical results are compared with the experimental ones obtained in [Mangeney et al., Erosion and mobility in granular collapse over sloping beds, J. Geophys. Res. - Earth Surface, 115, (2010) F03040]. The mechanical model involves the pressure dependent viscoplasticity, which include Birgham (Von-Mises) or Drucker-Prager flow/no flow criteria and rusher general dependence of the viscosity on the rate of deformation and the pressure. Concerning the numerical approach we have used an iterative decomposition-coordination formulation coupled with the augmented Lagrangian method in an ALE context.

We have used a time implicit (backward) Euler scheme for the time discretization of the field equations, which gives a set of nonlinear equations for the velocities, stress deviator and the pressure field. At each iteration in time, an iterative algorithm is used to solve these nonlinear equations. Specifically, the variational formulation for the velocity field is discretized using the finite element method. To overcome the non-differentiability of the viscoplastic and frictional terms an iterative decomposition-coordination formulation coupled with the augmented Lagrangian method was adapted here.

This model makes it possible to well reproduce the dynamics and deposit of granular collapse over inclined beds.

Ioan R. Ionescu, Professor, LSPM, University Paris 13, Sorbonne-Paris-Cité, 99, Av. JP Clément, 93430 Villetaneuse, France, ian.r.ionescu@gmail.com
Numerical modeling of elastoviscoplastic fluid flows

Pierre Saramito (1), Ibrahim Cheddadi (2), Francois Graner (3)

(1) Lab. J. Kuntzmann, U. Grenoble, France
(2) Lab. J. L. Lions, U. Pierre et Marie Curie, Paris, France
(3) Lab. materiaux & systemes complexes, U. Diderot, Paris, France

The Herschel-Bulkley rheological fluid model includes terms representing viscosity and plasticity. In this classical model, below the yield stress the material is strictly rigid. Complementing this model by including elastic behavior below the yield stress leads to a description of an elastoviscoplastic (EVP) material such as an emulsion or a liquid foam.

We first include this modification in a completely tensorial description of cylindrical Couette shear flows. Both the EVP model parameters, at the scale of a representative volume element, and the predictions (velocity, strain and stress fields) can be readily compared with experiments. We perform a detailed study of the effect of the main parameters, especially the yield strain. We discuss the role of the curvature of the cylindrical Couette geometry in the appearance of localization; we determine the value of the localization length and provide an approximate analytical expression. We then show that, in this tensorial EVP model of cylindrical Couette shear flow, the normal stress difference strongly influences the velocity profiles, which can be smooth or non-smooth according to the initial conditions on the stress. This feature could explain several open questions regarding experimental measurements on Couette flows for various EVP materials such as emulsions or liquid foams, including the non-reproducibility that has been reported in flows of foams. We then discuss the suitability of Couette flows as a way to measure rheological properties of EVP materials.

Next, we compute the first solutions of the EVP model for another discriminant benchmark, namely the flow around an obstacle. We compare it with experiments of a foam flow and find an excellent agreement with the spatial distribution of all important features: we accurately predict the experimental fields of velocity, elastic deformation, and plastic deformation rate in terms of magnitude, direction, and anisotropy.

Our results demonstrate that the behavior of soft glassy materials cannot be reduced to an intermediate between that of a solid and that of a liquid: the viscous, the elastic and the plastic contributions to the flow, as well as their couplings, must be treated simultaneously. Our approach opens the way to the realistic multi-dimensional prediction of complex flows encountered in geophysical, industrial and biological applications, and to the understanding of the link between structure and rheology of soft glassy systems.
Tuesday 19 November 2013
SHEAR THINNING AND YIELD STRESS BEHAVIOUR OF SUSPENSIONS OF CHLORELLA VULGARIS MICROALGAE

Antoine Souliès\(^{1}\), Jeremy Pruvost\(^{1}\), Jack Legrand\(^{1}\), Cathy Castelain\(^{2}\), Teodor I. Burghelea\(^{2}\)

\(^{1}\) GEPEA, UMR-6144, LUNAM Université, Université de Nantes, CNRS, Bd. de l'Université, CRTT-BP 406, 44602 Saint-Nazaire Cedex, France

\(^{2}\) UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609,44306 Nantes Cedex 3, France

A systematic study of the rheological properties of solutions of non-motile microalgae (Chlorella vulgaris CCAP 211-19) in a wide range of volume fractions is presented. As the volume fraction is gradually increased, several rheological regimes are observed. At low volume fractions (but yet beyond the Einstein dilute limit), the suspensions display a Newtonian rheological behaviour and the volume fraction dependence of the viscosity can be well described by the Quemada model (Quemada, Eur Phys J Appl Phys 1:119–127, 1997). For intermediate values of the volume fraction, a shear thinning behaviour is observed and the volume fraction dependence of the viscosity can be described by the Simha model (Simha, J Appl Phys 23:1020–1024 , 1952). For the largest values of the volume fraction investigated, an apparent yield stress behaviour is observed. Increasing and decreasing stress ramps within this range of volume fractions indicate a thixotropic behaviour as well. A deeper insight into the physical mechanisms underlying the shear thinning and the apparent yield stress regime is obtained by an \textit{in situ} analysis of the microscopic flow of the suspension under shear during both the rheometric flow and a separate plane micro-channel flow. The shear thinning regime is associated to the formation of cell aggregates (flocs). Based on the Voronoi analysis of the correlation between the cell distribution and cell sizes, we suggest that the repulsive electrostatic interactions are responsible for this microscale organisation. The apparent yield stress regime originates in the formation of large-scale cell aggregates which behave as rigid plugs leading to a maximally random jammed state.

Antoine Souliès, Mr., GEPEA UMR-6144, LUNAM Université - Université de Nantes and CNRS, Bd. de l'Université, CRTT-BP 406, 44602 Saint-Nazaire Cedex, France,
Tel: +33 (0)240 172 671
Email: antoine.soulies@univ-nantes.fr
INFLUENCE OF SURFACE PROPERTIES ON THE CREEPING FLOW OF A YIELD STRESS FLUID AROUND SPHERES

Laurent JOSSIC, Fiacre AHONGÚIO, Albert MAGNIN
Laboratoire Rhéologie et Procédés - UMR 5520
BP 53
38041 Grenoble Cedex 9 - France

The flow of a fluid around a sphere is a fundamental study of fluid mechanics. Although a lot of data concerning some non-Newtonian fluids can be found in the literature, the data related to yield stress fluids are scarce and fragmented, particularly with slip conditions.

This experimental study focuses on the creeping flow of a gel around spheres. The gel considered in this study, consists of a dispersion of deformable micro-gels filled with solvent. The assembly of the micro-gels gives mechanical strength to the fluid which is reflected by the presence of a yield stress. Two spheres have been considered. The first sphere – rough sphere – has a roughness greater than the characteristic size of the micro-gels. The second sphere – smooth sphere – has a roughness smaller than the characteristic size of the micro-gels. In addition, their surfaces have respectively been chosen hydrophilic and hydrophobic. These tribologic properties enable a total adherence of the gel on the rough sphere and slip on the surface of the smooth sphere. Depending on them, the slip phenomenon specific to yield stress fluids, affects significantly the drag force and the velocity field. The study provides both global (drag coefficients) and local (velocity fields) measurements with controlled surfaces. The observations are related to the parameters of the Herschel-Bulkley model and the interfacial friction law of the gel obtained by rheometric and tribologic characterizations.

The measurements have been performed with an experimental device moved at a constant controlled velocity. The global measurements show that the drag coefficient obtained with the rough sphere are twice the one measured with the smooth sphere. These results, presented for different Oldroyd numbers, i.e. the ratio between plastic and viscous effects, have revealed that the tribologic properties play a major role in the adherence of the gel on a surface. They enabled to propose a criterion for predicting the stability of a sphere with regards to the fluid/sphere interface. The kinematic fields which have been determined by PIV have enabled to quantify the velocity fields around the spheres. This local analysis has revealed a dissymmetry between the upstream and the downstream of the flow. It has also shown that the rigid and sheared zones are wider upstream than downstream. Concerning the effect of tribologic conditions, the analysis highlighted that the slip phenomenon contributes to reduce the influence of the sphere on the flow through more confined sheared and rigid zones.

Laurent JOSSIC, Laboratoire Rhéologie et Procédés, laurent.jossic@grenoble-inp.fr
Dip-coating of a vertical plate from a bath of yield stress fluid

Mathilde MAILLARD, Jalila Boujlel, Philippe Coussot
Laboratoire Navier (ENPC-ISF/TTAR-CNRS), Université Paris-Est, Champs sur Marne

Many industrial techniques rely on interactions between yield stress fluids and solids. This is in particular the case for the coating of objects, a process widely used in painting, food or building industries. Here, we are interested in characterizing in detail the specific technique of dip-coating of a vertical plate from a bath of yield stress fluid. The key issue is to understand the formation process of the layer coated on the plate in particular to predict its thickness.

We carried out such tests with Carbopol gels. The force versus time response was analyzed in order to determine the influence on the process of the geometrical parameters of the problem, the duration between immersion and withdrawal of the plate, the velocity of the plate and the yield stress of the fluid. The internal characteristics of the flow generated by the immersion then withdrawal of the plate was also studied thanks to PIV (Particle Image Velocimetry).

Inside the bath, we show that a liquid layer of uniform thickness forms along the plate while the rest of the fluid stays solid. Our data then prove that during withdrawal, in our range of fluid yield stresses and velocities, the layer coated on the plate has a uniform thickness and there is no drainage of the fluid along the plate, in contrast with simple liquids. From these observations, we develop a method to determine the thickness of the coated layer. The characteristics of the coated layer are independent of the geometrical parameters while the duration of rest between immersion and withdrawal has a little influence on them. However the thickness of the coated layer increases slightly with the velocity of the plate but strongly with the yield stress of the fluid.

The dimensionless thicknesses (obtained by scaling the experimental thickness by that associated with flow stoppage over a vertical plane) represented as a function of the Bingham number gather along a single master curve. This proves that the formation of the coated layer is governed by these two dimensionless values, which implies that there is no influence of the surface tension at first order. Moreover, the thickness of the coated layer is far smaller than the critical thickness for flow stoppage over a vertical plane. The analysis of the velocity profiles along the plate in the bath shows that this kind of coating is closely linked to the flow of the liquid layer along the immersed plate and suggests that the coated layer results from the separation of the liquid layer into two parts: one remaining in the bath while the other is stuck on the plate.

Mathilde MAILLARD, dip-coating of a vertical plate from a bath of yield stress fluid, Laboratoire Navier - 2 allée Kepler - 77420 Champs sur Marne - France, 01.81.66.84.46, mathilde.maillard@ifsttar.fr
Flow of liquid foams in two-dimensional porous media

Siân A. JONES¹, Benjamin DOLLET¹, Baudouin GERAUD¹, Yves MEHEUST², Isabelle CANTAT¹

¹ Institut de Physique de Rennes, UMR 6251 CNRS/Université Rennes 1, Rennes, France
² Géosciences, UMR 6118 CNRS/Université Rennes 1, Rennes, France

Liquid foams, dispersions of gas bubbles in a continuous liquid phase, are a yield stress fluid with elastic properties. When a foam flow is confined by solid walls, viscous dissipation mostly arises from the contact zones between the soap films and the walls, which gives very peculiar friction laws. In particular, foams potentially invade narrow pores much more efficiently than Newtonian fluids, which is of great importance for enhanced oil recovery. To quantify this effect, we study experimentally flows of foam (of bubble side length a) in model two-dimensional porous media, where we use image analysis to quantify elasticity, plasticity and flow [1].

We first quantify the velocity (or flux) ratio between two parallel straight channels of different width b (Fig. 1, left). We show that as long as b > 3a, the two velocities are equal. In narrower channels, the foam structure is modified, which has a strong influence on the velocity. In particular, when b < a, we have a “bamboo foam” (train of films perpendicular to the channel) which can be either unfavourable or favourable depending on the ratio between b and the distance between the films. We show that another effect controlling the velocity in a narrow channel is the capillary pressure that a film has to overcome when exiting a narrow channel. We rationalise our findings in a model and propose predictions of the velocity ratio as a function of the width of the two channels [2].

We briefly present two other configurations relevant to natural porous media. First, we show that in a convergent and a divergent channel in parallel (Fig. 1, middle), there is a coupling between the elastic stress and the dissipation in the foam, favouring the flux in the convergent channel even if the foam is not highly confined. Second, we present the phenomenology of preliminary experiments of a foam flowing through a series of circular obstacles (Fig. 1, right). We show that the flow crucially depends on the ratio between the bubble size, obstacle radius and gap between obstacles.


Fig. 1 - Snapshots of our model porous media. From left to right, foam in two parallel straight channels, in two parallel tilted channels (skeletonised images), and in a disordered array of obstacles (raw images).

Dr. Benjamin DOLLET, Institut de Physique de Rennes, Campus Beaulieu, Bâtiment 11A, 35042 Rennes Cedex, France. Tel: +33 2 23 23 50 38. E-mail: benjamin.dollet@univ-rennes1.fr
THE SPECIFICITY OF YIELD STRESS FLUID FLOWS THROUGH POROUS MEDIA

Thibaud CHEVALIER, Stéphane RODTS, C. CHEVALIER and Philippe COUSSOT

Laboratoire Navier, Université Paris-Est, Champs sur Marne, France

The flow of yield stress fluids through porous media is of interest for various applications: penetration of mortar glue in the surface porosity of solid materials, injection of muds, slurries or cement grouts to reinforce soils, injection of drilling fluids in rocks either for the reinforcement of the wells or for enhancing oil recovery. Although we can suspect that the strongly non-linear character of such fluids can lead to specific effects the detailed flow characteristics in such case are so far widely unknown. It has been suggested that due to the specificities of yield stress fluids the flows in porous media exhibit two original trends: as the pressure drop increases a wider region of fluid starts to flow, an effect occurring at a local scale; at a macroscopic scale the flow starts only along a specific path throughout the porous medium [1-2] and as the pressure drop is increased more flowing paths progressively form within the porous medium. With the help of a technique providing a complete information on the internal flow characteristics we provide the effective trends of flow of yield stress fluids in porous medium, which strongly differ from the above assumptions.

We carried out tests by injecting a yield stress fluid (an emulsion) through model porous media (bead packings) at different mean velocities. The density distribution of velocity of the fluid inside the whole sample is measured with an NMR technique, namely a pulsed-gradient spin echo (PGSE) sequence. From this distribution we deduce that there is apparently no fluid at rest in the sample even at low velocities (for Bingham number much larger than 1). This means that: (i) at a local scale there is no region at rest and (ii) at a macroscopic scale all regions start to flow at the same time.

Moreover, in our range of mean velocities, the velocity distributions are similar and do not differ significantly from that obtained for a Newtonian fluid. This means that in a porous medium the impact of the yielding character of the fluid on the flow characteristics is partly destroyed as a result of the disorder of the porous medium: in contrast with the flow characteristics in a simple geometry, each fluid element undergoes a flow history along which, on average, it goes through each velocity level according to a specific distribution; this distribution being independent of the rheological behavior of the fluid.


Philippe.coussot@ifsttar.fr
CONFINED FLOWS OF POLYMER MICROGEL

Baudouin GERAUD, Lyderic BOCQUET, Catherine BARENTIN

Institut Lumière Matière, UMR5306 Université Lyon 1–CNRS, France

Yield stress fluids such as gels, pastes or emulsions are commonly used in everyday life and are well described by the phenomenological Herschel-Bulkley rheological law, despite the microscopic mechanisms at the origin of their flow properties are still misunderstood. In this presentation, we investigate the question of short length scales and especially how are modified the flow properties of such fluids when they flow on length scales comparable to the typical size of their structure. Indeed, on such length scales, plasticity, structure rearrangement and wall roughness should greatly affect the flow properties of these fluids, and exhibiting their effects could help to better understand their behaviour.

To answer this question, we study the effects of confinement on flows of Carbopol, which is a simple yield stress fluid, with two experiments. We measure flow curves using a rheometer for different gap conditions, and we measure velocity profiles in rough micro-channels with a classical technique of Particle Imaging Velocimetry. Both experiments show a strong disagreement between the bulk rheology and the behavior of the fluid under confinement [1], and both exhibit a typical length of some microns. The analysis of the velocity profiles within the framework of the fluidity model [2] allows to rationalize this length as a cooperativity one, standing for the rearrangements during the flow.


Baudouin Géraud, Phd, Université Claude Bernard Lyon 1
Domaine Scientifique de La Doua
Bâtiment Kastler, 10 rue Ada Byron
69622 Villeurbanne CEDEX, France +33 (0) 6 69 17 68 97, baudouin.geraud@univ-lyon1.fr
A JEFFREYS RHEOLOGY FRAMEWORK FOR GELS UNDER LAOS

Paulo DE SOUZA MENDES¹, Roney THOMPSON², Alexandra ALICKE¹, Ricardo LEITE¹

¹Pontifícia Universidade Católica-RJ, Rio de Janeiro, RJ 22543-900, Brazil
²LMTA-PGMEC, Universidade Federal Fluminense, Niterói, RJ 24210-240, Brazil

ABSTRACT

We show that a Jeffreys framework is suitable to interpret physically LAOS rheology data of structured materials like gels, that possess transition from solid-like to liquid-like behavior. The four stages of this transition, namely (i) pure elastic solid, (ii) viscoelastic solid, (iii) viscoelastic liquid, and (iv) viscous liquid, are perfectly captured as the structuring level of the material decreases. Stress amplitude and frequency are independently varied, and two classes of motion are observed, characterized by a non-sinusoidal and a sinusoidal shear-rate response, respectively: structure-changing motions, when the stress amplitude is above the yield stress and the frequency is of the order of the reciprocal of the thixotropic characteristic time; and constant-structure motions, when either the stress amplitude is below the yield stress or the frequency is much larger than the reciprocal of the thixotropic characteristic time.

Paulo R. de Souza Mendes, Professor, PUC-Rio, +5521-99829853, pmendes@puc-rio.br
THE SURFACE TENSION OF YIELD STRESS FLUIDS

Jalila BOUJLEL and Philippe COUSSOT

Laboratoire Navier, Université Paris-Est, Champs sur Marne, France

Various industrial process involve the formation of a layer of a yield stress fluid over a solid surface: coating of fibers with ink or paint, spreading of mortar or plaster on walls, application of cosmetic foams, gels or emulsions on skin, etc. So far the characteristics of yield stress fluid flows along solid surfaces have generally been considered under the assumption that interfacial effects were negligible and viscous effects were dominant. One reason is that we do not have clear information about the effective surface tension of such materials. For fluids made of elements in suspension in a simple liquid, such as foams, emulsions, suspensions, colloids, it was suggested that surface tension is simply equal to that of the interstitial liquid, since all the elements (bubbles, droplets, particles, etc) and in particular those situated along the fluid-air interface, are generally surrounded by liquid. Actually the above physical argument might fail for concentrated systems for which the liquid layer along the interface is very thin (such as in some emulsions or foams), or when the components of the liquid layer along the air-fluid interface are unknown (such as in some concentrated pastes).

Here we focus on the possibility of measuring the surface tension of a yield stress fluid with the help of a technique derived from the Wilhelmy technique, i.e. by withdrawing a film from a fluid bath. We show that before a progressive breakage of the film, the force amplitude goes through a maximum which is independent of the initial depth of penetration and the timing for blade lifting, but increases with the material yield stress and the blade thickness. This critical force is shown to reflect both capillary and viscous effects, even at vanishing blade velocity. We demonstrate that the ratio of this force to the blade perimeter provides the surface tension of the yield stress fluid in the limit of low (<<1) Capillary number (ratio of yield stress times blade thickness to surface tension). Moreover we show that all our data for the force to perimeter ratio fall along a master curve which may be used to deduce the surface tension from measurements obtained at Capillary number up to 1, even if viscous effects are significant. Finally Carbopol gels appear to have almost the same value of surface tension whatever their yield stress, but this value is almost 10% smaller than that of pure water.

Jalila BOUJLEL, Dr., Saint-Gobain Recherche, jalila.boujlel@hotmail.fr
EXPERIMENTAL INVESTIGATION OF VISCOPLASTIC FREE-SURFACE FLOWS IN STEADY UNIFORM REGIME: HYDRAULIC PROPERTIES AND VELOCITY PROFILES

Guillaume CHAMBON, Assia GHEMMOUR, Mohamed NAAIM

Irstea, ETNA Research Unit, Grenoble, France

Free-surface flows of viscoplastic fluids are involved in a variety of industrial and geophysical applications. Yet, accurate and well-documented experimental data on such flows remain rare. In particular, the capacity to predict the flow properties (velocity, thickness, etc.) on the base of conventional rheometrical characterization of the fluid, has seldom been tested. We report on experiments aiming at investigating finely the hydraulic properties of gravity-driven flows in steady uniform regime. Results obtained with two distinct viscoplastic fluids, namely a kaolin slurry and a Carbopol microgel, will be presented. Within the range of investigated shear rates, both these fluids obey a Herschel-Bulkley constitutive law, whose parameters (yield stress, consistency, and flow index) have been obtained through parallel-plate rheometrical tests. Great care has been devoted to the determination of the experimental uncertainties associated to the measured stress-strain rate relations. The free-surface flow experiments have been performed in an inclined conveyor-belt channel allowing us to generate gravity-driven surges which remain stationary, with an immobile front, in the laboratory frame. Both global and internal measurements were conducted. At the scale of the flow, the relations between flow height, flow discharge, slope angle, and fluid rheological parameters have been systematically explored. In the case of Carbopol, which is transparent, we also measured high-resolution velocity profiles inside the flow using a PIV technique.

These numerous experimental data will be compared to theoretical predictions based on the independent determination of the fluid constitutive parameters. With the kaolin slurry, the measured flow heights appear to be in good agreement with the predictions, within experimental error bars, thus validating the Herschel-Bulkley rheological model used for the fluid. With Carbopol, on the contrary, we observe a systematic discrepancy between measured and theoretical flow heights. A non-dimensional representation, in which datapoints obtained for different slope angles and different values of the rheological parameters are expected to collapse, reveals that the experimental results effectively define a master curve, but are clearly shifted from the prediction. Interestingly, however, the shape of the velocity profiles is fully consistent with that expected for a Herschel-Bulkley fluid. The apparent stress-strain rate relations that can be deduced from these profiles indicate a Herschel-Bulkley behaviour with values of yield stress and consistency that are approximately 10% larger than those obtained from the rheometrical tests. We will demonstrate that such a correction of the rheological parameters, which cannot be attributed to experimental errors, can actually explain all the experimental data obtained with Carbopol. Potential interpretations for this discrepancy will be discussed, and seem to converge towards the existence of a scale effect to take into account when determining the rheological properties of this polymeric microgel.

Guillaume Chambon, PhD, Irstea – Domaine Universitaire – BP 76 – 38402 St Martin d'Hères Cedex – France, phone: +33 4 76 76 27 66, e-mail: guillaume.chambon@irstea.fr
Oscillating Couette flow of a Carbopol fluid.

Laurent LACAZE, Olivier THUAL, Audrey FILELLA, Alice HARANG

Institut de Mécanique des Fluides de Toulouse, UMR 5502, France

General context
Many fluid flows encountered in the environment or in industrial processes are controlled by the dynamics of complex mixtures, which can be considered in many cases as an individual non-newtonian fluid with a complex rheology. Concentrated suspensions of particles in water such as mud, for instance, are generally modelled using this assumption. The study of a fluid model, which displays the general characteristics of the fluid rheology encountered in natural situation, is therefore developed in many laboratory experiments. In the present case, Carbopol is used as a fluid model, which generally allows to highlight the influence of a yield stress as well as a non-linear relationship between shear stress and strain rate. Moreover, this specific fluid is transparent: standard optical measurements such as particle image velocimetry (PIV) can therefore be used. In most cases, complex flows encountered in natural configurations are unsteady, which therefore implies a temporal fluctuation of the shear. A better knowledge of the influence of an unsteady shear on the dynamics is therefore crucial to develop predictive models for natural flows.

The definition of the rheological models used to describe these complex fluids are generally not trivial and can show their limitation in some configurations. One of the reasons that can be attributed to this limitation is the change of scale from rheological model obtained with rheometer to larger scale flows which are characterised by a more complex dynamics.

Experimental configuration and results
The present study is devoted to the experimental investigation of an unsteady cylindrical Couette flow in which the angular velocity of the inner cylinder is imposed while the outer cylinder remains fixed. The imposed angular velocity profile is a cosine function with two parameters, which are the frequency and the amplitude (or maximum angular velocity). Two different concentrations of Carbopol have been used (0.11% wt and 0.25% wt). Using a PIV method, the radial profile of the azimuthal velocity is measured as a function of time (Fig. 1). This unsteady flow can easily be modelled thanks to a numerical integration of conservation equations with a given model for the rheology. However, the rheological model is less obvious to determine. In particular, it is shown that among the Herschel-Bulkley model, often used to describe steady flows of a Carbopol fluid, it is necessary to introduce a linear elastic model to take into account the elastic properties of the fluid which can be of main importance for the unsteady flow considered here (Fig. 1). This difficulty increases the uncertainty of the rheological characteristics obtained from a rheometer, because of the number of parameters to be determined but also because of the different assumptions associated with the rheological model considered. Here, we propose to optimize the parameters of the chosen model using the velocity profile obtained from the experiments together with the numerical model considered.

![Graphs](image)

Fig1. Radial profiles of the azimuthal component of the velocity at different times (time increases with decreasing velocity at r=7 cm). Different concentrations of Carbopol and amplitudes of the forcing are shown here.
Experimental and numerical results are shown on the upper plots and lower plots respectively.

Olivier Thual, IMFT Allée du Pr. Camille Soula, 31400 Toulouse. 0033 5 34 32 29 45.
Olivier.thual@imft.fr
EXPERIMENTAL INVESTIGATION OF THE RAYLEIGH-BÉNARD CONVECTION IN A YIELD STRESS FLUID

Zineddine Kebiche, Cathy Castelain, Teodor I. Burghela

- UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609, 44306 Nantes Cedex 3, France

An experimental study of the Rayleigh-Bénard convection in a yield stress fluid (Carbopol 980) is presented. By combined integral measurements of the temperature difference between two parallel plates and local flow velocity in a wide range of heating powers \( P \), two distinct regimes are observed. For heating powers smaller than a critical value \( P_c \), a purely conductive regime is observed. A gradual increase of the heating power beyond this onset reveals a convective regime manifested through a sublinear dependence of the temperature difference between plates on the heating power. Simultaneously with this, local measurements of the flow fields simultaneously reveal a nonlinear increase of the roll pattern amplitude. Regardless the concentration of Carbopol, the Rayleigh-Bénard convection in the Carbopol gel is found to emerge as an imperfect bifurcation that can be correctly modelled by the Landau theory of phase transitions. A critical slowing down phenomenon is observed corresponding to the onset of convection. The scaling laws of the convective onset \( P_c \) and of the corresponding temperature difference between plates \( \Delta T_c \) with the relevant material properties are discussed. The talk will close with a comparison of our findings with existing previous works.

Cathy Castelain, Dr., UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609, 44306 Nantes Cedex 3, France

Tel: +(33) - (0)2 40 68 31 47
Email: Cathy.Castelain@univ-nantes.fr
THE EFFECT OF INITIAL TEMPERATURE OF COOLING ON THE GEL STRENGTH OF WAXY CRUDE OIL

Diogo E.V. ANDRADE
Ana Cristine B. da CRUZ
Admilson T. FRANCO
Cezar O.R. NEGRÃO

Thermal Science Laboratory (LACIT), Post-graduate Program in Mechanical and Materials Engineering (PPGEM), Federal University of Technology-Paraná (UTFPR), Brazil

Abstract:

Gelation is an important issue on the production and transportation of waxy crude oil. At low temperatures, crystallization of wax results in gelation of the material when the flow is interrupted. In such cases, pressure required to restart waxy crude oil flows in subsea pipelines can be much larger than usual steady-state pressure. The literature has shown that not only the temperature but also the shearing and thermal histories have great influence on the gel strength of the material. This paper investigates the effect of the initial temperature of cooling on the gel strength of waxy crude oils. In order to accomplish that rheological tests are carried out under static and dynamic cooling conditions. Experimental results show there is a critical initial temperature that provides the highest viscosity on a dynamic cooling and the highest yield stress on both dynamic and static cooling. However, the influence of the initial temperature is more pronounced on static than on dynamic cooling as the yield stress can vary one order of magnitude. A discussion about the reason for the existence of such critical temperature is also presented. It is expected that these results may help the understanding of gelation and the design of oil production pipelines.

Keywords: Waxy crude oil, Rheological tests, Initial temperature, Gel Strength.

Paper presenter: Diogo E. V. Andrade, MSc, Address: Av. Sétê de Setembro, 3165, 80230-901, Curitiba, PR, Brazil, Phone: +55 41 3310 4772, Fax: +55 41 3310 4852, e-mail address: diogoandrade@utfpr.edu.br
Local Rheology Analysis of Waxy Oils

Rafael MENDES¹, Guillaume VINAY², Guillaume OVARLEZ³, Philippe COUSSOT³

¹Petrobras, Brazil; ²IFPEN, France; ³Université Paris-Est, France;

Abstract
MRI velocimetry tests were conducted in a Couette geometry with a waxy crude oil and an equivalent model fluid. The model fluid, which is a mixture of mineral oil and wax, exhibits (i) a simpler composition, which allows a more straightforward analysis of the phenomena originated by the paraffinic components; and (ii) a macroscopic behavior analogous to the waxy crude oil but in a higher range of temperatures, which simplifies the experimental procedures. The MRI data provide a direct information on the local flow characteristics, which associated with stress measurement, give the effective constitutive equation of the material unaffected by flow heterogeneities.

The transient and steady state behavior of the material was studied at ambient temperature after different histories of cooling (mainly with or without shear during cooling). The rheological behavior observed is qualitatively in agreement with the macroscopic behavior observed in conventional rheometry tests.

These waxy oils show a yield stress at low temperatures due to the presence of solid wax crystals. The buildup of the structure formed by these crystals was measured during the cooling process in a range of shear rates. Then, the flow restart and various start-stop tests were performed, providing data for kinematic and mechanical analyses. When the fluid is cooled at rest, it presents a high yield stress, so that for speed controlled flow restart a shear localization may occur. Once the flow is restarted, the material presented a behavior similar to the cases where it was cooled under high shear: a much lower yield stress. When the material is cooled at low shear rates, its restructuring capacity at rest was higher. The breakdown of the structure presented an overall irreversible behavior, but a weak and slow rebuild could be measured, similar to particles settlement in low velocity flows.

Rafael Mendes, Mr., 1-4 avenue de Bois Préau, Rueil-Malmaison, France, +33147527329, rafael.mendes@petrobras.com.br
YIELD STRESS OF A WAXY CRUDE OIL
CONSIDERED EITHER AS A GEL OR A SUSPENSION

T. Palermo (TOTAL); I. Henaut (IFPEN)

A rheological characterization of a waxy crude oil, aiming at predicting restart pressure, is reported. This crude oil exhibits severe properties with respect to wax: WAT=63°C and PP=45°C. Yield stress of the gelled oil was estimated from elastic modulus measurements for a wide range of temperature and for different cooling scenarios. After gelled oil breaking, the system behaves like a slurry of wax crystals whose rheological behavior was described according to flow curves measurements at different temperatures. It is showed that wax slurry can be considered as a suspension of aggregated particles. Thus, shear-thinning behavior is explained by expressing the viscosity as a function of the effective volume fraction of wax crystals that varies with the shear stress. With such an approach, yield stress of the slurry can be deduced as the shear stress for which the effective volume fraction tends to the maximum packing. Finally, it is argued that depending on the strength of the gelled oil, the restart pressure is either connected with the breaking mechanism of a solid or with the capability of decreasing the effective volume fraction of a suspension.
PILOT PLANT HANDLING AND RHEOLOGICAL BEHAVIOR OF COLLOIDAL PETROLEUM COKE-IN-WATER FUEL SUSPENSIONS

Gustavo NUÑEZ\textsuperscript{1}, Hidekel OLMEDO, Nelson ROJAS, Suyin TORRES, María BRICEÑO

Nano Dispersions Technology, Inc., Panama

INTRODUCTION
Back in the 70’s and 80’s coal-in-water slurries were considered as an alternative fuel to substitute oil for power generation. However, some technical hurdles and decreasing oil costs put an end to this concept. At present, an increasing oil price horizon and diminishing volumes of fuel oil and bunker due to refinery deepening conversion are driving the development of cheaper fuels. We are developing coal, petroleum coke (pet coke) and asphaltite aqueous suspensions\textsuperscript{1-3} in which the majority of particles are colloidal in size: the combustion of these fuels has been successfully tested. This feature increases fuel reactivity and solves most of the issues that hindered coal-in-water slurries wider use, such as fast sedimentation and atomizers abrasion. We have focused on pet coke that has a relatively low cost per heat value. This paper presents our observations of the flow characteristics of a mostly colloidal pet coke suspension. We have carried out both conventional rheometric evaluations and pilot plant piping tests. This material is viscoplastic and this feature requires implementing some “tricks” to facilitate its handling.

EXPERIMENTAL AND PILOT PLANT RESULTS
About 800 kg of a 61 % (w/w) pet coke colloidal suspension was manufactured in our pilot plant, using an in-line wet comminution device. Steady shear and dynamic tests were carried out in a rotational rheometer; this material is highly shear thinning, exhibits a yield stress and a moderate viscoelastic behavior. The most unusual property is that apparent viscosity and yield stress increase with temperature above 35 °C, though this effect is reversible. Flow behavior was also evaluated using a tube viscometer having pipes of different diameters (0.5 to 1.5 inches) and lengths (1 to 6 m). Pressure drop was measured as a function of flow rate and these data was used to generate shear stress as a function of apparent shear rate flow curves. It was found that the apparent shear viscosity was significantly lower than the one obtained in the rheometer and the rheological behavior was also simply shear thinning or Newtonian. The flow curves show little evidence of a yield stress. However, the viscoplastic nature of this material does affect handling, i.e., the suspension flows with more ease, out of tanks, when there is mixing near the region of the vessel outlet.

CONCLUSIONS
The observed pipe behavior may be interpreted as a lubricated flow in which the continuous phase migrates to the wall thereby reducing friction. Acknowledging this phenomenon has a positive impact in equipment costs and handling operations.


Maria L. Briceño, R&D Manager, Nano Dispersions Technology, City of Knowledge, Panamá, phone 005073170274; fax 005073170464, briceno@nanodl.com. (\textsuperscript{1} In memoriam)
SCREEN EXTRUSION – A CHALLENGE FOR VPF SIMULATION

Ian WILSON

Department of Chemical Engineering and Biotechnology, University of Cambridge, UK

Viscoplastic materials are frequently used in extrusion processes as the products retain their shape after forming. A wide range of extrusion devices exist, some of which involve complex geometries and deformation patterns that are a challenge for both analytical and computational approaches. There is, however, considerable benefit to be gained from being able to predict the behaviour of viscoplastic materials in these devices.

Screen extrusion is employed in the pharmaceutical and agrochemical industries to generate small (~ 1 mm diameter) strands of extrudates which are subsequently rounded into nearly spherical pellets by spheronisation. The material is fed into the gap between a moving blade and a multi-holed screen, with hole area fraction around 0.25. Motion of the blade generates a region of high stress at the nip between the blade and the screen, and material is forced through the screen and the blade passes. The problem is similar to a cavity with a moving lid but the passage of material through the lid introduces significant differences.

Experimental results are presented for a novel laboratory screen extruder device which reproduces the important features of industrial screen extruder units in a two-dimensional geometry. Measurements are made torque, forces and screen deflection (the screen flexes as the blade passes). Experimental results are presented for a pharmaceutical paste, along with results from simple modelling approaches.

The aim of the paper is to present the geometry and observations in order to promote discussion within the VPF community as to how such real systems can be best modelled. We are happy to share the data with interested groups.
NUMERICAL AND EXPERIMENTAL INVESTIGATION OF DRILLING FLUID FLOW START-UP

Cezar Otaviano Ribeiro NEGRÃO
Gabriel Merhy de OLIVEIRA
Tiago José COGO
Admilson Teixeira FRANCO

Thermal Science Laboratory (LACIT), Post-graduate Program in Mechanical and Materials Engineering (PPGEM), Federal University of Technology-Paraná (UTFPR), Brazil

Abstract
Fluids that gelify when not submitted to shear stress are largely employed in several industries. An example is the oil industry, which uses a wide variety of those materials, such as drilling fluids and waxy crude oils. The drilling fluid is designed to build up a gel-like structure at rest in order to keep cuttings under suspension avoiding the bit obstruction at the bore bottom. As a consequence, high pressures that can damage the well structure are needed to break the gel up. This study presents a mathematical model to simulate the flow start-up of drilling fluids gelified in within a long pipe. The transient flow is considered one-dimensional, isothermal, weakly compressible and laminar. The model is based on the continuity, momentum equations and on an equation of state. The equations are solved by the method of characteristics that converts partial differential equations into ordinary ones which are solved iteratively. An elasto-visco-plastic constitutive equation is employed to represent gel breaking and fit to rheological data. The radial shear stress distribution is considered linear and the velocity field is integrated along the pipe cross section in order to evaluate the shear stress at pipe wall in different axial position. The model results were corroborated by experimental data obtained from a 50 m long flow loop that is built as coil and placed within a controlled temperature chamber. The drilling fluid within the loop is left to rest at a constant temperature and then pressurized by an alternative pump. Pressures measured at different positions along the 50m long pipe were compared to values obtained from the model.

Keywords: Start-up flow; Transient compressible mathematical model; Experimental Loop; Elasto-visco-plastic fluid model.

Paper presenter: Cezar O. R. Negrão, PhD, Av. Sete de Setembro, 3165, CEP 80.230-901, Curitiba, PR, Brazil, phone: +55 41 3310 4658, fax: +55 41 3310 4852, e-mail: negrao@utfpr.edu.br
ISO-DENSE DISPLACEMENT AND START-UP FLOWS OF YIELD STRESS FLUIDS

Gustavo MOISES¹, Ian FRIGAARD², and Monica NACCACHE³

¹Petrobras, Brazil; ²University of British Columbia, Canada; ³Pontificia Universidade Catolica do Rio de Janeiro, Brazil

Abstract
Displacement of a yield stress fluid by another fluid is a relatively common flow, that occurs in the restart of pipelines and in the primary cementing process. Two features are of critical importance: (i) whether or not the flow is able to start; (ii) the degree to which the in situ fluid is removed during the displacement. Where the yield stress is significant it is quite common that even if the flow starts, significant residual fluid is left behind during the displacement. Here we focus on yield stress fluid displacements in the absence of any significant buoyancy forces, which is most relevant to the restart of waxy crude oil pipelines.

We present the results of an experimental study using laboratory fluids (Laponite, Carbopol, Xanthan, Glycerin and water). The experiments are conducted in 4m long horizontal flow loop of 19mm diameter, visualized from the side and above. A variety of fluid pairs are used. We observe some instances of wall slip as well as many experiments where the viscoplastic fluid yields and is either partially or fully displaced. We present an overview of the types of observed behaviour and characterise the displacement efficiency for the range of experiments.

Gustavo Moises, MSc., Unit 106 – 2720 Acadia Rd. Vancouver Canada V6T 1R9, tel: 1 6042218990, gustavomoises@yahoo.com
INTERRMITTENT FLOW IN YIELD-STRESS FLUIDS SLOWS DOWN CHAOTIC MIXING

Emmanuelle GOUILLART, Jalila BOUJLEL, Dawn WENDELL
Franck Pigeonneau and Pierre JOP
Surface du verre et interfaces, UMR 125 CNRS/Saint-Gobain, France

Many mixing situations involve fluids with non-Newtonian properties: mixing of building materials such as concrete or mortar are based on fluids that have shear-thinning rheological properties. Lack of correct mixing can waste time and money, or lead to products with defects. When fluids are stirred and mixed together at low Reynolds number, the fluid particles should undergo chaotic trajectories to be well mixed by the so-called chaotic advection resulting from the flow. Previous work to characterize chaotic mixing in many different geometries has primarily focused on Newtonian fluids. First studies into non-Newtonian chaotic advection often utilize idealized mixing geometries such as cavity flows or journal bearing flows for numerical studies.

Here, we present experimental results of chaotic mixing of yield stress fluids using rod-stirring protocol with rotating vessel. We describe the various steps of the mixing and their dependence on the fluid rheology and speeds of rotation of the rods and the vessel. We show that using chaotic advection to mix yield stress fluids is less efficient than mixing Newtonian fluids, due to the presence of fluid that does not flow when it is below the yield stress, and only flows intermittently. This result is confirmed via numerical simulations. Anomalously slow mixing is observed when the synchronization of different stirring elements leads to the repetition of slow stretching for the same fluid particles.

We also describe the chaotic mixing of two yield stress fluids of different rheological properties, and the mixing of a yield stress fluid with a Newtonian liquid.

Polymer gels as phantoms for MRI device testing

John R. de Bruyn¹, Corey Rae McRae², Leesa Fleury¹, William B. Handler¹, and Blaine A. Chronik¹

¹ Department of Physics and Astronomy, University of Western Ontario, London, Ontario, Canada N6K 3A7
² Institute for Quantum Computing, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1

Medical devices such as pacemakers and implants must be rigorously tested before they can be used in magnetic resonance (MR) imaging scanners. A major problem is rf heating of tissues or device materials due to electric currents induced by the time-varying electromagnetic fields present in the scanner. This heating could cause serious injury to the patient and/or damage to the device. "Phantoms" which mimic the properties of tissue are used in testing the MR compatibility of devices. Ideally, such phantoms should match the mechanical, electrical, and thermal properties of tissue under the conditions that prevail inside an MR scanner, but this is difficult to achieve in practice. Currently, gels based on polymers such as poly(acrylic acid) or hydroxyethylcellulose are commonly used phantom materials, and their preparation and use is governed by ASTM standards. We will review the desired properties of MR phantoms and discuss the degree to which they are met by currently used materials and standards. We will then outline methods for testing and modeling the mechanical, electrical, and thermal behavior of phantom materials, and discuss approaches to the design of materials that will give improved performance as phantoms.

John R. de Bruyn, Professor, Department of Physics and Astronomy, Western University, 1151 Richmond Street, London, Ontario, Canada N6K 3A7.

phone: +1 519-661-2111 x 86430
fax: +1 519-661-2033
email: debruyn@uwo.ca
Applied rheology on sludge suspension in water treatment systems

Holm, R*, Haldenwang R^, Chhabra R~

* RH Consult, Stockholm Sweden, ^ CPUT, Cape Town, South Africa, ~ IIT, Kanpur, India

Abstract

Pumping, mixing and separation of suspensions are core operations in industrial flow processing systems. Due to operations such system are applid in handling different suspension, which typically require more energy as for example the suspension concentration increase. In conventional design of such industrial flow systems, a compensation (de-rating) referred on handling water is used in order to avoid operating challenges stemming from the viscoplastic effect of the suspension. However, in many flow systems, this results in over-sizing of the pumps, mixer units and the auxiliary equipment. Therefore, it is desirable to incorporate the viscoplastic effect and endeavour to achieve an adaptive system design and obtain optimal operating performances. Additional motivation in such applications is due to the world-wide efficient energy use and in many areas water has become a scarce resource. For example, in a treatment process (industrial or municipal) where less water is used, the sludge concentration increases which affects for example the pumpability due to the increasing degree of non-Newtonian characteristics like shear-thinning and yield stress. The objectives of this study are two-fold; firstly to conduct rheological characterisation of waste water activated excess sludges of different concentrations and secondly to investigate the viscoplastic effect on the operating performances.

A portable flow rig was designed and commissioned for this purpose. It is basically a tube viscometer which allows the determination of suspension rheology and the testing of pumping performance. The pump performance and rheology data were acquired simultaneously in three different test pipe sizes (63 mm, 52 mm and 27 mm). The sludge originated from a municipal waste water treatment plant via a decanter unit without adding any polymers to obtain different sludge concentrations to test. The sludge temperature was controlled during the experimental tests in pipeline section.

All sludge concentrations (3.4% - 7.2% total solid concentration) showed varying levels of shear thinning behaviour and yield stress levels. The sensitivity of the parameter to the concentration indicated the sludge's rheological variability. In the turbulent region, the pipe size dependency was obvious, and data branched off from the single laminar curve. This indicated clearly the transition region observed in the pipes of different diameters used in this work. The deterioration in pumping performance due to sludge rheology was linked to the sludge concentration. Finally, the suspension behaviour was uniquely observed during circulation in the flow rig. This was further elaborated to include in system design criterions.
IMPACT OF WALL-SLIP EFFECTS ON YIELD STRESS MEASUREMENTS IN CYCLOPENTANE HYDRATE SLURRY

Amit AHUJA and Jeffrey F. MORRIS
Levich Institute and Department of Chemical Engineering, The City College of New York, New York, New York, 10031, USA.

Abstract
Rheology of hydrate slurries is of prime importance in the operation of petroleum pipelines. In this study, a hydrate slurry is prepared in-situ using liquid cyclopentane (CP) as the hydrate former at atmospheric conditions from a density-matched water-in-oil emulsion by quenching it to a lower temperature at a fixed shear rate. A phase transition, from initial deformable water droplets dispersed in a continuous oil to a solid particle suspension, takes place during which the viscosity increases by several orders of magnitude and jamming may occur. This is a clear indication of hydrate formation on the dispersed water droplets and subsequent agglomeration. For cases in which a finite steady state viscosity is obtained, further rheological experiments are performed. Particularly, effects of wall slip on the measurements of yield stress are examined for varying water volume fractions using a stress-controlled rheometer equipped with roughened and smooth-walled cylindrical cups with a vane tool. The roughened cup with vane fixture, which suppresses wall slip, is used to make a comparison of various yield stress measurement methods. Decreasing shear stress ramp, oscillatory stress ramp, and nonlinear viscoelastic methods are used. In the last of these, the maximum in elastic stress, which is the product of elastic modulus (G') and strain, gives a measure of yield stress. Good agreement for the yield stress is obtained by the various methods, and the yield stress is found to be increasing function of water volume fractions, with the minimum water fraction for which a yield stress was measureable being 16%. Yield stresses for water fractions above 30% exceeded instrument limits. Results are reported in terms of time evolution of yield stress of hydrate slurries. The smooth cup with vane rotor exhibits significant wall slip effects on the inner wall of the cup, which is clear from large fluctuations in viscosity during the slurry preparation, and an underestimation of yield stress. The yield stress with smooth geometry can lead to 75% lower values than using roughened geometry.
BOUNDARY INTEGRAL SIMULATIONS OF DEFORMATION OF VISCOPLASTIC DROPS IN EXTENSIONAL AND COMPRESSIONAL VISCOUS FLOWS

Olga M. Lavrenteva, Irina Smagin, Avinoam Nir

Chemical Engineering Dept., Technion – Israel Institute of Technology, Israel

The slow deformation of viscoplastic drops in axisymmetric compressional and extensional viscous flows is simulated making use of a variation of the integral equation 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 at the drop surface using the integral expressions for the adjoined domains. Thus, the problem is reduced to an integral equation in a bounded domain, the reduction of which is the main advantage of this method.

The study was focused on the established shapes of the drops and of the unyielded regions within them and their temporal evolution. The computations were carried out for a variety of capillary numbers, Ca, viscosity ratios, $\lambda$, and Bingham numbers, $Bn$. The solution predicts critical capillary numbers, beyond which the deformation becomes unstable and drops break-up. The dependence of these critical capillary numbers on the governing parameters at these critical states is reported.
Thursday 21 November 2013
Natural convection of a Bingham fluid in a vertical channel

author's Name SURNAME (11-point Arial bold, centered)
Ida Karimfazli, Ian Frigaard

Affiliation, Country (11-point Arial, centered)
University of British Columbia, Vancouver, Canada

First-level headings (11-point Arial bold, left-justified)
Normal text (11-point Arial, justified, single spaced)

Vertical ducts filled with yield stress fluids and with differentially heated walls are found in the drilling and cementing of oil wells, as well as potentially in other construction geometries and geophysical contexts. In these settings it is of interest to determine whether or not the thermal heating effects are sufficient to promote fluid motion and eventually instability. As an archetypical flow we consider a vertical plane channel between two differentially heated walls. In addition to the constant temperature difference there is a stabilizing vertical gradient in the imposed temperature. This configuration was studied by Bergholz [1], in the case of Newtonian fluids.

The base flow is governed by 2 dimensionless parameters: a stratification parameter and a Bingham number. Above a critical Bingham number we find that there is no motion, regardless of the stratification parameter. We study the rich structure of solutions found below this critical Bingham number. For most of the dimensionless parameter space we find solutions with 2 or 3 unyielded plugs, and mainly we have explored the behaviour of these solutions. Of academic interest is the fact that for sufficiently large stratification parameter and small Bingham number it appears we can find infinitely many unyielded plug regions - a peculiarity for a steady flow in a finite domain. We present a complete picture of the different flows in the parameter space governed by Bingham number and stratification parameter.

References

Uncertain who would present – correspond with:
Ian Frigaard
Departments of Mathematics & Mechanical Engineering,
University of British Columbia
frigaard@math.ubc.ca
1-604-822-3043 / 1-604-822-1316
THE PLANAR SQUEEZE FLOW OF BINGHAM PLASTICS

Larisa MURAVLEVA

Lomonosov Moscow State University, Russia

We develop an asymptotic solution for the planar squeeze flow of a viscoplastic Bingham media between two parallel plates. Squeeze flow problem have attracted significant attention over the years. Lipscomb and Denn probably first have shown that the usual lubrication approximation in squeeze flow of Bingham fluids leads to a paradox which refers to the existence or non-existence of a true unyielded plug region. The lubrication approximation predicts that plug region moves with a speed which slowly varies in the principal flow direction. The axisymmetric squeeze flow between two coaxial disks was studied in [1],[2]. They showed numerically that unyielded material can only exist only around the stagnation points of flow near the centers of the disks.

For the asymptotic analysis we applied technique suggested in [3],[4]. The velocity field consists of a central region of extensional flow and sheared region adjacent to the plates. The central pseudo-plug region is region of plastic flows bounded by the pseudo-yield surfaces.

For numerical simulation we have used the augmented Lagrangian method. This algorithm gives true unyielded regions with exactly zero strain rate. Our aim consists in determination the location and shape of rigid zones, so ALM is extremely suitable for this purpose. Simulations were carried out for a wide range of yield stress value and for different aspect ratios. The numerical results confirmed asymptotic analysis. Our calculations show that unyielded regions are located near the centers of the plates (as in axisymmetric case). Moreover, we also observed another interesting phenomenon: unyielded regions appear at the free surfaces around the stagnation points. We consider slip, no-slip and partial slip at the plate interfaces. Numerical experiments for the two-layered material with different yield stresses of the layers were carried out.

This work is partially supported by Rus. Gov. Program “Kadry”, contract #8226.


Larisa Muravleva, Dr.,
Leninskie gory, Main Building,
Department of Mechanics and Mathematics,
Lomonosov Moscow State University,
127006, Moscow, Russia
+7 916 347 77 37 (cell) - +7 495 699 52 87 (home) - +7 495 939 43 43 (work) - +7 495 939 20 90 (fax)
lvmurav@gmail.com
On the Landau-Levich problem for a viscoplastic fluid

Miguel MOYERS-GONZALEZ\(^1\), Phillip L. WILSON\(^3\), Marla SWEID\(^2\), Cathy CASTELAIN\(^2\), Teodor Burghelea\(^2\)

\(^1\) Department of Mathematics and Statistics, University of Canterbury, Private Bag 4800, Christchurch, New Zealand
\(^2\) - UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609, 44306 Nantes Cedex 3, France

Abstract

A systematic investigation of the Landau-Levich problem of a viscoplastic material is presented. The validity of the Landau-Levich scaling is investigated via integral scale measurements of the width of the coating film thickness performed for different values of the yield stress in the presence and in the absence of wall slip. To gain a deeper insight into the physical origins of the experimentally observed deviations from the classical 2/3 scaling a full characterisation of the time resolved flow field around the moving solid is performed and the main differences of the viscoplastic flow patterns with respect to their Newtonian counterpart are highlighted.

Using a lubrication approximation approach we provide an asymptotic solution for the thickness of the film, valid for small capillary numbers. Analytical and experimental results for the scaling law are in good agreement.

Miguel Moyers-Gonzalez, Senior Lecturer,
University of Canterbury
Private Bag 4800
Christchurch
8140
NZ
Ph:+64 3 364 2987 ext. 7666
Miguel.moyersgonzalez@canterbury.ac.nz
ON THE MODELING OF YIELD STRESS DUE TO TUBE-TUBE INTERACTIONS IN CARBON NANOTUBE SUSPENSIONS

Natale GIOVANNIANTONIO\textsuperscript{a}, Gilles AUSIAS\textsuperscript{b}, Marie-Claude HEUZEY\textsuperscript{a}, Pierre CARREAU\textsuperscript{a}, Julien FEREC\textsuperscript{b}

\textsuperscript{a} Center for Applied Research on Polymers and Composites (CREPEC), Chemical Engineering Department, École Polytechnique de Montréal, PO Box 6079, Station Centre-Ville, Montréal, QC, Canada H3C 3A7

\textsuperscript{b} Laboratoire d'Ingénierie des MATériaux de Bretagne (LIMATB)

Université Européenne de Bretagne, rue de St Maudé, 56325 Lorient, France

Carbon nanotubes (CNTs) hold remarkable promises for the next generation of material with huge potential applications. Nevertheless, CNT melts and suspensions are inherently difficult to process and in order to design efficient processing schemes, it is necessary to fully understand and predict their rheological behavior. In this work, a new model is developed in order to explain the shear thinning of untreated CNT suspensions, one of their rheological signature. The CNTs are described as rigid cylinders dispersed in a Newtonian matrix and the evolution of the system is controlled by hydrodynamic and rod-rod interactions. The force due to the interactions is modelled as a non-linear lubrication force which is a function of the relative velocity at the contact point, and it is weighted according to the contact probability. The total stress tensor is evaluated calculating the well known fourth order orientation tensor and a new fourth order interaction tensor. The Fokker-Planck equation is numerically solved for steady state simple shear flows using a finite volume method avoiding the need of closure approximations. At low shear rates, the model tends to predict a solid behavior depending on the interaction force. Furthermore, the model is extended to bead suspensions.
COSSERAT-BINGHAM FLUIDS

Vladimir SHELUKHIN

Lavrentyev Institute of Hydrodynamics, Russia

We consider Cosserat-Bingham fluid which is both a micropolar medium and a viscoplastic material. On one hand, such a fluid exhibits microrotational effects and microrotational inertia; the fluid can support the couple stress, the body couples and the nonsymmetric stress tensor. On the other hand, the fluid stiffens if its local stresses and local couple stresses do not exceed some yield stress $\tau_c$ and an yield couple stress $\tau_s$, respectively. We are mainly interested in incompressible fluids, but nevertheless we will also discuss the general situation.

We focus on constitutive laws for the micropolar non-Newtonian fluids which can support yield stresses. Such fluids include animal blood, cutting transport by drilling mud, and granular flows. In mechanics of the classical Bingham fluid, there is only one yield stress $\tau$, because the local stress state is characterized completely by only one tensor; it is the Cauchy stress tensor $\tau$. To characterize stresses in the micropolar fluid, one should take into account the couple stress tensor $\boldsymbol{\tau}'$ also; this is why we incorporate a yield couple-stress $\tau_s$. As for local deformations, they are characterized also by two tensors which allow to calculate the velocity gradient and the spin gradient; both these tensors should vanish in the zone of stiffness, the strong plug zone. In contrast to the classical Bingham fluid, the micropolar Bingham fluid may have a weak plug zone where the spin gradient vanishes whereas the velocity gradient does not vanish.

We restrict ourselves to a simple micropolar viscoplastic fluid. The corresponding constitutive equations require a minimal number of viscosity coefficients. To illustrate the equations derived, we consider shear flows between two parallel planes. We show that the apparent viscosity increases as the canal thickness decreases in agreement with the inverse Fahraeus—Lindquist effect for the blood seepage through a narrow capillary tubes at high values of hematocrit. Observe that, within the Cosserat—Bingham approach, there is no flows for low values of the canal thickness. As for applications in transport of drilling cuttings, the model developed here predicts that even small increase of the drilling mud discharge may result in a significant pressure growth within the borehole if the cutting concentration and the mud composition are such that the rotation viscosities, corresponding to the mud-cutting mixture, are not negligible. The borehole pressure control is of great importance in the well stability problem.

Vladimir Shelukhin, professor, Lavrentyev Institute of Hydrodynamics, Pr. Lavrentyev 15, Novosibirsk 630090 Russia, fax:+7 383 3331612; e-mail: shelukhin@list.ru
STRUCTURE FORMATION DURING VIBRATION OF SUSPENSIONS OF HARD SPHERES AND CARBOPOL SPONGES

Ronald PHILLIPS
Department of Chemical Engineering and Materials Science
University of California, Davis, CA
USA

Complex fluids, including particulate suspensions, emulsions, and viscoelastic fluids, exhibit a variety of interesting surface structures when subjected to vertical vibration. These structures include holes, "kinks," heaps, and protrusions comparable to the oscillons seen in granular media. Although several explanations for these phenomena have been proposed, there is currently no quantitative, widely accepted theory or model to explain them. We have studied the behavior of viscoelastic solutions filled with swollen, polymeric Carbopol "microsponges" when subjected to vertical vibrations. This system of soft, gel-like particles makes an interesting contrast to our second system, which consists of highly-filled dispersions of glass spheres, suspended in aqueous solutions with varying density.

Our experiments with both fluids have yielded surprising and previously unreported results, and the behavior of the two materials is strikingly distinct. Starting as an initial "blob," the Carbopol flows radially outward, ultimately self-segregating into an inner region where flow is minimal, and an outer region where a recirculating flow exists only in a region near certain azimuthal angles. In the region where flow is present, holes form, and the locations of the holes coincide with the vertices of regular polygons. We have observed the formation of up to eight holes, always in a geometric pattern, depending on the volume of fluid studied. The hard-sphere dispersions of glass spheres also exhibit holes, but not in a regular pattern. In addition to holes, the glass dispersions form heaps and craters, as has been reported by others. At the edge of mounds of suspension, very sharp ridges form in a sawtooth pattern that does not appear to have been reported previously.

We are using the equations of fluid mechanics, in conjunction with the "lubrication approximation," to interpret our results. Particularly for the glass-particle suspensions, we have also identified dimensionless groups that determine the phase diagram for the system. These results are relevant to applications where complex fluids are of necessity subjected to the mechanical vibrations, and also to applications where the vibration is introduced intentionally to unlock a jammed system.

Ronald J. Phillips, Professor, UC Davis, Department of Chemical Engineering and Materials Science,
1 Shields Ave., Davis, CA 95616
Phone: 001-530-752-2803
Fax: 001-530-752-1031
e-mail: rjphillips@ucdavis
FREezING IN SHAPES IN MULTyLAYER FLOWS

Contributors:
S. Hormoz1,2, G. Dunbracht1, A. Maleki/Zamenjani1 and I.A. Frigaard1,2
Presenter: S. Hormoz, (hormoz@math.ubc.ca)

1) Department of Mechanical Engineering, University of British Columbia
2) Department of Mathematics, University of British Columbia

Stable multi-layer flows can be achieved at high Reynolds numbers by using a yield stress fluids in a lubricating outer layer. These flows have been demonstrated to be linearly and non-linearly stable as well as observable experimentally and computationally; see Frigaard (2001), Moyers-Gonzalez et al. (2004), Huen et al. (2007), Hormoz et al. (2011a) and Hormoz et al. (2011b).

We present results of experimental, computational and theoretical studies targeted at extending the visco-plastic lubrication concept to patterned extrusion products and to the transport of encapsulated fluid droplets. In the experimental and computational parts, we show that by controlling the flow rates and rheology of different fluid streams it appears possible to engineer wavy walled tubes/channels, inserts and to produce droplets of varying shapes and sizes. In all cases the yield stress of the fluids "freezes in" the interface shape between simultaneously pumped streams of two fluids. A distinction between this method and other droplet forming techniques is that length-scales are governed by the inlet conditions and the fluid rheological properties, rather than by capillary phenomena. This opens up possibilities for application in industries that do not operate on the micro-scale, as in most large scale industrial processing (e.g., oil, food, personal care and drug industries). We also present the result of an asymptotic solution that gives the relation between the size of encapsulated droplet and the state of stress in the flow.

References:


UPSCALING APPROACH TO THE BEHAVIOR OF VISCOPLASTIC SUSPENSIONS

Xavier CHATEAU

Université Paris-Est, Laboratoire Navier (UMR 8205), France.

Heterogeneous systems consisting of particles (rigid or deformable) suspended in a non-Newtonian fluid medium are encountered in many situations. Despite its interest for practical purposes, rigorous methods able to predict the overall rheological properties of a suspension made up of components having known properties have not yet been built. The main difficulty in modeling the behavior of suspensions comes from the fact that the material is multiscale and contains many interacting constituents. It is therefore not possible, even using large numerical simulation, to describe in great detail the flow of the suspending fluid at the particle scale and then to accurately predict the overall behavior of the suspension especially in the concentrated regime. The aim of this paper is to show how it is possible to obtain estimates for the overall rheological properties of Newtonian and non-Newtonian suspension in the framework of upscaling approaches.

In the first part of the presentation, pattern based approaches to the behavior of linear (elastic or viscous) suspensions will be presented. These pattern based homogenization approach aims to account for particle to particle hydrodynamic interactions more rigorously and accurately than classical homogenization approaches. In this goal, the average of strain rate and stress over each heterogeneous fluid phase are estimated by solving a "simplified" boundary value problem aiming to describe the hydrodynamic interactions between suspended particles.

Then, the nonlinear problem is addressed. In this situation, estimates for the overall rheological properties are obtained by replacing the original nonlinear upscaling problem by a linear homogenization problem for a suspension of objects immersed in a heterogeneous linear fluid with viscosity equal to the apparent viscosity of the non-Newtonian fluid. In both parts, theoretical estimates for rigid particles, bubbles and drops will be compared to experimental data.
FLOW OF A THIXOTROPIC FLUID AROUND A CYLINDER

Alexandros SYRAKOS\textsuperscript{1}, Andreas ALEXANDROU\textsuperscript{2}, Georgios GEORGIOU\textsuperscript{1}

\textsuperscript{1}Department of Mathematics and Statistics, University of Cyprus, Cyprus
\textsuperscript{2}Department of Mechanical and Manufacturing Engineering, University of Cyprus, Cyprus

Abstract
We study the flow of a thixotropic fluid around a cylinder. The rheology of the fluid is described by means of a structural viscoplastic model based on the Bingham constitutive equation, regularised using the Papanastasiou regularisation. The yield stress is assumed to vary linearly with the structural parameter, which equals one for fully developed skeleton structure and zero for completely broken structure. The structural parameter follows a first-order rate equation which accounts for the material structure break-down and build-up. The results were obtained numerically using the Finite Element Method. Simulations were performed for moderate Reynolds numbers, so that flow recirculation is observed behind the cylinder, but no vortex shedding.

Alexandros Syarakos, Dr., University of Cyprus, P.O. Box 20537, 1678 Nicosia, Cyprus. Tel: +357 22893412, e-mail: syarakos.alexandros@ucy.ac.cy
ELASTIC AND INERTIA EFFECTS IN VISCOPLASTIC FLUID FLOWS THROUGH AN ABRUPT EXPANSION-CONTRACTION

Daniel D. DOS SANTOS, Sergio FREY
Federal University of Rio Grande do Sul, Brazil

Mônica F. NACCACHE, Paulo R. DE SOUZA MENDES
Pontifical Catholic University of Rio de Janeiro, Brazil

Abstract
A study of the steady flow of an incompressible elasto-viscoplastic fluid through an expansion followed by a contraction is performed, using a constitutive equation that takes into account thixotropy, and the elastic behavior of viscoplastic liquids below the yield stress. The equation is based on the Oldroyd-B constitutive equation for viscoelastic fluids, modified to accommodate structuring-level dependent relaxation and retardation times, and viscosity. The structuring level is determined by a structure parameter, obtained via an evolution equation.

The numerical solution of the governing equations is obtained via the finite element method, using a four-field Galerkin least-squares (GLS) formulation in terms of the structure parameter, extra-stress, pressure and velocity. This GLS formulation has as major features the use of simple combinations of finite element interpolations, and a stable approximation for either elastic- or viscous-dominated flow regions. The geometry is kept constant, and the role of inertia, elasticity and yield stress effects are investigated for a non-thixotropic fluid. The yield surfaces, elastic deformation, viscosity and relaxation time fields are obtained and analyzed for different combinations of the governing parameters. Moreover, some flow visualization using Laponite suspensions is shown. The trends observed show a strong interplay among elasticity, inertia and yield stress, and proved to be physically meaningful and in accordance with the related literature.
EROSION OF A YIELD-STRESS FLUID

Li-Hua LUU*, Pierre PHILIPPE* & Guillaume CHAMBONb

a. IRSTEA, 3275 route de Cézanne, 13182 Aix-en-Provence, France.
b. IRSTEA, 2 rue de la Papeterie, 38402 St-Martin-d’Hères, France.

Context
Bed erosion induced by rapid gravity flows of complex fluids, such as mudflows or avalanches, still remains poorly understood. A specificity of these natural flows is that, generally, the material forming the static bed has mechanical properties similar to those of the flowing material (mud/mud, snow/snow). In this experimental study, we use yield-stress fluids to model both the eroding flow and the eroded bed with an original approach that captures the process of erosion in terms of solid-liquid transition.

Experimental setup
The hydrodynamics of erosion is created by the laminar flow of a model yield-stress fluid in a rectangular pipe where an obstacle is settled. Upstream of the obstacle, a solid-liquid interface between a flow zone and a dead zone appears. The erosion of the yield-stress fluid is induced by varying the flow rate by a pump. In this work, we chose to use a polymer microgel (carbopol) characterized by a Herschel-Bulkley rheology. The transparency if this material is exploited for internal visualization techniques such as Particle Image Velocimetry (PIV). Our approach aims to investigate the dominant physical mechanisms of erosion by combining an accurate rheological characterization of the yield-stress fluid using a rheometer, with the observation of the morphological evolution of the frontier in between flow and dead zone as well as local measurement of related hydrodynamic parameters.

First results
Detailed velocity profiles obtained by PIV will be presented. Far from the obstacle, these profiles are consistent with a Poiseuelle-type flow, with maximum shear rates at the walls and a plug in the middle of the pipe. Close to the obstacle, on the contrary, the profiles display a change of curvature sign in the vicinity of the dead zone. The shear rate tangential to the dead zone interface, calculated from the velocity profiles, evolves continuously from zero in the static domain, to a maximal value in the vicinity of the solid-liquid interface, before decreasing to zero when reaching the flow plug in the center of the pipe. The possibility to describe this behaviour in terms of a simple Herschel-Bulkley rheology will be discussed. To that purpose, a systematic investigation will be conducted by varying flow rate, obstacle size and concentration of carbopol, and the results will be analyzed in terms of characteristic scaling laws for the position of the solid-fluid interface and maximum shear rate. Ultimately, our goal would be to predict the shape and size of the dead zone as a function of the experimental conditions and fluid properties, and hence to formulate an erosion law fundamentally related to the viscoelastic character of the fluid and its solid-liquid transition.
LAMINAR UNSTEADY PIPE FLOW OF A CARBOPOL GEL

Antoine POUMAERE$^1$, Miguel MOYERS-GONZALEZ$^2$, Cathy CASTELAIN$^1$, Teodor I. BURGHELEA$^2$

1) UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609, 44306 Nantes Cedex 3, France
2) Department of Mathematics and Statistics, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

An experimental study of a laminar unsteady pipe flows of a Carbopel gel is presented. The investigation of the solid-fluid transition in an unsteady rheometric flow in the presence and in the absence of the wall slip reveals a strong coupling between the irreversible deformation states and the wall slip phenomenon. Particularly, the presence of wall slip nearly suppresses the scaling of the deformation power deficit associated to the rheological hysteresis with the rate at which the material is forced. In-situ measurements of the flow fields performed during an increasing/decreasing stepped pressure ramp reveal three distinct flow regimes: solid (plug-like), solid-fluid and fluid. The time resolved measurements of laminar unsteady flows driven by an increasing/decreasing controlled pressure ramp reveal an irreversible yielding scenario similar to that observed in the rheometric flows. The deformation power deficit associated with the hysteresis observed during the increasing/decreasing branches of the pressure ramps reveals a dependence on the rate at which the unsteady flow is driven consistent with that observed during the rheological measurements in the presence of slip. The dependence of the slip velocity on the wall shear stresses reveals a Navier-type slip behaviour only within the fluid flow regime, which indicates that the wall slip phenomenon is directly coupled to the solid-fluid transition in this flow configuration as well. A universal scaling of the slip velocity with the wall velocity gradients is found and the slip length is independent on the characteristic time of forcing \( \tau \). The paper closes with a discussion of the main findings, their possible impact on our current understanding of the yielding and slip behaviour of Carbopel gels. Several steps worth being pursued by future experimental/theoretical studies are proposed.

Teodor I. Burghelea, Dr., UMR 6607, Laboratoire de Thermocinétique, LUNAM Université - Université de Nantes and CNRS, La Chantrerie, Rue Christian Pauc, B.P. 50609, 44306 Nantes Cedex 3, France
Tel: +(33) - (0)2 40 68 31 85
Email: Teodor.Burghelea@univ-nantes.fr
ON THE SLOW SETTLING OF ROUGH AND SMOOTH SOLID SPHERES
IN A YIELD-STRESS FLUID

Yulia Holenberg\textsuperscript{1}, Olga M. Lavrente\textsuperscript{a}, Uri Shavit\textsuperscript{2}, Avinoam Nir\textsuperscript{1}

\textsuperscript{1}Chemical Engineering Dept., Technion – Israel Institute of Technology, Israel
\textsuperscript{2}Civil and Environmental Engineering Dept., Technion – Israel Institute of Technology, Israel

Particle tracking velocimetry (PTV) and image velocimetry (PIV) were used to study the slow sedimentation of solid spherical particles in a quiescent 0.07\% w/w Carbopol gel under gravity. PTV was used to establish the shape of the yielded region surrounding the settling particles, while PIV was employed to obtain the flow field inside this region boundary. The technique and the experimental system followed our previous work on such motion of viscous Newtonian drops. The resulting shapes of the yielded region were compared with various theoretical predictions available in the literature. Several differences appear between the measured and all calculated shapes. The experimental result does not exhibit a fore-and-aft symmetry, and the yield in the advancing side of the moving particle is, in general, thicker than the one in the trailing side. Furthermore, there is evidence that a small yielded wake exists around the axis of symmetry on the trailing end.

Perhaps the most interesting phenomenon that was observed is that the shapes of the yielded region around smooth spheres resemble the experimental results that were obtained for viscous drops. This suggests the existence of a slip of the gel on the smooth surface which, most likely, originated from seepage of the low viscosity solvent from the gel, forming a thin lubricating layer near the solid surface.


Avinoam Nir, Chemical Engineering Dept., Technion, 32000, Haifa, Israel,
tel: +972 48292119, fax: +97248295672, avinin@techunix.technion.ac.il
Poster session

1- Modelling of the rheological properties of bentonite suspensions
M. Gareche¹, A. Allali², N. Zeraibi¹, F. Rob², J. C. Dupin³ (¹FHCC, Laboratoire génie physique des hydrocarbures, Université M'hamed Bougara, Boumerdes, Algérie, ²IPREM-EPCP, Université de Pau et des Pays de l'Adour, Pau, France, ³IPREM-ECP, Université de Pau et des Pays de l'Adour, Pau, France)

2 - Analysis of static zone shape in simulated extrusion flow of viscoplastic pastes
M. Bryan (University of Cambridge, United Kingdom)

3 - Development of a unique rheological model for hair gel describing the solid-like and the liquid-like behaviour
J. Quignon¹, J.-C. Baudez¹, S. Amziane² (¹IRSTEA, UR TSCF, France, ²Université Blaise Pascal, Department of Civil Engineering, France)

4 - A methodology for the selection of the state equation and adsorption isotherm
S. Rosales-Anzola¹, M. Garcia-Sucre², E. Lopez³ (⁴PVDSA-INTEVEP, Venezuela, ⁵IVIC, Venezuela, ⁶ENSIC, France)

5 - Rheological behavior of polyelectrolyte solutions
K. Benyounes, A. Mellak, A. Benmounah (Université M'hamed Bougara, Algeria)

6 - Prediction of pressure transmission during a kick of gas in well drilling operations
G. M.de Oliveira, J. F. Galdino, A. T. Franco, C. O.R. Negrao (Thermal Science Laboratory, Post-graduate Program in Mechanical and Materials Engineering, Federal University of Technology-Paraná, Brazil)

7 - Study of structural changes of water confined in the BRIJ-30 reverse micelles by instrumental methods
M. Kurtanidze, T. Butkhuzi, N. Kokiashvili, M. Rukhadze (Faculty of Exact and Natural Sciences, Javakhishvili Tbilisi University, Georgia)

8 - Rheological characterization of liquids by an acoustical method
B. B. Damdinov (Buryat State University, Molecular Acoustics Laboratory of Buryat Scientific Center of RAS, Ulan-Ude, Russian Federation)

9 - Finite element approximations for entry flows of thixotropic elasto-viscoplastic fluid flows
C.E. Fonseca¹, D.D. Dos Santos¹, F.B. Link¹, S. Frey¹, M. Naccache², P.R. De Souza Mendes² (¹Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Brazil, ²Department of Mechanical Engineering, Pontificia Universidad Catolica-RJ, Brazil)
ABSTRACTS

Abstracts are listed following program order

The abstracts are published in their original format as they were sent to Organizing Committee.
MODELLING OF THE RHEOLOGICAL PROPERTIES OF BENTONITE SUSPENSIONS

Mourad GARECHE\textsuperscript{1}, Ahmed ALLAL\textsuperscript{2}, Noureddine ZERAIBI\textsuperscript{1}, François ROBY\textsuperscript{2} et Jean Charles DUPIN\textsuperscript{3}

\textsuperscript{1}FHC, Laboratoire génie physique des hydrocarbures, FHC, Université M'hamed Bougara Boumerdes (Algérie)
\textsuperscript{2}IPREM-EPCP, Université de Pau et des Pays de l'Adour, Hélioparc, 2 av. Pierre Angot, Pau 64053, (France)
\textsuperscript{3}IPREM-ECP, Université de Pau et des Pays de l'Adour, Hélioparc, 2 av. Pierre Angot, Pau 64053, (France)

Abstract

Our work concerns water based drilling muds. Our objective is to establish the correlation between the microstructure of the fluid and its rheological properties. In this study, we focused ourselves on clay-water mixtures, which constitute the base of these muds. We studied their rheological behavior and more particularly the linear viscoelasticity for various clay weight fractions \(\phi_m\) (2, 4, 5, 6 and 8%). Our objective being to establish the link between the fractal structure of these suspensions (via the yield stress and the elastic module) and the complex shear modulus \(G^*(\omega)\). In this article, we will show that, starting from the gel fractal dimension, it possible to predict the variation of \(G^*(\omega)\) according to the angular frequency \(\omega\) of the water-bentonite suspensions.

GARECHE, Dr., Laboratoire génie physique des hydrocarbures, FHC, Université M'hamed Bougara Boumerdes (Algérie), 00 (213) 555 729 521, m_gareche@yahoo.fr
ANALYSIS OF STATIC ZONE SHAPE IN SIMULATED EXTRUSION FLOW OF VISCOPLASTIC PASTES

Matthew BRYAN

University of Cambridge, United Kingdom

Viscoplastic materials are often used in the manufacture of products through extrusion. Due to their plastic behaviour, the green part is able to retain its shape long enough to be fired, sintered or otherwise hardened. A good understanding of the material rheology and fluid mechanics of the extrusion process are necessary to ensure creation of accurate, reproducible and defect-free extrudates.

Flow visualisation experiments have confirmed the existence of a predominately extensional region upstream of the extrusion die, bounded by unyielded, static zones of material (Götz and Buggisch, 1993). Reliable prediction of the existence and shape of static zones is important for die design and interpretation of experimental data from rheological characterisation tests.

Extrusion of stiff viscoplastic materials such as particulate pastes and granular suspensions is characterised by significant wall slip. However static zones, by definition, are stationary at the wall – a discontinuity in behaviour difficult to capture with simulation of simple frictionless boundaries.

The influence of wall slip on static zone shape, size and behaviour was investigated systematically in this work using a commercial FEM code. A regularised Herschel-Bulkley material undergoing cylindrically axisymmetric extrusion was simulated using the Navier slip boundary condition and compared with results reported for simple fluids, perfectly plastic and viscoplastic materials.

The simulation results indicate the presence of two characteristic regimes: absence of static areas at low wall friction, whereby the fluid streamlines follow the wall contours exactly, and separation, whereby the streamlines leave the wall far from the die face, following a curved path to the die entrance.

Flow visualisation studies for well-defined H-B and other materials indicate that the true static zone shape lies in the transition between these two regimes. Simulation of this transition has been found to predict simultaneously the static zone shape and the mean reported extrusion pressure to a good degree of accuracy, which may serve as a useful result for effective simulation in more complex geometries.

Mr Matthew Bryan, Department of Chemical Engineering and Biotechnology, University of Cambridge, New Museums Site, Pembroke Street, Cambridge CB2 3RA, UK +447807548543 mpb52@cam.ac.uk
DEVELOPMENT OF A UNIQUE RHEOLOGICAL MODEL FOR HAIR GEL DESCRIBING THE SOLID-LIKE AND THE LIQUID-LIKE BEHAVIOUR

Justine QUIGNON¹, Jean-Christophe BAUDEZ², Sofiane AMZIANE²

¹ IRSTEA, UR TSCF, Domaine des Palaquins, 03150 Montoldre, France
² Université Blaise Pascal, Department of Civil Engineering, Clermont-Ferrand, France

The transition from solid-like to liquid-like behaviour is a common feature of pasty materials [1, 2] and has found a wide range of industrial applications. Despite all the studies carried out over the past decades to model the rheological behaviour of pasty materials, literature still focuses on partitioning the states of matter into two distinct categories: solid or liquid. Current models are appropriate to describe pastes either in solid or liquid state, but the transition between these two regimes is rarely modelled, and the models obtained are never available in transient flow. We propose a novel approach for modelling the rheological behaviour of polymeric gels made of Carbopol. The aim is to describe both solid and liquid regimes with a single model, in both transient and steady state.

Current modelling of the solid-liquid transition of pasty materials is quite rare, and always based on a decomposition of the shear stress on solid and liquid contributions that depend on a structural parameter [3]. While the critical shear stress at which flow starts depends on time, the critical deformation does not. To make our model more appropriate to describe Carbopol gel in both transient and steady state, we have chosen to consider the material like a Maxwell fluid but we introduced a scalar parameter \( \lambda \) to take into account the changes of the structure, as describes by Quemada [4].

By overlapping dynamic and creep tests, we are able to model the kinetics of build-up and breakdown to the internal structure. By introducing these kinetic equations into our scalar parameter, we show that our model is in good agreement with the experimental results, in both transient and steady states.

References
A METHODOLOGY FOR THE SELECTION OF THE STATE EQUATION AND ADSORPTION ISOTHERM

Sergio D. Rosales-Anzola1,2; Máximo Garcia-Sucre2; Edeluc Lopez1,3
2 Instituto Venezolano de Investigaciones Científicas (IVIC), Centro de Estudios Interdisciplinarios de la Física, Altos de Pipe, Carretera Panamericana, Km. 11, Edo. Miranda, C.P. 1204, Apartado 20632, Caracas, Venezuela.
3 Ecole Nationale Supérieure des Industries Chimiques (ENSIC), Institut National Polytechnique de Lorraine (INPL), Nancy-Université, 1, rue Grandville – BP 20451 – 54001-Nancy Cedex, France

Generally, the selection of the state equation and adsorption isotherm is based only on the fit between theoretical and experimental value of the surface tension. From these equations, properties as concentration at the surface are calculated, which is necessary for calculating the surfactant required to cover a given surface area. A miscalculation of the concentration on the surface may lead to an erroneous characterization of a formulation, and possibly underestimation or overestimation of the surfactant performance. As a consequence many of the conclusions that could be carried out in an investigation could have a deficiency in the analysis of results by unknowing the actual surface concentration. A necessary but not a sufficient condition that must fulfill an equation of state and adsorption isotherm is predicting surface tension values.

The present work shows methodology for the selection of the state equation and adsorption isotherm, not only based on the prediction of surface tension values but also on the elasticity values, in order to have reliable values of concentration at the surface.
RHEOLOGICAL BEHAVIOR OF POLYELECTROLYTE SOLUTIONS

Khaled BENYOUNES ¹, Abderrahmane MELLAK¹ and Abdelbaki BENMOUNAH²

¹Laboratoire Génie Physique des Hydrocarbures, Faculté des Hydrocarbures et de la Chimie, Université M'hamed Bougara de Boumerdès, 35000, Algerie

²Unité de Recherche Matériaux, Procédés et Environnement (UR-MPE), Faculté des Sciences de l'ingénieur, Université M'hamed Bougara de Boumerdès, 35000, Algerie

The rheology of aqueous solutions of polyelectrolyte (polyanionic cellulose, PAC) at high molecular weight was investigated using a controlled stress rheometer. Several rheological measurements: viscosity measurements, creep compliance tests at a constant low shear stress and oscillation experiments have been performed. The concentrations ranged by weight from 0.01 to 2.5% of PAC. It was found that the aqueous solutions of PAC do not exhibit a yield stress, the flow curves of PAC over a wide range of shear rate (0 to 1000 s⁻¹) could be described by the Cross model and the Willamson models. The critical concentrations of polymer c* and c** have been estimated. The dynamic moduli, i.e., storage modulus (G') and loss modulus (G'') of the polymer have been determined at frequency sweep from 0.01 to 10 Hz. At polymer concentration above 1%, the modulus G' is superior to G''. The relationships between the dynamic modulus and concentration of polymer have been established. The creep-recovery experiments demonstrated that polymer solutions show important viscoelastic properties of system water-PAC when the concentration of the polymer increases.

Keywords: Polyanionic cellulose, viscosity, creep, oscillation, Cross model

Khaled Benyounes, rheological behavior of polyelectrolyte solutions, +213790830538, khaled_benyounes@yahoo.fr
PREDICTION OF PRESSURE TRANSMISSION DURING A KICK OF GAS IN WELL DRILLING OPERATIONS

Gabriel Merhy de OLIVEIRA
Jonathan Felipe GALDINO
Admilson Telxeira FRANCO
Cezar Otaviano Ribeiro NEGRÃO

Thermal Science Laboratory (LACIT), Post-graduate Program in Mechanical and Materials Engineering (PPGEM), Federal University of Technology-Paraná (UTFPR), Brazil

Abstract
An important task during well drilling in deep water is the control of the bottom hole pressure within a narrow range. Whenever the bottom hole pressure becomes smaller than the pore pressure there is a risk of formation fluid invasion, such as oil, natural gas or water, into the well. The formation fluid influx is called kick and if it is not controlled can escalate to a blowout when the formation fluid reaches the surface. Therefore, a small inflow of gas should be detected as soon as possible. Nevertheless, pressure is only measured while drilling and also a small influx of gas cannot change significantly the bottom hole pressure. Another indication of kick is the volume gain of drilling fluid at the surface tank which is only noticed when a large amount of gas has come into the well. After the kick has been detected, the well is closed and the pressure tends to stabilize throughout the well. The current work presents a compressible transient flow model to predict pressure transmission within the wellbore when a gas influx occurs followed by the well closure. The model comprises the conservation equations of mass and momentum which are solved by the method of characteristics. Drilling fluids are admitted to behave as a non-Newtonian Bingham fluid with time-dependent shear stress defined as a function of shear rate and strain. The influx of gas is considered to be dependent on the rock permeability and on the pore pressure. Model results show that the pressure changes depend on the pressure wave propagation and occur more slowly for higher viscosity fluids. Besides, due to the fluid yield stress, the pressure does not stabilize uniformly along the well after the well has been closed.

Keywords: Gas influx, drilling fluid, Bingham fluid, time-dependent yield stress, transient compressible flow

Paper presenter: Gabriel Merhy de Oliveira, MSc, Av. Sete de Setembro, 3165, CEP 80.230-901, Curitiba, PR, Brazil, phone: +55 41 3310 4772, fax: +55 41 3310 4852, e-mail: gabrielm@utfpr.edu.br
Study of structural changes of water confined in the Brij-30 reverse micelles by instrumental methods

Manoni Kursanlidze, Tinatin Butkhuzi, Nino Koklashvili, Marina Rukhadze*

Department of Chemistry, Faculty of Exact and Natural Sciences, Javakhishvili Tbilisi University, Georgia

Abstract. The binding of o-nitroaniline (o-NA) to the micelles of Brij-30 was determined by UV-visible spectroscopy. Structural changes of water pools of reverse micelles in the presence or absence of structure-making and structure-breaking ions and nonionic additives was investigated by IR-Spectroscopy. The electrical conductivity of water-in-n-hexane microemulsions stabilized by Brij-30 was studied as a function of water content in both pure microemulsions and in the presence of kosmotropic and chaotropic additives. Freezing (exothermal DSC) and melting (endothermal DSC) processes in reverse microemulsions in the presence of ionic and nonionic kosmotropes and chaotropes was investigated by differential scanning calorimetry method (DSC).

Keywords: Reverse micelle, Confined water, o-Nitroaniline, Brij-30, Free water, Bound water, Trapped water, Kosmotropic additives, Chaotropic additives

Introduction. Reverse micelles are isolated, surfactant-coated water droplets, which have arisen as an appropriate model for confined water in biological systems. Complexity of water structure becomes enormous when it is confined to nanometer-scale cavities. Therefore investigation of the properties of water core of the reverse micelles is urgent and topical. The goal of the proposed work was to study the influence of different ionic and nonionic additives introduced in the water core of reverse micelles by using infrared and ultraviolet-visible spectroscopy, differential scanning calorimetry and electrical conductivity methods.

Experimental. Absorption spectra in UV-vis region were taken on Optizen spectrophotometer in 1 cm path length, stoppered quartz cells. IR absorption spectra were recorded in a IR spectrophotometer Specord M80. Study of thermal properties of reverse microemulsions within temperature interval (-70) °C (+30) by DSC was carried out in endothermal and exothermal mode on the DSC 200-F3 Maya. Electrical conductivities were measured using a conductivity meter Jenway 4510.

Results and discussion. Different values of binding constants of the molecular probes to Brij-30 reverse micelles under the influence of ionic and nonionic kosmotropes and chaotropes were found. Changes in bound, trapped and free water fractions under the influence of kosmotropic and chaotropic additives were revealed by IR-spectroscopy technics. The fractions of water distributed in the different phases of the reverse microemulsions by differential scanning calorimetry method were estimated. The influence of amount of water on the conductivity of the Brij-30 reverse microemulsions in the presence of ionic and nonionic additives was revealed.

Conclusion. Results may be useful in the investigations of structure of confined water in biological systems.

Marina Rukhadze, Dr., Prof., 3, l.Chavchavadze ave, Tbilisi, 0128, Georgia, +995599 197525, marina_rukhadze@yahoo.com
Rheological characterization of liquids by an acoustical method

Dr. Bair B. Damdinov, Buryat State University, Molecular Acoustics Lab of Buryat Scientific Center of RAS, Ulan-Ude, Russian Federation

Low-frequency ($10^3$) shear elasticity of liquids for the first time has been found by acoustic resonance method. Elasticity can be explained by the fact that in liquids there is unknown earlier low-frequency viscoelastic relaxation process. Therefore detail investigation of the shear elasticity has fundamental importance for the correct understanding of the nature of liquid state as a whole. The resonance method has high sensitivity to inhomogeneities of structure of investigated objects. Now viscoelastic properties of colloidal suspensions of nanoparticles are studied by using this method. We apply an acoustic resonance method for measuring of the shear visco-elastic properties (real and imaginary shear moduli) of various liquids and suspensions. It was shown that tested materials have measurable shear moduli at experimental frequency 74 kHz. It was shown that its elastic and viscous properties depend on amplitude of resonator oscillation.


Related publications:
FINITE ELEMENT APPROXIMATIONS FOR ENTRY FLOWS OF THIXOTROPIC ELASTO-VISCOPLASTIC FLUID FLOWS

Cleiton FONSECA, Daniel D. DOS ANTOS, Fernanda B. LINK, Sergio FREY
Department of Mechanical Engineering, Federal University of Rio Grande do Sul, Brazil

Mônica F. NACCACHE, Paulo R. DE SOUZA MENDES
Department of Mechanical Engineering, Pontifical Catholic University of Rio de Janeiro, Brazil

Abstract

In this article, numerical simulations via the finite element method is undertook to study entry flows of elasto-viscoplastic materials that present thixotropic behavior. The model herein employed is the one introduced by de Souza Mendes (2011) for structured fluids. This model is based on both an Oldroyd-B-type equation and the (SMD) viscoplastic viscosity function – proposed by de Souza Mendes and Dutra (2004) – modified in such a way to allow either fluid relaxation time as viscoplastic viscosity depends on rheology. This is accomplished by computing a scalar parameter – denoted by structure parameter – that deals with microscopic changes in material structure in following way: for fully-structured material zones, it said to be one and, for fully-unstructured ones, it equals zero. Such a parameter is determined by the solution – coupled with the mass and motion and viscoelastic equations – of an evolution equation that is made up of the substantial derivative of the structure parameter, on its left hand side, and source terms controlling the build-up and breakdown of the material microstructure, on its right hand side.

All results are obtained by means a four-field GLS-type method in terms of the structure parameter, extra-stress, pressure and velocity fields. They are designed to estimate the morphology of unyielded regions as well as the determination of the structuring level distribution in entry flows of thixotropic elasto-viscoplastic fluids down a one-to-four sudden planar expansion. The computational domain is partitioning into a bi-linear Lagrangian finite element mesh, for all primal variables. All simulations attest the relevance of a proper determination of the structuring level on the accurate computation of the shape and location of unyielded regions, along with the strong influence of elasticity on the asymmetry their yield surfaces.

Sergio Frey, Professor
Rua Sarmento Leite 425, Porto Alegre, RS 90050-170
Tel.: + 55 51 3308 3907, Fax: +55 51 3308 3222
frey@mecanica.ufrgs.br