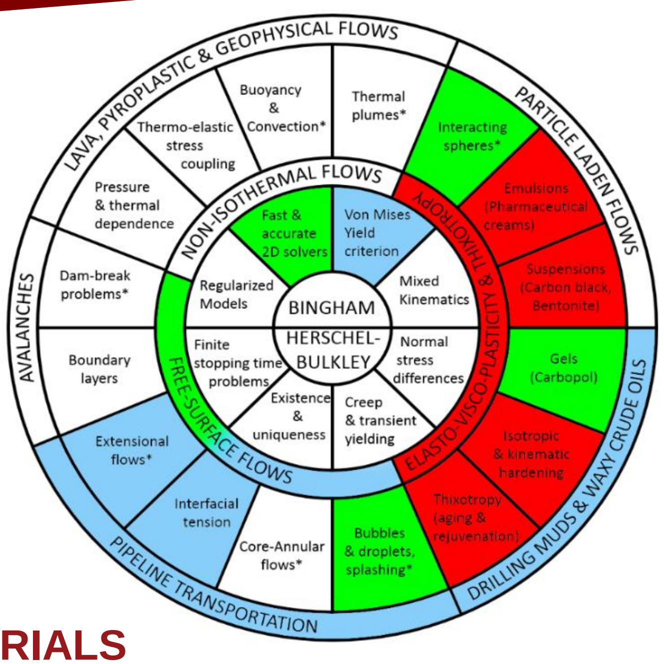
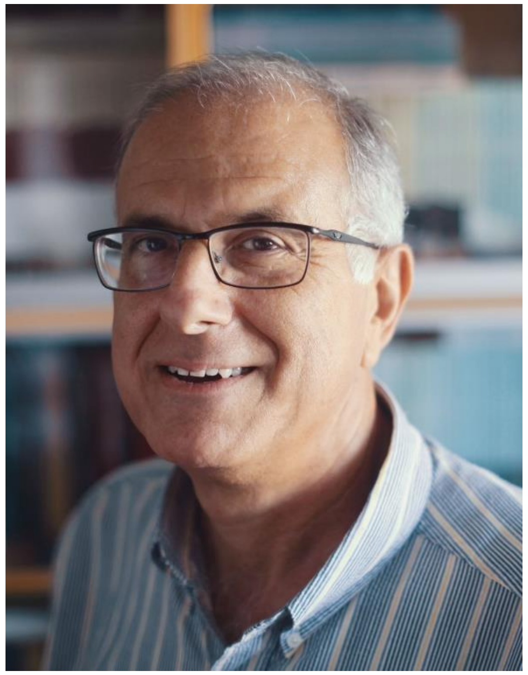
Hellenic Foundation for Research & Innovation (H.F.R.I.)

Description of the funded research project

1st Call for H.F.R.I. Research Projects to Support Faculty Members & Researchers and Procure High-Value Research Equipment



Title of the research project: MODELING AND FLOW OF ELASTO-VISCOPLASTIC MATERIALS



Principal Investigator: JOHN TSAMOPOULOS

Reader-friendly title: STUDY OF THE FLOW AND THE RHEOLOGICAL PROPERIES OF COMPLEX MATERIALS, SUCH AS SUSPENSIONS, EMULSIONS, CRUDE OIL, COSMETICS, PHARMACEUTICALS, ETC.

Scientific Area: CHEMICAL ENGINEERING

Institution and Country: UNIVERSITY OF PATRAS, GREECE

Host Institution: UNIVERSITY OF PATRAS

Collaborating Institution(s): UNIVERSITY OF BRITISH COLUMBIA (CANADA) & CNRS-BORDEAUX (FRANCE)

Project webpage (if applicable): http://fluidslab.chemeng.upatras.gr/

Budget: 188,000 €

Duration: 3 YEARS

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Research Project Synopsis

The proposed research focuses on predicting and controlling the deformation and flow of a group of composite materials abundant in nature and industry, called Yield-Stress (YS) or elasto-visco-plastic (EVP) materials. These start to flow when sufficient stress is applied to them, according to the von Mises criterion, otherwise they behave as solids. The stress required to start their flow is important in their production, storage, transport, packaging, and use. The conditions for their liquefaction and the surface at which this phase-change takes place in the material, the so-called "yield surface", play an important role in the relevant processes.

The measured yield stress depends on the measurement method and the different conditions under which it is carried out. There are a variety of approaches to standardize YS materials in Industries and Universities, without a general consent. Therefore, the challenge of predicting their flow is clear as researchers focus only on a specific material, a family of materials or an application, while it is imperative to adopt an effective and correct approach to achieve (a) accurate determination of their rheological properties, (b) development of more precise constitutive models, (c) introduction of guidelines for their optimal use, and (d) accurate calculation of their deformation and flow in complex geometries, taking into account their discontinuous behavior on the yield surface.

The purpose of this research is the development of constitutive models for EVP materials and their testing in homogeneous and specific practical and complex flows and is divided as follows: (a) Development of a comprehensive model by integrating physical mechanisms, which take place in the mesoscale and testing it in simple flows, (b) use of existing and new EVP models in particulate flows and (c) Study of time-dependent flows, such as extensional and startup flows of VP and EVP materials.

Project originality

A common hypothesis for the rheological modeling of YS materials was their ideal behavior, according to which they are either completely rigid solids or flow as generalized Newtonian liquids, neglecting elastic and thixotropic phenomena. For example, Carbopol gels are supposed to liquefy immediately when the second invariant exceeds the yield stress (von Mises criterion). However, with this hypothesis, the experimentally observed loss of symmetry or the appearance of an acute angle in its shape cannot be predicted in the creeping buoyancy-driven flow of a bubble. The inability to predict is caused by the lack of elasticity in the constitutive equation.

We were one of the first groups world-wide to present the idea of EVP materials and accurately predicted the experimental data for a sphere falling in Carbopol. Another controversial proposition was that in extensional flows the second invariant is not sufficient to predict the material fluidization. This indicates the difficulty of correctly determining the yielding criterion for different materials in different flows. The idea of thixotropy was recently introduced, but most researchers have used it ignoring the effects of kinematic hardening, as thixotropy was extensively studied earlier. Thixotropy was introduced into YS systems based on a structural parameter, calculated from an evolution equation containing the competing terms of material aging and rejuvenation.

In this research effort we will combine elastic and thixotropic behavior to develop a generally applicable EVP model and test it in rheometric and practical flows. A major difficulty in calculating the flows of EVP materials is the discontinuity that occurs at the yield surface. With our model, the flow and stress fields will be calculated in the whole space occupied by the material and the yield surface will be calculated a posteriori, because our model will be valid in both the solid and the liquid area.

Expected results & Research Project Impact

Upon successful completion of our research project we will have developed a rheological model for elasto-visco-plastic materials that will include elastic and thixotropic phenomena. The model will be tested in rheological flows and used in flows of practical importance. For example, the displacement and movement of crude oil from underground reservoirs or submarine pipelines, as well as flows where EVP materials, e.g. Carbopol, contain particles. These are important for the stability of emulsions and suspensions, such as movement, interaction and deformation of droplets or bubbles due to buoyancy. Extensional flows will also be studied, and we will seek to develop a method for measuring surface properties of EVP materials, such as surface tension, which is extremely difficult due to the interference of the yield stress.

In recent years, research interests worldwide have had a dual focus: cleaner environment and economic growth. Important elements for achieving them are the optimum characterization, standardization, production and processing of composite materials and additives.

Industries that produce or use YS materials are printing, paper making, healthcare, construction, cosmetics, food processing, waste treatment. Despite their importance, often even their basic characteristics cannot be predicted, such as the minimum pressure drop required to start a flow, which means that whole processes are designed empirically. In addition, their flow determines the size of natural disasters such as: flow of mud, lava and avalanches which are all yield-stress materials. Therefore, the damage from these disasters cannot be prevented.

Another important parameter is the training of young scientists in the development and application of the above and then their employment in the relevant industries for the proper predicting and controlling of their flows, the development of reliable constitutive models, so that numerous industries remain competitive and reduce their requirements for natural resources (e.g. water).

The importance of this funding

We were the first research team to use an EVP model in the complex flow around a particle due to buoyancy. So, we explained experimental observations, which were puzzling the scientific community for more than 10 years, and I received the "Bingham Medal" during an international conference. In our widely used publication, we showed that elasticity affects the flow of Carbopol gels, which were considered ideal VP materials, affecting both the yield surfaces and the critical starting stress. With the proposed research program, we intend to expand our efforts and include thixotropy in our model. This is the goal of many research teams around the world, but we believe that with this funding we will remain at the forefront. The application of the new models in complex flows of industrial interest and in the exploration of crude oil in Greece is the second long-term goal of our team and the proposed research effort will open new avenues for our laboratory.

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