frontiers in Physics

EDITORIAL
published: 11 February 2020
doi: 10.3389/fphy.2020.00018

Check for updates

Editorial: Non-local Modeling and Diverging Lengthscales in Structured Fluids

Abram H. Clark[1] *and Joshua A. Dijksman*[2*]

[1] *Department of Physics, Naval Postgraduate School, Monterey, CA, United States,* [2] *Physical Chemistry and Soft Matter, Wageningen University & Research, Wageningen, Netherlands*

Keywords: structured fluids, non-local modeling, gradient plasticity, emulsions and foams, granular materials, wormlike micellar fluids, metallic glasses, earthquake dynamics and mechanics

Editorial on the Research Topic

Non-local Modeling and Diverging Lengthscales in Structured Fluids

OPEN ACCESS

Edited by:
Giancarlo Ruocco,
Center for Life NanoScience (IIT), Italy

Reviewed by:
Luca Cipelletti,
Université de Montpellier, France

Correspondence:
Joshua A. Dijksman
joshua.dijksman@wur.nl

Specialty section:
This article was submitted to Soft Matter Physics, a section of the journal Frontiers in Physics

Received: *20 December 2019*
Accepted: *22 January 2020*
Published: *11 February 2020*

Citation:
Clark AH and Dijksman JA (2020) Editorial: Non-local Modeling and Diverging Lengthscales in Structured Fluids. Front. Phys. 8:18. doi: 10.3389/fphy.2020.00018

What do sand, toothpaste, mayonnaise, and bulk metallic glass have in common? These materials, while very different in many ways, are all *structured fluids*, which can act like fluids or solids with no obvious change to their microstructure. In traditional materials, a phase change is directly linked to a change in structural ordering: fluids are disordered, or *amorphous*, and solids have their atoms organized into lattices. In contrast, structured fluids consist of a collection of building blocks (e.g., sand grains, bubbles, or metal atoms) that are always arranged in an amorphous way, regardless of whether they are behaving like a solid or a fluid. The physical mechanisms that control the fluid-solid transition in structured fluids—whether it is contact interactions, the specific spatial order, the topology of contacts among particles, or all of the above—are still a matter of debate. Multiple different engineering communities, physicists, and physical chemists have been trying to unravel similar questions concerning these materials over many decades.

In recent years, a consensus has emerged that structured fluids can be well described on a mesoscopic level using constitutive laws that are inherently *non-local*. This means that the local flow behavior at some point in the material is not simply a function of the local stress, as it is for Hookean solids or Newtonian fluids or even more elaborate models such as Mooney-Rivlin or Hershel-Bulkley. Instead, it depends on the stresses in other, nearby locations in the material, meaning that local stresses as well as stress gradients are important. In many cases, this correlation length associated with the stress gradient terms has been shown to grow very large and even diverge near the yielding point of the material [1, 2]. In the last decade, it has become clear that such non-local or gradient-based models can be used to *quantitatively* describe flow fields of a wide range of structured fluids, including emulsions [3], granular materials [4], and wormlike micellar liquids [5]. These models join work spanning multiple decades in the field of metallurgy [6, 7], where similar ideas have been used to describe the fluid-solid transitions in nanostructured materials.

These descriptions have emerged nearly independently in some cases, and communication between different scientific communities is always a challenge. To build bridges between fields, in this Research Topic, we have collected mini-reviews from five distinct subfields. Our goal is to provide a concise introduction into the different, but overlapping, non-local modeling perspectives that have emerged in various corners of literature on structured fluids. We note that similar efforts have been done in the form of review articles, such as Nicolas et al. [8], and that developments are ongoing [9]. As complementary set of articles, we aim here to be broad instead of deep and focused, allowing scientists from each subfield to give a brief summary. This collection especially highlights the experimental relevance of non-local models, namely that these non-local effects can be directly observed in macroscopic systems. Non-local models are successful in capturing these effects, yet they are still largely empirical. Quoting [10], "among the central outstanding questions in the 'gradient approach' is the determination of the phenomenological coefficients measuring the effect of the various gradient terms, as well as the physical basis and origin of these terms." Despite many advances in the field of non-local modeling, this is still as true now as it was in 1992. Our hope is that this collection of articles encourages communication between the various communities studying structured fluids and forms a platform to eventually help ground these non-local or gradient-based modeling approaches in a solid microscopic understanding.

We present five articles, each of which highlights non-local modeling in a different field and/or with a different aim. Dijksman gives an overview of recent experiments on flowing emulsions and the corresponding non-local theoretical description. Kamrin discusses non-local models for flowing granular matter, which were inspired by the work on emulsions but extended to a fully three-dimensional theory and extensively tested against experiments. Lerouge and Olmsted describe similar work for wormlike micelles and other polymeric fluids. Their overview covers several important constitutive equations that have been put forward in the last ten years. Aifantis describes how gradient approaches have been used in describing plasticity and crack propagation in the past four decades and explores even wider application of gradient modeling. Finally, Dahmen et al. present recent work on a simple model which could help to explain similarities in different types of structured fluids, in particular why diverging cooperative length scales appear to govern the behavior near yield for these materials.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

ACKNOWLEDGMENTS

This article was made possible by Office of Naval Research Global Visiting Scientist Program VSP 19-7-001 and by the Office of Naval Research under Grant No. N0001419WX01519.

REFERENCES

1. Bocquet L, Colin A, Ajdari A. Kinetic theory of plastic flow in soft glassy materials. *Phys Rev Lett.* (2009) **103**:036001. doi: 10.1103/PhysRevLett.103.036001
2. Kamrin K, Koval G. Nonlocal constitutive relation for steady granular flow. *Phys Rev Lett.* (2012) **108**:178301. doi: 10.1103/PhysRevLett.108.178301
3. Jop P, Mansard V, Chaudhuri P, Bocquet L, Colin A. Microscale rheology of a soft glassy material close to yielding. *Phys Rev Lett.* (2012) **108**:148301. doi: 10.1103/PhysRevLett.108.148301
4. Henann DL, Kamrin K. A predictive, size-dependent continuum model for dense granular flows. *Proc Natl Acad Sci USA.* (2013) **110**:6730–5. doi: 10.1073/pnas.1219153110
5. Masselon C, Salmon JB, Colin A. Nonlocal effects in flows of wormlike micellar solutions. *Phys Rev Lett.* (2008) **100**:038301. doi: 10.1103/PhysRevLett.100.038301
6. Zbib HM, Aifantis EC. On the structure and width of shear bands. *Scripta Metallurgica.* (1988) **22**:703–8.
7. Zhu HT, Zbib HM, Aifantis EC. Strain gradients and continuum modeling of size effect in metal matrix composites. *Acta Mechanica.* (1997) **121**:165–76.
8. Nicolas A, Ferrero EE, Martens K, Barrat JL. Deformation and flow of amorphous solids: Insights from elastoplastic models. *Rev Mod Phys.* (2018) **90**:045006. doi: 10.1103/RevModPhys.90.045006
9. Benzi R, Divoux T, Barentin C, Manneville S, Sbragaglia M, Toschi F. Unified theoretical and experimental view on transient shear banding. *Phys Rev Lett.* (2019) **123**:248001. doi: 10.1103/PhysRevLett.123.248001
10. Aifantis EC. On the role of gradients in the localization of deformation and fracture. *Int J Engi Sci.* (1992) **30**:1279–99.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.