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Relevance of Complex Fluids and Polymers to Develop More Sustainable Machinery

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Abstract

The use of electric fields for flow control and droplet manipulation has recently caught the eye of researchers, thanks to its wide array of potential applications in fields like engineering and medicine. The interaction between electro-mechanics and fluid behavior at the interface has led to the development of many micro and nano-scale fluidic devices. Moreover, using polymeric fluids to mimic complex fluids is becoming increasingly important in various industries, including food engineering, chemical processing, and oil recovery. These applications clearly highlight how vital fluid behavior is for understanding essential functions. As a result, exploring droplet dynamics and the flow of complex fluids in relation to electromechanics has become a hot topic in research lately. Despite significant advancements in this area, there are still key aspects of the electro-hydrodynamics of individual viscoelastic droplets and the electronic kinetics of continuous viscoelastic fluid flow that remain unexplored, which are the main focus of this work.

Keywords: Complex Fluids, Polymers, Sustainable Machinery.

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Introduction

We live in a fluid-filled planet. Both the water we drink and the air we breathe are fluids. The flow of air provides the oxygen necessary for life and keeps us comfortable. These materials are viscoelastic, meaning they are neither totally elastic nor totally viscous (Knez et al., 2014). These materials store and release energy in a frequency-dependent fashion, just like deformable solids. Ferrofluids, micelles, cytoplasm, polymer materials, living cells, maize starch, and liquid crystals are just a few of the complex fluid examples we encounter on a daily basis (Lutz et al., 2016). Anisotropic complex fluids are materials, like liquid crystals, that have anisotropic diffusivity due to a preferred orientation and local spatial homogeneity. Materials such as cytoplasm and micelles are actually very diverse and do not have a preferred alignment direction. Complex fluids have special properties because of their complex dynamics and structures, which can alter significantly at the micro and nanoscales and can exhibit gradual changes over brief periods of time. The necessity to comprehend the dynamics of complicated fluids is highlighted by a number of significant technical applications, including quick switching in LCDs (liquid crystal displays), medication delivery in the medical industry, and applications in paints, food, cosmetics, coolants, oil recovery, and plastic manufacturing (Brunner, 2010). Complex fluids and polymers play a vital role in creating more sustainable machinery by helping to develop lighter, more durable, and energy-efficient materials. They also support circular economy principles through options that are biodegradable and recyclable. By preparing bio-based polymers, we can effectively tap into renewable resources while also cutting down on the use of non-renewable ones. Plus, bio-based polymers can break down quickly into harmless substances in biological environments, helping to reduce pollution (Tadmor & Gogos, 2013).

Literature Review

Metallotropic liquid crystals are fascinating materials made up of both organic and inorganic molecules. Their phase transitions are influenced by temperature, concentration, and the ratio of inorganic to organic components. Another intriguing category of liquid crystals is polymeric liquid crystals (PLCs). These special materials combine the qualities of liquid crystals and polymers to produce "hybrids" that have many of the novel qualities of polymers but still display the same mesophases found in ordinary liquid crystals. PLCs can be divided into main chain and side chain PLCs based on how the mesogens are attached to the polymer backbone. Main chain polymer liquid crystals, or MC-PLCs, are produced when mesogens are incorporated into the main chain of the polymer. However, side-chain polymer liquid crystals (SC-PLCs) are produced when the mesogens are connected to the polymer as side chains by a flexible "bridge" known as a spacer (Shokrani et al., 2012). For flexible polymers to exhibit liquid crystal properties, rod-like or disk-like components must be added to their chains. The arrangement of mesogens greatly influences the type of PLC that develops. Additionally, more complex structures like as liquid crystal networks, liquid crystal elastomers, and coupled side chain and main chain LCPs are emerging in the realm of liquid crystal polymers. There are two different kinds of LC-polymer composites, depending on the weight proportion of the polymer. A polymer weight concentration of 20% or more is required to form Polymer Dispersed Liquid Crystals (PDLC). They create some quite inventive materials that combine the special qualities of liquid crystals with polymers by spreading microscopic droplets into a polymer matrix (Zhu et al., 2016).

Methodology

The findings suggest that micro-flows relevant to physiology can produce streaming potential that is adequate for powering biosensors and implantable medical devices, which usually need power in the micro to milli Watt range. By exploring the relationship between the viscoelastic nature of blood and the negatively charged poroelastic EGL, we investigate the induced streaming potential and its potential physiological applications. Modeling various industrial and biological fluids as continuous viscoelastic fluids has provided valuable insights for numerous applications. However, to fully grasp how electrical actuation affects these fluids, we must consider the impact on individual fluid entities, like droplets. Among various phenomena, the merging of isolated liquid drops is a common occurrence that can be significantly influenced by the addition of polymeric substances, giving the liquid a viscoelastic quality (Krajnik et al., 2011).

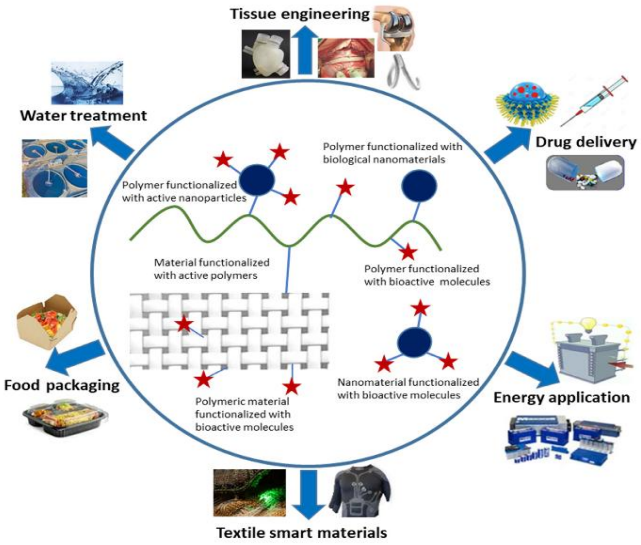


Fig. 1: Functional polymer

A flexible polymer can be thought of as a long chain made up of many monomers. When stretched out, a polymer can reach sizes of several tens of micrometers. Typically, this size is either much smaller than or at most equal to the smallest scale of turbulence. In this section, we treat the polymer as a passive entity that is carried along by the flow of the fluid, ignoring any influence it might have on that flow. By observing how polymers behave on a molecular level, especially their mechanical and rheological properties, we can learn a lot from how they relax after being suddenly deformed from their equilibrium state (Najiha et al., 2016). Typically, their response is viscoelastic, featuring both elastic components that depend on strain and viscous components that depend on time. In the linear regime, which occurs after small deformations, the elastic properties observed at short times or high frequencies stem from the entanglement of the polymer chains. However, over longer times, gradual changes in the environment lead to the flow of the polymers.

Results and Discussion

A key factor in droplet coalescence is how we manage the merging of two separate droplets, which helps us understand the dynamics of bridge growth as the final daughter droplet forms. We can gain precise control over the behavior of the intermediate liquid bridge by harnessing the effects of an exciting AC electric actuation combined with a small number of polymeric inclusions found in the droplets. These experimental results are further explained by a straightforward unified theory that reveals a common pattern in the early growth of the liquid bridge. Since the viscoelastic properties introduced by the polymer inclusion significantly change how droplets merge when subjected to electrical actuation, we also delve into the electro-wetting dynamics of a polymeric viscoelastic droplet by examining how it responds to external stimuli in relation to its rheology.

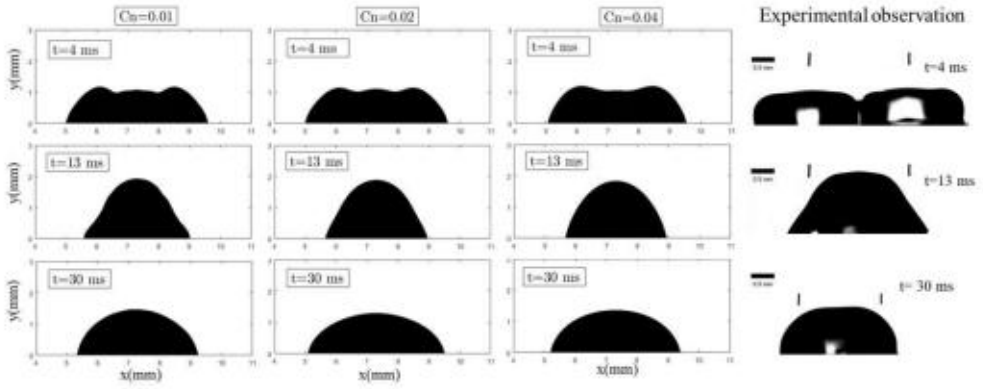


Fig. 2: Computationally obtained interface profiles for different values

Dilute polymeric fluids and various biological viscoelastic fluids tend to have very short relaxation times, making their determination a process that can be time-consuming, costly, and quite complex to replicate in a lab environment. To tackle this challenge, we're looking into a new approach that leverages the oscillatory electrowetting response of tiny droplets, similar to how a free mass-spring-damper vibrating system works.

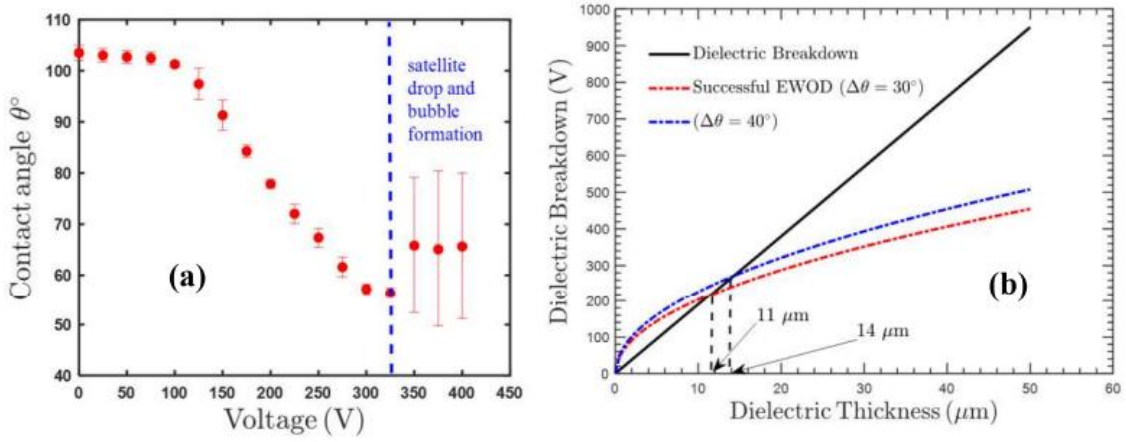


Fig. 3: (a) Contact angle saturation and (b) dielectric breakdown for PDMS as dielectric with breakdown strength

These results provide a new and simple approach to electrically-modulated on-chip spectroscopy by closely matching the reported relaxation time values from more sophisticated laboratory settings. The goal of this method is to find ultra-short relaxation times for a variety of unexplored viscoelastic fluids.

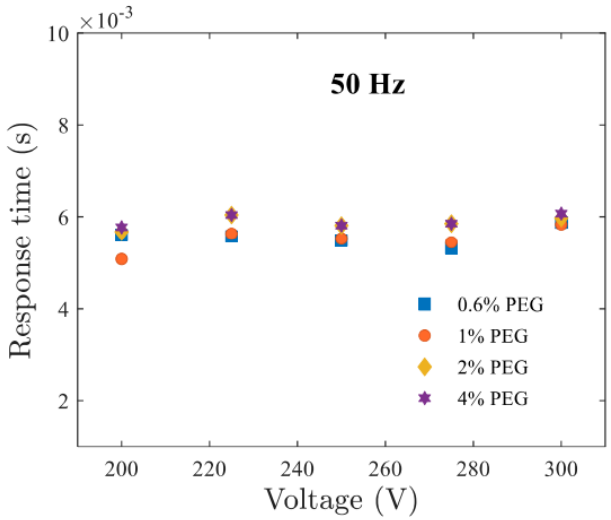


Fig. 4: Drop response to electric voltage

The way flexible polymers interact with fluid flows is a fascinating yet complex topic in the realm of soft matter physics. Experiments in the lab reveal that even a tiny number of polymers can significantly alter the properties of turbulent flows, like reducing drag.

Conclusion

Among these composites, polymer blends stand out. When processed under the right conditions, the dispersed phase can stretch into long, thin fibers. Once solidified, these fibers provide reinforcement, giving the composite impressive strength. When a liquid-crystalline polymer makes up the fibrillar phase, this effect is particularly noticeable. Polymer-

dispersed liquid crystals, which have enormous potential for electro-optical applications, are another intriguing example. These liquid crystal droplets are embedded in a matrix of polymers. I think these composites are fascinating from a scientific perspective. They entail the dynamic interaction of three distinct length scales: the macroscopic flow behavior, the mesoscopic interface between them, and the molecular or supramolecular structure within each component. However, theoretical and numerical analysis of these materials has proven difficult due to their complexity. The primary obstacle is the two components' shifting and altering interface. These are often treated as sharp boundaries in traditional fluid dynamics, which necessitates certain requirements. Several modeling techniques have been created to address this issue.

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