Tribotronic control and energy storage attributes of metal-oxide nanofluid interfaces.

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Power Distribution and Energy Storage

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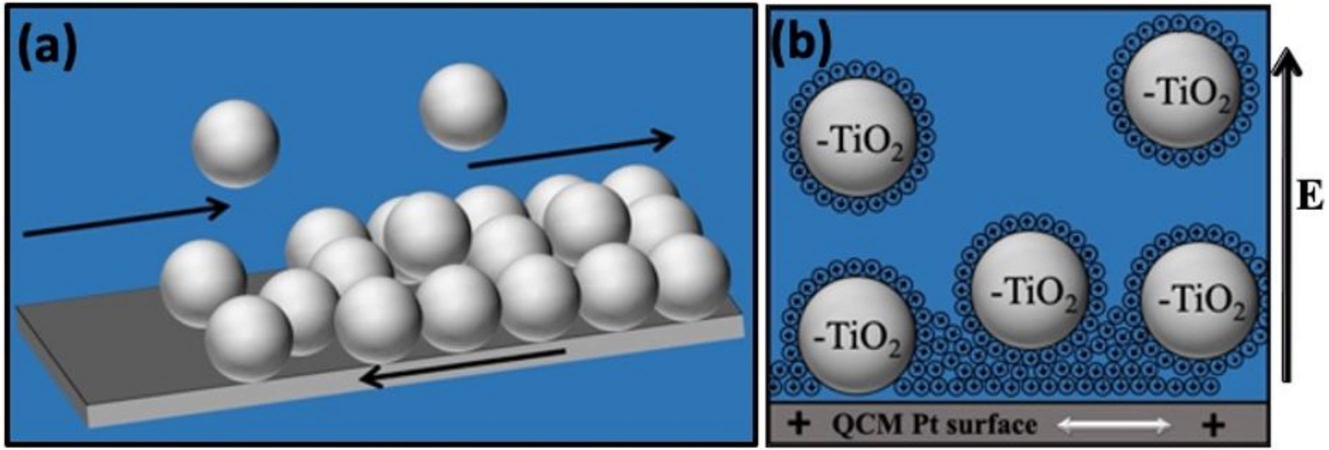
Introduction

- Metal-oxide nanoparticles (NP) are of increasing interest for technological applications due to their ease of production, biocompatibility, and environmental friendliness [1-6], which contrasts with many current additives used in oil which are toxins
- NP such as Al_2O_3 and TiO_2 can enhance the performance of lubricants, [7,8] thermal energy storage materials [9,10] and heat transfer fluids,and TiO_2 NP embedded into or deposited atop electrodes enhance the performance of batteries, [11-13] photocatalysts [14] and photovoltaic devices. [15,16]
- Using electroactive nanofluids in flow batteries can significantly improve performance, [2,17,18] and potential impacts on large-scale energy storage systems and refueling times for electric vehicles.[2]
- Understanding mechanical and tribological properties (viscosity, friction/lubricity, wear and abrasiveness), particularly under electromagnetic fields, is vital to predicting overall device performance, both due to the reliance on NP flow in devices and since metal-oxide NPs are often charged in suspension

Objective



- Current oil additives are toxins. They need to be replaced by something more environmentally friendly
- Climate change is the defining global challenge. Improvements in energy efficiency are an essential component in reducing carbon emissions, particularly in passenger vehicles. This requires advances in technology to improve electric vehicle batteries, both in storage and fast refueling.
- Previous work [8], noted a feature in TiO_2 suspension data, attributed to NP pushing through the water layer over an electrode. This is a potential energy storage mechanism and will be explored in this work.
- Tribotonic design encompasses the real-time use of internal and external fields to configure them for optimal mechanical energy efficiency and system energy storage attributes

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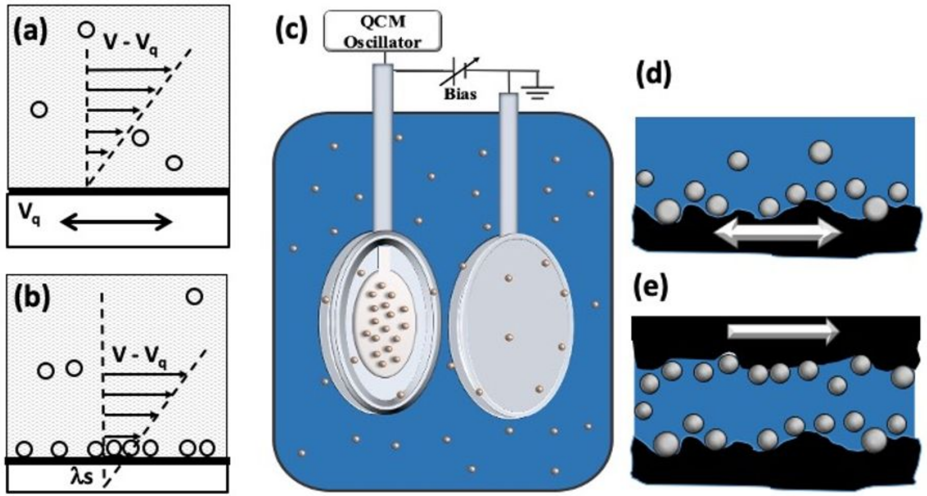
Methods



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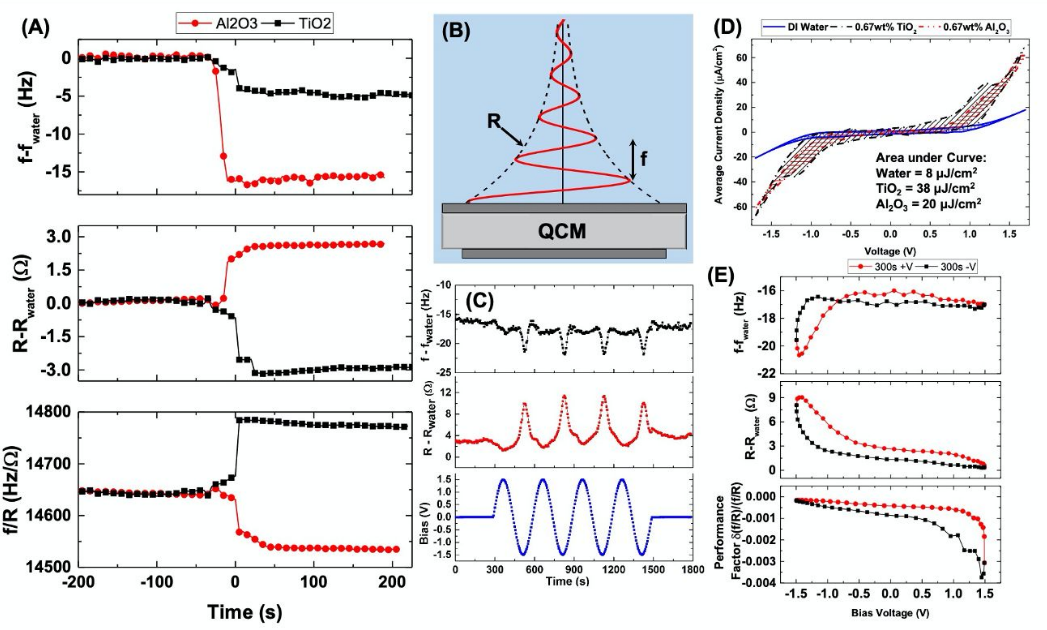
- Two Pt Quartz Crystal Microbalances (QCM) were loaded into holders and dipped into the NP suspension [8]
  - QCMs oscillate transversely (d) at 5 MHz (resulting in a m/s scale shear speed)
  - This models a lubricated contact with a thick lubrication layer (similar to hydroplaning)
- The suspensions used were 0.67wt% TiO2 and 0.67wt% Al2O3, with water as the base liquid [8]
- An electric field (100 N/C) was applied as sinusoidal waves to the suspension by applying a bias across the QCMs, using the QCMs as electrodes [8]
- Positive bias voltages attracts (repels) TiO_2 (Al_2O_3) NP towards (away from) the surface, changing both the number of nanoparticles near the surface as well as the location of the hydrodynamic slip plane [8]

Methods



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- Tribology measurements taken via QCM consist of frequency (f) and motional resistance (R), from which the performance factor (d(f/R)/(f/R)) is found [8]
- Motional resistance reflects drag forces over the surface of the QCM, and the performance factor is linked to macroscale friction shifts [20]
- Energy storage data was taken using the same 2 QCM setup to take cyclic voltammetry (CV) measurements [19]
  - Bias voltage was changed using either a sine or triangle wave, and the resulting changes in current were measured

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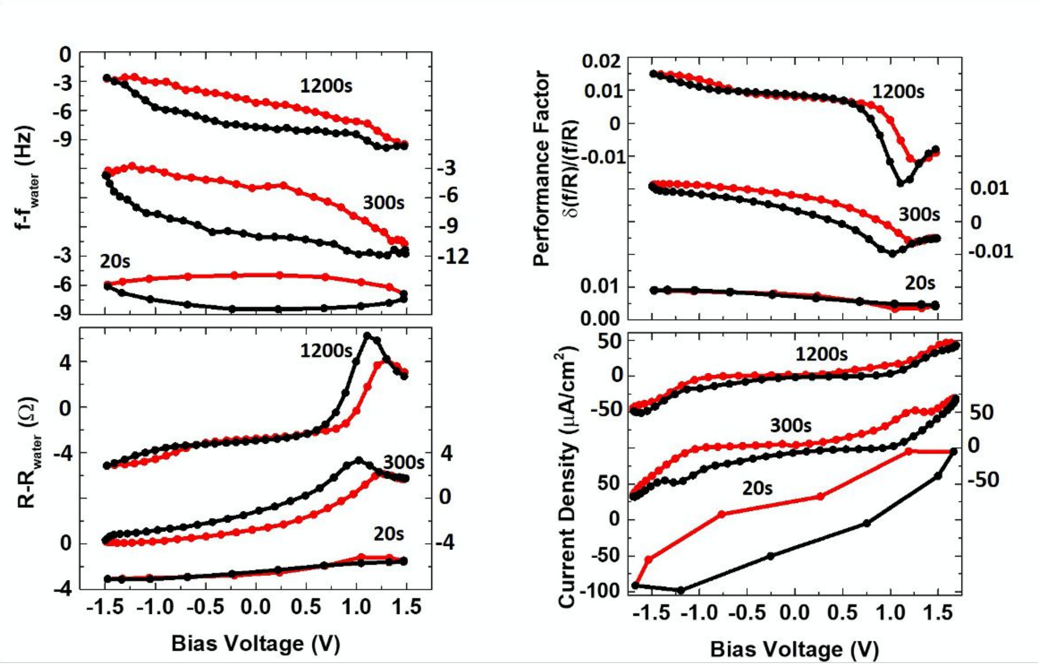
Results: TiO_2 Tribology vs Energy Storage Data



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- Electric field frequencies were applied with periods of 20s, 300s, and 1200s
- Strong asymmetry between attractive and repulsive bias, most notable in the motional resistance data starting at the 300s period
- The feature may arise from repositioning of TiO_2 NPs as they are pressed into the water molecules at the electrode surface
- Energy storage data also shows bulbs of energy storage at the bias as the tribological feature was observed

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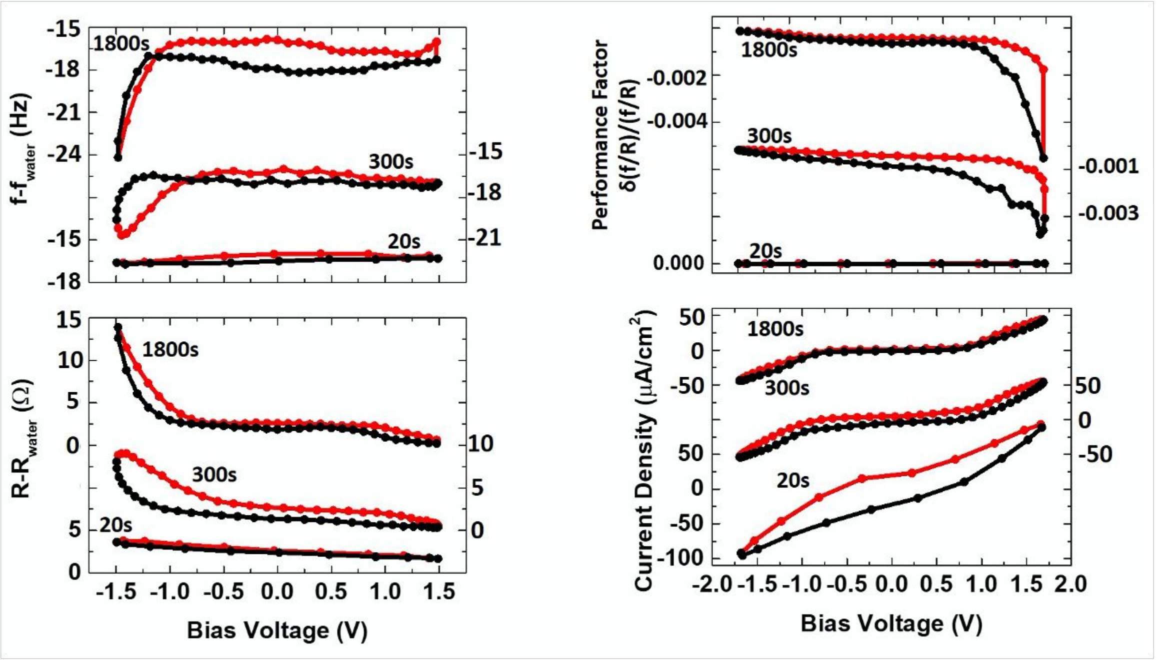
Results: Al_2O_3 Tribology vs Energy Storage Data



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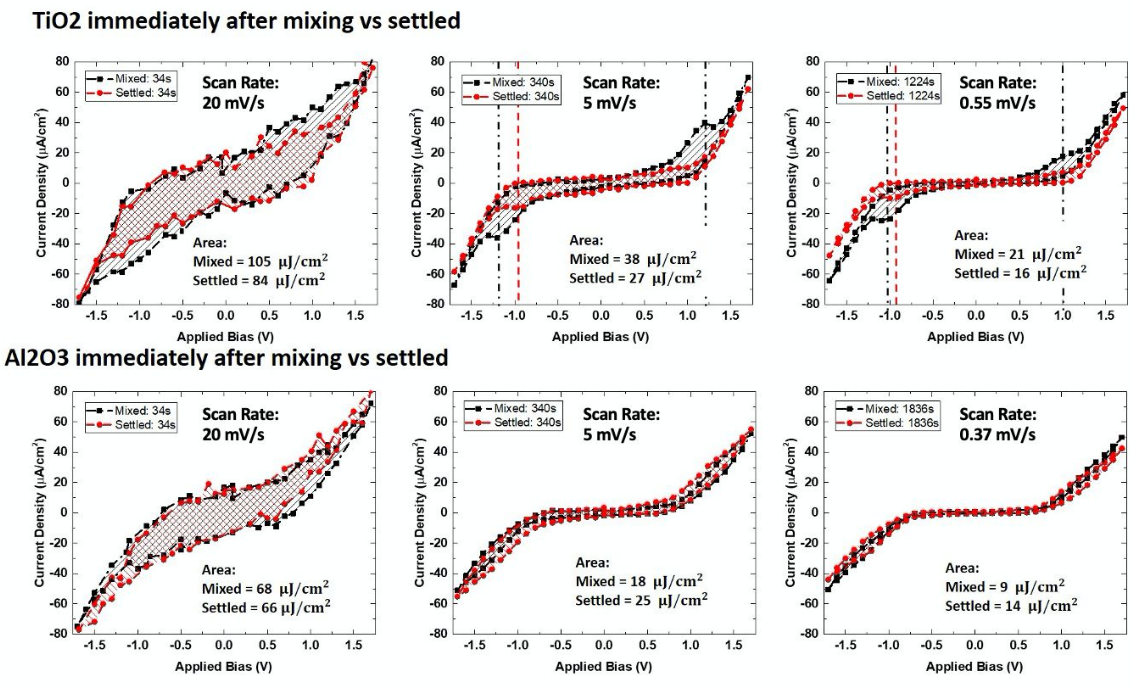
- Electric field frequencies were applied with periods of 20s, 300s, and 1800s
- Strong asymmetry between attractive and repulsive bias
- The feature observed in TiO_2, does not appear in the Al_2O_3 data
- Energy storage data also does not have the same energy storage capabilities as TiO_2 suspension

Results: Cyclic Voltammetry



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- CV measurements comparing well mixed suspensions (black) and suspensions left to settle out the NPs (red) for TiO_2 (top) vs Al_2O_3 (bottom) for 3 different linear sweep rates
- Area under the curve represents the total charge stored
- Well mixed TiO_2 shows notably higher energy storage than Al_2O_3
- Settled TiO_2 shows less energy storage than well mixed TiO_2, while Al_2O_3 mixed vs settled closely match

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Conclusions

- TiO_2 suspensions were observed exhibit enhanced energy storage capabilities relative to pure water or aqueous Al_2O_3 suspensions, suggesting a viable approach for the design of a "smart power device" with optimal mechanical energy efficiency.
- The study confirms suggestions of an earlier study that employed electric fields in systems of nanoparticle suspensions. In particular it confirms their potential for energy storage, and demonstrated potential for future investigations and energy applications.

Future work

- Further cyclic voltammetry measurements on TiO_2 to see how the energy storage of TiO_2 in suspension compares to TiO_2 NPs embedded in electrodes
- Explore these effects on different electrode surfaces or in different bases other than water

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