XI International Symposium on Electrohydrodynamics (ISEHD2025)

Book of Abstracts

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Abstracts

#4 - Oral

Energy And Exergy Analysis Of EHD Drying

EHD in gases

Alex Martynenko

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Keywords: Thermodynamics, Energy Conservation, Mass Flux

Abstract Text
Electrohydrodynamic drying is a novel non-thermal drying technology with extremely low energy consumption. A thermodynamic study, followed by energy and exergy analysis, has been accomplished to understand the reason for energy-efficient drying. The thermodynamic study showed that drying efficiency depends on the air temperature. Energy analysis was carried out according to the first law of thermodynamics, while exergy analysis was based on the second law of thermodynamics. The efficiency of the process was measured as a specific energy/exergy consumption in kJ per kg of evaporated water.
Exergy flows in an open steady-state EHD system are shown in Figure 1.
From exergy analysis, we concluded that most energy for water evaporation comes from the surrounding air. Comparative analysis showed the advantages of EHD compared to other sustainable drying technologies, based on renewable energy sources.

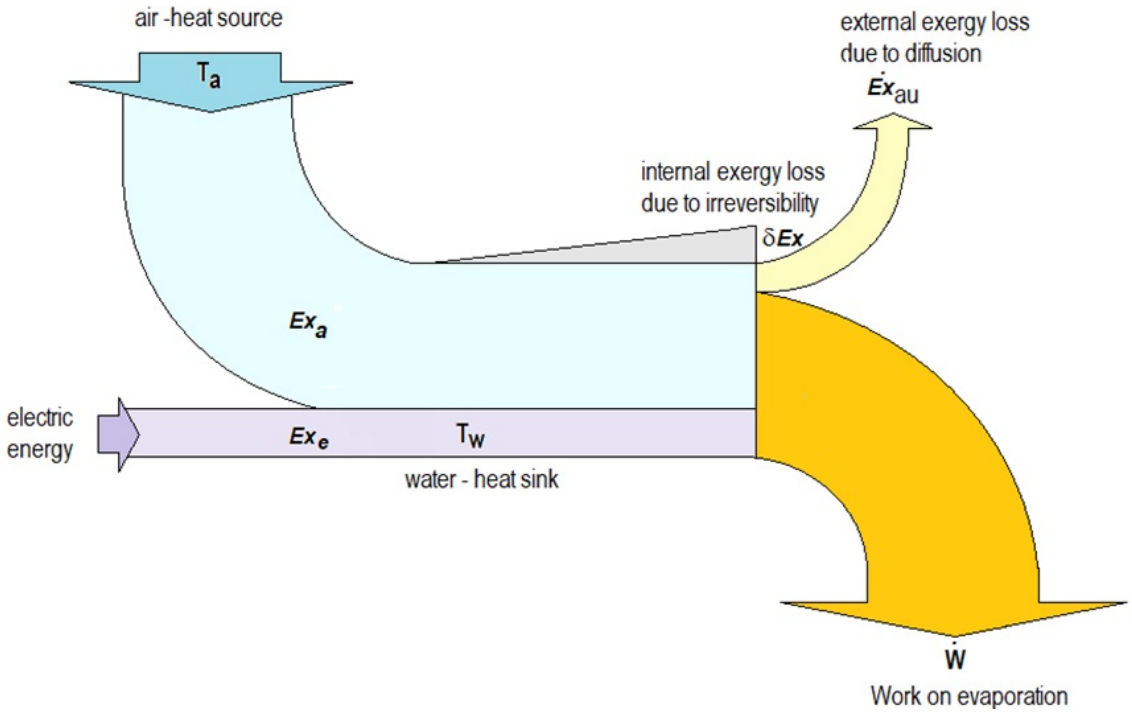

Figure 1 – Schematics of an exergy flow in an open steady-state EHD system

#5 - Oral

Viscoelastic Effect On Electrically Induced Dynamics In A Suspended Droplet: A Mathematical Approach

EHD in liquids

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Keywords: UCM Model, Weight Parameter, Non-Newtonian Index, Leaky Dielectric

Abstract Text
The deformation (D) of droplets due to electrohydrodynamics (EHD) is important in various microfluidic applications, particularly for viscoelastic (VE) fluids, which have been less studied compared to Newtonian fluids. This gap motivated our present mathematical analysis. The novelty of this work lies in its ability to predict the EHD behavior of suspended droplets using known properties while adhering closely to the underlying physics.

We developed an approximate mathematical model for leaky dielectric VE droplets suspended in a surrounding VE medium under a DC electric field within the Stokes flow regime. Our analysis is limited to low electric field intensities and small deformation, with the Weissenberg number (Wi) restricted to 1. The electrical behavior is described by the Laplace equation, while hydrodynamics is governed by the Cauchy Momentum Equation (CME), coupled with the Upper Convected Maxwell (UCM) model to explore the EHD behavior of VE droplets.

In this analysis, we also examine the effects of the weight parameter (δ) and the non-Newtonian index (ηn). The parameter δ represents the contribution of Newtonian tangential stress to the total stress, while ηn emphasizes the impact of electrical forces on the deformation of non-Newtonian fluids. We consider different combinations of the droplet and surrounding fluid, including Newtonian (N) and non-Newtonian (NN) cases.

Our mathematical model is compared with the experimental results of Ha and Yang by plotting D against the electric capillary number (CaE). The comparison shows excellent agreement between the predicted deformation and experimental data within the regime of small deformations and low electric field intensity. The results align with Ha and Yang's [1] analysis, indicating minimum deformation in the N-NN case and maximum deformation in the N-N case.

Additionally, we conducted flow field analysis by generating streamline patterns within and around the droplet. The results show that unlike the close streamlines in Newtonian fluids, streamlines lose their proximity in non-Newtonian cases. This study on VE fluids' EHD behavior can contribute to designing microfluidic devices for industrial applications.

1 HA et. al, Jounal of of Fluid Mechanics 405, 131–156, '2000'.

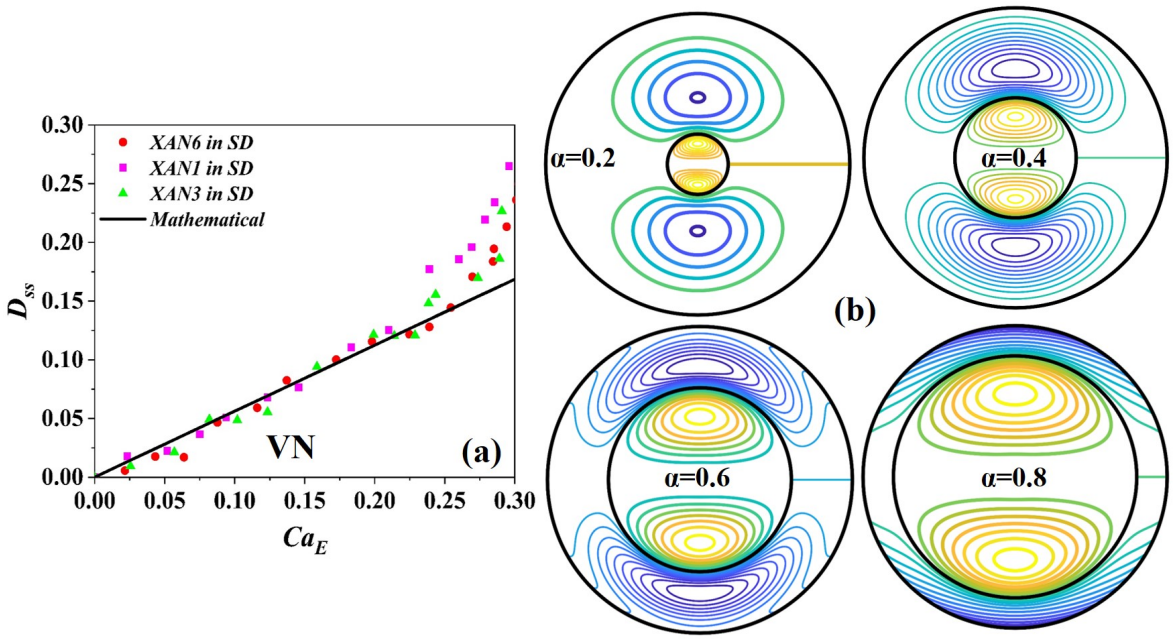

Figure 1: **(a)** Plot of D against Ca_E for validation of mathematical model where the VE droplet is suspended in Newtonian medium, **(b)** Streamline patterns for NN-NN case at different confinement (α).

#7 - Oral

Numerical Modeling Of A Nanosecond DBD Discharge In An Icing Environment

EHD in gases

Marie Bibal[1], Guillaume Dufour[1], Gerjan Hagelaar[2], Konstantinos Kourtzanidis[3], Louis Reboul[4]

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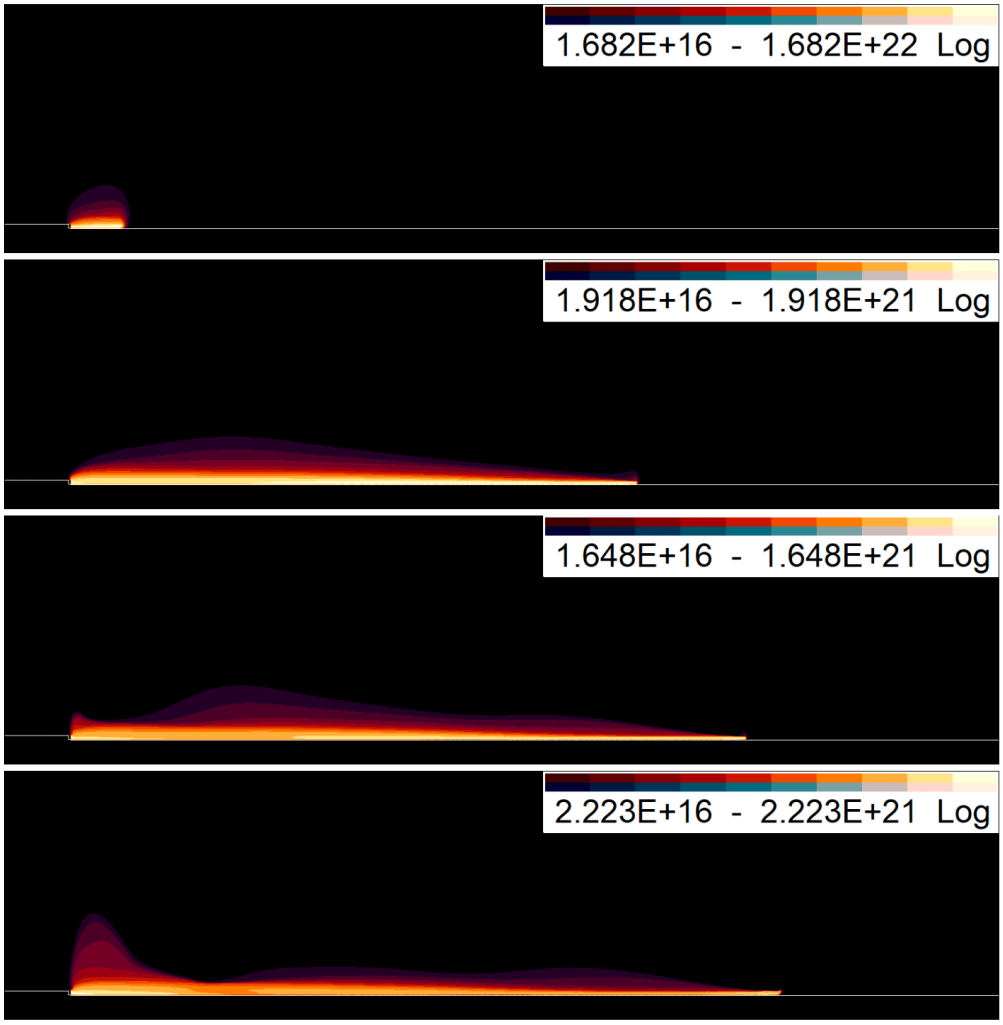
Keywords: Dielectric Barrier Discharge, Plasma, Fluid Model

Abstract Text
Ice accretion on aircraft surfaces is a critical issue when flying in cold weather conditions, posing significant safety risks. One of the emerging deicing technologies proposed to address this challenge involves the use of surface dielectric barrier discharge (DBD) plasma actuators. A DBD system consists of two electrodes separated by a dielectric layer: one electrode is exposed to the surrounding air, while the other is embedded within the dielectric material. In this work, we explore through numerical modeling the possibility of using the thermal effects produced by these devices for deicing and anti-icing purposes.

We investigate several key parameters, including the Joule heating generated by the plasma discharge in the gas, the average position where energy is deposited, and the average duration of energy transfer. Under dry air conditions, we conducted numerous simulations (The figure illustrates an NS-DBD calculation) using various kinetic models to quantify the errors associated with the reduced model. This study highlights the significant role that photo-ionization plays in streamer dynamics, emphasizing that its integration into the chemical model is essential.
Additionally, the influence of boundary conditions on the simulation domain is examined. The results indicate that a reduced domain can be utilized to decrease simulation time without affecting the plasma discharge and energy deposition. A humid air chemistry model was developed based on the water vapor description proposed by Zhu (Zhu and al, Journal of Physics D: Applied Physics, 2020). The influence of varying percentages of water vapor in the air on the heat deposited by the DBD was then investigated.
Simulations were also conducted with ice/water, which was modeled as a dielectric material. It was observed that the streamer can propagate along the surface of the ice/water and deposit energy at this interface.



Simulation of a NS-DBD using the PlasmaSim code (electron density in m3 at 1ns, 10ns, 20ns, and 27ns from the start of the pulse)

#8 - Oral

Decomposition of Acetic Acid Using Pulsed Plasma Generated in N2-O2 Gas

Others

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Keywords: OH Radical, Water Treatment, Acidic Solution

Abstract Text
This study investigated the acetic acid decomposition characteristics of pulsed plasma generated in an N2-O2 gas mixture. The water treated in the experiment was a solution of acetic acid, a model persistent organic compound. In this study, the pulsed plasma was generated by varying the mixing ratio of nitrogen and oxygen. The plasma was generated at the liquid surface of an aqueous acetic acid solution and decomposition treatment was performed for 30 minutes. The initial concentration of the acetic acid solution was approximately 25 mg/L. The initial concentration of the acetic acid solution was about 25 mg/L, i.e., the TOC (total organic carbon) concentration was about 10 mg/L. The highest decomposition rate of acetic acid was obtained when the ratio of nitrogen to oxygen was 25:75. The TOC decomposition rate at that time was 45%. Our results indicate that the gas mixture ratio affects the formation of OH radicals. The reaction mechanism at the gas-liquid interface is currently under investigation.

#9 - Poster

The Impact Of The Polarization Layer On Electrohydrodynamic Drying Efficiency

EHD in gases

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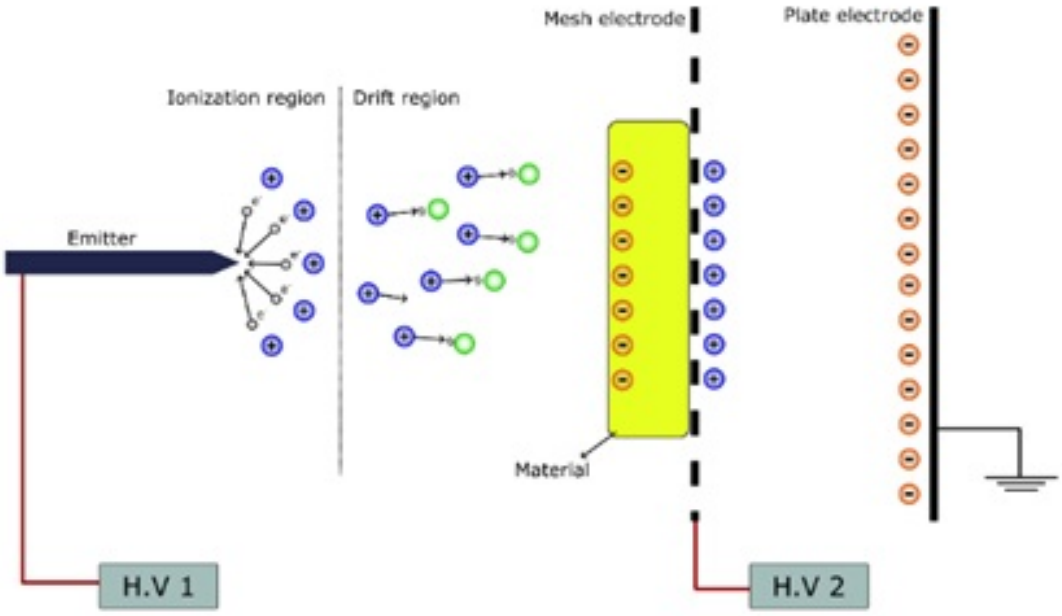
Keywords: Electrohydrodynamics, Polarization Layer, Electroporation, Drying Efficiency

Abstract Text
Growing emphasis on sustainability, energy-efficient, non-thermal technologies sparked the interest in electrohydrodynamic (EHD) drying. However, despite over three decades of research, limited understanding of the underlying mechanisms—such as convective moisture removal, electroporation, and electro-osmotic flow—continues to hinder the technology's optimization and practical application [1]. Electroporation refers to the electrically induced increase in the number and size of hydrophilic nanopores in cell membranes, enhancing membrane permeability. This occurs due to an elevated electric potential difference across the membrane caused by an external electric field, which increases transmembrane water transport. The cell membrane, acting as a dielectric barrier, experiences electrical stress that grows with field strength, leading to pore expansion or membrane rupture if the threshold is surpassed [2]. The comparative analysis of DC vs AC application in EHD drying showed the benefits of DC electric field [3]. However, changes in material conductivity and surface polarization with water removal could significantly impact drying efficiency. The effect of the polarization layer on the drying efficiency has never been evaluated. We propose a novel approach to assess the impact of the material conductivity and polarization layer on the diffusivity and drying efficiency. The proposed setup configuration is shown in Figure 1.

This study will allow us to evaluate the impact of the polarization layer on electroosmosis, electroporation and electrocapillarity in capillary-porous material under drying and contribute to a deeper understanding of electrically induced dewatering mechanisms.

References
[1] Martynenko, A., Kudra, T. (2016). Electrically-induced transport phenomena in EHD drying – A review. Trends in Food Science & Technology, 54, 63–73. https://doi.org/10.1016/j.tifs.2016.05.019
[2] Iranshahi, K., Onwude, D. I., Martynenko, A., & Defraeye, T. (2022). Dehydration mechanisms in electrohydrodynamic drying of plant-based foods. Food and Bioproducts Processing, 131, 202–216. https://doi.org/10.1016/j.fbp.2021.11.009
[3] Martynenko, A., Kudra, T. (2022) Alternating versus direct current in electrohydrodynamic drying. Drying Technology, 40, 2382-2395. https://doi.org/10.1080/07373937.2021.1942899


Mesh electrode
Plate electrode
Ionization region
Drift region
Emitter
Material
H.V 1
H.V 2

#10 - Oral

Visualization Of Liquid-Vapor Interface Oscillation In Parallel Plate Electrodes By Wavy Dielectrophoresis

EHD of multi-phase flows

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Keywords: Fast Oscillation, Resonance, Two-Phase Flow, Wavy Dielectrophoresis

Abstract Text
In phase change heat transfer, the liquid-vapor interfacial velocity is one of the most important parameters governing the phenomenon. In this study, we measured the velocity of the liquid-vapor interfacial oscillation driven by wavy dielectrophoretic (DEP) forces. An offset sinusoidal electric-field of Epp = 2 kV/mm, which is parallel to the liquid-vapor interface of the HFE7100, was applied using parallel plate electrodes as shown in Figure 1. The time-varying DEP force was applied to the liquid-vapor interface in the direction opposite to gravity. The frequency of the applied voltage was varied between 1 Hz and 100 Hz. When DC voltages were applied, the interface height was measured to be proportional to the square of the electric field, as previously reported. At 1 Hz, the amplitude (difference between maximum and minimum height) was 8 mm. With increasing frequency (up to 20 Hz), the maximum interface height and the amplitude of the interface oscillation were decreased. At frequencies above 25 Hz, the interface behavior changed significantly: at frequencies below 20 Hz, the interface remained in a horizontal linear shape and moved up and down, while at frequencies above 25 Hz, the interface shape appeared as a standing wave, as shown in Figure 2. This was called DEP resonance. The DEP resonance persisted up to 90 Hz and the amplitudes of the interface oscillation were decreased with increasing frequency. The propagation velocity of the wave was calculated from $v = f\lambda$ to be v = 270 mm/s, which is almost the same as the propagation velocity of a long wave $v = \sqrt{gh}$ where h is the mean height of the interface. Therefore, this wave is considered to be a gravity-induced long wave at shallow depth. The interface oscillation velocity in the vertical direction reached a local maximum at 25 Hz, which was faster than the interface oscillation velocity calculated from the bubble departure frequency and diameter measured in the HFE7100 boiling experiment [1,2].
[1] El-Genk, M. S., Bostanci, H., International Journal of Heat and Mass Transfer, 2003.
[2] da Silva, I. I et al., 18th Brazilian Congress of Thermal Sciences and Engineering, 2020.

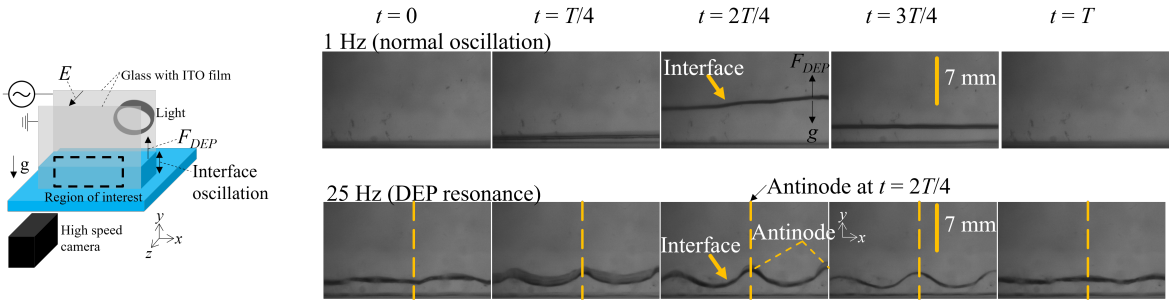

Figure 1 Experimental setup. Figure 2 Liquid-vapor interface behaviors at 1 Hz and 25 Hz.

#11 - Oral

Numerical Investigation On The Effect Of Non-Autonomous Charge Injection In EHD-Assisted Charging Of A Latent Heat Thermal Storage System

Fundamental Electrohydrodynamics

Amirabbas Ghorbanpour Arani, James Cotton, Ethan Chariandy

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Keywords: Non-Autonomous Charge Injection, Lattice Boltzmann Method, Electro-Convection, Latent Heat Thermal Storage System

Abstract Text
The present study aims to investigate the effect of different charge injection functions on electrohydrodynamically driven flows, focusing on three specific injection models: the Heaviside step function, Schottky, and autonomous injection. Previous research predominantly relied on the autonomous charge injection, which oversimplifies the boundary condition and neglect the influence of the electric field, resulting in space charge density distribution on the boundary and within the medium that does not accurately mimic the realistic charge injection phenomena. This study utilizes the lattice Boltzmann method (LBM) to simulate the behavior of paraffin wax, a phase change material (PCM), in a latent heat thermal storage system (LHTSS) under both autonomous and non-autonomous charge injection. Initially, the solid PCM begins melting due to thermal conduction from the hot top wall, after which electro-convection generated by charge injection from a central circular electrode in the LHTSS enhances heat transfer rate. An LBM solver was employed to solve six strongly coupled partial differential equations, including the Navier-Stokes equation, continuity equation, energy equation, Nernst-Plank equation, Gauss's law, and the definition of electric field. The code was verified against various benchmarks, including analytical solutions of the electrical equations at the hydrostatic state, the Stefan problem, and local Nusselt number on a flat wall heated by a curved boundary, demonstrating the accuracy and reliability of the simulations. The electrode in the simulation is under 10 kV and charges are collected by two flat electrodes at the top and bottom of the computational domain. Heat transfer coefficient, Nusselt number, heat flux, liquid fraction over time, and the space charge density pattern at the boundary and within the domain were plotted for each charge injection function. The results for Schottky and Heaviside step functions of injection are very close but differ from autonomous injection significantly despite identical current for all cases. Also, Schottky and Heaviside step functions of injection melts 96 percent of the solid wax, while pure conduction melts only 36%. An EHD enhancement factor is defined to show that 53% heat transfer enhancement can be achieved per one milliwatts electrode power input.

#12 - Oral

Optoelectronic Control Of Active Janus Particles: Trajectory Reconfiguration And Mobility Reversals

Particles and cells manipulation

Sankha Das[1], Pablo García-Sánchez[2], Antonio Ramos[2], **Gilad Yossifon**[1]

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2. University of Seville, Seville, Spain

Keywords: Optoelectronics, Janus Particles, Active Particles, Electrokinetics

Abstract Text
Self-propelling active particles represent a dynamic and interdisciplinary research frontier with promising biomedical and environmental applications. However, their autonomous motion makes it challenging to control their trajectories. This study employs optically patterned electrodes on a photoconductive substrate, utilizing a digital micromirror device (DMD), to dynamically regulate the movement regions of self-propelling particles, specifically metallo-dielectric Janus particles (JPs). Unlike previous studies where passive micromotors were manipulated by a translocating optical pattern, this system uses the optically patterned electrode to delineate the area within which JPs move autonomously. Notably, JPs avoid crossing the edges of the optical region, allowing for the constraint of their movement area and dynamic shaping of their trajectories [1]. The DMD system enables the simultaneous manipulation of multiple JPs, facilitating the self-assembly of JPs into stable active structures, such as JP rings, with precise control over the number of participating JPs and passive particles. Recently, we observed a second intriguing mobility reversal in optoelectronically-driven JPs [2]. This reversal appears to be linked to asymmetry in the photoconductivity of the underlying substrate, localized beneath the JP, due to the self-shading effect of the metallic hemisphere when illuminated from above. Multiple control tests, including bottom-side illumination, and numerical simulations support this proposed mechanism.

[1] S. S. Das, G. Yossifon, Optoelectronic Trajectory Reconfiguration and Directed Self-Assembly of Self-Propelling Electrically Powered Active Particles, arXiv: 2302.04784, Advanced Science, 2206183 (2023).
[2] S. S. Das, P. García-Sánchez, A. Ramos, G. Yossifon, Understanding the Origin of a Second Mobility Reversal in Optoelectrically Powered Metallo-Dielectric Janus Particles, Submitted (2024).

#13 - Oral

PWP Measurement Of Liquid Charge Charges Distribution Under DC Field

EHD in liquids

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2. ESPCI, Paris, France

Keywords: Liquid Charges, Electrical Double Layer, Space Charge Measurement

Abstract Text
Regardless of the liquid used, it exhibits a non-zero electrical conductivity, indicating the presence of electric charges. Although this distribution is often assumed to be homogeneous, it is actually influenced by the presence of an interface (electric double layer) or an external electric field. The local accumulation of electric charge can significantly affect the reliability of equipment such as power components. There are very few experimental methods available to measure the distribution of electric charges in liquids accurately and sensitively. For several years, the PPRIME Institute has been working, notably with the Pressure Wave Propagation (PWP) method, to adapt space charge measurement techniques from solids to liquids. These measurements have been used to observe the spatial and temporal reorganization of electric charges when a dielectric liquid and a semiconductor liquid are subjected to an external DC electric field (Fig. 1).

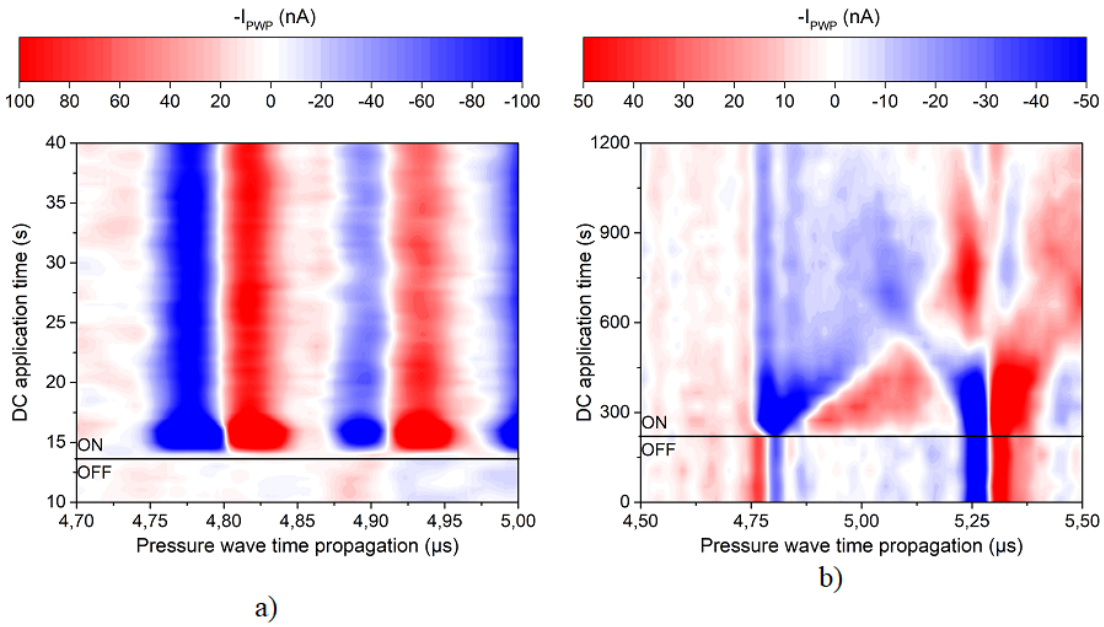

Fig. 1. Electrical response obtained by PWP method on dielectric (a) and semi-conductive (b) liquids under external DC electric field.

#14 - Oral

Enhanced Nano-Droplet Generation By Counter Ionic Liquid Electrospray Configuration For Efficient CO2 Absorption

EHD of multi-phase flows

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2. Graduate School of Mechanical and Aerospace engineering, Tohoku University, Sendai, Japan
3. National Institute of Advanced Industrial Science and Technology, Sendai, Japan

Keywords: Ionic Liquid, Counter Electrospray, Atomization, Carbon Dioxide Absorption

Abstract Text
Ionic Liquid (IL) has great ability of CO2 absorption. The atomization of IL increases a specific surface area, and it enhances the performance of CO2 absorption. However, it is difficult to atomize IL due to its very high viscosity. Electrospray is one of the atomization techniques of IL. IL supplied through a nozzle is atomized by applying a high voltage between the nozzle and the counter electrode resulting in the generation of nano-droplets of IL. In this study, the effect of the flow rate of IL and the nozzle configuration on the CO2 absorption is clarified for the two types of IL electrosprays: one has a single nozzle and the other has counter nozzles in which the nozzles are arranged by facing each other. The CO2 absorption performance is evaluated with a loading rate that is defined as the ratio of the molar amount of absorbed CO2 to that of supplied IL. As a result, there is an optimum flow rate of IL for the loading rate under a constant flow rate of CO2 gas. In addition, the loading rate for counter-nozzle electrospray is higher than that for single-nozzle one at a constant total flow rate. Through the visualization of the spray, it is found that counter-nozzle electrospray more widely spreads in a radial direction compared to single-nozzle configuration. Moreover, the generated droplets collapse each other near the counter electrode to be further atomized as clearly shown by the droplet size distribution measurements. CO2 absorption experiments confirmed that the higher CO2 absorption performance was realized by the counter-nozzle electrospray due to more diffusive spray and miniaturization of droplet.

#15 - Oral

Impact Of An External Static Electric Field During The Foaming Process: Equipment Design And First Results

Others

Michel Havet[1], Adrien Garcia[1], Sylvie Swyngedau Chevallier[1], Luc Guihard[1], Anthony Oge[1], Tzvetelin Dessev[2], Alain Le Bail[1]

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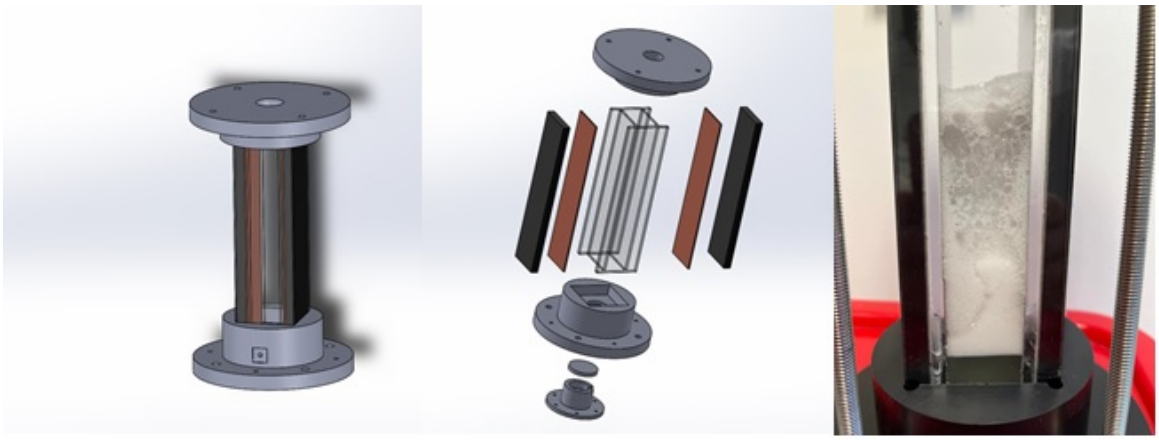
Keywords: Foam - Electric Field - Interface - Surface Tension - Stability

Abstract Text
Food foams are intricate systems of gas bubbles dispersed in a liquid. Their stability, i.e maintaining their structural integrity over time, remains a challenge for various applications. The primary hurdle arises from the natural tendency of foams to collapse, coalesce, or break, leading to a loss of their porous texture and functionality. This study focuses on a set-up designed to evaluate the attributes of foam, encompassing its generation and stability. This involves gas phase incorporation into a liquid medium to generate foam. The experimental setup entails placing the liquid sample within a chamber with a glass column that incorporates stainless steel flat parallel electrodes (30x200 mm, gap 5cm). A Static Electric Field (SEF) was applied to the foam either during foaming or after foaming. The combination of video imaging with computational algorithms enabled the extraction of dynamic foam behavior data, such as foam collapse and drainage patterns. Experiments were performed on Whey Protein Isolate (WPI) and Chickpea aqueous solutions. Gas injection (air 10 mL/s) and SEF were simultaneously applied for 120 s. Image acquisition were then initiated (1 Hz acquisition rate) to observe the destabilization phase of the foam during 15 minutes. Our observations revealed distinctive trends in foam stability according to the SEF level. As the SEF increases, we noticed a remarkable shift in the foam's stability, which yielded changes in the volume of the liquid phase. This observation signifies that, under the influence of an external SEF during the foaming period, the liquid remains in the foam state for a longer period. This was attributed to a reduction in the size of gas bubbles escaping from the frit, thus diminishing surface tension. These smaller and more uniform gas bubbles incorporated into the liquid phase exhibited heightened stability and limited the disproportionation effect of foam destabilization (ripening). Furthermore, the SEF might influence protein conformation and weak intermolecular interactions, further contributing to foam stabilization. These results are promising for the conception of an innovative food foam equipment able to produce a high-quality foam under SEF while reducing the energy required to create the new interfaces.



Sketch of the column for foaming process under electric field

#16 - Oral

Fundamental Characteristics Of Ionic Liquid Electrospray With Pump-Free Porous Emitter For Enhanced CO2 Absorption

EHD of multi-phase flows

Hidemasa Takana[1], Shin-Ichi Kawaharada[1], Takashi Makino[2], Mitsuhiro Kanakubo[2]

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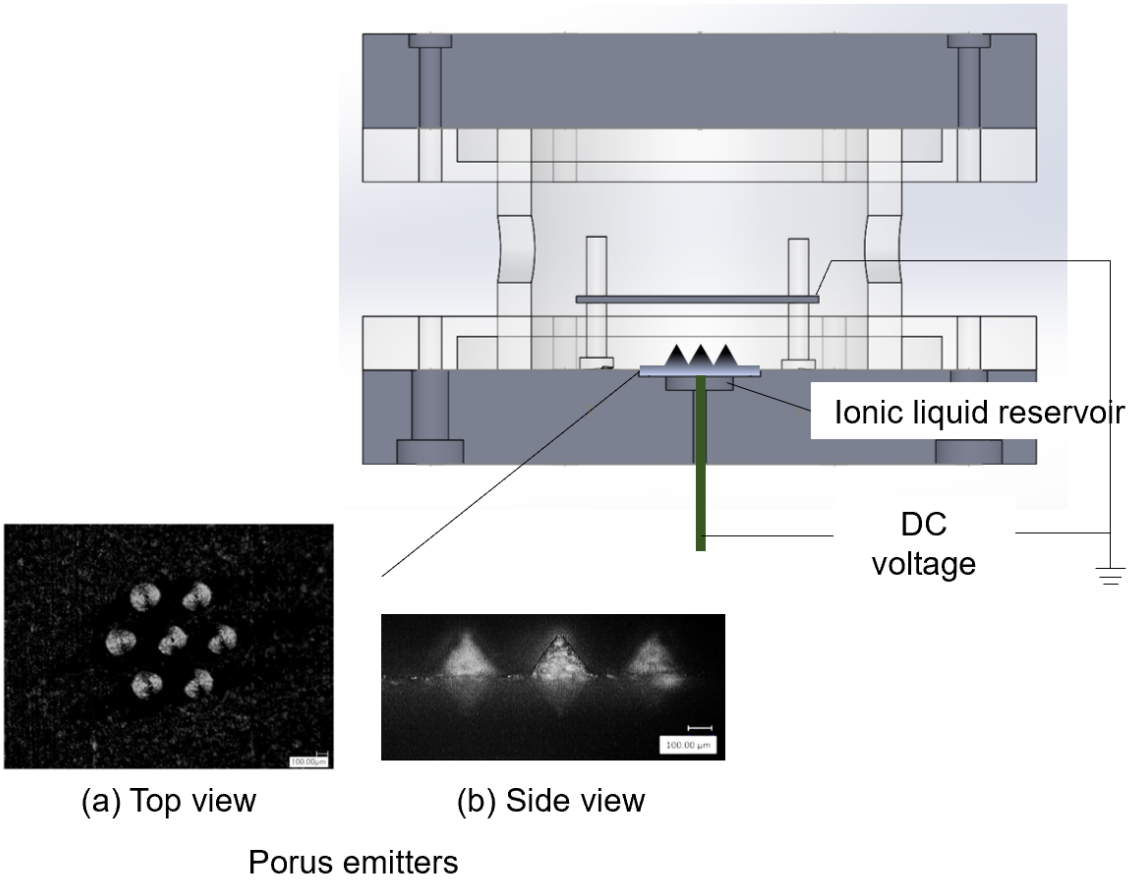
2. National Institute of Advanced Industrial Science and Technology, Sendai, Japan

Keywords: Electrospray, Ionic Liquid, CO2 Absorption. Porus Emitters, Pump-Free

Abstract Text
For crewed long-term deep-space missions, the control of the atmospheric CO2 level in the space cabin is key in modern spacecraft environmental control and life support systems during the exploration. Recently, ionic liquids have garnered significant attention as an energy-efficient innovative liquid absorbent for CO2. Takana et al. proposed ionic liquid electrospray to make the most use of ionic liquids' CO2 absorption kinetic capability by generating nano-order fine droplets. It was experimentally demonstrated that the fine droplets were successfully generated by using ionic liquid electrospray. The fine droplets with a high specific surface area enhanced the surface reaction of CO2, resulting in the significant decrease of the CO2 concentration in the closed chamber.
In this study, the innovative ionic electrospray method using porous emitters has been proposed as the pump-free electrospray system. Using the porous material as the emitters, ionic liquid is fed proactively by capillary effect from the reservoir at the optimum flow rate for the spray. The starting voltage for electrospray with porous emitter under atmospheric pressure was clarified as its fundamental characteristics. The effect of array configuration of porous emitters; i.e. distance between emitters, counter electrode alignment, etc. has been experimentally elucidated.
The ionic liquid droplets with the averaged size of 13 nm were successfully generated using the porous emitters. It was found that the spray current increases by 120 % with changing the emitter intervals from 0.45 mm to 1.0 mm due to less interaction between the spray from emitters. As a result, under the optimized configuration, the absorbed CO2 amount improves by 3.4 times more compared to the case without applied voltage.


Ionic liquid reservoir
DC
voltage
(a) Top view
(b) Side view
Porus emitters

#18 - Oral

Hybrid Heat Exchanger And Wet Electrostatic Precipitation For Collecting Water And Saving Energy

EHD of multi-phase flows

Hui Fu[1], Qinzhen Zheng[2], Shuran Li[3], Zhen Liu[3], **Keping Yan**[3]

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2. Jiangsu Hengtong Intelligent Equipment Co.,Ltd., Suzhou, China
3. Zhejiang University, Hangzhou, China

Keywords: Wet Electrostatic Precipitator, Ion Wind, Heat Exchanger

Abstract Text
Integration of gas-liquid heat exchanger with electrical discharge processes have been proposed for specific applications [1], such as controlling ash resistivity, reducing gaseous velocity near the collection electrodes to improve electrostatic precipitation, operating high-temperature precipitation and enhancing heat transfer efficiency without polluting the water and gases. By integrating a wire-cylinder type wet electrostatic precipitator with a gas-aqueous heat exchanger, both gas cleaning and heat saving can be simultaneously realized [2,3]. Both laboratory tests and small pilot demonstrations have confirmed that the heat transfer coefficient can be enhanced by a factor of 2-2.5, and water drop can be collected at an energy cost of around 800-1000kg(H2O)/kWh, which would benefit a number of industries in North-West part of China. The water cost is around 6-10CNY/t, and the electricity generation cost is around 0.1-0.4 CNY/kWh.
This paper will discuss its technical feasibility for promoting industrial applications.

Reference:
1. K. Yan, “Corona plasma generation”, PhD Dissertation, TU/e, 2001
2. H. Fu, et al, “Convective heat transfer enhancement by corona discharge in a wire–cylinder electrostatic precipitator with the water cooling system”, Journal of Electrostatics. 2023, 125: 103845
3. H. Fu et al, “Fog Droplet Collection by Corona Discharge in a Needle–Cylinder Electrostatic Precipitator with a Water Cooling System”, Separations. 2022; 9(7):169

#19 - Oral

A Physics-Informed Neural Network Solver For Electro-Convection Flow

EHD in liquids

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2. Department of Mechanical Engineering, Union College, Schenectady, United States
3. Dpto. Física Aplicada III, ETSI, Universidad de Sevilla, Sevilla, Spain

Keywords: PINN, Electro-Hydro-Dynamics, Simulations

Abstract Text
This study presents a novel Physics-Informed Neural Network (PINN) solver for directly addressing electro-convective processes, exploring its feasibility and effectiveness as a versatile alternative to traditional numerical methods. PINNs, integrating physical laws directly into neural network training, offer significant potential for complex, multi-physics problems such as Electro-hydro-dynamics (EHD), where conventional solvers may struggle with high-dimensional, nonlinear behaviors. In this work, we systematically examine the influence of crucial hyperparameters—including mesh generation, loss weighting, activation functions and network architecture—on the accuracy, convergence, and robustness of the PINN solution. By utilizing Ray Tune for automated hyperparameter optimization, we identify optimal configurations that enhance the solver's performance, stability, and generalization capabilities.
To validate the accuracy and reliability of our PINN solver, we conducted a detailed comparative analysis with conventional numerical simulations on classic EHD setups, specifically cavity and parallel plate configurations. The PINN solver not only demonstrated high fidelity to traditional results but also successfully captured the well-known hysteresis curve characteristic of electro-convective flow, a hallmark behavior in EHD systems that showcases the solver’s ability to model complex, nonlinear phenomena. This achievement underscores the potential of PINN frameworks in accurately reproducing physical behaviors in challenging multi-physics domains.
Our findings highlight the PINN solver’s advantages in computational efficiency and its adaptability to varying simulation conditions, pointing to its suitability for further applications in EHD. This research broadens the scope of PINN applications within EHD, offering a powerful tool for advancing numerical research and providing new insights into electro-convective dynamics. This study also offers a promising pathway for extending the frontiers of computational fluid dynamics in EHD.

#20 - Oral

Numerical Simulation For Decomposition Of Organic Compounds In Water By Plasma Generated Above Solution Under Consideration Of EHD-Induced Liquid Flow

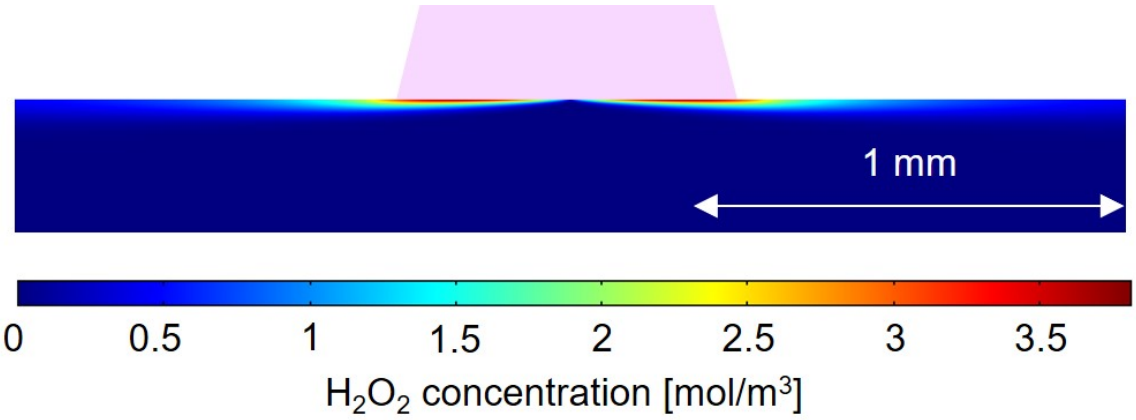
Others

Nozomi Takeuchi

Institute of Science Tokyo, Tokyo, Japan

Keywords: Plasma, OH Radical, Water Treatment, EHD Flow

Abstract Text
Numerical simulation for decomposition of persistent organic compounds in water by plasma generated above a solution was conducted under consideration of EHD-induced liquid flow. The changes in the mass transfer of reactive oxygen species and decomposition efficiency will be discussed.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H2O2 concentration [mol/m3]

#21 - Poster

Design And Optimization Of Multi-Needle Electrospray To Increase The Throughput Of Electrospray-Based Devices

EHD in liquids

Rukhsar Parveen, Rochish Madhukar Thaokar, Y S Mayya

Indian Institute of Technology Bombay, Mumbai, India

Keywords: Electrospray, Multineedle, Increase Throughput, Optimization

Abstract Text
An electrospray is an atomization technique that ejects extremely fine and highly charged droplets through an electrified needle. Electrospray forms due to the electrohydrodynamic instability in a conducting liquid dispensed through a needle in the presence of an electric field. The droplets become unstable when the electric charge on it reaches the Rayleigh limit. Electrosprays have been extensively employed in various applications, including nanoparticle generation for drug delivery, atomic spectroscopy, pesticide dispersion, inkjet printing, metal plating, and the production of silicon films, etc.
An important limitation of electrospray systems is their low throughput (typically 500-1000 microliters/hr). For the suitability of electrospray systems in commercial applications, it is therefore critical to enhance the throughput of electrospray systems. In this context, the design and optimization of multi-needle configurations are crucial. The performance of an electrospray is significantly influenced by properties of the liquid, such as surface tension and electrical conductivity, which in turn affect the design parameters of electrospray-based devices. Additionally in multi-needle systems, design parameters such as spacing between the needles, their configuration, and equitable flow distribution in the needles become important.
This study focuses on the fundamental principles of electrospray, with particular emphasis on multi-needle electrospray systems. An in-house design of a multi-needle spray apparatus, as illustrated in given Figure, was developed to investigate the effect of inter-needle distance. To optimize the efficiency of the electrospray, key parameters such as droplet velocity, size distribution, transit time, and evaporation time were calculated. The study also explores the flow rate-voltage regime that supports the formation of a stable cone-jet mode.

#22 - Poster

Flow Reversal In Ring Actuator – What's Wrong With The Numerical Model?

EHD in gases

Kazimierz Adamiak

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Keywords: Flow Actuators, Dielectric Barrier Discharge, Electrohydrodynamic

Abstract Text
Among many electrohydrodynamic devices proposed for flow control is the ring actuator. It is based on the dielectric barrier discharge between an exposed ring electrode supplied with a high sinusoidal voltage and a buried circular electrode, which is grounded. The experimental observations published in [1] discovered surprising reversal of flow direction, if the ring radius decreases below some critical value. This phenomenon has a credible theoretical explanation, which is based on the difference between the gas discharge in the positive and negative voltage half-cycles. An approximate numerical model of the process, which neglects photoionization, confirms this explanation, although for slightly different actuator configurations [2]. However, a more complete model of this problem, when the secondary emission of the seed electrons from dielectric surface is replaced with seed electrons generated by photoionization, is not able to reproduce the experimental data. Possible factors causing this lack of agreement will be discussed in the paper.
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#23 - Poster

Analysis Of Power Spectral Entropy Characteristics Of Electrostatic Gait Signals Based On Human Electrostatic Field

Electrostatics

Sichao Qin, Pengfei Li, Ruoyu Han, Xi Chen

Beijing Institute of Technology, Beijing, China

Keywords: Electrostatic Gait Signals, None Contacted Manner, Gait Characteristics

Abstract Text
Gait characteristics are important indicators for evaluating human health status and movement ability, and are of great significance for early detection, diagnosis, and rehabilitation guidance of diseases. Gait signals detection based on human electrostatic field has the advantages of non wearable, low-cost, and long-term direct acquisition of full cycle signals compared to existing methods. On the basis of introducing the principle of gait signal detection based on human electrostatic field, this article conducts power spectral entropy spectrum feature analysis on the electrostatic gait signals of control subjects, hemiplegic patients, and Parkinson's patients collected in the experiment, and draws box plots of the power spectral entropy value. The results showed that there were significant differences in power spectral entropy values due to the influence of pathologies of different diseases. The power spectral entropy value of hemiplegic patients is the highest, followed by Parkinson's patients, and the power spectral entropy value of healthy controls is the lowest. The data distribution of power spectral entropy in three different groups shows significant differences ($p<0.05$). This study explores feasible technical approaches to quantitatively evaluate the stability and complexity of subjects' gait using electrostatic gait signals.

#24 - Oral

Analysis Of The Surface Potential Of SiO_2 Wafers After Two-Fluid Spray Using Pure Water

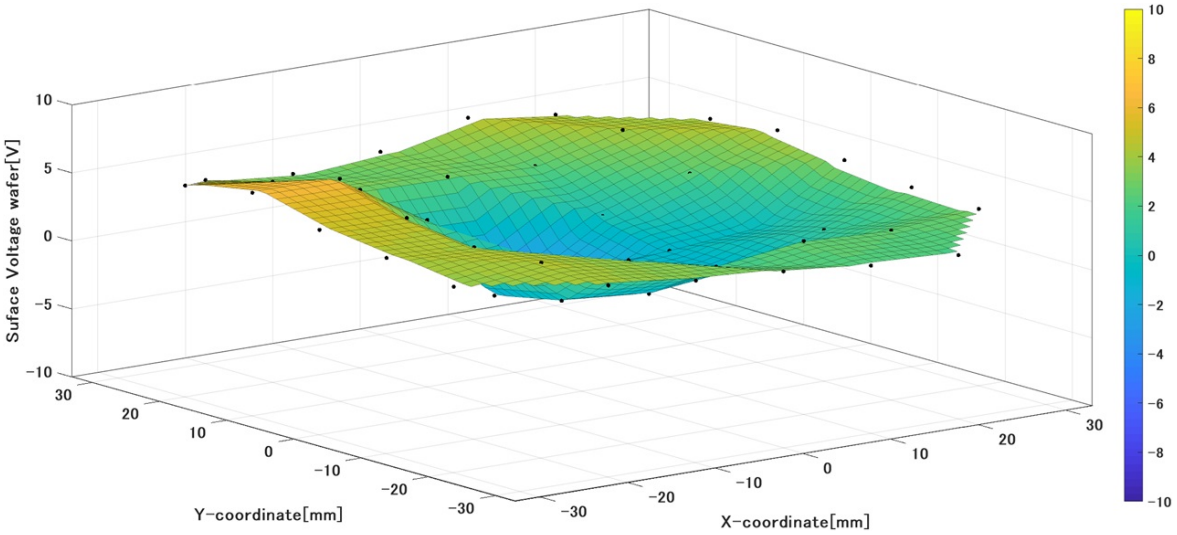
EHD of multi-phase flows

Yoshiyuki Seike, Kousei Ito, Ittetsu Watanabe, Yusuke Ichino, Noriyuki Taoka, Tatsuo Mori

Aichi Institute of Technology, Toyota, Japan

Keywords: Two-Fluid Spray, Electrostatic Discharge, Semiconductor, Cleaning

Abstract Text
In semiconductor chip manufacturing, cleaning processes for particle removal and resist stripping are critical steps that determine yield. Among these cleaning methods, two-fluid spray cleaning, which mixes compressed gas and pure water to create a spray, is widely used. However, when performing two-fluid spray cleaning with pure water, a charging effect occurs on the wafer surface, leading to electrostatic discharge (ESD) issues. To avoid ESD, we analyzed the charging phenomenon of SiO_2 wafers during two-fluid spray cleaning using pure water. When measuring the surface potential of an SiO_2 wafer sprayed with pure water using a two-fluid spray, the surface potential of the sprayed areas exhibited a negative polarity (Figure 1). It has been found that the flying droplets of sprayed pure water exhibit positive polarity, meaning the polarities of the flying droplets and the wafer surface charge are opposite. To confirm this phenomenon, we induced a charge on the SiO_2 wafer by applying tens of kilovolts using a needle electrode and measured the surface potential of the SiO_2 wafer. As a result, the polarity of the SiO_2 surface matched the polarity induced by the needle electrode. This finding suggests that when pure water is sprayed for cleaning using a two-fluid spray, the charging of the SiO_2 wafer is likely caused by triboelectric charging between the sprayed water film and the SiO_2 wafer.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#25 - Poster

The Role Of Charge Transfer In Mass Transfer In EHD Drying

EHD in gases

Alex Martynenko

Dalhousie University, Truro, Canada

Keywords: Transport Phenomena, Charge Transfer, Electrolysis, Air Drying

Abstract Text
Early research on EHD mass transfer considered the ion-drag force a major factor driving mass flow from the material surface. The linear drying kinetics, observed in EHD drying of saturated capillary-porous material suggested a convective mode of mass transfer. Conjugate modelling of the EHD phenomenon connected convective mass transfer to enhanced heat transfer (Defraeye and Martynenko, 2018).

At the same time, the effect of EHD-induced charge transfer on convective mass transfer has never been studied. Assuming the similarity between electrolysis in ionized liquids and gases, we tested the validity of Faraday's law for convective mass transfer in EHD drying. Our experiments show a linear relationship between mass and charge transfer for current densities below 10 mA/m2 (Martynenko et al., 2017). Above 10 mA/m2 the mass/charge relationship becomes nonlinear. Experimentally determined mass/charge ratio ranged from 10 to 24 g/C, much above the theoretical value, expected from Faraday's law. It tells even if the direct effect of charge on the mass transfer existed, it was much smaller than pressure- and temperature-driven evaporation.

Another effect of EHD charge transfer is related to the saturation of air with charged particles, which creates a volumetric charge density of up to 0.06 C/m3 (Zhong et al., 2019). Electric field accelerated charged particles to the velocity, proportional to applied voltage (Robinson, 1961). Charge transfer to the material was proportional to the squared velocity of the ionic wind. At the same time, mass transfer was linearly dependent on the velocity of ionic wind. This suggests the major effect of aerodynamic flow on the mass transfer.

The effect of interference of EHD-induced vortices on the charge transfer was studied in experimental design with different electrode geometries (Martynenko & Kudra, 2020). We found that large spacing between emitters minimizes interference between aerodynamic vortices, favouring charge/mass transfer. In contrast, small spacing between emitters transfer increases interference and turbulence, negatively impacting charge/mass transfer. The same negative impact is observed due to mechanical crossflow with Re>2300. We can conclude that the efficiency of electroconvective mass transfer increases under optimal spacing of emitters and laminar airflow.

#26 - Oral

Effect Of Electric Field On Moisture Transport In Porous Media During Electrohydrodynamic Drying

EHD of multi-phase flows

Pejman Naderi, Alex Martynenko

Dalhousie University, Truro, Canada

Keywords: Electrodiffusion, Porous Media, Mass Transfer Enhancement

Abstract Text
Drying moist porous media, such as food, remains energy-intensive, often causing thermal degradation and high operational costs. Electrohydrodynamic (EHD) drying offers an efficient alternative, leveraging electric fields to enhance moisture removal. Ionic wind generated by the electric field drives convective mass transfer. However, with the decrease in moisture content, diffusion internally restricts moisture transport. Porous structures, whether inherent or formed during drying, critically impact transport mechanisms. Electric fields interact with charged particles, dipoles, and polarizable molecules, rearranging complex structures like cell membranes and modifying diffusive resistance to moisture transport. While ionic wind improves surface dehydration by reducing boundary layer resistance, internal electric fields can enhance mass transfer deeper within the material [1].

Electric fields impart surface charges on cellular components, creating unbalanced distributions and driving fluid movement through electrostatic forces. Such phenomena become pronounced as drying advances, with factors like electric permittivity and the conductivity of remaining water. Moreover, dielectrophoresis facilitates the translational motion of neutral particles in non-uniform fields, impacting both liquid and vapor transport. Electroporation of cell membranes could be another factor, accelerating internal mass transfer [2].
We aim to employ numerical simulation with COMSOL Multiphysics to explore the effect of uniform and non-uniform electric fields on moisture transport in a porous matrix, offering insights into optimizing EHD drying for industrial applications.

References
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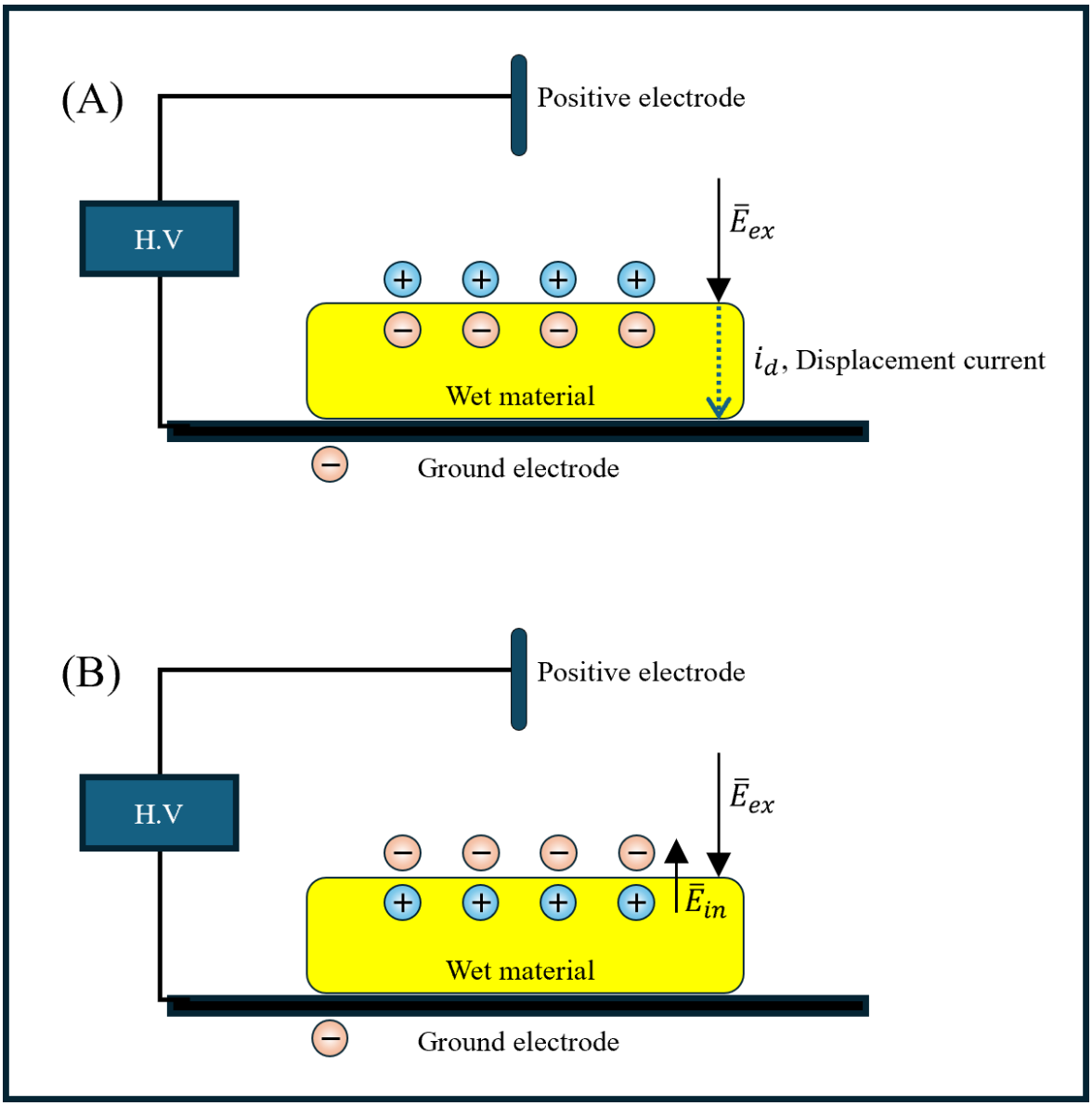
[2] Iranshahi, K., Onwude, D. I., Martynenko, A., & Defraeye, T. (2022). Dehydration mechanisms in electrohydrodynamic drying of plant-based foods. Food and Bioproducts Processing, 131, 202–216. https://doi.org/10.1016/j.fbp.2021.11.009



Charge distribution at the surface of wet material in EHD drying. A) Transient response after application of DC electric field; B) Formation of steady state EDL

#27 - Oral

Evaluation Of Effect Of Electrode Shape On Electrohydrodynamic Heat Transfer Enhancement In Phase Change Materials

EHD in liquids

Mostafa Koura, Ethan Chariandy, James Cotton

McMaster University, Hamilton, Canada

Keywords: Electrohydrodynamics, Phase Change Materials, Latent Heat, Energy Storage

Abstract Text
Latent Heat Thermal Energy Storage Systems (LHTESS) are a type of thermal storage that uses Phase Change Materials (PCMs) as a medium for thermal energy storage. An ideal system charges quickly and readily discharges when necessary. Since the PCMs used in these systems are often high Prandtl number fluids, forced convection is favorable for heat transfer enhancement. As such, the use of electrohydrodynamics (EHD) to induce forced convection in the liquid phase is a topic of interest. The complex nature of EHD requires experimentation and modelling to be fully defined. Therefore, making a practical thermal cell requires understanding the nature of the enhancement for a realistic cell design. This paper explores potential designs for a realistic thermal cell that can be upsized for large scale use. Several electrode designs were compared to determine if an optimal design exists and what it may be. Particle Image Velocimetry (PIV) was used to compare the resultant flow and evaluate the impact of the electrode design on the induced fluid flow patterns and subsequent heat transfer enhancement.

#28 - Oral

Adiabatic Bubble Growth And Detachment Under AC Electric Fields

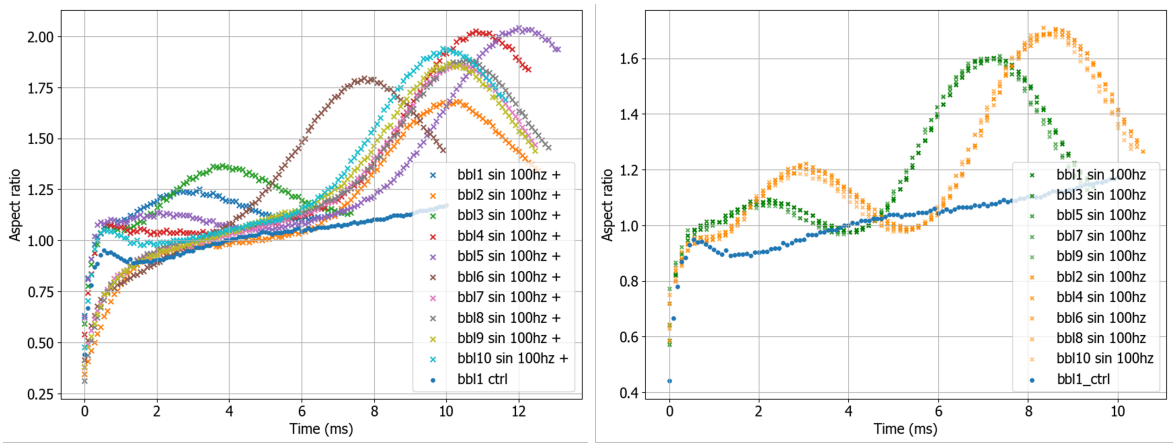
EHD of multi-phase flows

Tianle Gu, Samuel Siedel

Grenoble INP, Grenoble, France

Keywords: Bubble Dynamics, Electrohydrodynamics, HFE-7100

Abstract Text
The growth and detachment of bubbles in a dielectric fluid from a surface is a fundamental research topic for various engineering applications, including advanced heat exchangers, electrolysis, and cooling in space. DC electric fields have been regarded as effective tools for manipulating the bubble interface and accelerating the removal of bubbles, due to the induced dielectrophoretic and electrostrictive forces and consequent interfacial stress.
In the present study, air bubbles injected into HFE-7100 were studied experimentally in the presence of AC electric fields. At various frequencies and waveforms, novel behaviours of bubble dynamics were observed, including but not limited to field-forced oscillations (Figure 1-a), varying lifespans, and volumes at detachment. In addition, the sine waves with a changing polarity at certain frequencies tend to separate the oscillation modes of successive bubbles into two groups with an alternating pattern (Figure 1-b), suggesting the bubble initiation being modulated to two specific instants of the waveform. The subsequent investigation using a 1 Hz square wave with changing polarity confirmed the presence and significance of the free charges-associated electrophoretic (Coulomb) forces, which were eliminated at frequencies higher than 1000 Hz for the current configuration. Moreover, under square waveforms of certain frequencies, the intervention of electric stress at the change of polarity is the major cause of bubble detachment, which could lead to a significantly shortened lifespan.
Previous research has suggested that, compared to the polarization forces, the Coulomb effect easily dominates the phenomenon in its presence. However, our observations collectively suggest that the complex bubble dynamics result from the coupled effects of polarization and Coulomb forces. The Coulomb force most likely came from charge injection, the mechanism of which is time-dependent and materials-dependent. The periodic characteristics and the impact of bubble history on bubble growth and detachment should be taken into consideration in future investigations associated with AC electrics in dielectric fluids.



(a) **(b)**

(a) Aspect ratio (height/width) evolution of 10 successive bubbles under an asymmetric sine wave of 0 to 12 kV at 100 Hz. (b) Aspect ratio evolutions of 10 successive bubbles under a symmetric sine wave of -12 to 12 kV at 100 Hz.

#29 - Oral

Numerical Modeling Of Dust Particle Motion In A Corona Discharge-Based Ionic Wind Cleaning System For Solar Panels

EHD in gases

Khelifa Yanallah[1], Mohamed Ridha Bouazza[1], Amar Tilmatine[2], Francisco Pontiga[3], Ayyoub Zouaghi[4], Nezha Kadous[5], Yassine Bellebna[6]

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2. APELEC Laboratory, Djillali Liabes University of Sidi Bel-Abbes, Sidi Bel Abbes, Algeria
3. Departamento de Física Aplicada II, Universidad de Sevilla,, Sevilla, Spain
4. Univ Lyon, Ecole Centrale de Lyon , INSA Lyon, Université Lyon 1, CNRS, Ampère, UMR5005, 69130, Ecully, France, Lyon, lyon, France
5. APELEC Laboratory, Djillali Liabes University of Sidi Bel-Abbes, Sidi Bel Abbes, Algeria&Mustapha Stambouli University of Mascara, Algeria, mascara, Algeria
6. APELEC Laboratory, Djillali Liabes University of Sidi Bel-Abbes, Sidi Bel Abbes, Algeria&Mustapha Stambouli University of Mascara, Mascara, Algeria, sidi Bel Abbes, Algeria

Keywords: Numerical Modeling; Ionic Wind; Corona Discharge; Sand Dust Cleaning; PV Panel.

Abstract Text
To address the efficiency losses in solar energy conversion caused by dust accumulation, innovative solutions are being explored to prevent dust adhesion and facilitate dust removal from solar panel surfaces [1]. Among these, the use of ionic wind generated by corona discharge has shown promise as a technique for mitigating dust build-up [2].
Electric wind can be generated through both positive and negative corona discharges, driven primarily by ion movement. In a corona discharge, the intense electric field at a sharp electrode ionizes air molecules, producing ions that drift toward the grounded electrode. Through collisions with neutral air molecules, these ions transfer momentum, thereby generating the electric wind.
The cleaning system consists of a blower device that generates the electric wind while moving in a linear motion along the length of the panel. The moving device carries the dust along the longitudinal direction of the inclined panel. This motion of the device, like a broom, enables contactless cleaning of the panel's surface.
In this context, this study aims to investigate the mechanisms governing dust particle motion within an ionic wind cleaning system for solar panels. A thorough understanding of the effects of operating parameters on particle trajectories and displacement distances is crucial for optimizing the system's efficiency and identifying factors that may limit its performance. A numerical model has been developed that takes into account Coulomb, dielectrophoretic, and image forces, as well as gravitational, drag, and van der Waals adhesion forces. The Coulomb and drag forces are computed based on the numerical solution of Poisson's equation, coupled with the continuity equation for charged particles and the Navier-Stokes equations.

References:
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#30 - Oral

Magneto-Electro-Osmotic Micro-Stirring: A Pathway To Enhanced Molecular Transport

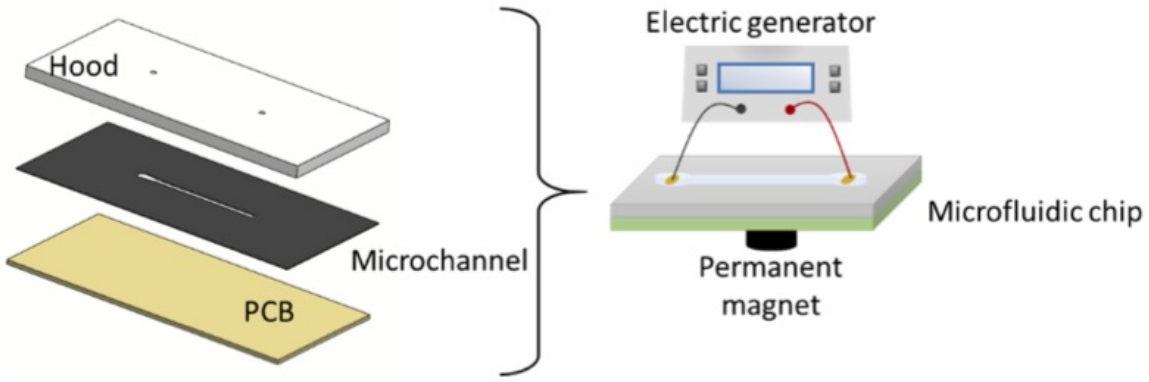
Others

Léna Gonzalez[1], Clémence Biscara[1], Jean-Maxime Roux[1], **Laurent Davoust**[2]

1. CEA, Grenoble, France
2. Grenoble-Alpes University, Grenoble, France

Keywords: Electroosmosis, Magnetohydrodynamics, Stirring, Microchannel

Abstract Text
To achieve effective stirring at microscale remains a challenge despite the need for enhancing molecular transport in biological microsystems. In this paper, a method is proposed to generate controlled micro-stirring by exploiting the interplay between electric and magnetic fields.
When an electric field is applied along a microchannel filled with a ionic liquid buffer, electroosmotic flow arises from the formation of electric double layers (EDL) along the channel walls. EDLs are characterized by native surface electric charges immobilized at the channel walls, that are balanced by a thin boundary layer of opposite charges. For conditions where the Debye thickness remains much smaller than the transverse size of the channel and where an axial electric field acts on the non-uniform charge distribution within the EDL, a Coulombic force is generated that further drives liquid motion under viscous shear.
We present comprehensive numerical simulations of this electroosmotic flow modified by the presence of a permanent magnet situated beneath the bottom wall of a microchannel. This configuration allows for the exploration of a magneto-electro-osmotic microflow, not only for the purpose of micro-stirring generation but also to investigate the underlying physical mechanisms that govern this innovative microfluidics configuration.
An experimental device (figure a) is also developed which is essentially based on a microchannel whose bottom wall is equipped with a permanent magnet. The latter introduces a non-uniform magnetic field that, in combination with the electric field, generates low magnetic Reynolds number vortices. These vortices give rise to recirculating flows as made evident by numerical simulations and experiments (see figure b). Such patterns are relevant for applications requiring stirring or collection of biological targets. Fluorescent microparticle image velocimetry (micro-PIV) confirms the presence of these vortices within the microchannel, with vortical structures driven by a nonuniform Lorentz force. The spatially varying Lorentz force induces pressure gradients, which are identified as the mechanism responsible for micro-stirring so observed.
This work provides a basic understanding of how controlled electric and magnetohydrodynamic forces can be harnessed to achieve efficient microscale mixing, offering new avenues for applications in microfluidic systems and biological transport.



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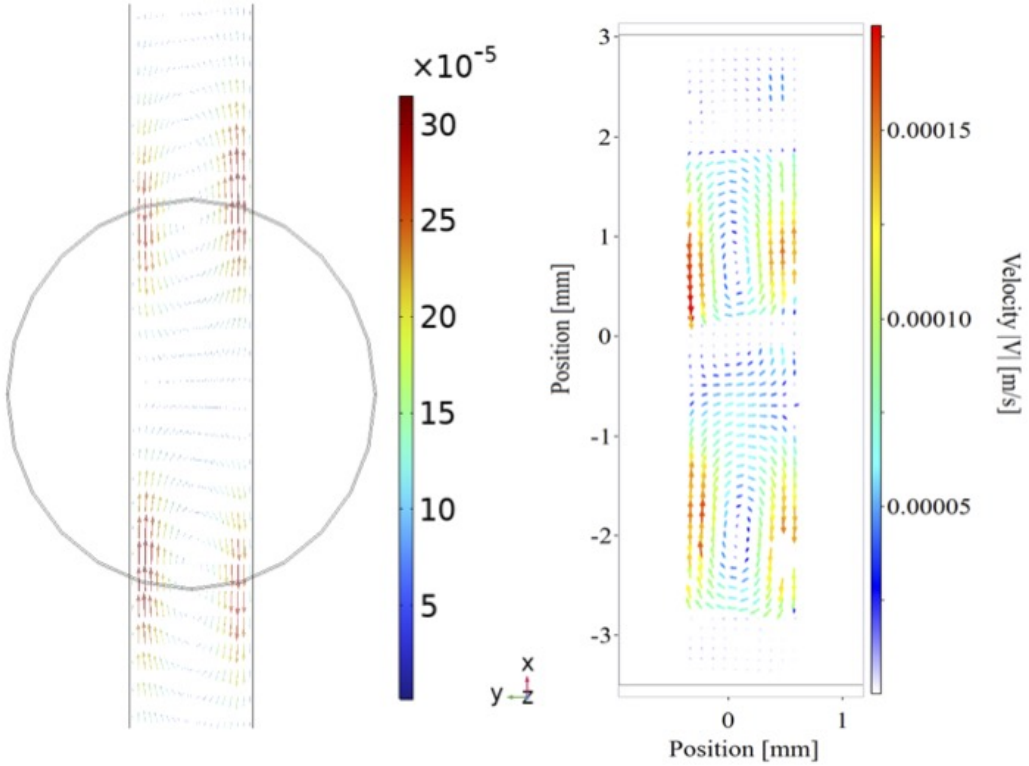

(b)

(a) Device to promote a magneto-electro-osmotic channel flow, (b) Velocity fields as obtained from numerical simulations (left) and from Particle Image Velocimetry (PIV) (right) under a voltage of 20 V, with a 3mm-sized cylindrical magnet located just beneath the microchannel.

#32 - Oral

Heat Transfer Enhancement Driven By Thermo-Electro-Hydrodynamics (TEHD): Influence Of The Marangoni Effect

EHD in liquids

Guillaume Braye[1], Laurent Davoust[1], Rachelle Hanna[1], Pedro Ángel Vazquez[2]

1. Grenoble-Alpes University, Saint Martin D'Hères, France
2. Universidade de Sevilla, Sevilla, Spain

Keywords: TEHD Torque, Vorticity, Cavity, Liquid Surface

Abstract Text
A dielectric liquid subjected to a temperature gradient and a non-uniform electric field experiences two body forces, along with an additional surface stress if a liquid surface is present. The first body force is the classical buoyancy force, driven by thermally-induced density gradients. When the temperature gradient is misaligned with Earth's gravity, a steady buoyancy-driven convective loop can form. The second body force arises from the non-uniform electric field and the temperature-dependent dielectric permittivity and electrical conductivity, both of which can be approximated as linear to first order. This thermoelectrohydrodynamic (TEHD) force exists independently of thermally-induced buoyancy, making it a promising mechanism for enhancing heat transfer under microgravity conditions.

Optimal tilting of the thermal gradient relative to the electric field direction generates a TEHD torque, resulting in counter-rotating vortex pairs within a differentially heated closed cavity[1,2]. In an open cavity with a liquid surface, temperature-dependent surface tension induces a Marangoni stress, which significantly alters the recirculating flows (see attached Figure).

This study explores the interplay between Marangoni stress and TEHD torque using numerical simulations. A dimensionless framework is proposed to identify key parameters for optimizing heat transfer, with particular attention given to the role of the electrical relaxation frequency.

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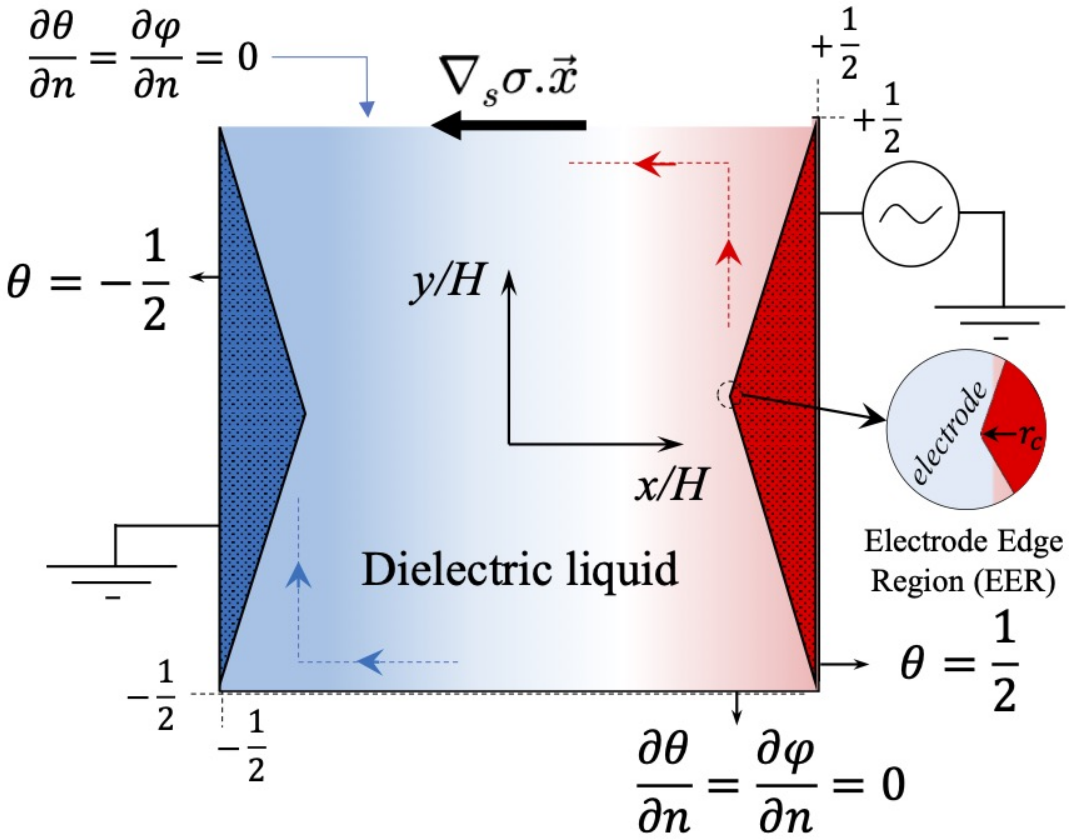


A differentially heated cavity with a liquid surface at the top, subjected to an imposed non-uniform electric field.

#33 - Oral

Numerical Modelling Of EHD Liquid-Vapour Flow Redistribution In Co-Axial Heat Exchangers

EHD of multi-phase flows

James Lemoine, James Cotton

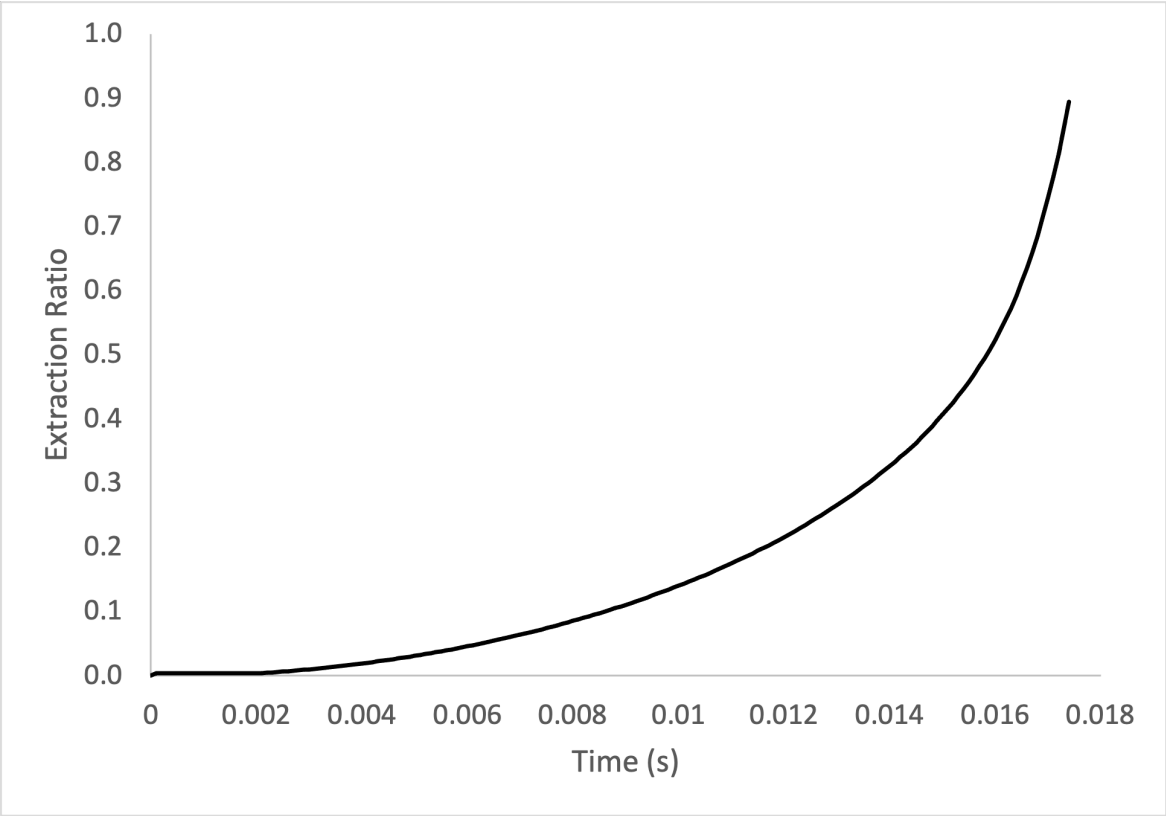
McMaster University, Hamilton, Canada

Keywords: Two-Phase, Liquid-Vapour, Numerical Modelling, Flow Redistribution

Abstract Text
Modelling two-phase liquid-vapour flows with electric fields offers insights into how electrohydrodynamic (EHD) forces influence flow redistributions. Robust numerical models are critical for designing novel electrode designs and increasing knowledge of EHD flow structures. When modelling two-phase fluids, interface tracking methods like the moving mesh model have an infinitesimal interface which helps to maintain surface tension and EHD forces. These forces are dependent on the gradient of the interface, therefore having a defined interface allows the forces to maintain their magnitude.

One of the common geometries that is used in EHD experiments is the coaxial heat exchanger. The two-phase fluid is in an annulus between a charged central electrode and a grounded pipe. When the fluid's void fraction is high and the fluid flow is a stratified regime, a sudden electric field is applied which pulls the liquid up to the electrode. This phenomenon is called liquid extraction. Previous studies have experimentally and numerically modelled liquid extraction but were unable to equate the time it takes the fluid to reach the electrode between the two while implementing EHD, surface tension, and gravity forces.

In this study, liquid extraction was modelled in COMSOL using the Moving Mesh two-phase model. The geometry and initial liquid level was set to model the experiment done by Sadek et al in 2008. EHD interfacial pressures were applied with gravity and surface tension forces. The liquid extraction timing was found and was compared to experimental timing seen previously by Sadek's group. With the exact geometry and all physics modelled, the experimental results were reevaluated with new information gained from the numerical model and it was seen that the timing for liquid extraction was consistent with the experiment.



Ratio of liquid extraction from initial liquid level to electrode height versus time

#34 - Oral

Observation And Simulation Of ElectroHydroDynamical Effects For Mass Transfer Study In Surface-Based Biosensing Applications

Particles and cells manipulation

Pauline Zimmer[1,2,3,4,5], Oleh Andreiev[1,2,3,4,5], Emmanuelle Laurenceau[1,2,3,6,5], Jean-François Bryche[7,8,9], Jean-Pierre Cloarec[1,2,3,6,5], Michael Canva[1,7,10,9], Marie Frénéa-Robin[1,2,3,6,4], Julien Marchalot[1,2,3,6,4]

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2. National Institute of Applied Sciences of Lyon, Villeurbanne, France
3. Claude Bernard University, Lyon 1, Villeurbanne, France
4. Ampere Laboratory, Ecully, France
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9. 3IT - Interdisciplinary Institute for Technological Innovation, Sherbrooke, Canada
10. Sherbrooke University, Sherbrooke, Canada

Keywords: Electro-Osmosis, Mass Transfer, Top-Bottom Electrodes, Surface-Based Biosensors

Abstract Text
Mass transfer can limit surface-based biosensors' performance, especially when detecting low-concentration species[1]. To overcome this limitation, Dielectrophoresis (DEP) and Alternating Current Electroosmosis (ACEO) are combined to enhance mass transfer, increasing target concentration near the sensor[2]. This study introduces a method for directly observing electrohydrodynamic (EHD) effects induced orthogonally to the electrodes, enabling real-time assessment of optimal parameters through vortex shape analysis and target tracking.
The experimental setup includes a comb-shaped electrode (100 µm wide with 200 µm gaps) and a flat counter-electrode separated by a 160 µm-high microfluidic chamber. The combined ACEO and DEP effects were visualized using 1 µm-diameter fluorescent latex microbeads as tracers, with images captured at 60 frames per second. The device's lateral view provided a comprehensive picture of vortex shapes, depletion areas, and capture zones on the electrodes.
The influence of electric field parameters—frequency, voltage, and solution conductivity— was studied on vortex formation and particle collection. Slip velocity measurements on microstructured electrodes were highest at a conductivity of 5 mS/m and increased with voltage. Aligning with previous studies using coplanar electrodes, the optimal frequency depended on conductivity[3], while higher conductivity reduced velocity.
Side observations enabled complete chamber visualization, allowing detailed vortex and target distribution tracking. This method, combined with image stacking, enabled the monitoring of depletion area and capture zones on electrodes. Combined with a custom COMSOL® model for the top-bottom electrode setup, this experimental approach offers a robust tool for understanding EHD phenomena and optimizing biosensor performance through targeted mass transfer enhancement.

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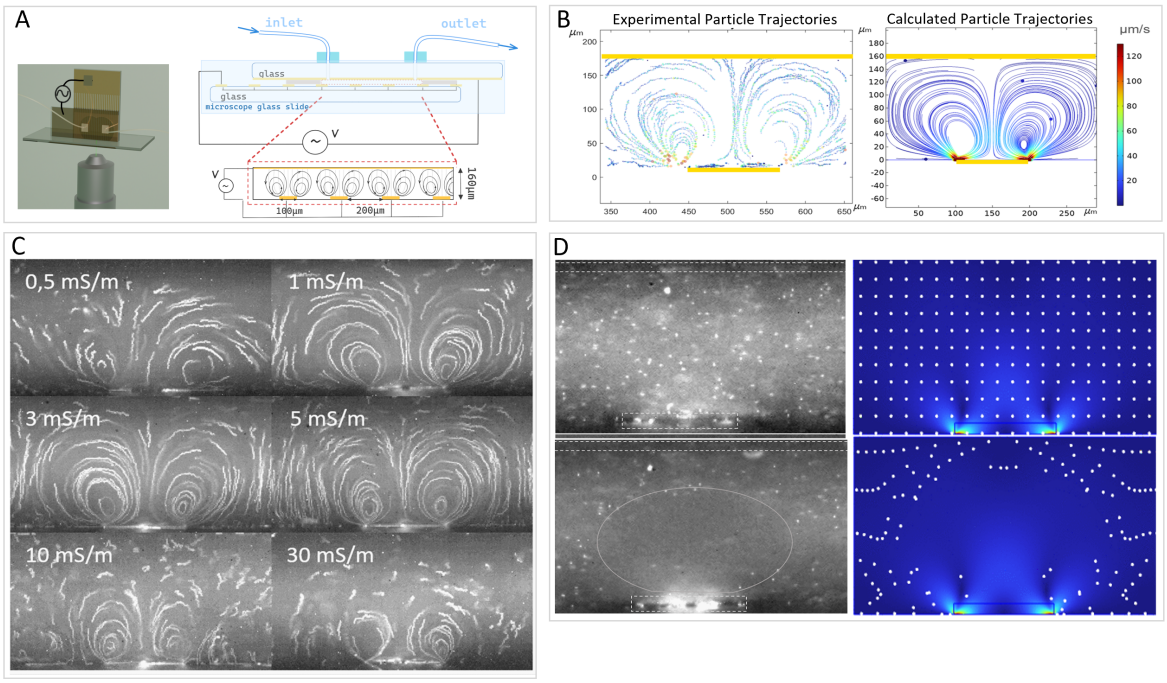
Acknowledgment:
This work was supported by the OBOPHICS project (ANR-22-CEO4-0015) operated by the French National Research.



(a) Device image and schematic cross-sectional view of the microfluidic chamber. (b) Experimental and simulated velocity maps obtained under a 6 Vpp, 1 kHz electric field in a 1 mS/m KCl buffer. (c) Vortex images at 6 Vpp and 1 kHz for various solution conductivities. (d) Experimental and simulated chamber images before and after applying the same electric field parameters and medium conductivity than b for 30 s.

#35 - Poster

Efficiency Of Static And Alternating Electric Fields For EHD Drying

EHD in gases

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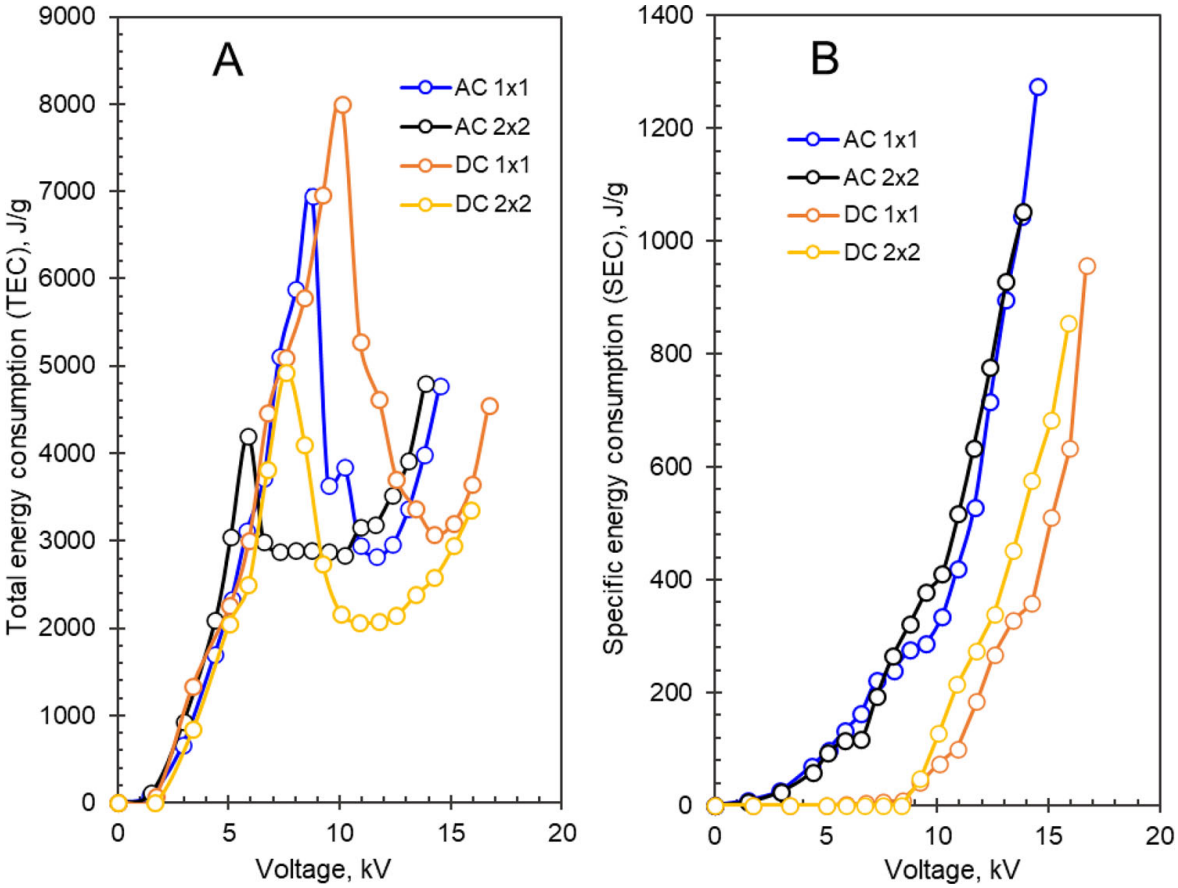
2. Ingenium Naturae Pvt Ltd, Gujarat, India

Keywords: High-Voltage, Discharge, Energy Efficiency, Drying Efficiency

Abstract Text
Electrohydrodynamic (EHD) drying is a non-thermal, scalable technology, suitable for drying heat-sensitive products. The efficiency of EHD drying with an alternating electric field of 60 Hz was compared with the effect of the static electric field. EHD drying of wet material was carried out using multi-pin electrodes with 1x1 or 2x2 cm spacing between pins and pins with 25o or 41o cone angle. Analysis of volt-ampere characteristics and drying kinetics revealed that the DC electric field is more efficient than AC due to the higher drying performance. However, specific energy consumption in the AC field is larger because of thermal effects in the air and material under drying. Measurements showed a significantly higher alternating current (up to 40 mA/m2) compared to direct current (about 1 mA/m2). We concluded that the higher energy efficiency of a static electric field is related to smaller currents and smaller heat dissipation losses in the air and material. At the same time, the heating of the material could be beneficial for water transport and evaporation.

From a practical standpoint, both AC and DC electric fields could be used for dewatering of wet material. At first glance, AC electric field is the preferable option for industrial settings, where AC power is readily available. On the other hand, DC power is the preferable option for rural communities, assuming the availability of solar or wind energy. In this context, it is important to compare not only specific but also total energy consumption (Figure 1). The exergy analysis could shed light on this issue. The identified gap in existing knowledge is the limiting factor in the scale-up of this drying technology for industrial and rural drying scenarios. The present work is the first step toward the quantitative evaluation of drying efficiency and energy consumption of EHD drying under comparable conditions.



Total (A) and specific (B) energy consumption in EHD drying in alternating and static fields

#36 - Oral

Characteristics Of Liquid Phase Continuous Arc Discharge Plasma

EHD in liquids

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Keywords: Liquid Phase Discharge, Gliding Arc Plasma, Discharge Characteristics

Abstract Text
Discharge plasma represents a novel approach to molecular activation, offering the potential to achieve higher energy density and active substance concentration under ambient temperature and pressure conditions. Especially in-liquid discharge significantly enhances reaction efficiency between plasma and liquid reactants, facilitating the realization of reactions that are challenging to be achieved with conventional chemistry. Gliding arc discharge plasma has garnered considerable attention due to its simple device, large processing volume, and high energy efficiency, with expectations of its scalability for industrial applications. Presently, gliding arc discharge occurs in the gaseous phase, which presents certain constraints in the treatment of liquid feedstocks. In this work, liquid phase continuous arc discharge plasma is realized, enabling the gliding arc discharge can be triggered directly in the liquid without carrier gas. The time-space, electrical, optical and active particle characteristics of the liquid phase continuous arc discharge plasma are investigated. The results demonstrate that the liquid phase continuous arc discharge plasma exhibits the property of continuous propagation, achieving a propagation distance of 1 m. The liquid phase continuous arc discharge plasma moves at speeds of up to 36.0 cm/s during propagation. The initiation of the plasma occurs in microbubbles due to Joule heating at the smallest point of the electrode gap. The generation of various activity particles (·OH, ·O, ·H, H2O2) is a continuous process during the plasma propagation. The work paves the way for potential applications of gliding arc discharge, offering new technological avenues for plasma technology in diverse fields, including water treatment, material synthesis and energy conversion.

#37 - Oral

Visualization Of Dust Removal Characteristics For Electrodynamic Dust Shields With Parallel Electrodes Under Martian Atmosphere

Particles and cells manipulation

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Harbin Institute of Technology, Harbin, China

Keywords: Electrodynamic Dust Shield, Martian Environment, Visualization

Abstract Text
The low-pressure and high-dust storm environment on Mars poses significant challenges to the normal operation of energy harvesting devices, such as solar panels, in future Martian missions. Traditional mechanical cleaning methods are difficult to implement under Martian conditions. Electrodynamic Dust Shield (EDS) technology, which requires no mechanical contact or water, has emerged as a promising non-contact dust removal solution. However, studies on the visualization of EDS performance and dust removal behavior under simulated Martian conditions remain limited, especially regarding the effects of parallel electrode configurations on dust removal mechanisms in low-pressure environments. In this study, an experimental system was developed to simulate the Martian atmosphere, enabling a detailed visualization of the dust removal characteristics of EDS with parallel electrodes. By employing a two-phase high-voltage rectangular AC power supply with a peak voltage range of 0–20 kV and a frequency range of 1–50 Hz, the dynamic behavior of dust particles on electrode surfaces was captured and quantitatively analyzed. High-resolution high-speed imaging techniques and image processing algorithms were used to visualize the trajectories, aggregation patterns, and removal efficiency of dust particles under electric field influence. The results revealed that key factors such as electrode spacing, width, and inclination angle significantly impact cleaning performance, with specific parameter combinations achieving notable improvements in dust removal efficiency under low-pressure conditions. This study provides a comprehensive dynamic visualization analysis of the dust removal characteristics of parallel electrode EDS under simulated Martian conditions. It offers theoretical insights and experimental support for optimizing electrode designs and enhancing the application of EDS technology in future deep-space missions. These findings contribute to the development of advanced dust mitigation technologies for energy harvesting devices in Martian and other extreme environments.

#38 - Oral

The Mechanism Of Ionic Self-Phoresis

Fundamental Electrohydrodynamics

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Keywords: Diffusiophoresis, Active Colloid, Electrolytes

Abstract Text
A chemically active particle induces solute gradients in a solution due to the catalytic reactions at its surface. Consequently, the particle experiences self-phoresis, usually interpreted as normal phoresis (linear response theory) but in a self-generated gradient. However, the recently proposed mechanism of correlation-induced diffusiophoresis for neutral solutes [1,2] represents a change in this paradigm, since the solute-solute interaction (responsible for the correlations) leads to an activity dependent particle response, i.e., beyond linear response.

We dicuss the extension of this conceptual framework to the case of an electrolyte solution (ionic self-phoresis) [3]. In addition to the usual contribution to the phoretic velocity associated to the particle zeta potential (i.e., to the double-layer at its surface), there arises an independent contribution that involves solely the chemical activity of the particle, so that self-phoresis is predicted even at a vanishing zeta potential. We also present, in this framework, results on the influence of a finite ion size [4].

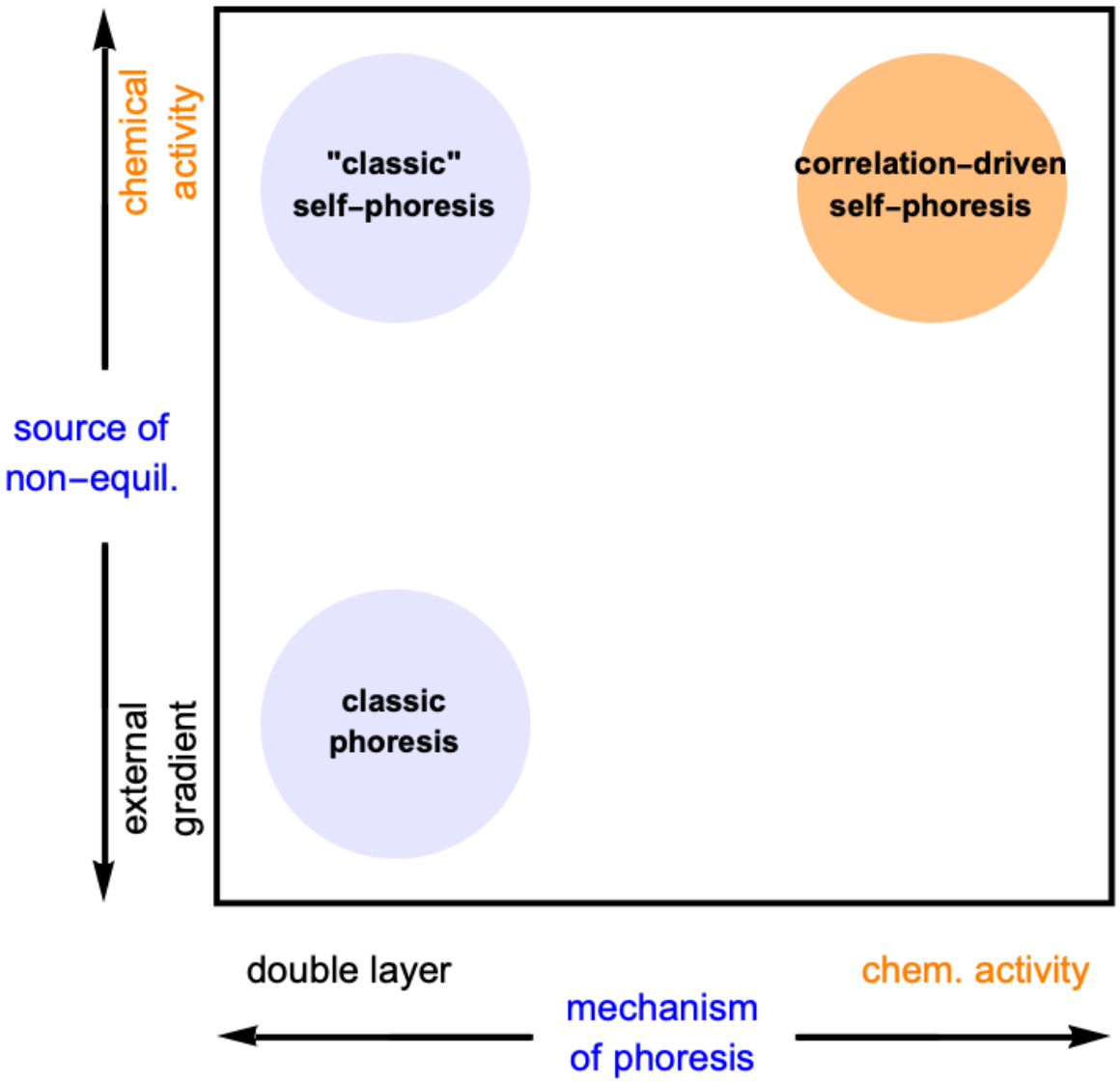
Overall, this extension provides a unifying perspective and opens up a connection with experimental investigations of ionic self-phoresis in order to address the rich variety of correlation-induced phoretic regimes predicted theoretically.

[1] A. Domínguez, M.N. Popescu, C.M. Rohwer, S. Dietrich, Physical Review Letters 125 (2020) 268002, https://doi.org/10.1103/PhysRevLett.125.268002

[2] A. Domínguez, M.N. Popescu, Current Opinion in Colloid & Interface Science 61 (2022) 101610, https://doi.org/10.1016/j.cocis.2022.101610

[3] A. Domínguez, M.N. Popescu, submitted, https://doi.org/10.48550/arXiv.2404.16435

[4] A. Domínguez, S. Kondrat, M.N. Popescu, in preparation.



The phoretic diagram that illustrates the different regimes of chemophoresis, depending on the source of concentration gradients (externally imposed vs. particle catalytic activity) and the mechanism which dominates the phoretic response (double layer vs. activity).

#39 - Oral

Large Eddy Simulation Of Turbulent Electro-Convection In Dielectric Liquids

EHD in liquids

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2. Union College, Schenectady, United States

Keywords: Electrohydrodynamics, Turbulence, Large Eddy Simulation, Dielectric Liquids

Abstract Text
Large eddy simulation (LES) serves as an important numerical approach for the investigation of turbulence, particularly in complex flow systems. Turbulent electroconvection (EC), though crucial for advancing our understanding of electrohydrodynamics (EHD), remains insufficiently studied in this field. This study utilizes LES within the finite volume method (FVM) framework to investigate EC turbulence induced by ion conduction in a cavity. The eddy-viscosity models are adopted to close the momentum equations, while the turbulent charge transport is captured using the turbulent Schmidt number. A comparison with direct numerical simulation (DNS) demonstrates that LES effectively captures the primary flow structures and dynamics of EC turbulence, showing good agreement with existing literature. The analysis reveals strong fluctuations and intermittency, with large-scale coherent structures significantly impacting charge transport and thermal plumes, ultimately influencing charge and heat transfer efficiency. This work deepens the understanding of EC turbulence and offers a foundation for exploring more complex EC turbulence mechanisms, with implications for energy and thermal management systems.

#40 - Oral

Plasma Catalytic Degradation Of Sulfamethoxazole In Water With Fe/Mn-LDO Catalyst

EHD in liquids

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1. School of Electrical Engineering, Dalian, China
2. Dalian University of Technology, Dalian, China
3. Research Unit Plasma Technology (RUPT), Department of Applied Physics, Ghent University, Gent, Belgium
4. School of Environmental Science and Technology, Dalian University of Technology, Dalian, China

Keywords: Plasma Catalysis, Layered Double Oxide, Reactive Oxygen Species,•OH Radical

Abstract Text
Dielectric barrier discharge (DBD) plasma can quickly degrade various recalcitrant organic compounds, but a complete mineralization of these compounds is difficult. Fe/Mn Layered metal oxide (Fe/Mn-LDO) was fabricated for enhancing the degradation of sulfamethoxazole (SMX) in a falling film plasma reactor. Mn0.5Fe0.5-LDO presented the best performance in promoting the degradation and mineralization of SMX compared to Mn-based catalyst, Fe-based catalyst, Mn0.75Fe0.25-LDO and Mn0.25Fe0.75-LDO. DBD treatment of 200 mL SMX solution with an initial concentration of 20 mg□L−1 obtained 51.8% SMX degradation efficiency in 15min at an energy consumption of 0.3W•h, while the presence of 1g/L Mn0.5Fe0.5-LDO in SMX solution promoted the SMX degradation efficiency to 100% at the same conditions. Moreover, 65.3% TOC was removed at a low energy consumption of 3.6 W•h. The characterizations of catalyst including XRD, FTIR, XPS, and reactive species measurement indicate that the positive role of Mn0.5Fe0.5-LDO catalyst in the degradation process of SMX is attributed to the catalytic conversion of ozone and hydrogen peroxide into •OH, and singlet oxygen, and the main catalytic active sites are Lewis acid and redox sites as well as oxygen vacancies. Three possible degradation pathways of SMX were preliminarily proposed according to nine detected intermediates, and their lower bioconcentration factors and reduced toxicity compared to SMX indicate that the proposed method in this study is an efficient pretreatment technology for conventional biochemical treatment of pharmaceutical wastewater.

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#41 - Oral

Numerical Simulation Of AC Electrified Jets In A Flow-Focusing Device

EHD of multi-phase flows

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2. Universidad de Sevilla, Sevilla, Spain

Keywords: Multiphase, Electrokinetics

Abstract Text
The application of electrohydrodynamics to the control of fluid flow in microfluidic devices is a very active and exciting field of research [1]. In this work, we explore the possibility of controlling the length of coflowing jets using AC electric fields. In [2], the authors present the results of applying an AC field in a microfluidic co-flowing device. The outer liquid focuses the inner liquid. For a given set of experimental conditions, the inner liquid breaks down into droplets near the entrance. When the inner phase is a conducting liquid (an aqueous solution), and the outer phase is a dielectric liquid, the application of an AC electric field induces a surface electric charge on the interface between the phases. The AC field acts upon this surface charge, stretching the jet. In this way, the AC field can be used to control the transition from the dripping to the jetting regime.

In this work, we present results of a numerical simulation of this problem. Numerical studies allow us to access physical magnitudes that are difficult or impossible to measure in the experiments. In particular, we are interested in the structure of the electric potential and field. We compare the results with experimental results, checking the dependence of the breaking length with the applied electric field via the electric Bond number BoE, and the frequency of the applied AC voltage. The figure below shows a comparison between the breaking length of the jet without and with an applied AC field. The color represents the value of the longitudinal component of the velocity.

[1] A. Ramos, ed., Electrokinetics and Electrohydrodynamics in Microsystems. Springer, 2011.
[2] Castro-Hernández, E., García-Sánchez, P., Alzaga-Gimeno, J., Tan, S. H., Baret, J. C., & Ramos, A. (2016). AC electrified jets in a flow-focusing device: Jet length scaling. Biomicrofluidics, 10(4). https://doi.org/10.1063/1.4954194

#42 - Oral

Problem Of Recombination Coefficient Specified By The Langevin Formula When Describing EHD Flows

EHD in liquids

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St. Petersburg State University, Saint Petersburg, Russia

Keywords: Electrohydrodynamics (EHD), Dissociation-Recombination Processes, EHD Pump, Recombination Coefficient

Abstract Text
When describing EHD flows, the recombination of ions is commonly characterized using the Langevin formula: $\alpha=e(b1+b2)/\varepsilon\varepsilon0$, where b1 and b2 are the mobilities of ions of different types.
In the present study, the limitations of this relationship are discussed, along with the necessity of its correction. This conclusion is based on a comparison of a current-voltage (I-U) and a flow-pressure (Q-P) characteristics obtained through experiment and numerical simulation for EHD systems.
The experimental systems include the "plane–six wires–plane" configuration and an EHD pump. The current-voltage characteristics are analyzed for systems of different geometries and for several dielectric liquids. Based on the coincidence of experimental and numerical current-voltage characteristics, the optimal recombination coefficient is determined. For all studied systems and liquids, the optimal value was found to be approximately 10 times smaller than that calculated using the Langevin formula.

#43 - Oral

NUMERICAL ANALYSIS OF THREE-DIMENSIONAL ELECTRO CONVECTION OF DIELECTRIC LIQUIDS IN A CUBICAL CAVITY

EHD in liquids

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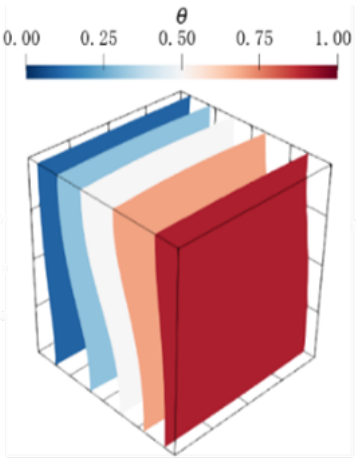
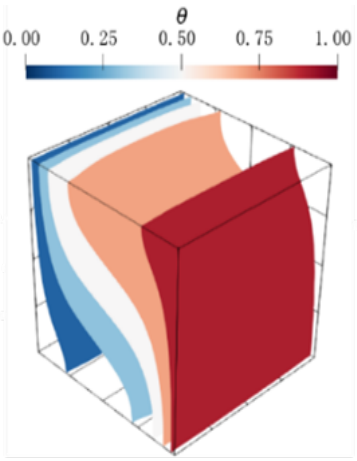
2. School of Energy Science and Engineering, Harbin, China

Keywords: Electrohydrodynamics, Electro-Thermo-Convection, Numerical Simulation, PIV

Abstract Text
In this study, we present numerical and experimental results of three-dimensional electro-thermo-convection of dielectric liquids in a cubical cavity. Specially, we consider the conduction mechanism for the generation of free charges. Two cases including heating from the bottom and the side wall are considered. Numerical simulations were performed with the open-source platform OpenFOAM. An experimental platform was designed, in which the PIV technique is used for velocity field measurement. We compared that the critical values with the onset of flow motion obtained by the numerical and experimental approaches. A discussion with the conduction model is presented. In addition, the heat transfer characteristics with electro-thermo-convection are discussed.



$Ra = 1 \times 10^3$ and $C_0 = 0.05$



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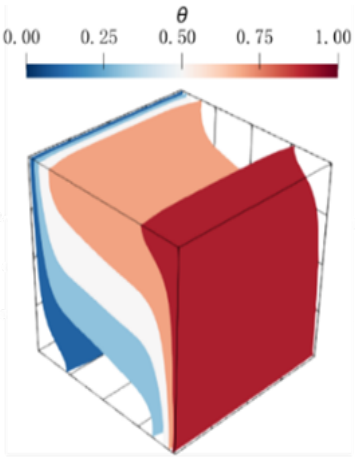

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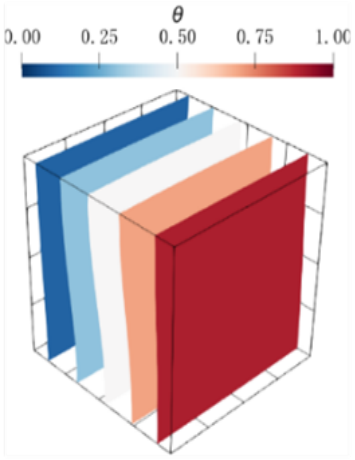

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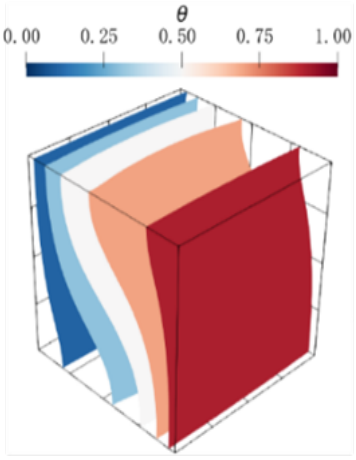

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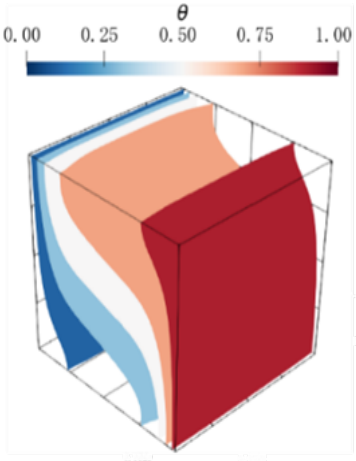

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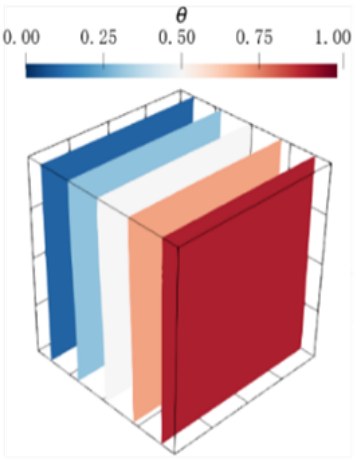

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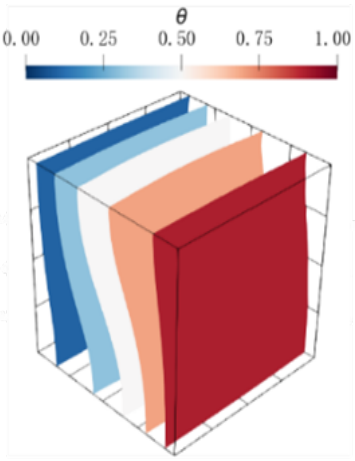

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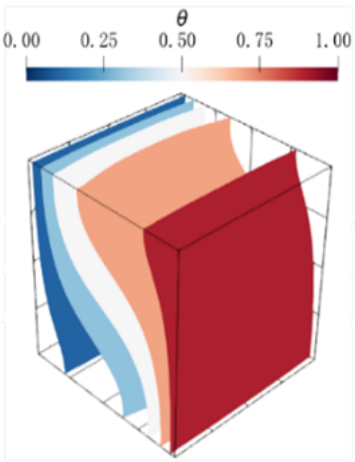

$Ra = 50 \times 10^3$ and $C_0 = 0.2$

Isothermal surface for different governing parameters

#44 - Poster

Experimental Investigation Of Relation Between Surface Charging And Ionic Wind In Facing Plasma Actuator

Fundamental Electrohydrodynamics

Yuki Ishii[1], Atsushi Komuro[2], Yutaka Kaneko[3], Shuji Otomo[1], Hiroyuki Nishida[1]

1. Tokyo University of Agriculture and Technology, Koganei City, Tokyo, Japan
2. National Institute of Advanced Industrial Science and Technology, Tsukuba City, Ibaraki, Japan
3. Institute of Fluid Science, Tohoku University, Sendai City, Miyagi, Japan

Keywords: Plasma Actuator, Dielectric Barrier Discharge, Pockels Effect

Abstract Text
Dielectric Barrier Discharge Plasma Actuator (DBD-PA) is a fluid control device consisting of only two electrodes separated by a dielectric. When an AC high voltage is applied between the electrodes, DBD-PA produces plasma and also produces electrohydrodynamic (EHD) forces that generate jets by momentum exchange between plasma particles and air particles. When a DBD-PA is installed with the jets vertical to the freestream, the two flow interfere with each other, creating a vortex that controls the flow. DBD-PA have advantages such as no mechanical moving parts, active control and quick response, so they are expected to be used for flow control.
Facing-PA, which has an additional AC electrode is known to be an effective method of controlling flow separation. The jets from the two AC electrodes collide and are deflected upwards, strengthening the vortex and improving the control of the fluid. In addition, it is known that Facing-PA can enhance discharges compared to general DBD-PA when the distance between AC electrodes is varied. This discharge enhancing mechanism is considered to be an increase in the electric charge on the dielectric surface compared to that of the conventional DBD-PA. However, no experimental investigation has yet been carried out, so this study aims to understand how electric charges affect Facing-PA discharge. To achieve this aim, we investigated the discharge extension length, flow field and surface charging of Facing-PA. These experiments were respectively carried out using direct camera imaging, the Particle Image Velocimetry (PIV) method and the Pockels measurement method.
From the discharge extension length and velocity field measurements, it was found that the discharge strength and momentum flow rate varied and peaked when the distance between the AC electrodes was varied. Moreover, the discharge extension length measurement confirmed the conditions for longer discharge in Facing-PA compared to general DBD-PA. The results of the potential distribution measurements confirmed a further charge accumulation and electrical field enhancement effects in the Facing-PA. This result suggests that, as expected, the strengthening of the electric field due to the accumulation of charge contributed to the enhanced discharge.

#45 - Poster

Design And Performance Of Swirling Flow-Based Electrostatic Precipitator

EHD of multi-phase flows

Kotaro Takamure[1], Taketo Haruki[2], Hiroshi Amano[2], Tetsuya Yagi[2], Tomohiro Degawa[2], Tomomi Uchiyama[2]

1. Akita University, Akita, Japan
2. Nagoya University, Nagoya, Japan

Keywords: Electrostatic Precipitator, Swirling Flow, Circular Pipe

Abstract Text
We developed a device to collect particles with significant inertial forces by combining Coulomb and centrifugal forces. A swirling flow and corona discharge from a sharp disk impart charges to particles, enabling their collection. Numerical simulations were conducted to analyze flow and particle behavior.
Figure 1 shows a schematic diagram of a cylindrical electrostatic precipitator. A slit nozzle generates a swirling flow inside the double cylindrical tube. A corona discharge, created by a disk installed inside the cylinder, imparts an electric charge to the particles, which are subsequently collected by the electrodes on the inner wall of the cylinder. The air flow rate was set to 0.75 m^3/min. A voltage of 16 kV was applied to the discharge wires and collecting electrodes in the corona discharge section, and a maximum current of 1 mA was discharged from the wires.
Figure 2 shows the positions of particles collected inside the device through numerical simulation, and Figure 3 depicts the velocity vector field of the device in the x-z section. The particle diameter was assumed to be 1 μm, representing a water particle, and the particles passing through the disk were given a charge of 2.7×10^{-16} C. The slit nozzle imparted a swirling motion to the particles, which were charged immediately after passing through the disk in the cylindrical tube. It was evident that the particles, after being charged, were effectively collected on the wall surface. The particle collection rate was 99.6%.

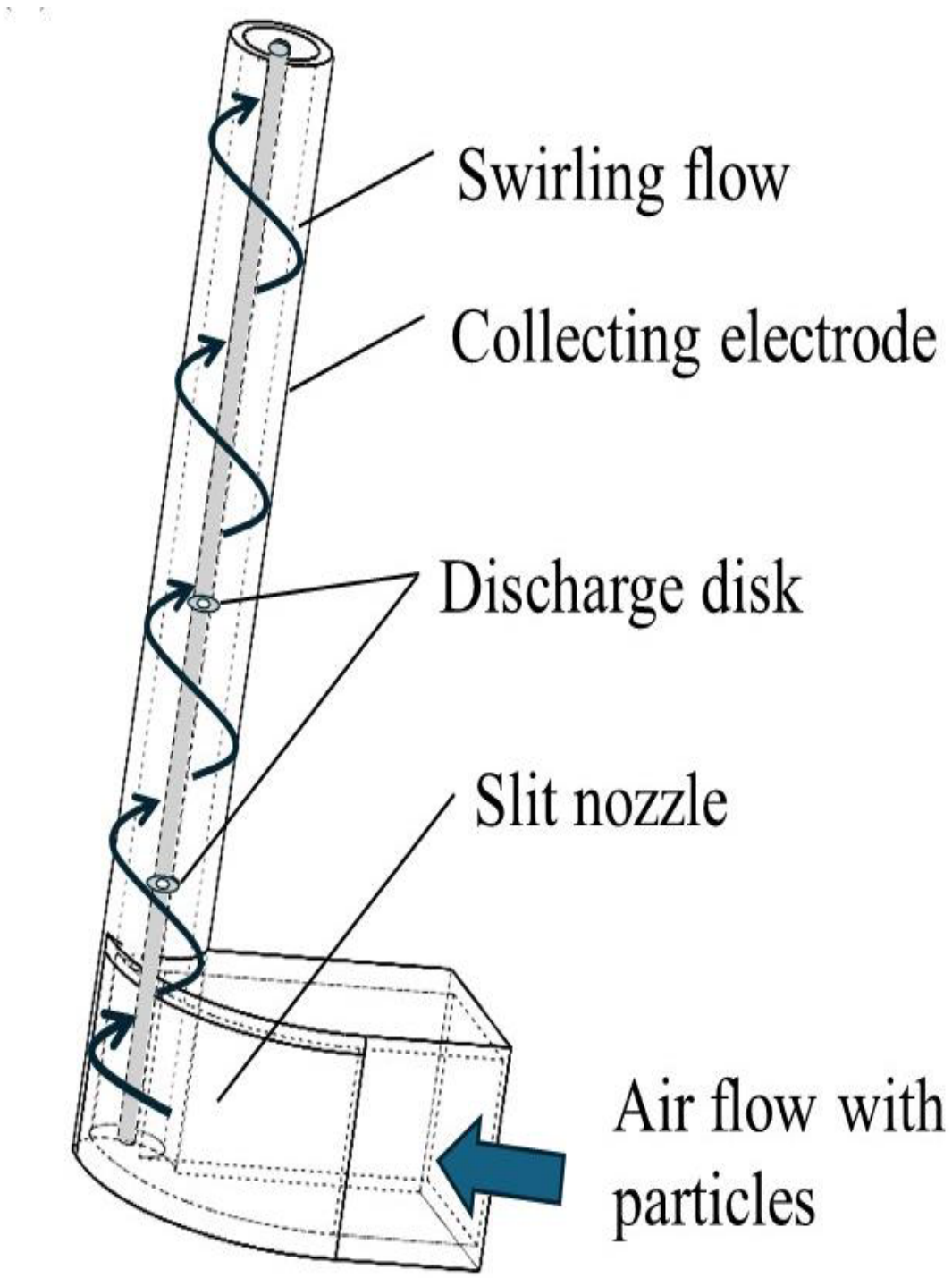

Fig. 1 Schematic of the electrostatic precipitator

#46 - Oral

Molecular Dynamics Simulation On The Collision Of Ionic Liquid Nanodroplets With Surfaces In An Electrospray Environment

EHD in liquids

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Advanced Space Propulsion and Energy Laboratory (ASPEL), School of Astronautics, Beihang University, Beijing, China

Keywords: Electrospray, Ionic Liquid, Droplet Impact, Molecular Dynamics Simulation

Abstract Text
The droplets emitted by electrospray are small in size, high in velocity, carry charges, and travel in an electric field, which makes the collision scenario between droplets and surfaces in the electrospray environment significantly different from that of general droplet collisions. The collision mechanism in such a complex environment is not yet fully understood. The collision between electrosprayed droplets and surfaces is an essential physical process in various applications of electrospray, such as electrospray propulsion, inkjet printing, and electrostatic spray deposition (ESD). Therefore, this study conducts simulations of the collision of nanodroplets in different electric fields and charge conditions, using ionic liquids, which are commonly used as working fluids in electrospray propulsion.
The results show that when the collision velocity is below the splashing threshold, the droplet completely deposits on the surface. However, in high-velocity collisions, the droplet completely shatters, dissociating into cations and anions, resulting in significant splashing, as shown in Figure 1 (a). In this case, the deposition characteristics of the collision are influenced by the oscillation between cations and anions and the applied electric field. When the applied electric field is weak, the oscillation between ions causes cations to deposit more easily, so that neutral droplets deposit a small amount of positive charge after collision. Only negatively charged droplets may deposit a neutral charge, as shown in Figure 1 (b). When the applied electric field is strong, the electric field separates the cations and anions, causing an imbalance in their quantities on the surface, resulting in the deposition of a large amount of charge. The amount of deposited charge is positively correlated with the electric field strength, as shown in Figure 1 (c). This study may contribute to a better understanding of the droplet-wall collision process in electrospray propulsion or deposition.

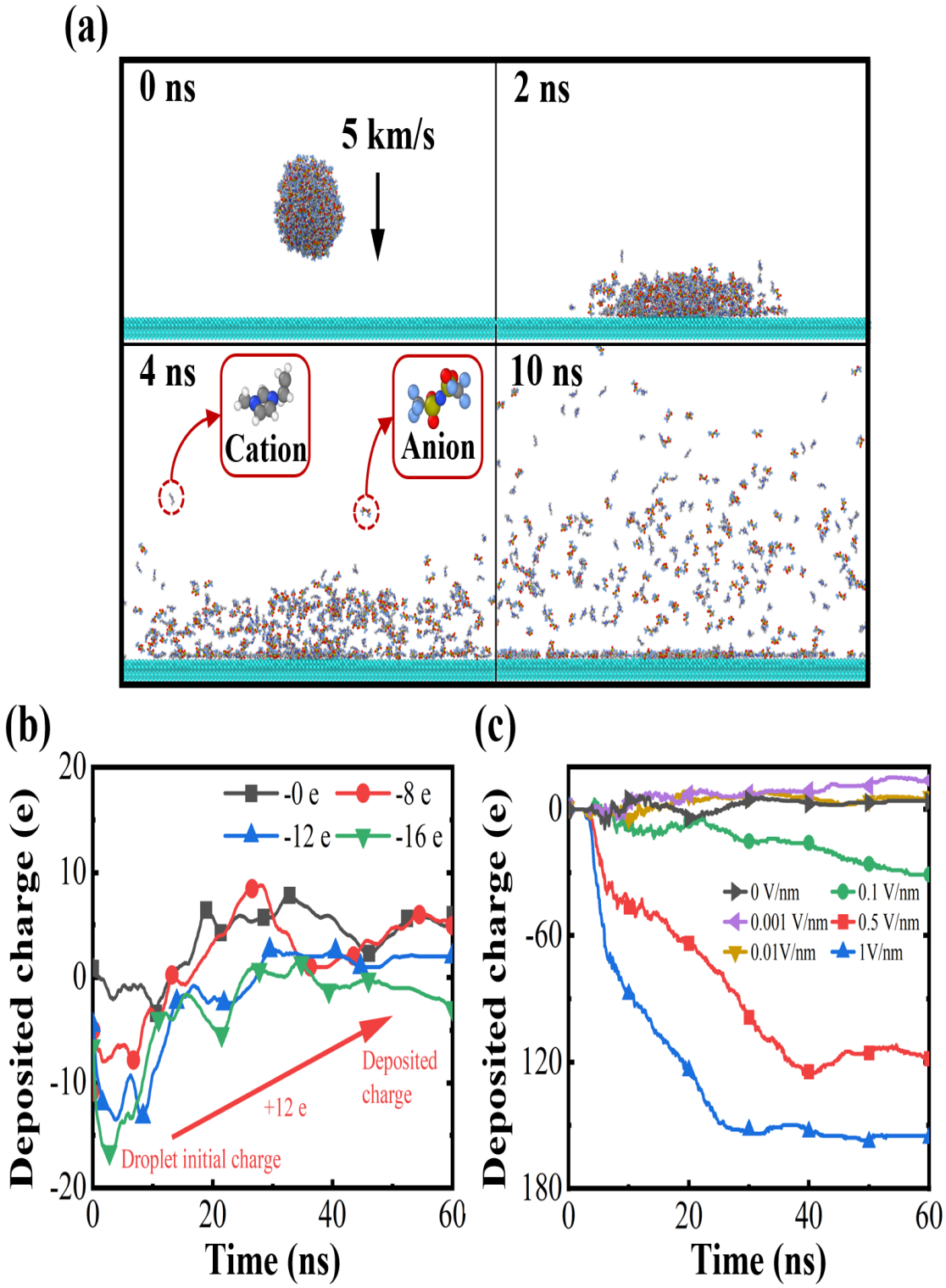


Figure 1 (a) Snapshots of high-speed droplet collision; (b) Charge deposition on the surface after collision of droplets with different charge levels; (c) Charge deposition on the surface after collision of neutral droplets at different electric field strengths.

#47 - Oral

Oscillatory Behavior Of Electrospray Under Periodic Electric Fields

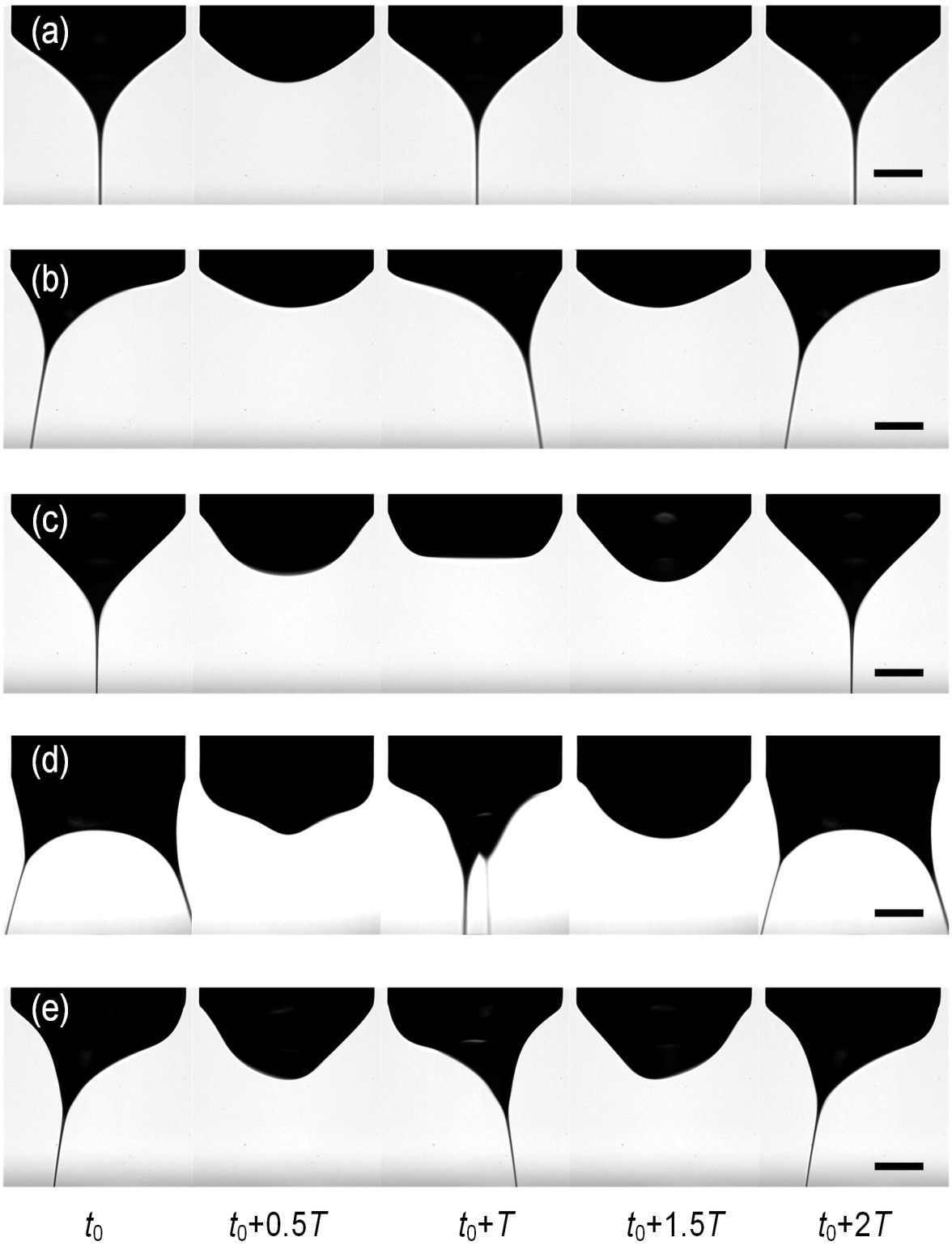
EHD in liquids

Qiyou Liu, Bingqiang Ji, Qingfei Fu, Lijun Yang

Beihang University, Beijing, China

Keywords: Electrospray, Oscillatory Behavior, Alternating Electric Field

Abstract Text
Electrospray has been widely used in various areas, especially in drop-on-demand techniques including electrohydrodynamic printing, nanomaterial production, and drug delivery, due to its ability to produce fine uniform droplets. The oscillating electric fields are adopted for additional control over EHD jetting behavior. This study focuses on an experimental investigation, systematically examining the oscillatory behavior of electrospray under alternating voltage electric field excitation. Using a high-speed camera, the pulsating modes of the electrospray were recorded under the influence of a continuous sinusoidal voltage waveform. The responses of different oscillation modes and their geometric characteristics to various disturbance parameters were analyzed and comprehensively discussed. The research identified five distinct oscillation modes of the electrospray under sinusoidal voltage excitation. The dynamic characteristics of each mode were explored, and phase diagrams of all five modes were constructed by dimensionless parameterization of the relevant variables.



Typical electrospray oscillation modes observed in experiments

#48 - Poster

Experimental Investigation Of The Influence Of Electrode Spacing On The Intensity Of Electric Wind

EHD in gases

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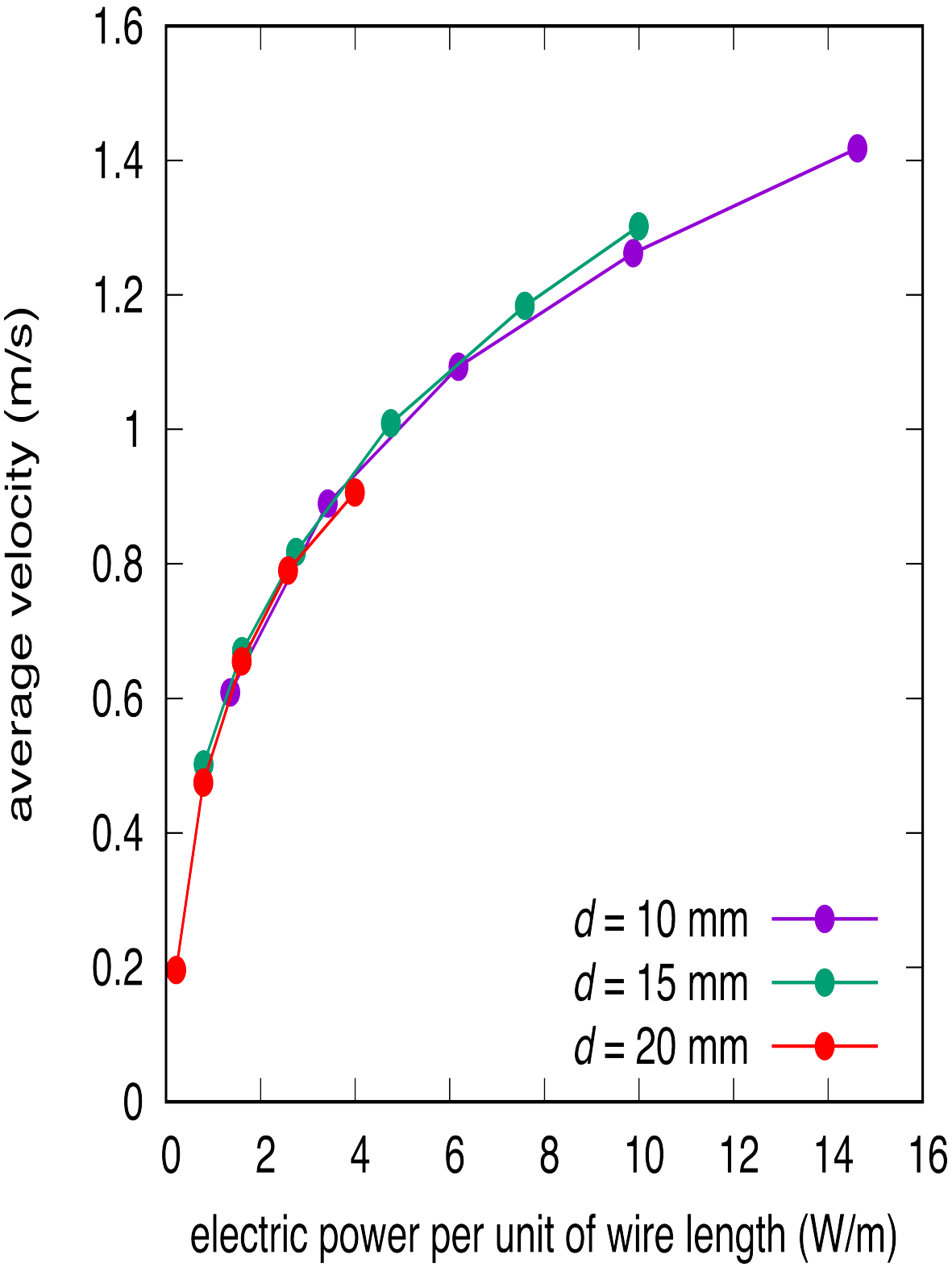
Keywords: Electric Wind, Ionic Wind, Corona Discharge

Abstract Text
Electrical discharges in gases are often accompanied by the generation of fluid motion, which is called electric wind or ionic wind. In particular, corona discharge has long been known to be an important source of electric wind, and there is currently growing interest in its possible applications in a wide range of technologies, such as in heat exchangers, EHD drying, fluid pumping, ion thrusters, etc. [1]

The electric wind intensity is affected by many different parameters, including the corona polarity, the applied voltage, the current intensity or the electrode configuration. This study will focus on the effect of electrode spacing on the intensity of the electric wind generated by a positive corona discharge. The corona wind reactor consisted of a prismatic duct, 10 cm wide, 1 cm high, and 24 cm long, open at both ends. The lower and upper plates of the duct were made of PTFE, while the lateral walls were made of PMMA. The corona electrode was a 10 cm long tungsten wire, 0.1 mm in diameter, situated between the two PTFE plates. The distance between the duct entrance and the corona wire was 6.3 cm. Two stainless steel rods, 1.45 mm in diameter, acted as ion collectors. These rods were arranged parallel to the wire and in contact with the PTFE plates. The distance along the channel between the wire and the rods was fixed at d = 1 cm, 1.5 cm, and 2 cm. Finally, the intensity of the electric wind was measured at the exit of the channel using a thermal anemometer with a hot ball probe (Ø 3 mm). The experimental results showed that the air velocity profile at the channel exit was approximately uniform, except near the boundaries, as may be expected from turbulent flow. Velocities above 1.5 m/s were recorded during the experiments, and the electric power per unit of wire length was found to be the relevant parameter to characterize the mean velocity at the exit of the reactor.

[1] E. D. Fylladitakis, M. P. Theodoridis, and A. X. Moronis. IEEE Transactions on Plasma Science, vol. 42, pp. 358-375, 2014.



Average velocity at the exit of the corona wind reactor as a function of the electric power per unit of wire length, for different distances between the corona wire and the collector electrodes.

#49 - Oral

Investigation Of Underwater Discharge Phenomena And Shock Wave Regulation

Electrostatics

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Insitute of Fluid Science, Tohoku University, Sendai, Japan

Keywords: Plasma, High-Speed Imaging, Numerical Modeling, Discharge Regulation

Abstract Text
Underwater discharge phenomena exhibit significant variability depending on experimental conditions such as voltage amplitude, polarity, liquid properties, current density, and pulse duration. Compared to microsecond pulsed discharges with low current density, high current density discharges (as studied in this work) display discharge characteristics that vary strongly with voltage polarity. These variations are manifested in mode changes in the discharge morphologies and propagation velocities. Understanding the factors influencing discharge characteristics, particularly the mode transitions, offers opportunities to modify energy conversion in the discharges. This study explores methods to regulate the shapes of discharge channels and the profiles of shock waves, aiming to enhance energy efficiency. To achieve this, discharge current interception experiments were designed and executed using a novel experimental setup. This setup delivers a microsecond pulsed discharge current with a relatively slow rise time, enabling precise control for the current through the water gap. By extinguishing the current at specific times, the shock wave generation processes were systematically studied both experimentally and numerically. The results reveal that only the initial stage of the discharge (approximately 5 μs in the studied cases) significantly contributes to shock wave intensity. These findings suggest potential methods for optimizing energy efficiency, which could be developed based on the insights gained from this study.

#50 - Oral

Investigation Of The Influence Ionic Liquid Electrospray Emission Processes In Hybrid Emitters Under Rapid Electric Field Variation

EHD in liquids

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Keywords: Electrospray Thruster, Ionic Liquid, Electric Field Variation

Abstract Text
Ionic liquid electrospray thrusters exhibit high specific impulse, low energy consumption, and are conducive to miniaturization, making them highly promising for attitude and orbital control of micro- and nanosatellites. Compared to conventional electrospray thrusters, hybrid emitter ionic liquid electrospray thrusters provide an extended range of thrust-to-specific impulse adjustability, enhancing their adaptability to a more diverse array of application scenarios. This study investigates the dynamic effects of rapidly varying electric fields, caused by alternating voltage polarity, on the emission process of hybrid emitters. Experimental results reveal that under rapidly varying electric fields, ionic liquid electrospray emits a large number of charged droplets in a short time, a phenomenon consistent with findings from capillary emitters. However, due to the intermediate electrode structure in composite emitters, subsequent ionic liquid emission exhibits significant differences, closely related to the charge characteristics of the emitted particles. In summary, while the direct influence of rapidly varying electric fields on the beam of composite emitter ionic liquid electrospray is evident, quantitative analysis remains lacking. Moreover, the correlation between the evolution of electrospray under rapidly varying electric fields and critical parameters, including flow rate and extraction voltage, remains insufficiently understood, necessitating further in-depth investigation.

#51 - Poster

Hydrophilic Treatment Of Graphite By Using Controlled Plasma-Induced Liquid Flow

Others

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Keywords: Atmospheric-Pressure Plasma, Plasma-Induced Liquid Flow, Hydrophilic Treatment, Graphite

Abstract Text
Last year, we successfully switched control of plasma-induced liquid flow.[1] While trying to elucidate the mechanism of plasma-induced liquid flows, we have come up with new ideas for its application. Graphite, with its excellent electrical conductivity, thermal conductivity, and high mechanical strength, is expected to be applied in areas such as reaction sites for fuel cell catalyst supports and conductive inks. However, graphite is hydrophobic, making it difficult to use in water or organic solvents, and therefore, it requires hydrophilization treatment. Currently, the most used method is chemical oxidation. This method, however, involves the use of strong oxidizing agents such as sulfuric acid and potassium permanganate, which leads to issues such as degradation in quality and a significant environmental impact. To solve these problems, a modification method using plasma has gained attention.[2] This approach is expected to enable high-quality hydrophilization with low environmental impact. In this study, we proposed a method to hydrophilize graphite using plasma-induced liquid flow. In the hydrophilization treatment of graphite using plasma-induced liquid flow, we considered that efficient hydrophilization of graphite could be achieved by utilizing the property of hydrophobic graphite to gather on the water surface and by controlled plasma-induced liquid flow. [3]

References
[1] Toshiyuki Kawasaki et.al.: Jpn. J. Appl. Phys. RC, 62, 060904 (2023).
[2] Seiko Uchino et.al.: Jpn. J. Appl. Phys. 53, 01AD05 (2014).
[3] Kecheng Shen et.al.: IEEE TPS. PP (99): 1-7 (2024).

#52 - Oral

Numerical Simulation Of Electrodeformation Of A Droplet Immersed In Oil Under The Influence Of An Alternating High-Frequency Electric Field

EHD of multi-phase flows

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St. Petersburg State University, Saint Petersburg, Russia

Keywords: Electrohydrodynamics, Computation, Comsol, Unsteady-State

Abstract Text
The investigation considers the problem of electrohydrodynamics of two-phase immiscible liquids. An example of this is the deformation of a conducting droplet suspended in a dielectric dispersion medium under the influence of an alternating high frequency electric field. Numerous experiments have been conducted on the electrodeformation of such droplets in a volume with electrodes under alternating electric voltage, resulting in various outcomes, such as the flattening of the droplet along the axis parallel to the electrodes and the stretching along the axis perpendicular to the electrodes. However, verified numerical models have not yet been developed for the electrodynamics of a droplet under high-frequency fields when a droplet surface fails to charge completely during one voltage cycle.
The article examines numerically the case of electrodeformation of a single droplet. Previously, steady-state numerical models were frequently employed due to the complicatedness of computing the unsteady-state ones in tasks with steep changes in liquid properties and moving interface line. This work presents a description of the mathematical expressions utilized for accurately calculating the accumulation of electric charge on the droplet surface, while also taking into account the characteristics of the moving geometry. Numerical simulations are performed using COMSOL Multiphysics software and are based on the arbitrary Lagrangian–Eulerian method.
The case of an alternating electric field is analyzed, resulting in various outcomes of electrodeformations that align with experimental data. As a result of this work, a validated numerical model for calculating unsteady-state current passage problems, considering the moving geometry, has been developed. The simulation technique can be applied for modeling electrical coalescence and other electrohydrodynamics two-phase problems under an alternating high frequency electric field.

#53 - Oral

Numerical Investigation Of Two-Dimensional Electro-Thermo-Hydrodynamic Turbulence: Energy Budget And Scaling Law Analysis

Fundamental Electrohydrodynamics

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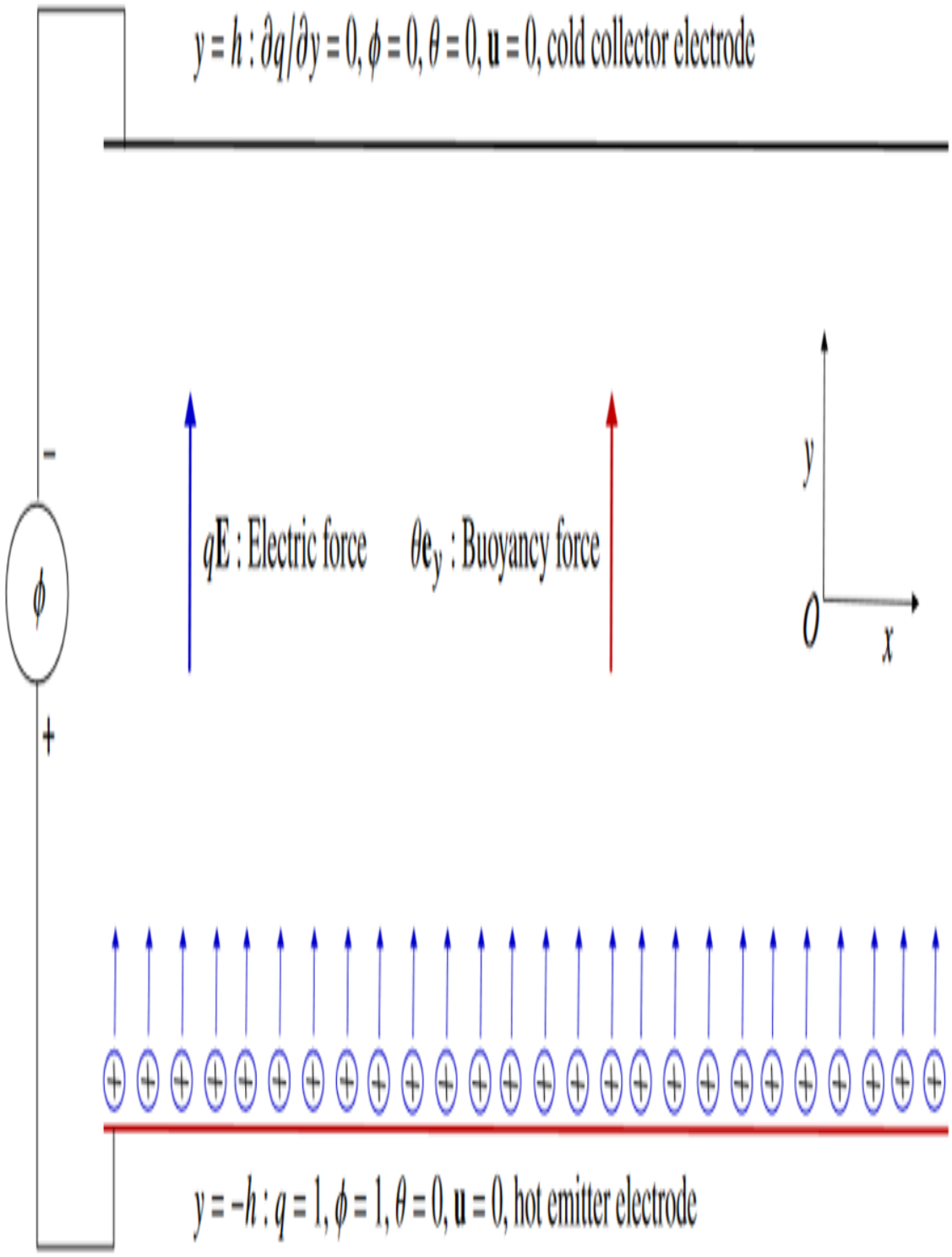
Keywords: Electro-Thermo-Hydrodynamic Turbulence, Energy Budget, Scaling Law Analysis

Abstract Text
In fluid systems involving heat and mass transfers, convection is a fundamental phenomenon where the large-scale motion of a fluid is driven, for example, by a thermal gradient and an electric field. When the driving forces are large, the fluid system exhibits a chaotic behavior and even develops into turbulence. Modeling convection has led to developing turbulence theory and energetic analysis for multi-physics systems. However, most previous works have been limited to relatively simple thermal convection phenomena driven solely by buoyancy force. In this work, we formulate the energetic relation of the turbulent electro-thermo-hydrodynamic (ETHD) convection and develop a two-dimensional (2D) spectral solver for numerical analysis of ETHD turbulence for a variety of driving parameters (forces). From the numerical analysis, we find a modified scaling behavior of heat transfer by the electric force and discover a new scaling behavior of the portion of kinetic energy contributed by buoyancy force as a function of a dimensionless forcing ratio. Finally, we show that the energy budget in the boundary layer of the 2D ETHD turbulence follows the scaling law previously found for the traditional 2D Rayleigh-B\'{e}nard Convection. This work marks the first step in the energy budget and scaling law analysis of ETHD systems and significantly improves our understanding of turbulent convection driven by both thermal and electric forces.



Physical model and boundary conditions of ETHD convection in a planar layer of dielectric liquid. The external forces (electric and buoyancy forces) interact with the viscous and inertial forces of the dielectric fluid, inducing convection flows after an initial perturbation. In the current configuration, the buoyancy force cooperates with the electric force to destabilize the flow.

#54 - Oral

Generation Of Micro-Discharge Plasma In A Pore: Effect Of The Pulse Voltage Characteristics

EHD in gases

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Keywords: Dielectric Barrier Discharge, Porous Material, Micro-Discharge, Pulse Parameters

Abstract Text
Porous catalysts have important applications in plasma catalysis processes for nitrogen fixation, chemical synthesis, environmental pollutant treatment, and others. Understanding the generation mechanism of micro-discharges in the pores is crucial for designing the catalysts suitable for plasma catalysis processes. In this research, the effect of micropores on the characteristics of nanosecond pulse dielectric barrier discharge plasma under different pulse parameters is simulated. A two-dimensional fluid model was established to simulate the micro-discharge characteristics in a pore at atmospheric pressure, mainly focusing on the effect of pulse voltage parameters, including voltage amplitude, pulse rise time, pulse width and pulse polarity. The results combined one-dimensional line graph and two-dimensional graph show that the pulse polarity significantly affects micro discharge. When the negative pulse voltage is applied, the existence of the pore has little effect on the electronic temperature, electric field and other parameters in the pore. However, applying positive pulse voltage on the dielectric results in higher gas ionization rate and total ion density, and electron density as well as electron temperature are higher, which can promote the formation of micro-discharges in the pore. In addition, high pulse voltage amplitude is more likely to produce micro discharge in a pore, while pulse rising edge time and pulse width mainly affect electron density and electron energy. With the rise time shortening, the electron density increases significantly, but the electron temperature rises slightly. Moreover, the shorter the pulse width, the higher the electron temperature and electron energy. Higher pulse voltage, shorter pulse rise time and narrower pulse width can result in stronger electric field in and near the pore, benefiting the generation of micro-discharge in a pore. The favorable factors for the formation of discharge in micropores are obtained, which provides theoretical support for the design of discharge structure in experimental research.

#55 - Oral

Visualization Of Electrohydrodynamic Convection Cells In A Phase Change Material Using Schlirien Imagery

EHD of multi-phase flows

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Keywords: Schlirien, Phase Change Material, Visualization, Heat Transfer

Abstract Text
An experiment was designed to assess the potential of schlieren imagery for visualizing EHD induced convection cells in the liquid phase of a PCM (Phase Change Material). The motivation behind using this new methodology has been to avoid the potential error from seeding particle charging when using PIV (Particle Image Velocimetry).
In PIV if the employed seeding particles have a different electrical permittivity to the working fluid, they can accumulate charge on their surface. This will lead to an additional coulomb force on the seeding particles which could be a significant source of error in the velocity measurement of the fluid. In this work, we use schlieren imagery to visualize EHD induced convection cells in the liquid phase of a PCM in a differentially heated macrocapsule. The methodology is totally non- intrusive, and does not require joule heating to create the density gradients necessary for visualization. Instead, density gradients are created by differentially heating the macrocapsule. The advection of temperature gradients (density gradients) in the working fluid are recorded through a Z type schlieren system with a DSLR. Using a customized optical flow measurement code, the videos are converted into velocity field measurements. EHD induced jet velocities of 18mm/s are recorded with a 99.7% confidence interval of +/- 1.6mm/s.

#56 - Oral

Coupling Characteristics Of Shock Waves Induced By Nanosecond Pulse Tri-Electrode Dual-Spark SDBD And Plasma Diagnostics

EHD in gases

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Dalian university of technology, Dalian, China

Keywords: Spark,Shock Wave, Pulsed Discharge,SDBD

Abstract Text
A three-electrode dual-spark discharge structure is introduced in this work, primarily focusing on the formation process of double sparks and the coupling characteristics of the induced shock waves. The characteristics in different discharge stages and the discharge mode transition are investigated using both electrical and optical diagnostics. Based on the spatiotemporal evolution of the discharge captured by an ICCD camera, it is observed that the discharge process under high voltage can be divided into two distinct stages: the streamer stage and the spark stage. Moreover, the simultaneous discharge of two sparks can be realized. This is because pre-position two symmetrical tips in this reactor could induce a large accumulation of charge. And this configuration strengthens the localized electric field under the same power supply excitation, thereby facilitating the stable, simultaneous discharge of two sparks. Concurrently, two pressure waves generated simultaneously produce a cumulative pressure effect. According to schlieren imaging, the coupled intensity can be increased by as much as 72.7%. Additionally, the spatiotemporal evolution of aerodynamic performance induced by repetitive pulsed spark discharge is examined through schlieren imaging system. The results indicate that the velocity of the shock wave leaving the surface is approximately 500 m/s. After the shock wave moves away from the dielectric, a mushroom-cloud-like airflow disturbance is observed. With increasing pulse counts, this disturbance continues to propagate upward due to heat accumulation. In addition, to characterize the effect of impact force on the surface of dielectric, a position detector is integrated with a measurement platform to convert the impulse into the underdamped vibration of a thin plate. The impulse is then converted into an electrical signal by the detector, and the target impulse is calculated through function fitting. The device features a simple structure, low cost, high sensitivity, and promising application prospects.

#57 - Poster

Enhanced Hydrogen Production Through Plasma Methane Decomposition With Soot

Others

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Keywords: Hydrogen, Discharge, Soot, Methane

Abstract Text
The development of inexpensive hydrogen generation methods is required to realize a hydrogen society. Hydrogen production by methane decomposition has been attracting attention in recent years because the enthalpy required is lower than that of water electrolysis. In particular, methane decomposition using non-thermal plasma has excellent start-up and shutdown characteristics, making it suitable for the use of electricity derived from renewable energy sources, but its decomposition efficiency has not been very high. In this study, we attempted to increase the efficiency of methane decomposition in plasma to obtain hydrogen by adding soot to the discharge field in methane. Soot not only reacts with acetylene, an intermediate product of methane decomposition, to produce hydrogen, but also decomposes methane due to its catalytic action. In the experiment, the discharge frequency and the amount of hydrogen produced were compared along with spectral measurements. The results showed that the formation of a discharge in a gas in which the influence of the previous discharge remains improves the hydrogen production efficiency. This is thought to be due to the influence of soot formed in the previous discharge. On the other hand, attempts to actively coexist soot in the discharge field have the problem that the soot short-circuits between the electrodes, making it difficult to continue the decomposition process. The short-circuit behavior of soot and the current countermeasures are also discussed.

#58 - Poster

Droplet–Particle Collection Efficiencies In Stokes' Regime

Fundamental Electrohydrodynamics

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Keywords: Collection Efficiency, Coulomb Force, Dipolar Firce, Stokes Regime

Abstract Text
From the perspective of human health, weather, and climate, air pollution in both indoor and outdoor areas is a major cause of worry. The relevant component in the ambient atmosphere in this context, is considered to be particulate matter, specifically in the form of aerosols. The origin of these particulate matters are construction sites, unpaved roads, smokestacks or fires. Particle pollution includes PM10 (particle size is 10 μms and smaller) and PM2.5 (particle size is 2.5 μm and smaller). To lower the concentration of particulate matter, a number of mitigation solutions are frequently used in indoor areas and industries. These technologies typically include (i) electrostatic precipitators, (ii) high-efficiency particulate air (HEPA) filters, and (iii) wet scrubbers and sprays for scavenging pollutants using charged or uncharged droplets.

The present Numerical Simulations, presented here, involve solving the equations of motion of an inertialess Particle for its trajectory that is scavenged on the Collector in Stokes' Regime. We present a model considering the following Electrostatic forces acting: i) the Coulombic force between a charged particle and a charged collector, ii) the Dipolar Force acting between an Uncharged Particle and a Charged Collector. We investigate the Collection Efficiency of particles onto the collector by investigating the Limiting Trajectory, using the Trajectory Method. These Efficiency curves harmonize with Analytical Solutions (Considering Non-stokesian Flow) for particle sizes greater than the collector size. The Coulombic attractive force is dominant for smaller particle sizes.

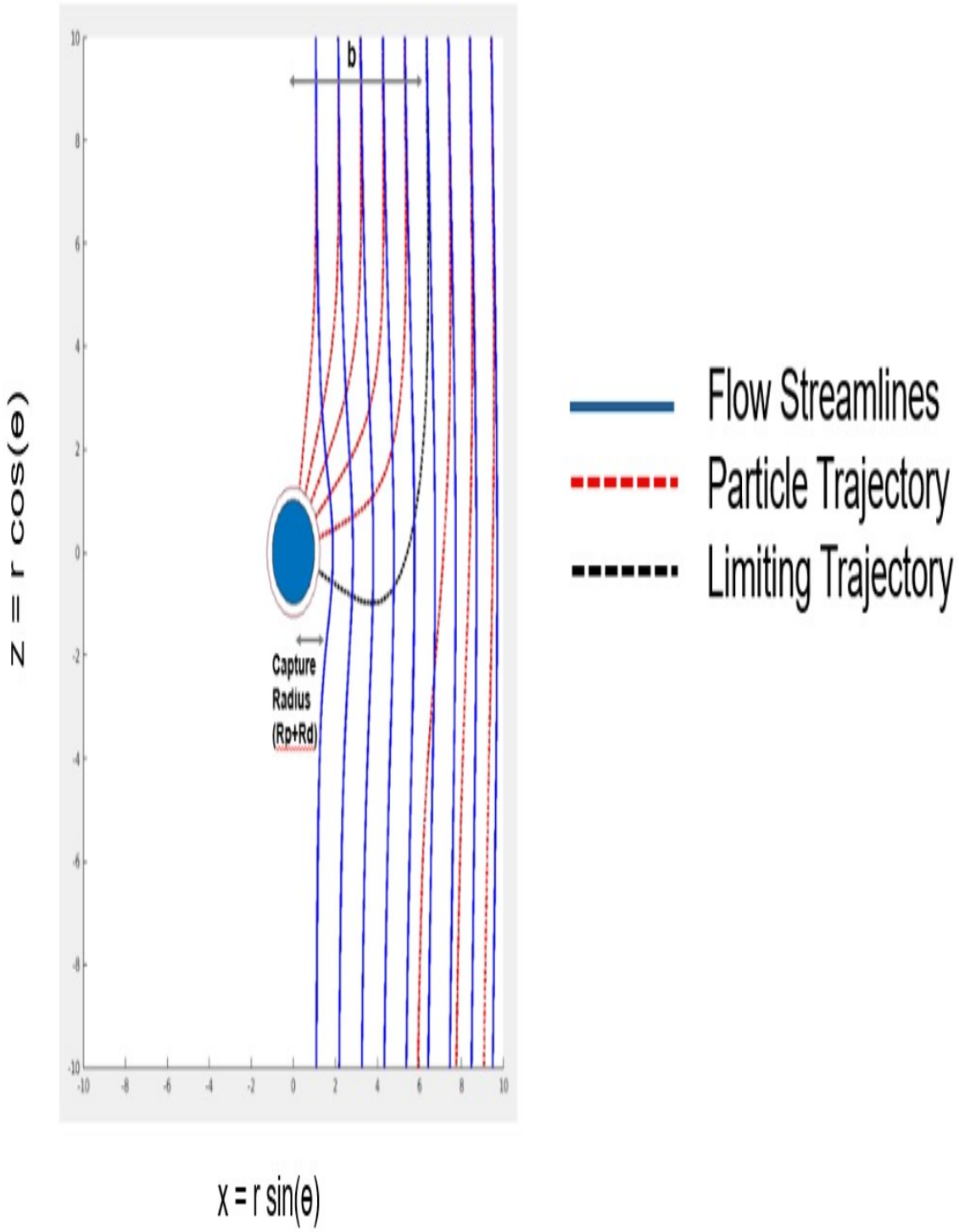

Figure 1 : Droplet Radius= 1 unit, Particle Radius=0.5 unit, Charged Droplet Qd = 1unit, Uncharged Particle=0 unit. Collection Efficiency E=5.44

#59 - Oral

Charged Phenomenon Of High-Speed Nanodroplet Impact On The Copper Plate

Electrostatics

Jiun-Shian Lee[1,2], Yun-Chien Cheng[3], Toshiyuki Sugimoto[4], Siwei Liu[2], Tomoki Nakajima[2], Takehiko Sato[2]

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Keywords: Nanodroplet, Condensation, Supersonic, Collision

Abstract Text
The available water on Earth is only 1%, compared with 98% of the sea. In addition, water is a crucial element for human life. Therefore, enhancing water technologies and using water more efficiently are necessary to address climate change, population increase, and industry promotion. Microdroplets have been researched for a long time and have many applications, such as cooling, cleaning, sterilization, and medical cosmetics. During the research history, microdroplets carrying charges were observed. Many researchers reported the phenomenon and its characteristics. However, microdroplet techniques have disadvantages, like colossal water usage and wetness on treatment surfaces.
A well-developed nanodroplet generator has been established in our laboratory. The water in the vessel is pressurized by the air gas and heated by the heater simultaneously. After issuing out of the nozzle into ambient air, the water vapor condenses to become nanodroplets. This system is super water-saving and non-wet after treatment, solving the microdroplet problem. Even more, it enhances the efficiency of all functions because of the larger contact surface area and higher inner pressure. The charged phenomenon is also observed when a metal plate connected to the current meter is placed under water spray. In this study, the mechanism of the charged phenomenon is clarified. The electric current, polarity, and potential are measured. The effect of nanodroplet size and number density have been investigated. Further results will be presented at the conference.

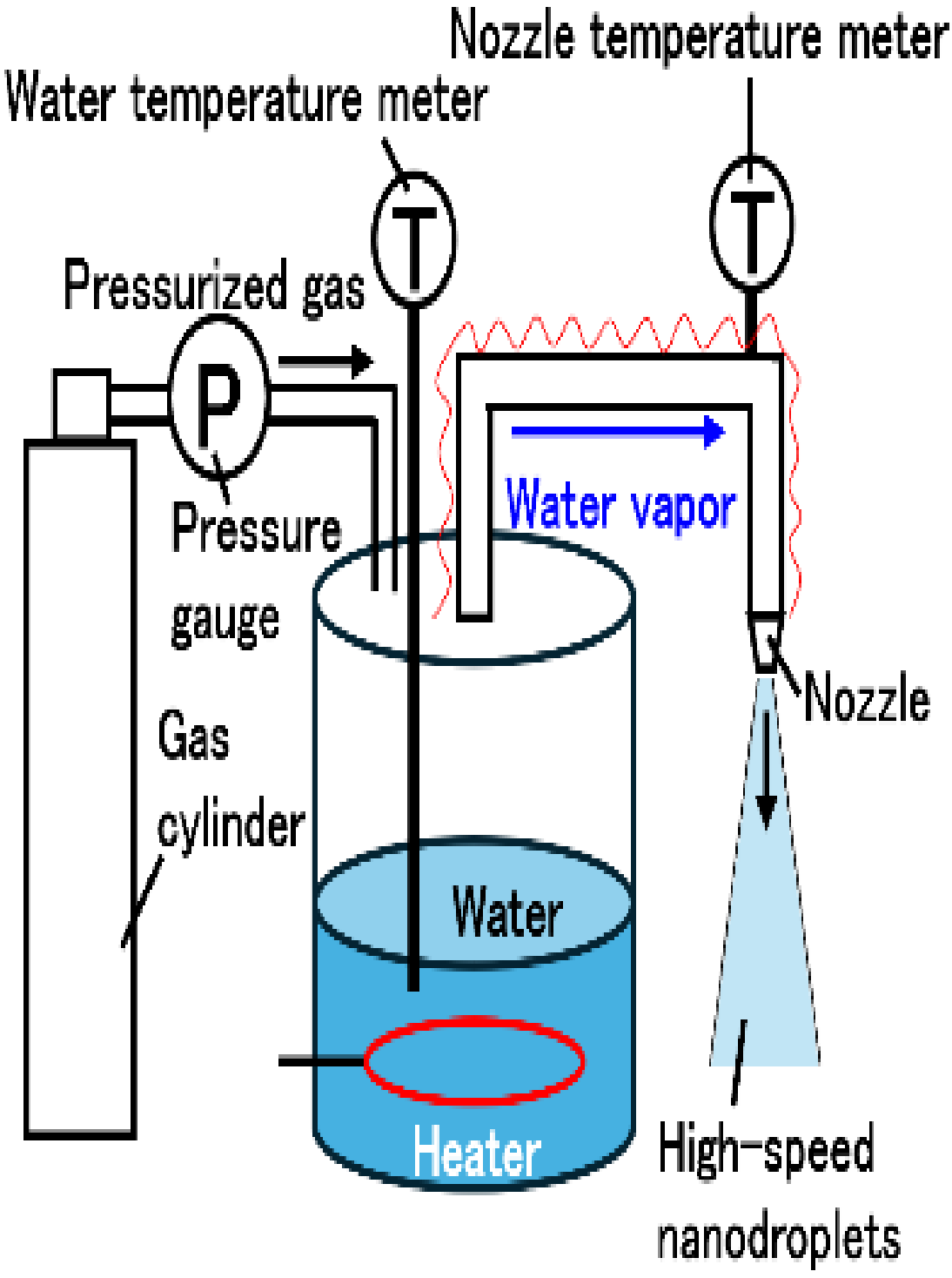

Fig.1 Schematic of the nanodroplet generator

#60 - Oral

Tracer Dynamics Driven By An Ion-Pairs Releasing Patch At A Wall

Particles and cells manipulation

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Keywords: Chemical Activity, Stokes Flow, Ionic Diffusiophoresis

Abstract Text
Patches of catalyst imprinted on supporting walls induce motion of the fluid around them once they are supplied with the chemical species ("fuel") that are converted by the catalytic chemical reaction. Their functioning has been studied by using simple models of activity involving either electrically neutral species [1,2] or redox mechanisms for metal patch on metal wall [3]. When the patch consists on enzymes that catalyze the breakup of their corresponding molecular substrates -- as it is often the case when bio-compatible applications are thought off -- the activity of the patch involves the release in the surrounding solution of pairs of (oppositely charged) ionic radicals. By using a simple model for such ion-pairs releasing activity of a patch imprinted on a planar wall [4], for this somewhat subtle non-equilibrium mechanism we determine analytically the self-induced chemical inhomogeneities and corresponding electric field in the solution, as well as the induced Stokes flow of the Newtonian solution that occupies the half space above the wall. The results are functions of the activity and of the electric charge densities (or, alternatively, the zeta potentials) at the wall and at the patch; they allow us to interpret the drift of tracers by the ambient flow and by their phoretic response to the composition inhomogeneities (as well as the induced electric potential), which is the observable usually studied in experimental investigations of such systems (see figure), and, e.g., to infer causes of changes observed when using different walls.

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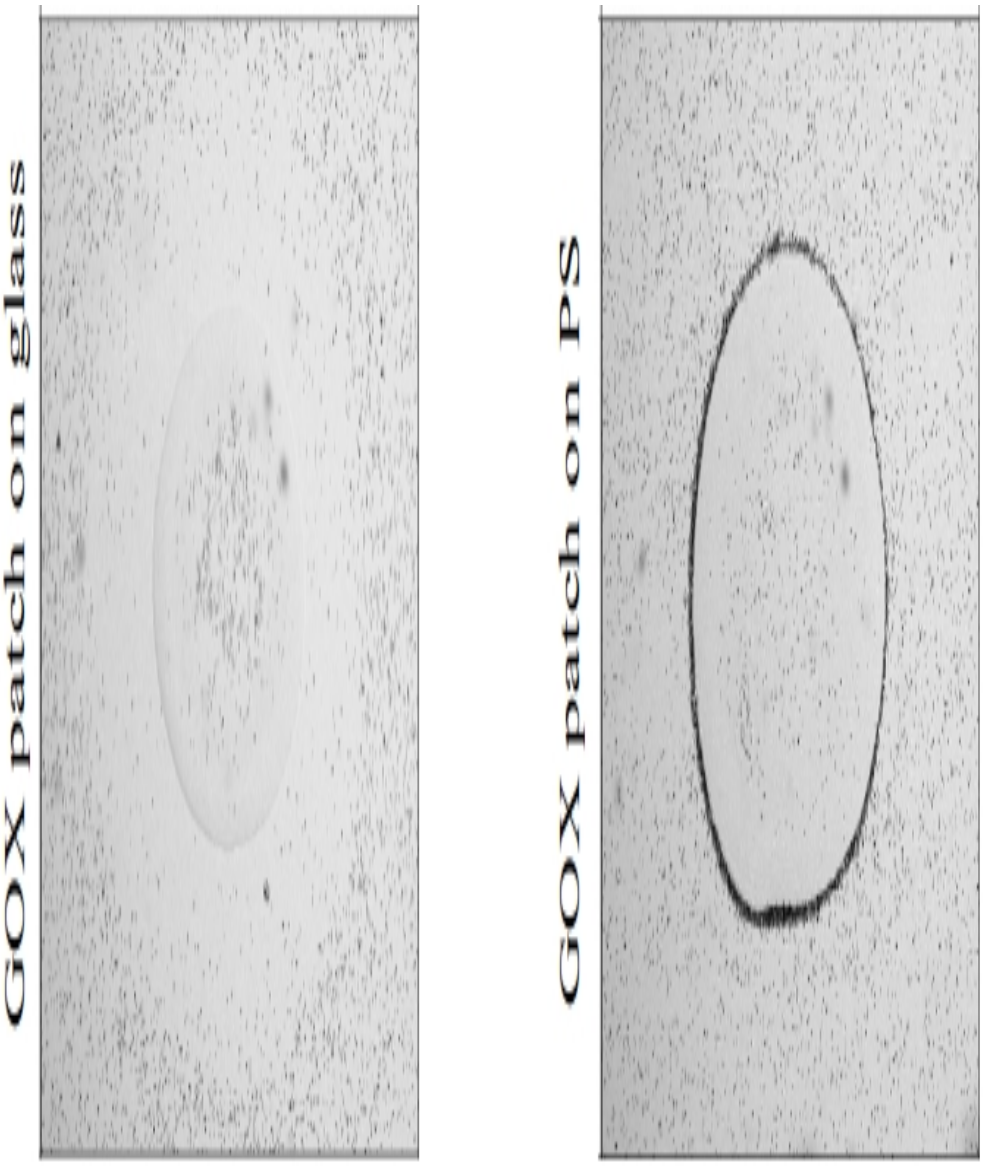

Figure: Emerging distributions of tracers in the vicinity of glucoseoxidase (GOX) patches (central disk shapes) imprinted onto either glass or UV-oxidized polystyrene (PS) walls. The system is immersed in a solution containing 0.5 mM glucose (so is chemically active); the dark dots are 3 μm diameter silica microspheres as tracer particles.

#62 - Oral

Ionic Wind Under Various Conditions In Ambient Air

EHD in gases

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Keywords: Corona Discharge, Ionic Wind, Net Charge Density, Spatial Distribution

Abstract Text
The characteristics of ionic wind determines the performance of ionizing blower used in many fields like electronic industry. We investigated in this work the spatial distribution of wind velocity and net charge density/ion flow of needle-ring DC corona discharge under different voltage polarities in ambient air. Results indicated that the wind velocity, the net ion number and their spatial distribution show different functions with the distance from the needle tip. In near region from the needle, the net charge density in positive and negative corona wind increases with the discharge current as a quadratic function. The ionic wind increases linearly with the applied overvoltage, but not in the region far from the needle. The wind of positive corona is faster than that of negative corona under the same applied voltage. But the negative ionic wind decays more slowly with the distance in both velocity and net charge density. The negative corona wind becomes faster than that of positive one after a critical distance. The negative corona wind extends a larger area in transverse direction. The different characteristics of positive and negative ionic winds result from the different kinetic behavior of positive and negative ions in ambient air.

#63 - Oral

Concentration Polarization Electroosmosis: Theory And Microfluidic Applications

Others

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2. Universidad de Oviedo, Oviedo, Spain
3. University of Southampton, Southampton, United Kingdom

Keywords: Electrokinetics, Microfluidics, Concentration Polarization

Abstract Text
We describe experimental characterization and theoretical modelling of a new AC electrokinetic effect termed Concentration-Polarization Electroosmosis, or CPEO [1,2]. This phenomenon describes steady-state electroosmotic flows that occur around charged insulating micro-structures in the presence of a low-frequency AC electric field. CPEO arises from concentration polarization (CP) due to surface conductance, meaning that the characteristic time is governed by diffusion, t□a^2/D (a is the length scale and D the diffusion constant of the electrolyte ions). As a result, CPEO is observed at low frequencies, e.g. around 300 Hz and below for a 1 μm-sized object immersed in a low-conductivity KCl electrolyte.

CPEO flows are studied around (i) features fabricated within microfluidic channels, such as pillars and constrictions [1,3], and (ii) charged microparticles [2]. A theoretical framework is presented based on recent analytical approaches in the limit of weak electric fields and/or small surface conductance. The new description gives explanation to different phenomena observed in electrokinetics, such as wall-particle repulsion of particles undergoing electrophoresis in microfluidic channels [4] or trapping in microfluidic constrictions [3]. Applications of CPEO have been proposed for particle fractionation based on size or surface charge [5].

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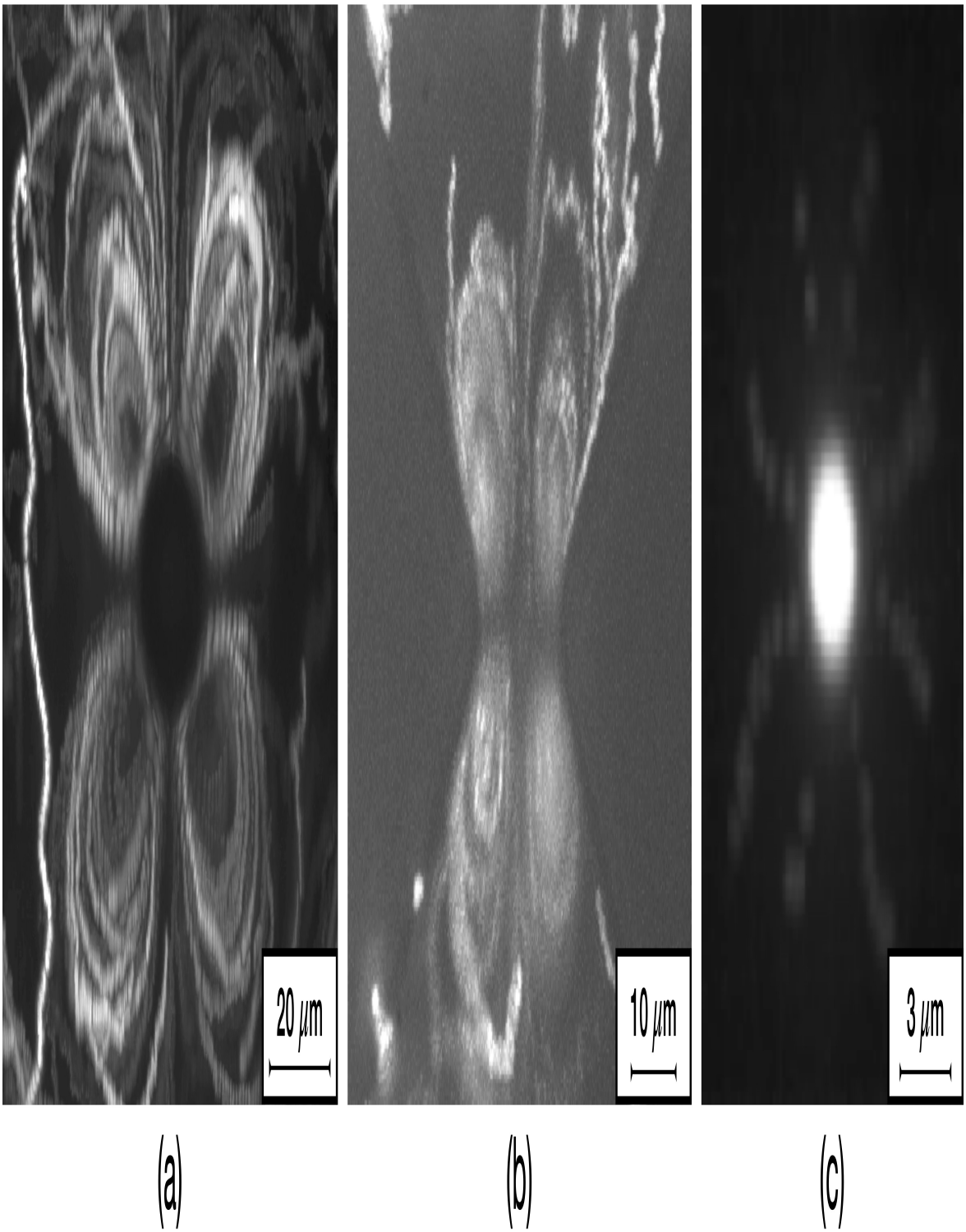

Figure 1. Experimental visualization of CPEO flow vortices using fluorescent tracers in (a) a microfluidic pillar, (b) a microfluidic constriction and (c) a microparticle.

#65 - Oral

Visualization Of Singlet Delta Oxygen Produced By Atmospheric Pressure Plasma Jet

EHD in gases

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Keywords: Single Delta Oxygen, Plasma Jet, Short Wave Infrared (SWIR) Imaging, Visualization

Abstract Text
Atmospheric pressure plasma jet (APPJ) is widely used for several medical, biological and agricultural applications. This plasma technology supplies highly active species such as reactive oxygen and nitrogen species (ROS & RNS) towards the target surface in the open air. In general, reactive oxygen species include hydroxyl radial (OH), superoxide anion(O2-), hydrogen peroxide (H2O2) and singlet delta oxygen (O2(a1□g)). In particular, OH radicals have a higher oxidation potential and have been the subject of much research, but their short lifetime has hindered their effective use. In many cases, the recombination of the OH radicals easily occur to produce hydrogen peroxide. On the other hand, Singlet delta oxygen (SDO) does not have as much oxidizing power, but it has a longer lifetime (4500 s). Therefore, SDO is being studied as an effective reactive species for cancer therapy and combustion efficiency. SDOs have not been studied much in the field of plasma science. One of the reasons that makes its detection difficult is that the emission from the transition between the excited state (0.98 eV) and the ground state is very weak. Recently, we have succeeded in the visualization of SDO for the first time by short wave infrared (SWIR) imaging using the InGaAs sensor. A plasma jet generator with two ring electrodes wrapped around the outside of a glass tube was used to generate helium plasma jets by applying a 20 kHz radio frequency. The plasma jet was generated in an open atmosphere as a thin plume a few cm from the glass tube outlet. No SDO was observed in the plasma generated by supplying helium as the plasma gas at 2 L/min. However, when a small amount of O2 additive is injected into the helium plasma, the SDO could be observed. The typical image of SDO is shown in Fig.1. In this case, there is no plasma jet outside the exit of the glass tube. It can be seen that SDO molecules are transported by the gas flow to the surface of the water in the Petri dish placed downstream.

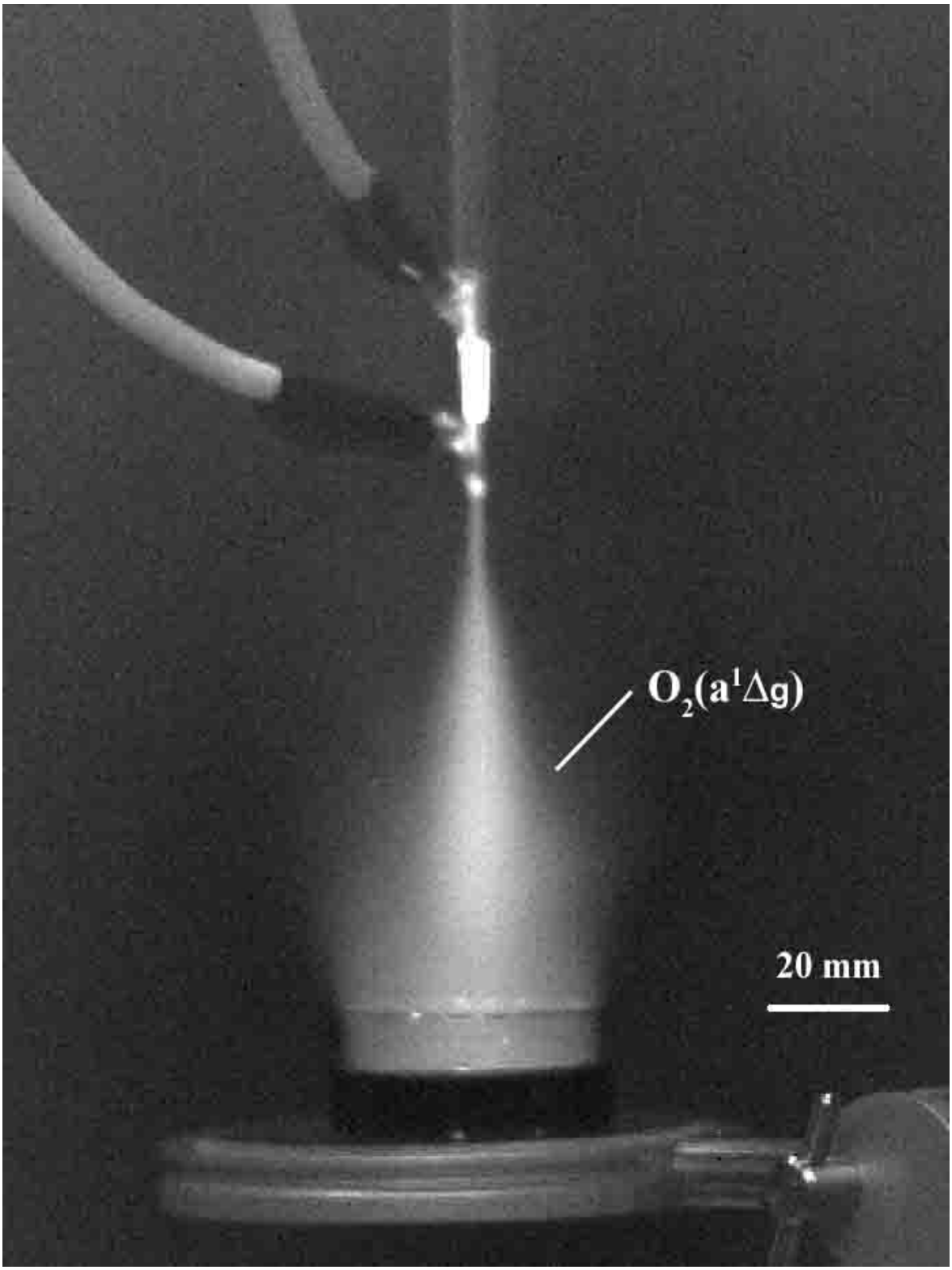

Fig. 1 Two-dimensional distribution of singlet delta oxygen produced by helium plasma jet containing 2% oxygen.

#66 - Oral

Universal Time-Scale Parameter For Describing The Coalescence Of Conductive Droplets Under Pulsed Electric Fields

EHD of multi-phase flows

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Keywords: Numerical Simulation, Arbitrary Lagrangian-Eulerian Method, Electrocoalescence, Two-Phase Liquid

Abstract Text
Electrocoalescence refers to the process in which electric fields are employed to merge individual droplets in immiscible liquids. One of the strategies to enhance this process is the application of pulsed voltage. It is evident that varying the pulse frequency leads to different outcomes. The limiting cases are low and high frequencies, where the behavior converges to that observed under a constant voltage. However, how can one predict the transition between the low- and high-frequency regimes? Moreover, what phenomena occur in the "intermediate" frequency range?
We employed the arbitrary Lagrangian–Eulerian approach combined with Gauss's law and the Navier–Stokes equations to numerically simulate the coalescence of two identical conductive droplets in an oil medium under the influence of a pulsed electric field. Frequency-dependent thresholds of electric field intensity separating complete coalescence from non-coalescence were obtained for a range of droplet radii.
Firstly, for all considered radii, an increase in the threshold was observed in the intermediate frequency range. Secondly, the dependencies for different radii were successfully generalized using a dimensionless time-scale parameter derived from a combination of the electric Weber number and the Ohnesorge number.
The proposed generalized dependency can be valuable for designing experiments on droplet electrocoalescence under non-stationary electric fields and for consolidating existing experimental and simulation results.

#67 - Oral

The Complex Structure Of Electrohydrodynamic Flows Arising In A Two-Phase Liquid With Weakly Conducting Dispersion Medium And Unequal Ions Mobilities

EHD of multi-phase flows

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Keywords: Two-Phase Immiscible Liquid, Dissociation Recombination Charged Layers, Electrocoalescence, Numerical Simulation

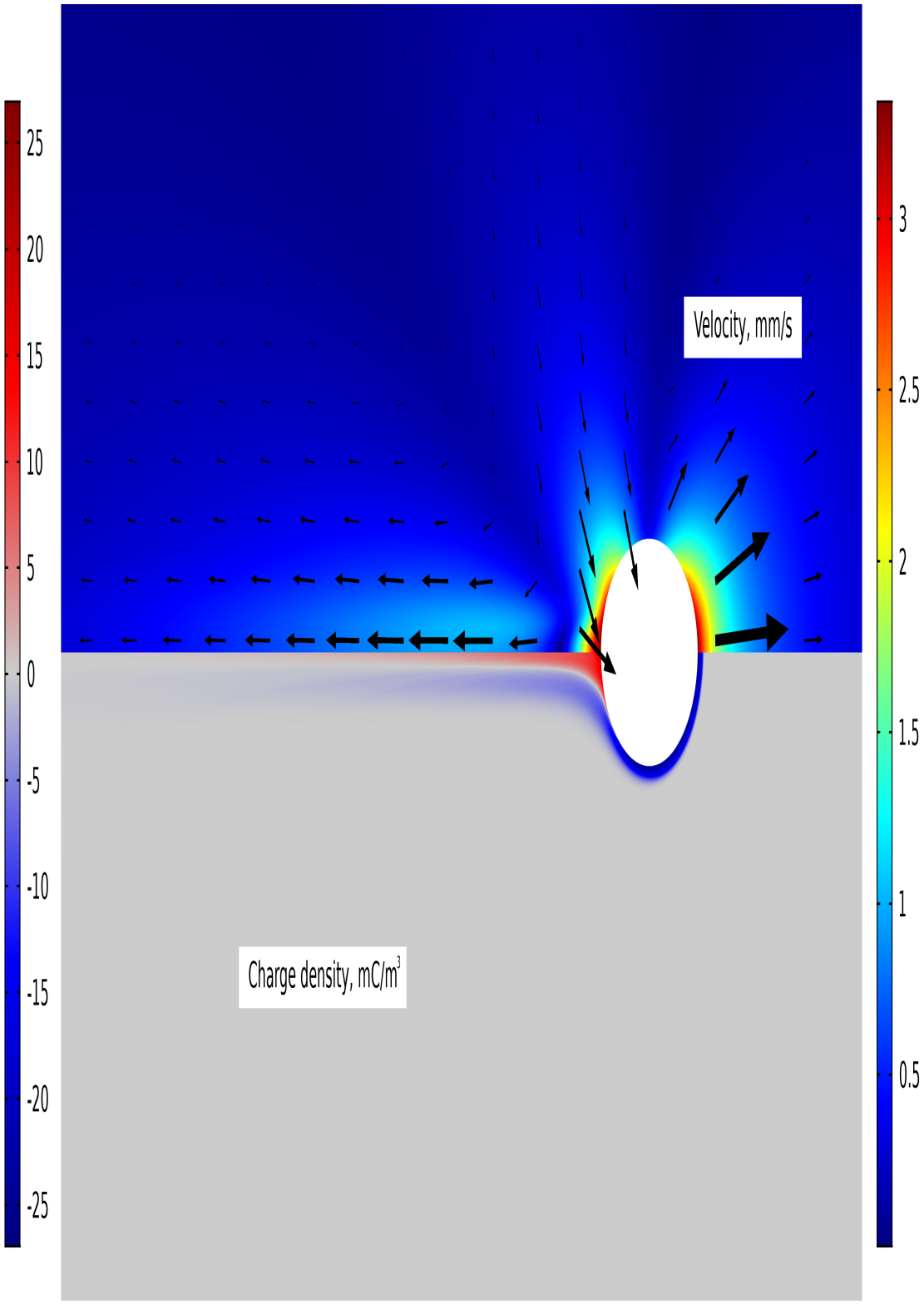
Abstract Text
In most cases the external dispersion medium is considered an ideal dielectric when the processes of electrodeformation and the interaction of conducting droplets (dispersed phase) suspended in a dielectric oil (dispersion medium) are considered. The large difference in phase conductivities makes it possible to effectively affect the strong electric fields on the division of two-phase liquids into components by combining small droplets into larger ones. However, according to recent data, the non-zero ionic conductivity of the dispersion medium leads to the occurrence of steady-state electrohydrodynamic flows around a single drop suspended in oil, and even to the charging of initially neutral droplets. The latter effect is possible if the mobilities of oppositely charged ions differ.

The goal of this study is to determine how the processes of dissociation and recombination in a dispersed medium with different ion mobilities affect the dynamics of droplets of the dispersed phase with a radius of about 1 mm in an external electric field.

The mobility of positive ions exceeded the mobility of negative ions by 1.25–5 times. In this case, more positive ions reach the surface of the droplet, and a positive total charge accumulates on it. This leads to the movement of the droplet in the direction of the external field under the action of the Coulomb force.

A trace remains behind the drop—a charged region in which a negative charge prevails. An increase in the electrical conductivity of the oil leads to a decrease in the length of this trace, but the charge density and the magnitude of the volumetric force acting in the trace increase. Within a specific range of conductivities, this results in a strong EHD flow directed away from the droplet and preventing the possibility of two droplets approaching each other.

It can be concluded that the difference in the mobility of ions of the dispersion medium leads to a fundamental change in the dynamics of droplets. The study examines the impact of various system parameters (oil conductivity, ion mobility, drop radius) on the qualitative and quantitative properties of the observed effects.



Surface and arrow plots of velocity magnitude (upper part of image) and space charge density (lower part of image) for the case of a strong EHD flow.

#68 - Oral

Effect Of Charge On The Coalescence Of A Water Droplet Suspended In Oil And A Water Layer

EHD of multi-phase flows

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Keywords: Electrocoalescence, Numerical Simulation, Charged Droplet, Droplet-Layer System

Abstract Text
This research focused at studying the processes that occur in electrocoalescers and other electrophysical devices which are based on the effect of applying an electric field on immiscible liquids. The main problem of designing such devices is the lack of information about the processes occurring inside which usually leads to the need for experimental tuning.

Many electrocoalescers involve a layer of water to the absorption of water droplets in the water-oil emulsion. In this case coalescence as well as partial coalescence can occur. The process of partial coalescence produces secondary droplets which become increasingly difficult to remove. For this problem important to identify the differences in the coalescence of charged and uncharged droplets.

Numerical model based on the “moving mesh” method was used to study the drop-layer system. Numerical models make it possible to obtain data relatively fast and accurate for any set of parameters of the system, as well as to investigate characteristics inaccessible from the experiment. The advantage of this method in comparison with the commonly used methods of the “phase field” and the “level set function” is that this one is free from the effect of false escape of the charge from the interface surface, which led to incorrect results.

The interaction of a charged droplet suspended in oil and a layer of water under the constant electric field was investigated. An analysis of the influence of electric charge on the volume of the separating drop and thresholds was carried out.

The presence of an electric charge increased the threshold for the transition to partial coalescence, while the threshold for the transition to stretching did not change. The volume of the separated drop in the partial coalescence mode has been significantly reduced, mostly due to the acquired speed.

#69 - Oral

Aerosol Jet Printed Surface Dielectric Barrier Discharge (AJP-SDBD) Plasma Actuators: Fabrication And Electromechanical Characteristics

Others

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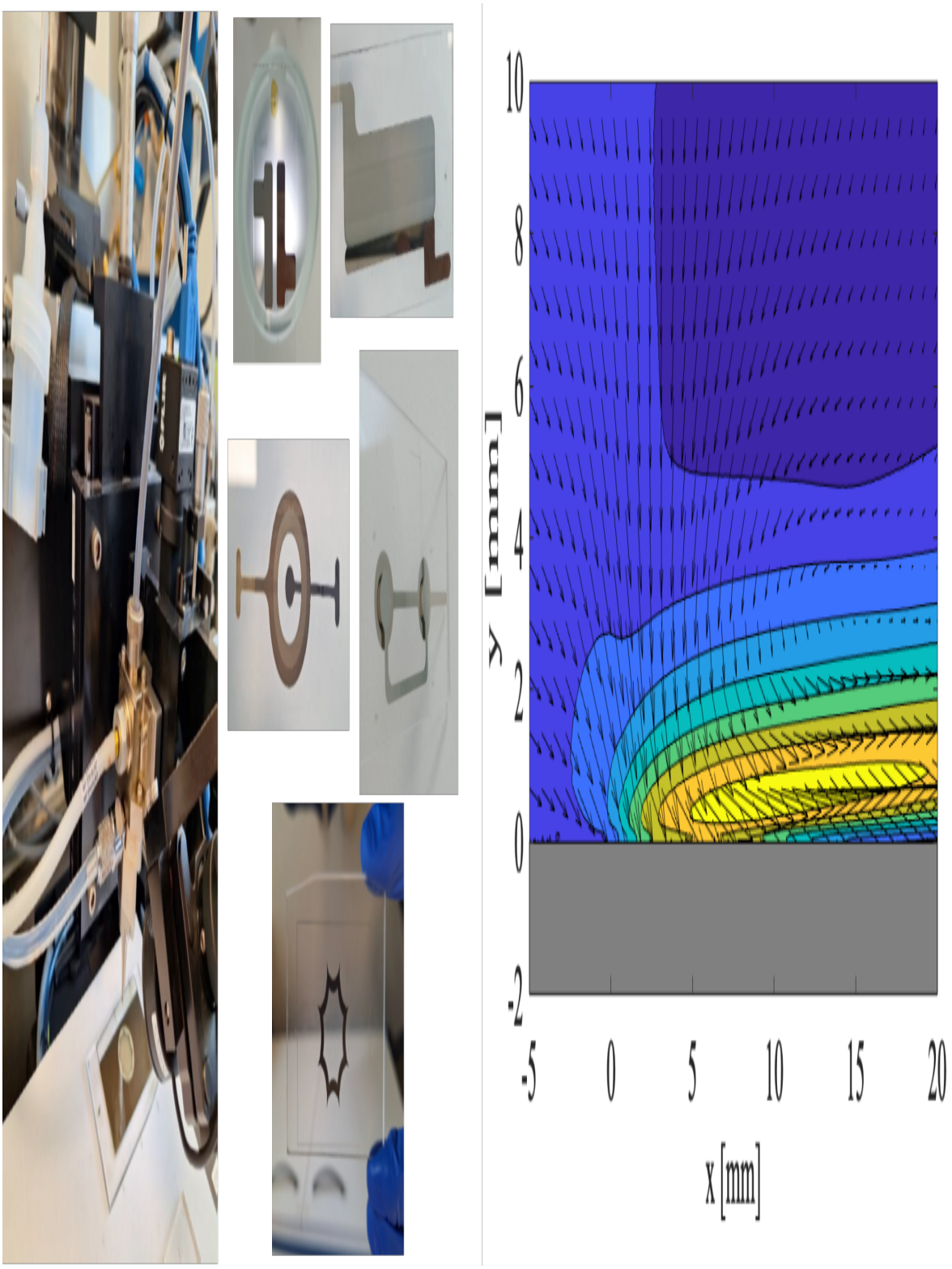
Keywords: Plasma Actuators, Ionic Wind, Aerosol Jet Printing, SDBD

Abstract Text
Surface Dielectric Barrier Discharge (SDBD) actuators have gained significant attention in various fields due to their ability to produce relatively strong and localized electrohydrodynamic (EHD) flows. SDBDs, created between two electrodes separated by a dielectric material, find applications in aerodynamic flow control, sterilization, gas surface and water treatment, combustion, in-atmosphere propulsion, CO2 conversion, electronic cooling etc. However, SDBD actuators are often limited by fabrication constraints leading to decreased robustness, longevity, repeatability and flexibility in design, hindering their electromechanical performance and applicability. Furthermore, current fabrication techniques are not capable of producing electrodes with fine features and complex geometrical shapes, which could potentially improve the plasma characteristics and EHD flow.
In this work, we present a novel fabrication technique based on Aerosol Jet Printing technology of conductive inks and characterize the Aerosol Jet Printed SDBD actuators (AJP-SDBDs) electromechanical performance. The AJP-SDBDs are fabricated without the need of masks, stencils or etching, with small feature sizes near 20 μm, print thickness from 100 nm to several microns, offering flexibility in the choice of substrates (plastic, ceramic, non-planar surfaces, bio-materials, flexible substrates) as well as the electrode material (silver, gold, tungsten etc.). These unique features of AJP are used to fabricate planar and annular SDBD designs, including custom-shaped patterned edges. When stressed under AC, High Voltage (HV) excitation, the AJP-SDBDs present rather stable and quasi-uniform operation. We compare the electromechanical characteristics of planar and annular AJP-SDBDs with typical designs found in literature (based on conventional fabrication techniques), in terms of ink-related electrical properties (through Van der Pauw-resistivity and Hall measurements), plasma electrical characteristics, material degradation and Particle Image Velocimetry (PIV) measurements of the induced jet.



Left: Various designs of AJP-SDBDs. Right: Time-averaged velocity fields for linear AJP-SDBD (35 kV, 2 kHz)

#70 - Oral

PIV Method In EHD Flow Diagnostics

Others

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Keywords: PIV, EHD Flow

Abstract Text
Electro-hydrodynamic flows are characterized by the interaction between the electric field and the fluid flow. These phenomena are particularly important in many engineering applications, such as actuators, micropumps, micromixers or cooling systems. Particle Image Velocimetry (PIV) allows for a detailed study of these phenomena, which leads to a better understanding of the mechanisms governing the flows and the optimization of engineering designs.
The PIV method is a laser-based technique used to measure the velocity and direction of fluid flow. It involves the introduction of small particles into the tested fluid, which are then illuminated by a laser. The camera records images of these particles in short time intervals, which allows for tracking their movement. Analysis of the image sequence allows for determining the velocity vectors at different points in the tested area. This allows obtaining a detailed flow velocity map, which is invaluable in studies on electro-hydrodynamic flows.
One of the main challenges in using PIV for electro-hydrodynamic flow diagnostics is ensuring adequate illumination, proper seeding and image acquisition under high electric field conditions. This requires specialized equipment and advanced image analysis techniques. Despite these challenges, PIV remains one of the most precise and versatile methods for measuring flow velocity.
In summary, Particle Image Velocimetry is an invaluable tool in electro-hydrodynamic flow diagnostics. It provides detailed data on flow velocity and direction, leading to a better understanding and optimization of engineering systems.

#71 - Oral

Electrohydrodynamic Water Flow Produced By A DC Discharge Ignited Above Its Surface

EHD in liquids

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Keywords: EHD Flow, Dc Discharge

Abstract Text
The interactions between a DC plasma discharge and a liquid are very complex, but very important to study due to various applications, such as water treatment. In this context, we developed a simple device that consists in applying a DC voltage between a needle placed a few millimeters above the surface of the liquid to be treated and a grounded electrode located inside the liquid (Fig.1a). When the voltage is increased, two discharges regimes can be observed: a corona regime (current of a few dozens of μA) and a normal glow one (current up to 10 mA). Moreover, due to different physical phenomena, several mechanical effects can occur: a gas flow induced by the discharge (ionic wind), a deformation of the liquid surface, and a liquid flow, all these electrohydrodynamic (EHD) phenomena being currently investigated by our team. In the present experimental study, we investigated the EHD flow induced inside the liquid with the help of a particle image velocimetry (PIV) system, in the case of the two discharge regimes.

In the case of a corona-like discharge, we studied the influence of the voltage polarity and the gap between the needle tip and the water surface. The liquid was pure water. First, we highlighted that the liquid flow was due to two EHD forces: an upward force in the liquid (white arrow in Fig.1b) and a surface force (red arrows in Fig.1b). Secondly, we showed that the flow is faster when the voltage is positive and when the gap is increased because the surface forces are stronger.

In the case of a normal glow discharge, we investigated the role of several input parameters, such as the voltage value, its polarity, the water conductivity, and the superficial tension. We highlighted that the polarity plays a role in the flow topology and that the liquid velocity increases with the applied voltage. Moreover, the velocity decreases when the water conductivity and the superficial tension are increased.

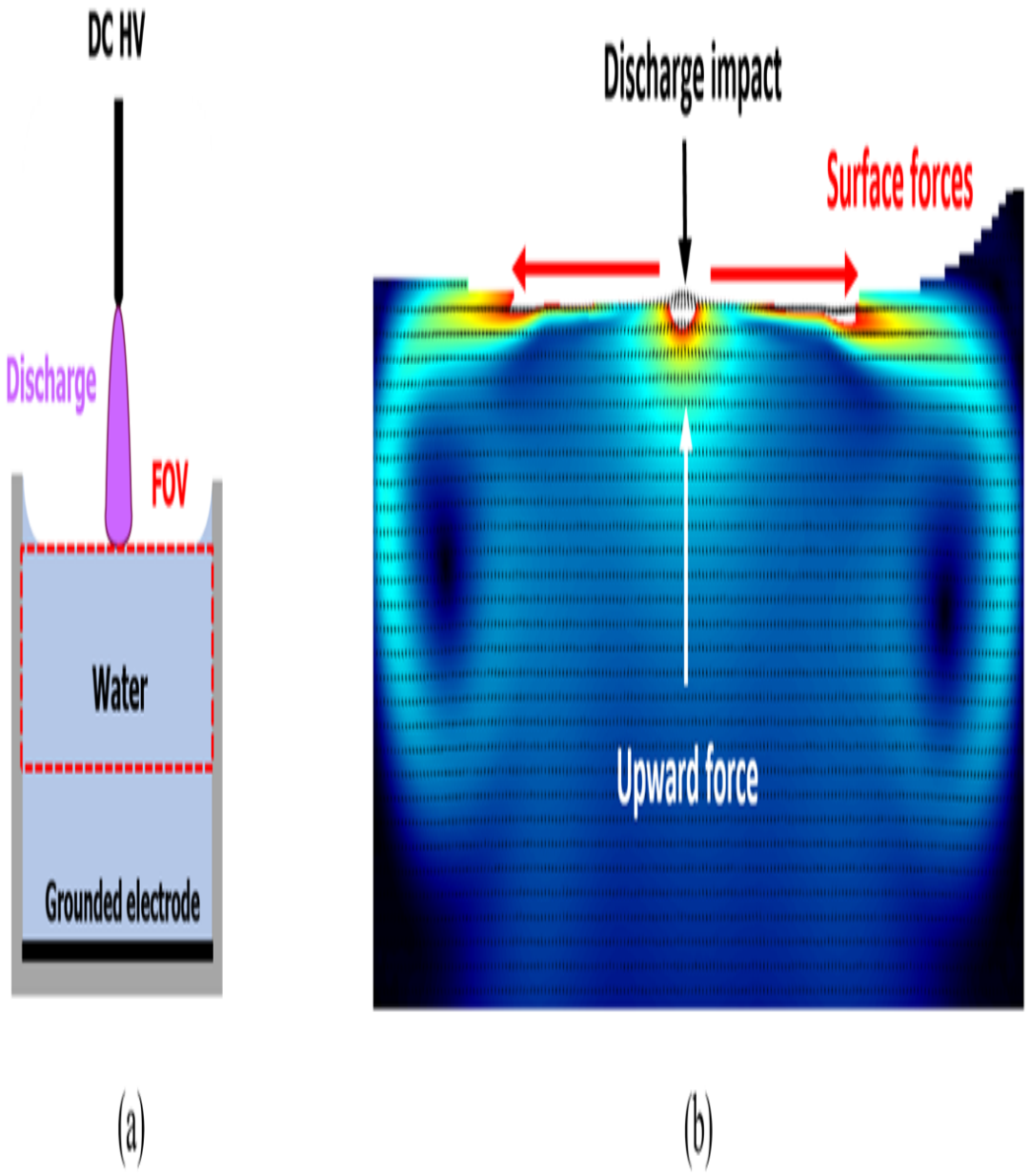

Fig. 1: Scheme of the experimental setup (a), example of water flow (b).

#72 - Oral

Electrical Discharge Characteristics In A Dielectric Liquid Flow In A Microchannel

Fundamental Electrohydrodynamics

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Keywords: Discharge Characteristics, Flow, Microchannel, Plana Electrodes

Abstract Text
The effect of fluid flow, both in the co- and counter flow direction with respect to the electric field direction, on discharge characteristics in a dielectric liquid has been studied. A set of 100 interdigitated planar electrode pairs were photolithographically fabricated on a thin glass substrate which acts as the bottom wall of a 100 micron high, 5 mm wide and 50 mm long microchannel. The width of the emitter and collector gold electrodes was 20 and 40 μm respectively, with inter-electrode spacing of 120 μm. Spacing between each adjacent electrode pairs is 240 μm. A syringe pump was used to induce a flow through the microchannel. Current was recorded at different applied DC potential across the emitter and collector electrodes at different flow rates. The results showed an increase in current when flow was induced compared to the no flow case for all applied fields. At low applied electric fields, the current increased as the flow rate increased; while at the higher applied electric fields, there was an optimum flow rate for maximum current.

#73 - Poster

Traveling-Wave Electrophoresis Of Micro-Particles

Particles and cells manipulation

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Keywords: Traveling-Wave, Electrophoresis, Microfluidics,

Abstract Text
We investigate theoretically the motion of microparticles suspended in a liquid under the influence of traveling-wave electrophoresis (TWE). TWE induces particle motion by applying traveling electric fields. In our case, the electric fields are generated by oscillating potentials applied on a periodic array of microelectrodes at the bottom of a microfluidic channel.

An analytical expression for the traveling-wave electric field is derived by solving the Laplace equation using Fourier series [2]. This solution is subsequently employed in numerical simulations of the particle trajectories.

Particle trajectories are simulated within a single wavelength of the traveling wave. A transfer function is built to relate the initial and final positions of a particle within a unit cell. This function enables us to predict the final height and phase of a particle given its initial conditions. Interestingly, the transfer function reveals regions of apparent chaotic behaviour as well as regions that act as particle attractors.

We have identified different types of particle trajectories based on initial conditions, leading to distinct long-term behaviours such as trapping or continuous motion. A comprehensive analysis of these trajectories will be provided.

References:
[1] Boyd F. Edwards et al. Physical Review Letters 2019, 102, 076103.
[2] Ramos et al. J. Appl. Phys. 2005, 97, 084906.

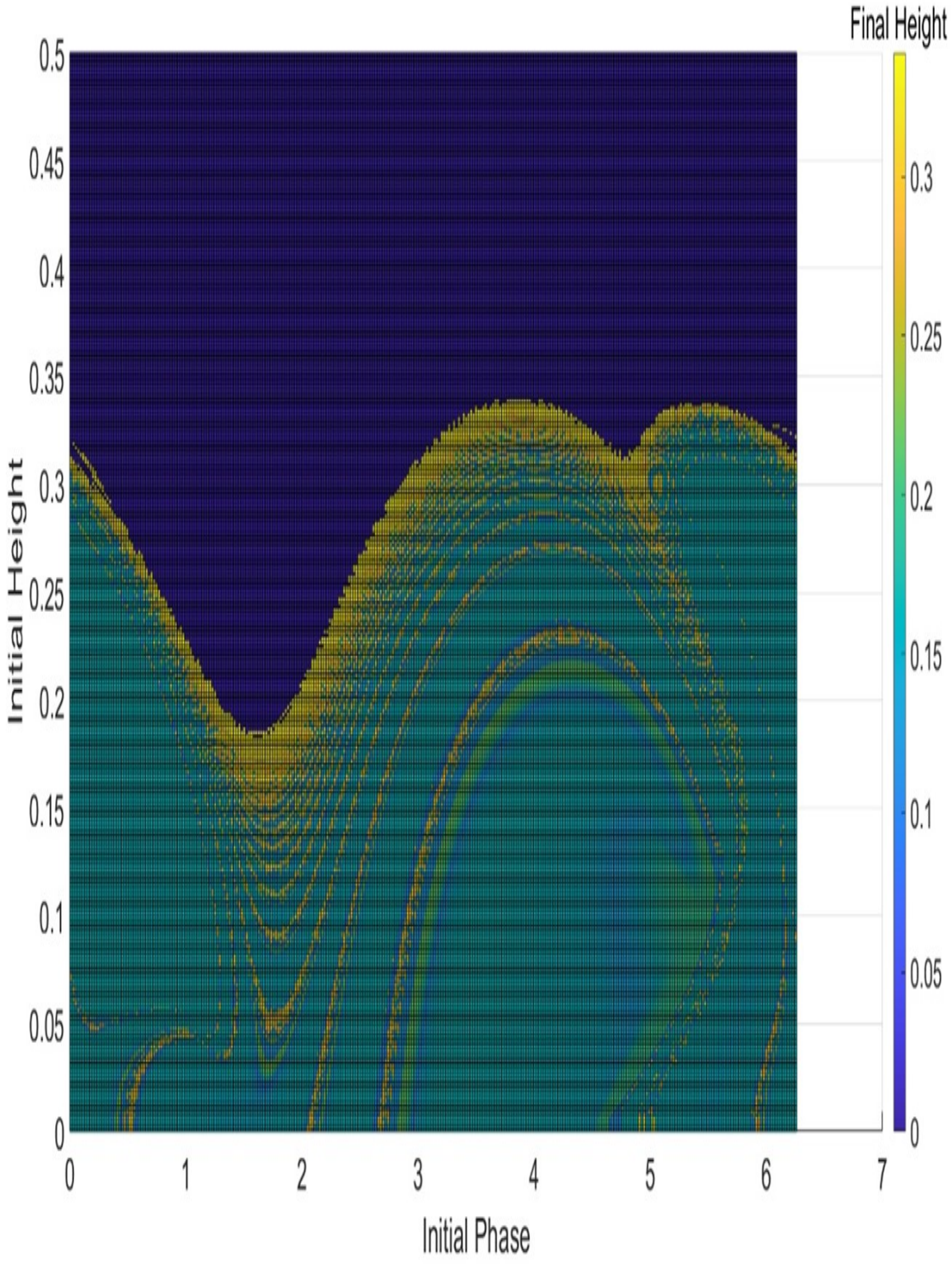

Figure 1. Transfer function providing the exit height normalized by the channel length.

#74 - Poster

Bipolar Electrospray For Generation And Delivery Of The Neutral Polymeric Particles

EHD in liquids

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Keywords: Electrospray, Bipolar Electrospray, Drug Delivery, Particle Neutralization

Abstract Text
Pulmonary drug delivery offers rapid, non-invasive treatment for lung diseases due to the extensive network of alveoli and high capillary density. Electrohydrodynamic atomization (EHDA) produces fine particles with adjustable rates. However, the high charge on the particles is a problem as they are easily attracted to the nose, mouth, or throat surface, preventing them from entering deep lung regions. To address this, we developed a bipolar electrospray system using two nozzles that spray two oppositely charged particles and neutralize each other (Fig. 1a). Experiments with isopropyl alcohol (IPA) clarified the working principles (Fig. 1b) while atomizing polyvinylidene fluoride polymer (PVDF) yielded particles within respirable size of 1–5 μm with minimal charge (Fig. 2). This simple, efficient method shows promise for inhalation-based drug delivery.

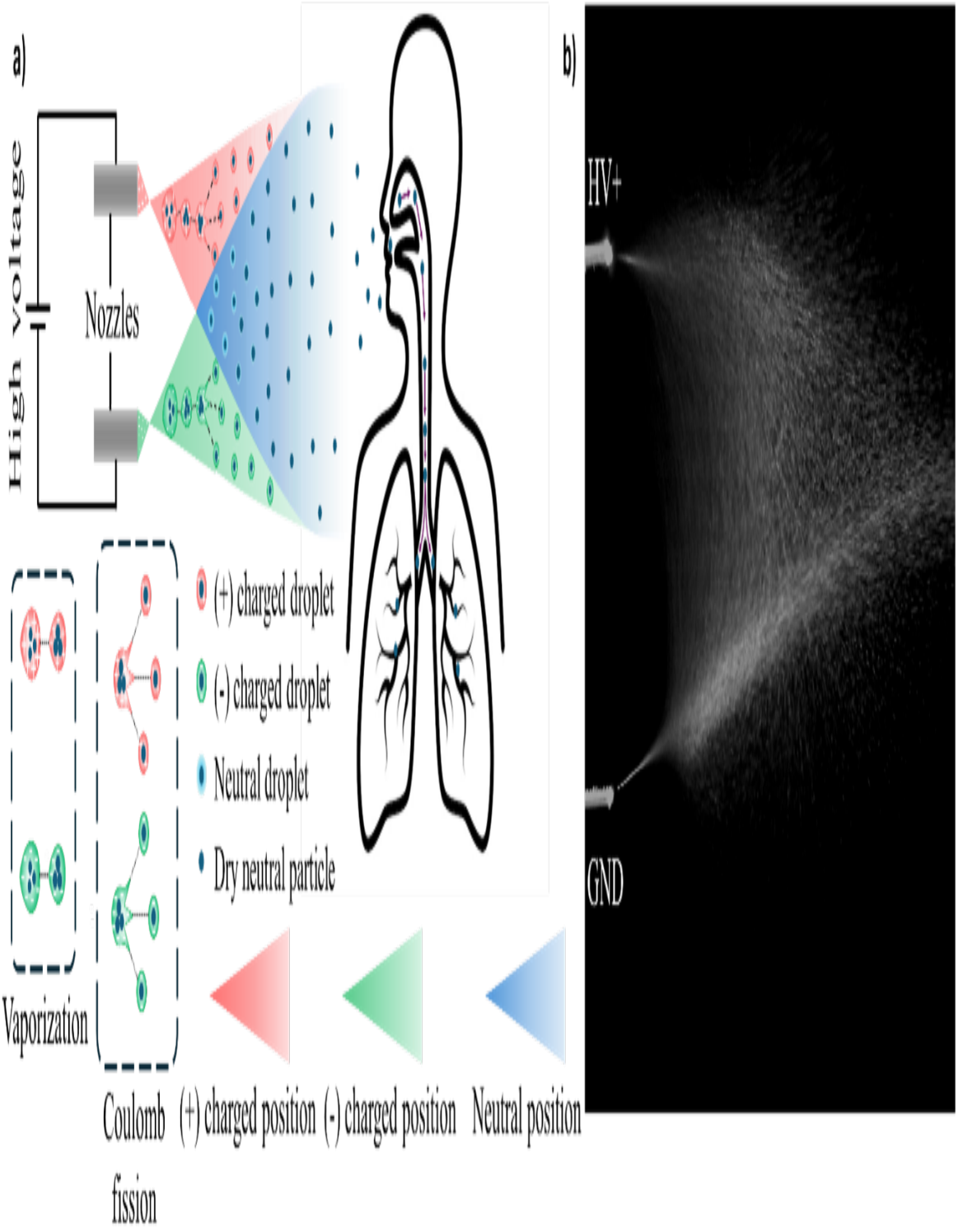

Figure 1: Bipolar electrospray. (a) Design concept. (b) Bipolar electrospray with IPA.

#75 - Oral

Improving Collection Efficiency And Energy Saving In A High Electric Field Type Electrostatic Precipitator With High Gas Velocity For Diesel

Others

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Keywords: Electrostatic Precipitator, Energy Saving, High Gas Velocity

Abstract Text
In this study, experiments were carried out to achieve a collection efficiency of 80% at a high gas velocity of 10 m/s in a high electric field electrostatic precipitator (ESP) [1] for diesel exhaust particles. The effects of electrode length and gas velocity were investigated.
The experimental system consisted of a diesel engine, a heat exchanger, and the ESP. The exhaust gas temperature was adjusted to 30°C by the heat exchanger and then flowed into the ESP. The gas velocity was adjusted to values between 1 m/s and 10 m/s. The ESP had a coaxial cylindrical structure composed of a high-voltage columnar electrode and a grounded cylindrical electrode. The gap distance was set at either 6.1 mm or 10 mm, and the electrode length ranged from 470 mm to 2000 mm. A negative DC voltage of 19 kV or 11.6 kV was applied to the columnar electrode, depending on the gap distance (10 mm or 6 mm, respectively). The particle mass concentration at the upstream and downstream sides of the ESP was measured, and the collection efficiency was calculated.
As a result, since no discharge current was detected under any conditions, it was revealed that energy was not consumed in the ESP. Furthermore, maximum collection efficiency of 86% was achieved at a gap distance of 6.1 mm, an electrode length of 2000 mm, and a gas velocity of 10 m/s, without energy consumption.
This work was supported by a Grant-in-Aid for Scientific Research (B), No. 23K22976, from the Japan Society for the Promotion of Science.

References
[1] Akinori Zukeran, et. al., Lecture Notes of Electrical Engineering, Vol. 1052, pp. 134-143, 2023

#76 - Oral

Design And Optimization Of A New High-Efficiency Needle-Fin Heat Dissipation Structure Based On Ion Wind Flow Field Morphology Optimization

EHD in gases

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Keywords: Ionic Wind, Flow Field, Electronics, Thermal Management

Abstract Text
As the integration and performance requirements of electronic devices continue to increase, effective temperature control and prevention of overheating have become key issues that need to be addressed. Ion wind, with its advantages of no noise, compact structure and customizable design, has become a heat dissipation technology with wide application potential. In this paper, a new pin-fin heat dissipation structure is designed, which can improve the heat dissipation performance by optimizing the ionic wind flow field distribution. Based on the hydrodynamic model, the effects of different voltages, electrode spacings (10-20 mm), fin spacings (3-5 mm) and fin angles (0°-30°) on the wind speed and flow field patterns of the ion wind are investigated in this paper. The results show that the wind speed increases with the voltage, the wind speed decreases with the slice gap, and the fin angle can slightly enhance the maximum wind speed, but the effect on the overall ventilation is small. Based on the simulation results, a new pin-fin heat dissipation structure is designed and fabricated, and the data show that the optimized pin-fin structure heat dissipation effect, compared with the traditional natural heat dissipation structure, the heat dissipation effect is greatly improved. In this paper, we study the optimization of the ion wind flow field distribution to improve the heat dissipation effect, and provide a new solution idea for the heat dissipation of high-power electronic devices and systems.

#77 - Oral

Numerical Study On Dynamics Of Falling Drop Over Hydrophobic Substrate Under The Influence Of Electric Field

EHD of multi-phase flows

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Keywords: Multiphase Electrohydrodynamics, OpenFOAM, Wetting Phenomenon, Contact Angle Dynamics

Abstract Text
The wetting phenomenon is how a liquid behaves after it comes into contact with any solid surface. It is quantized by the equilibrium contact angle between the liquids and the surface (θc). This phenomenon can be tweaked in many ways, like inducing ultrasonic vibrations on the surface, adding surfactants or contaminating the liquid. This article considers the effects of an external electric field as a tweaking agent.
The simulation uses OpenFOAM, an open-source computational fluid dynamics (CFD) software. Taking advantage of OpenFOAM's modular libraries, a solver capable of simulating multiphase flow under the effects of electric fields, named interEHDFoam, has been developed by modifying the interFoam solver. This solver is optimised for multiphase electrohydrodynamic flow and validated using the standard test cases [1]. Figures a and b show the validation for the jump of electric field across the interface and dissipation of electric charge in the domain, respectively, with standard analytical solutions [1]. Similarly, the simulation results (interFoam) pertaining to the drop dynamics on hydrophobic surfaces without electric field are validated using published experimental results [2] and shown in Figures c and d.
Further, the simulations have been set up to test for studying three parametric details: Weber number (We) as 0.94 (non-bouncing), 1.54 (transitional), and 2.73 (bouncing); $0.05 < Boe < 0.3$; $90 < \theta c < 165$. After careful observation and comparisons of available and computed data, it has been observed that as the electric field strength (Boe) increases, the effective force at the interface decreases. Thus, the spreading of the droplet over the substrate increases. It is also observed that the damping in the hysteresis of the drop reduces with the application of electric field.
[1] J. M. López-Herrera, S. Popinet, and M. A. Herrada, "A charge-conservative approach for simulating electrohydrodynamic two-phase flows using volume-of-fluid," J Comput Phys, vol. 230, no. 5, pp. 1939–1955, 2011
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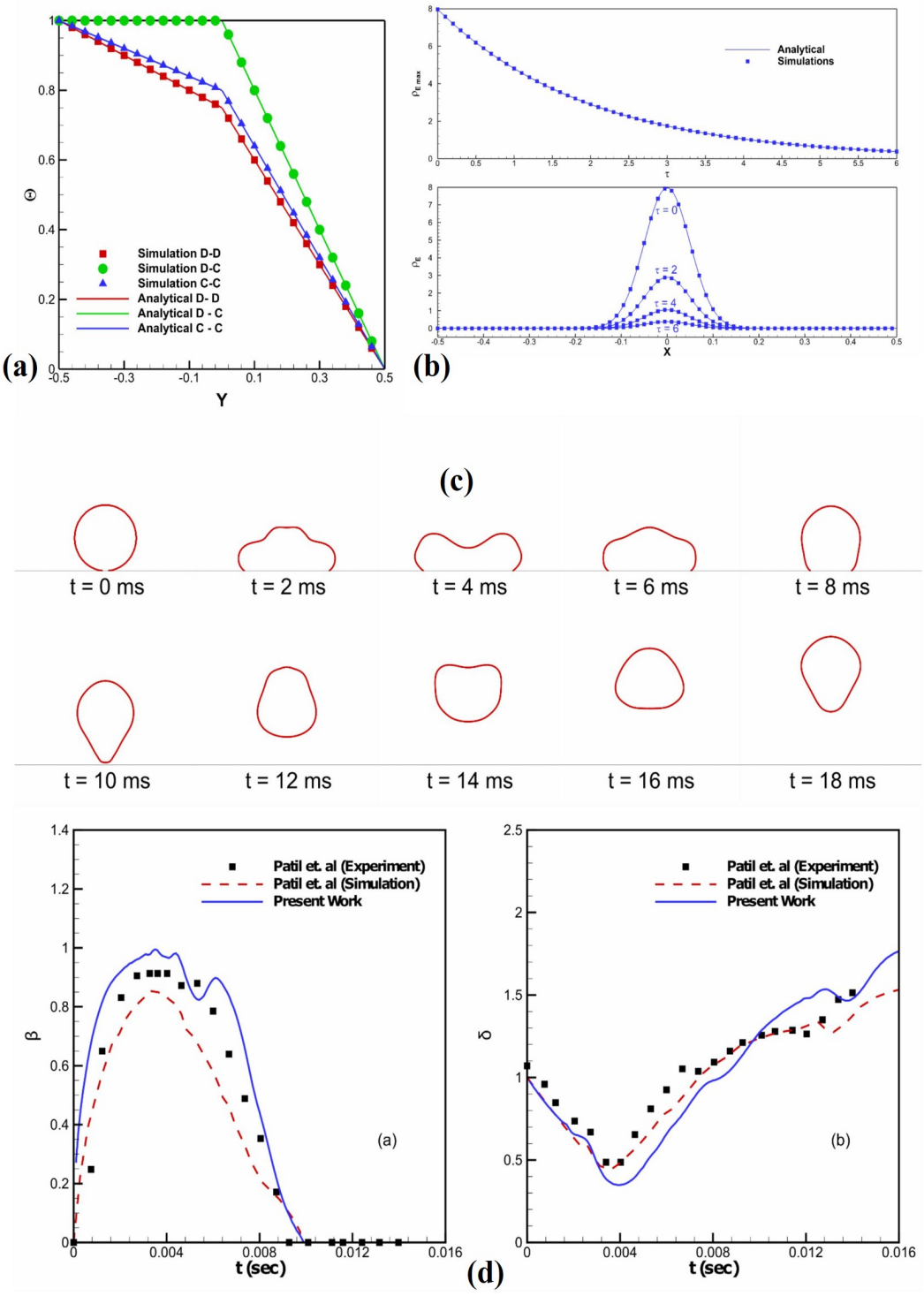

(a) Validation of Jump of Electric Field in Standing Column of 2 different Fluids - D-D: Dielectric-Dielectric, D-C: Dielectric-Conductive, C-C: Conductive-Conductive. The parametric details and analytical solution for the different cases can be found [1]. (b) Gaussian Charge Bump Relaxation - Upper Plot shows Temporal Decay of Maximum Charge Density, Plot Below shows the Temporal Decay

of Charge Density at different location (x-axis). (c) Temporal Evolution of Bouncing Water Droplet on Hydrophobic Substrate, We = 2.73, Re = 578, ,?Rec = 132°, ?c = 147°, ?Adv = 162°. (d) Validation of Simulation Result done against published Experimental Result given in [2], Left Curve: Temporal Evolution of Wetted Diameter (ß), Right Curve: Temporal Evolution of Maximum Droplet Height (d).

#78 - Oral

Comparison Of Initiation And Temporal Evolution Of Positive And Negative Ionic Wind Under Needle-To-Plate Electrode

EHD in gases

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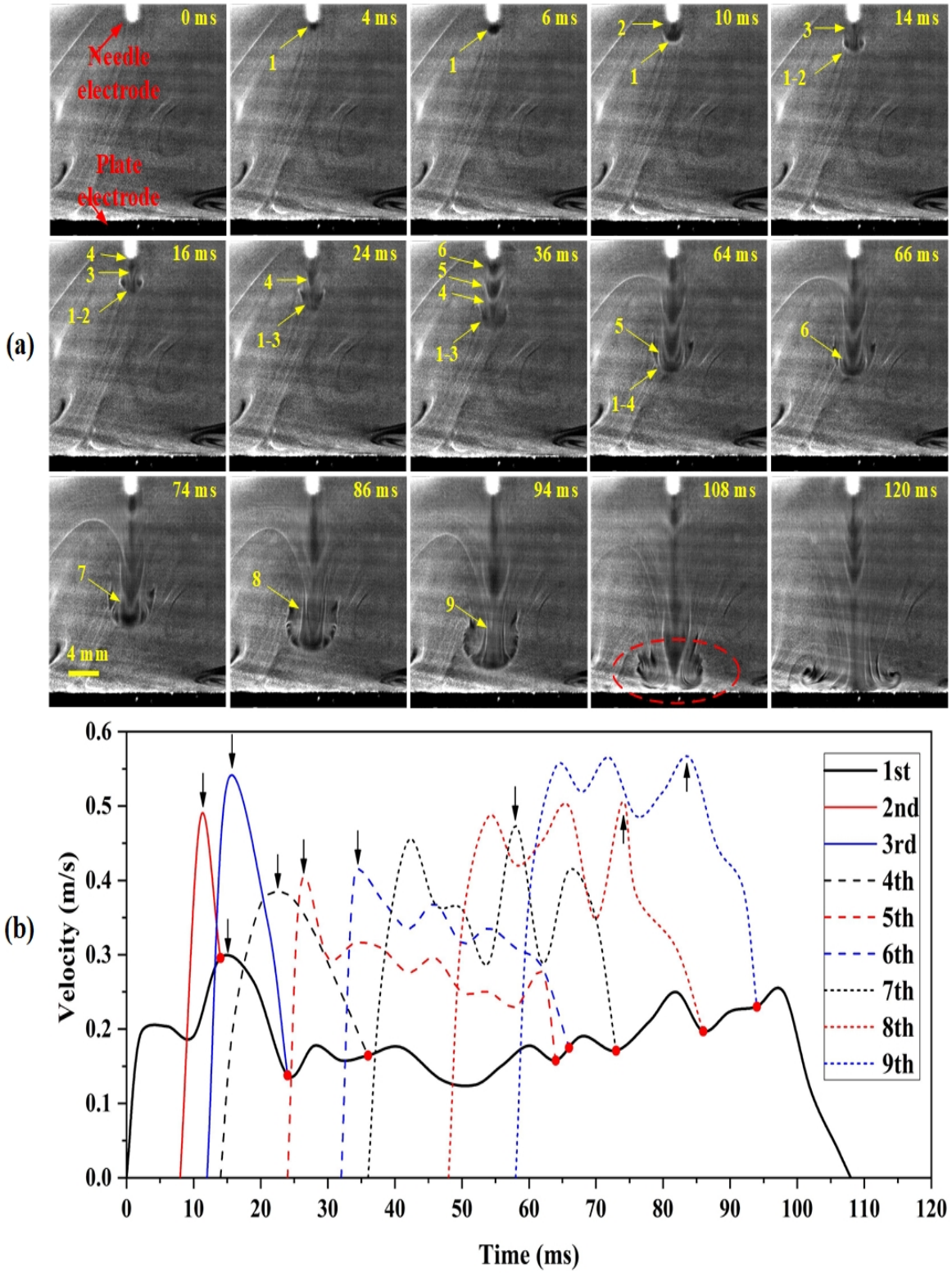
Keywords: Corona Discharge, Ionic Wind, Particle Image Velocimetry (PIV), Temporal Evolution

Abstract Text
Considerable research efforts have been devoted to ionic wind caused by corona discharge. While existing research mostly focuses on the optimization of electrode structure and improving the wind velocity profile, this paper studies the initiation and temporal evolution of the ionic wind produced by both positive and negative corona discharge through particle image velocimetry (PIV) technology, which is fundamentally important and crucial for industrial applications. The results show that there are multiple "small bubbles" in negative corona discharge ionic wind, and for positive ionic wind, that is a "I-shape" vertical and dark strip. The detailed initiation and temporal evolution of positive and negative ionic wind is analyzed through the volt-ampere characteristics, wind field distribution, velocity of wave head and the merging process of various "small bubbles". The experimental phenomenon and possible mechanism are discussed. This research will promote the understanding of the mechanisms of ionic wind produced by corona discharge under various polarities.



Initiation and temporal evolution of corona ionic wind under -4 kV and Velocity curves of different wave heads of ionic wind under -4 kV

#79 - Oral

Liquid Flows Driven By Plasma–liquid Interactions

EHD in liquids

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Keywords: Atmospheric-Pressure Plasma Jet, Plasma–liquid Interactions, Liquid Flows, PIV Measurement

Abstract Text
Understanding the interactions at the interface between plasma and liquid is essential for developing plasma technology involving liquids, such as plasma medicine, plasma agriculture, water treatment, and material synthesis. Plasma-driven liquid flows that can be generated even without any external devices in plasma-irradiated bulk liquid have recently attracted attention as one of the important phenomena caused by physical and chemical interactions at the plasma–liquid interface. Therefore, elucidating the mechanism of plasma-driven liquid flows is crucial to explain their interactions. Various possible driving forces have been proposed; however, the mechanisms remain unclear. Two types of plasma-driven liquid flows with different directions in bulk liquid have already been reported and comprehensively investigated. However, the relationship between the properties of the plasma jet and the two types of liquid flows still needs to be determined. Under such circumstances, we recently succeeded in instant switching control between the two types of plasma-driven liquid flows by changing the plasma generation conditions. The key point of this presentation is “what are the factors affecting the liquid flows?” The possible mechanisms will be suggested with the related experimental data.

#80 - Oral

Molecular Dynamics Simulation Of Electrical Conduction In Room-Temperature Ionic Liquids Under Strong Electric Field

EHD in liquids

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Keywords: Molecular Dynamics, Ionic Liquids, Electrical Conduction, Electric Field

Abstract Text
Room temperature Ionic liquids (RTILs) are a kind of room temperature molten salt completely composed of ions. With the advantages of high conductivity, nonvolatile, chemical stability or wide electrochemical windows. RTILs have been applied in batteries, fuel cells, electrospray thrusters. Recent research classified the RTILs as dilute electrolyte since only a few of ions, called ‘free ions’, contribute to the electrical conductivity and the formation of electrical double layer[1]. In addition, it was found that the number of free ions and, consequently, the conductivity increased with temperature. We use the open-source Molecular Dynamics (MD) code LAMMPS[2] to investigate the electrical conduction of RTILs in strong electric filed (~ 1 V/nm). A modified open-source Python-based post-processor PyLAT[3] is used for data processing. Figure 1 (a) shows the cubic simulation domain. We impose periodic boundary conditions in the directions of space and introduce an electric field in the Z direction. Figure 1 (b) shows that the current increases nonlinearly with the electric field. Unlike the effect of temperature, the number of free ions remains largely unchanged with increasing electric field. Although the distribution of ion coordination number does not change, the frequency at which a given ion changes its coordination number increases with the electric field. This is consistent with the decrease of the ion pair survival time with the electric field. Grotthuss mechanism may explain how the electric field influences the electrical conduction of RTILs under strong electric field. However, a more detailed analysis is needed to better understand the conduction mechanisms at high (~ 1 V/nm) and low electric fields (~ 0.1 V/nm).

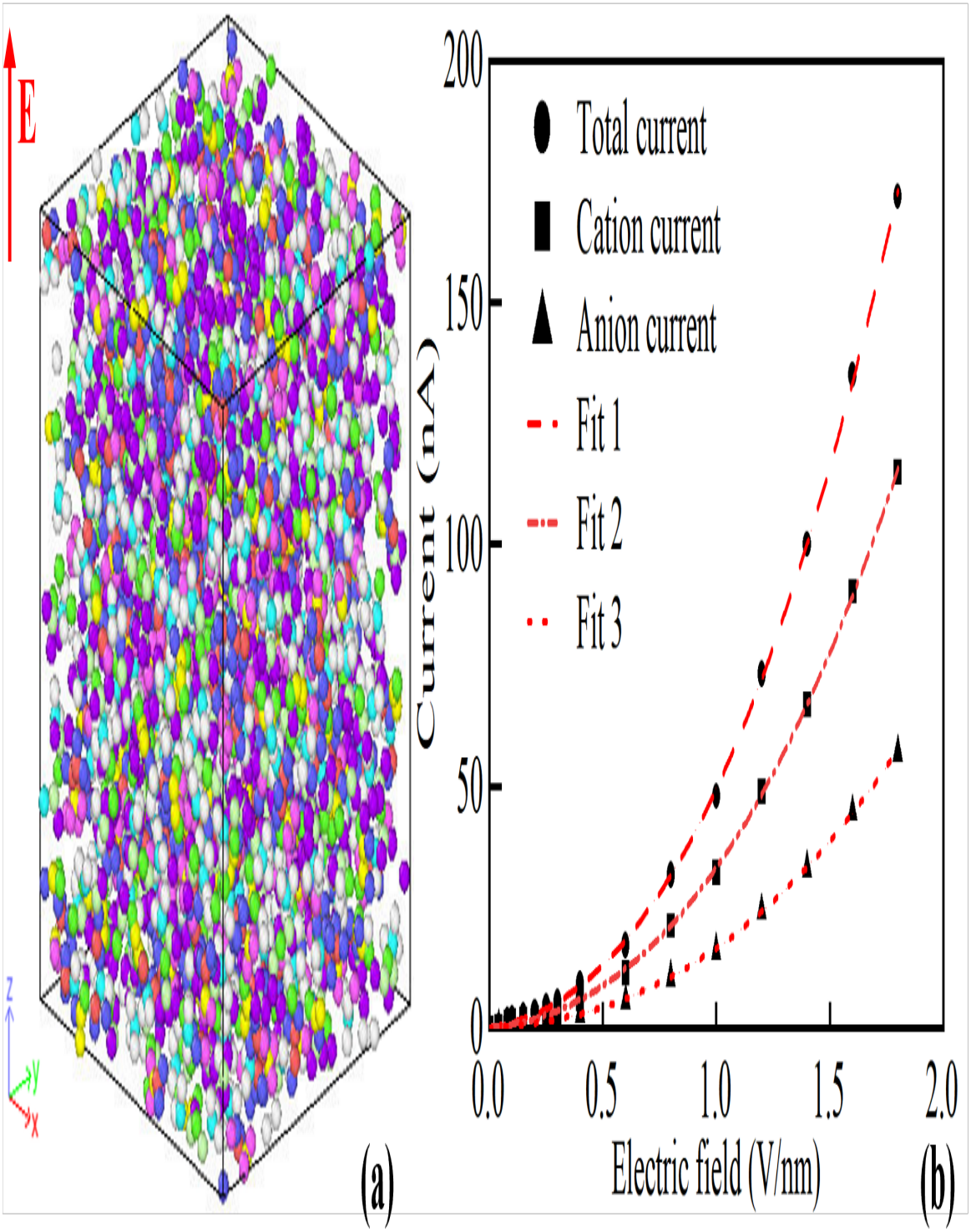

Fig. 1 (a) The cubic simulation domain with periodic boundary conditions. The electric field is along the Z direction; (b) The average total current, cation current, and anion current as a function of the electric field.

#81 - Oral

Plasma Jet Impacting The Surface Of A Liquid: Electrical Analysis And Electrohydrodynamic Flows

EHD in liquids

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Keywords: EHD In Liquids, Plasma Jet

Abstract Text
Argon and helium plasma jets are widely studied for their applications in medicine, biology, and chemistry. When a plasma jet comes into contact with the surface of a liquid, many physical phenomena occur. First, the contact between the plasma jet and water modifies its physical and electrical properties. Second, the plasma jet results in a flow inside the liquid due to several forces. The main goal of the present experimental work is to study this flow.

To produce the plasma jet, a high voltage sine wave is applied between a needle placed inside a glass tube and a conductive ring located around the external wall of the glass tube (internal and external diameters of 4 and 6 mm), the distance between the needle tip and the ring being equal to 1 mm. (Fig.1).
Then, if a flow of helium is produced inside the glass tube, a dielectric barrier discharge is ignited between the needle and the ring, and for certain values of voltage, frequency and flow rate, a visible plume of plasma can be observed at the outlet of the glass tube, called plasma jet (Fig.1).

During the oral presentation, we will first present the role of the input parameters (voltage, frequency, helium flow rate) on the electrical properties of the plasma jet, and its length. Secondly, we will analyze the flow inside the liquid (pure water in our case) with the help of a particle image velocimetry system (PIV). Fig.2 shows an example of the liquid flow with and without plasma. When there is only the helium jet (plasma off, on the left), the liquid flow is due to the helium flow along the water surface. When the plasma is on (on the right), the liquid flow is reinforced, due to the EHD forces occurring at the liquid surface and inside the liquid.

Fig. 1. Experimental setup.

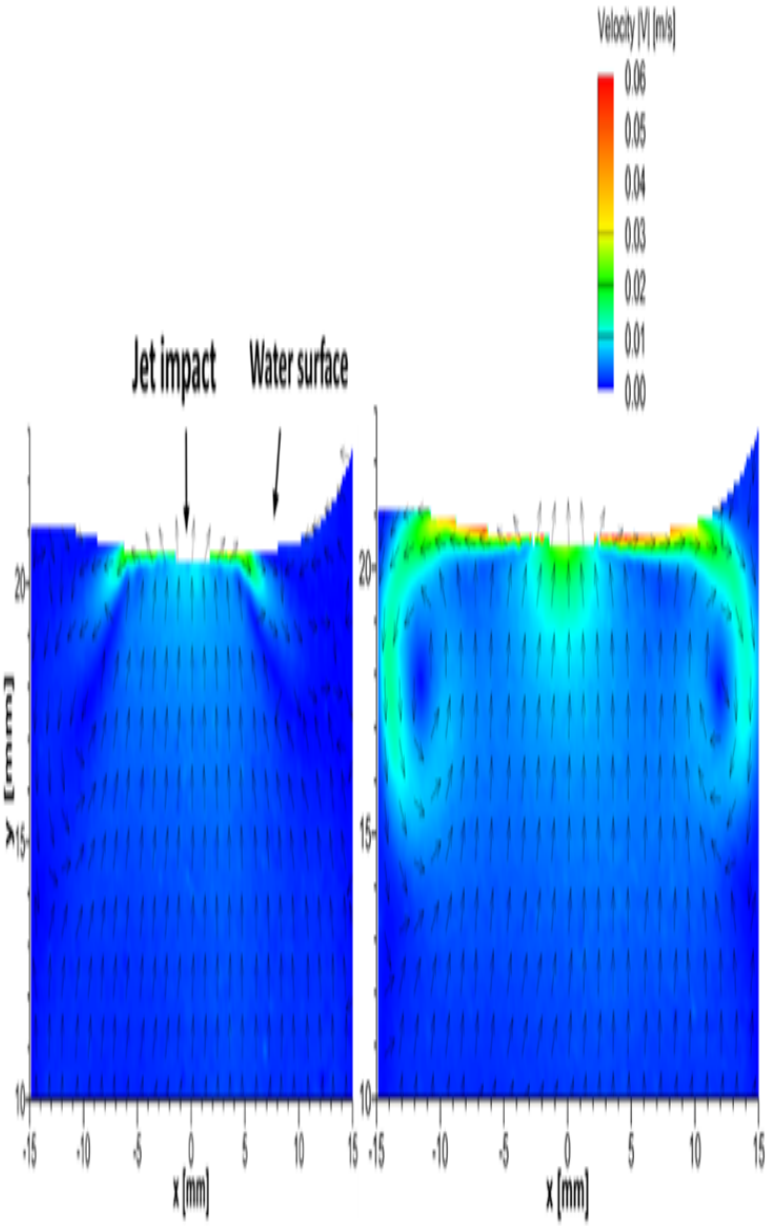

Fig. 2. Examples of velocity field of the liquid flow with plasma off (left) and on (right).

#82 - Poster

Time Evolution Of The Electrohydrodynamic Water Flow Produced By A Dielectric Barrier Discharge Ignited Above Its Surface

EHD in liquids

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Keywords: EHD In Liquids, Dielectric Barrier Discharge

Abstract Text
Over the past decade, the interaction between non-equilibrium plasmas and liquids has gained increasing significance due to various applications, such as water treatment. In this context, we developed a simple design consisting of a high-voltage needle placed a few millimeters above the surface of the liquid to be treated and a grounded electrode located below the glass tank containing the liquid (Fig.1a). Depending on the values of the applied voltage and its frequency, two discharges regimes have been highlighted: a corona regime (time-averaged current of a few dozens of μA) and a filamentary one (current pulses up to a few A). Moreover, due to different physical phenomena, several mechanical effects can occur: a gas flow induced by the discharge (ionic wind), a deformation of the liquid surface, and a liquid flow, all these electrohydrodynamic (EHD) phenomena currently being investigated by our team.

The experimental study presented here focuses on the EHD flow induced inside the liquid by an AC filamentary discharge ignited above its surface. For this, PIV (Particle Image Velocimetry) measurements have been conducted. Several input parameters have been investigated, including the gap, the liquid conductivity, and the liquid surface tension. For instance, Fig.1b shows an example of the liquid flow (in the Field Of View, FOV, shown in Fig.1a). Moreover, during our experiments, we highlighted that the flow velocity gradually decreases (Fig.1c). We demonstrated that it is due to an increase of the liquid conductivity when the discharge is on.

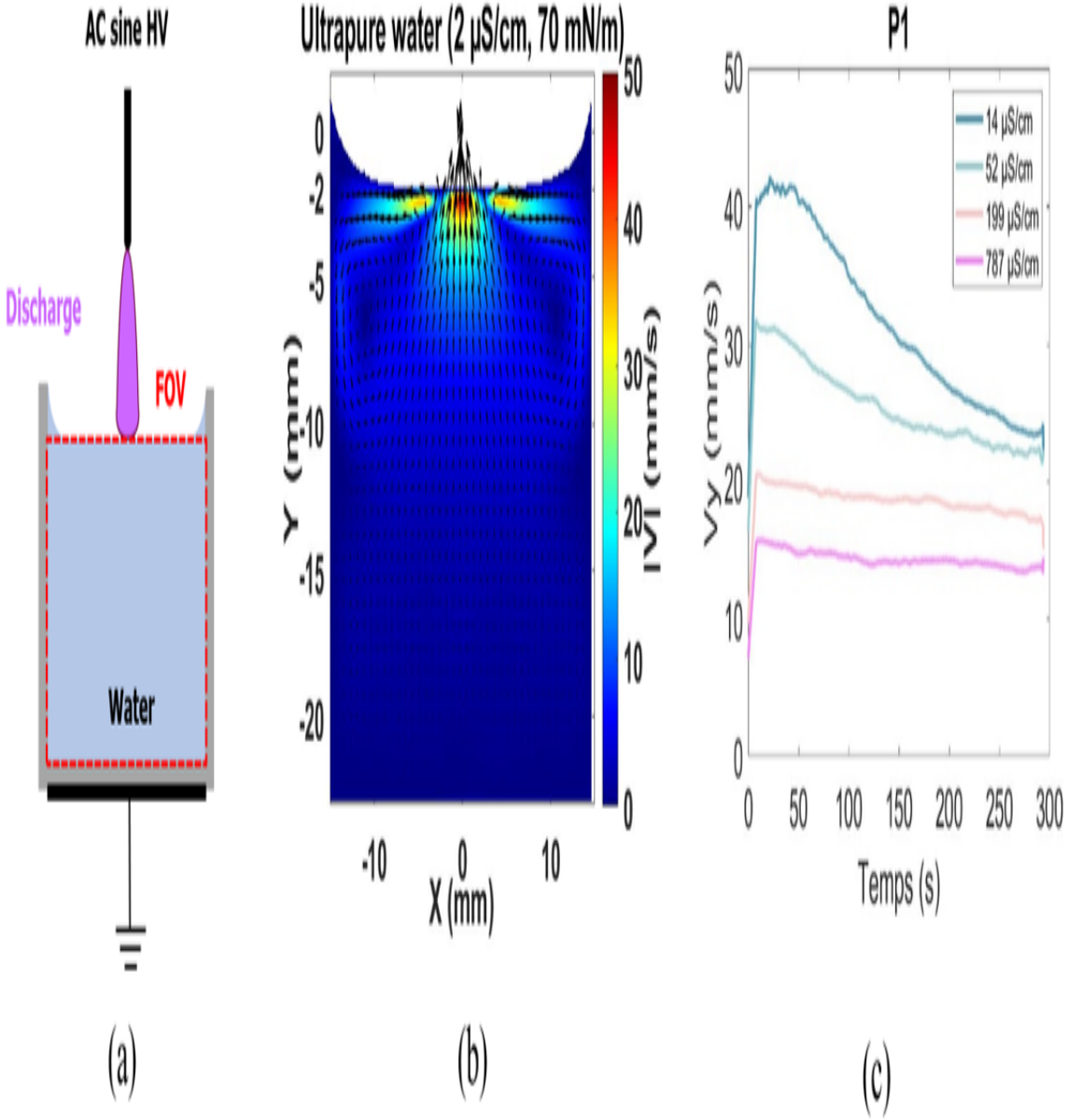

Fig. 1: Scheme of the experimental setup (a), example of water flow (b) and decrease of the velocity versus time (c).

#83 - Oral

Effect Of Voltage Slope On Electrohydrodynamic Force Generation In Pulsed Corona Discharges

EHD in gases

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Keywords: Corona Discharge, Streamer Discharge, Plasma Simulation

Abstract Text
In this study, we investigated the effect of the voltage slope on the generation of electrohydrodynamic (EHD) force in pulsed corona discharges.
We performed plasma simulation and compared the results with experimental results.
The results showed that in positive pulsed corona discharges, the streamers extended from directly below the needle electrode, whereas in negative pulsed corona discharges, the plasma distribution changed significantly, and the plasma spread in concentric circles around the high voltage electrode.
For positive discharges, it was found that the positive ions are generated by ionization at the leading edge of the streamer and spread by the electric field.
The EHD force is generated mainly at the leading edge of the distribution.
For negative discharge, negative ions were generated throughout the plasma distribution avoiding the vicinity of the needle electrode.
The EHD force is mainly generated where negative ions are produced, but the values are smaller than during positive discharge.
Depending on the polarity of the applied voltage, the discharge and the plasma distribution differ greatly, resulting in large differences in the EHD force distribution. This phenomenon has been observed in experiments as a difference in the ion wind distribution.
During positive discharges, the current has a peak at the beginning of the discharge and then decreases.
The integral of the downward EHD force over the entire distribution has a primary peak at the beginning of the discharge and then a secondary peak when the streamer reaches the ground electrode/dielectric.
When the voltage slope is higher, the discharge ignition voltage becomes higher, in addition, the current peak and EHD force peak also becomes higher.
When larger voltages amplitude is applied with the same voltage slope, the discharge ignition voltage becomes higher, and the current peak and EHD force peak are also higher.
Therefore, higher voltage amplitude could lead to more efficient EHD force generation.
Investigating this effect could lead to more efficient EHD force generation.

#84 - Oral

Influence Of Co-Existing Ions On Plasma-Induced Chemical Reactions At Gas–liquid Interface: Investigation Through Halogen Generation

Others

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Keywords: Plasma–liquid Interactions, Gas–liquid Interface, Halide Ions, Co-Existing Ions

Abstract Text
Plasma in contact with liquid is widely investigated aiming for various applications, such as water purification, material synthesis, medical and agricultural applications [1]. However, the mechanisms of such plasma applications have not been fully understood. To reveal their mechanisms, it is important to better understand plasma–liquid interactions, which are physical and chemical phenomena occurring at the gas–liquid interface. In our previous study, based on characteristics of halogen concentrations produced by plasma from halide (Cl^-, Br^-, and I^-) ions, we suggested a possibility that short-lived active species generated by plasma could react with solutes only at the topmost layer of the water surface [2]. In this study, to explore this possibility, we investigated how the characteristics of halogen generation were changed depending on co-existing ions with the halide ions. This is because we expect that the co-existing ions can alter the concentrations of halides ions at the topmost layer of the water surface, which probably changes the halogen concentrations generated by plasma in contact with liquid. In our experiments, a high voltage (H.V.) electrode was located above the water surface, and a grounded electrode was partly immersed in water. By applying DC high voltage between the H.V. electrode and the water surface, a DC plasma was generated between them. Fig. 1 shows iodine concentrations when the DC argon plasma was irradiated to a mixture solution of sodium iodide (NaI) and sodium perchlorate ($NaClO_4$) for 60 s. According to this figure, the iodine concentrations decreased with the increase in perchlorate (ClO_4^-) ions. However, this decrease would not be caused by reactions involving ClO_4^- ions because it is known that these ions do not react with OH radicals. Therefore, there is a possibility that the co-existing ClO_4^- ions could change the concentrations of the iodide (I^-) ions at the topmost layer of the water surface, which probably lead to the decrease in the iodine concentrations after the plasma irradiation.

This work was partially supported by JSPS KAKENHI Grant Number JP22K14244.

[1] S. Samukawa et al., J. Phys. D: Appl. Phys., 45, 253001 (2012).
[2] K. Tachibana and K. Yasuoka, J. Phys. D: Appl. Phys., 53, 125203 (2020).

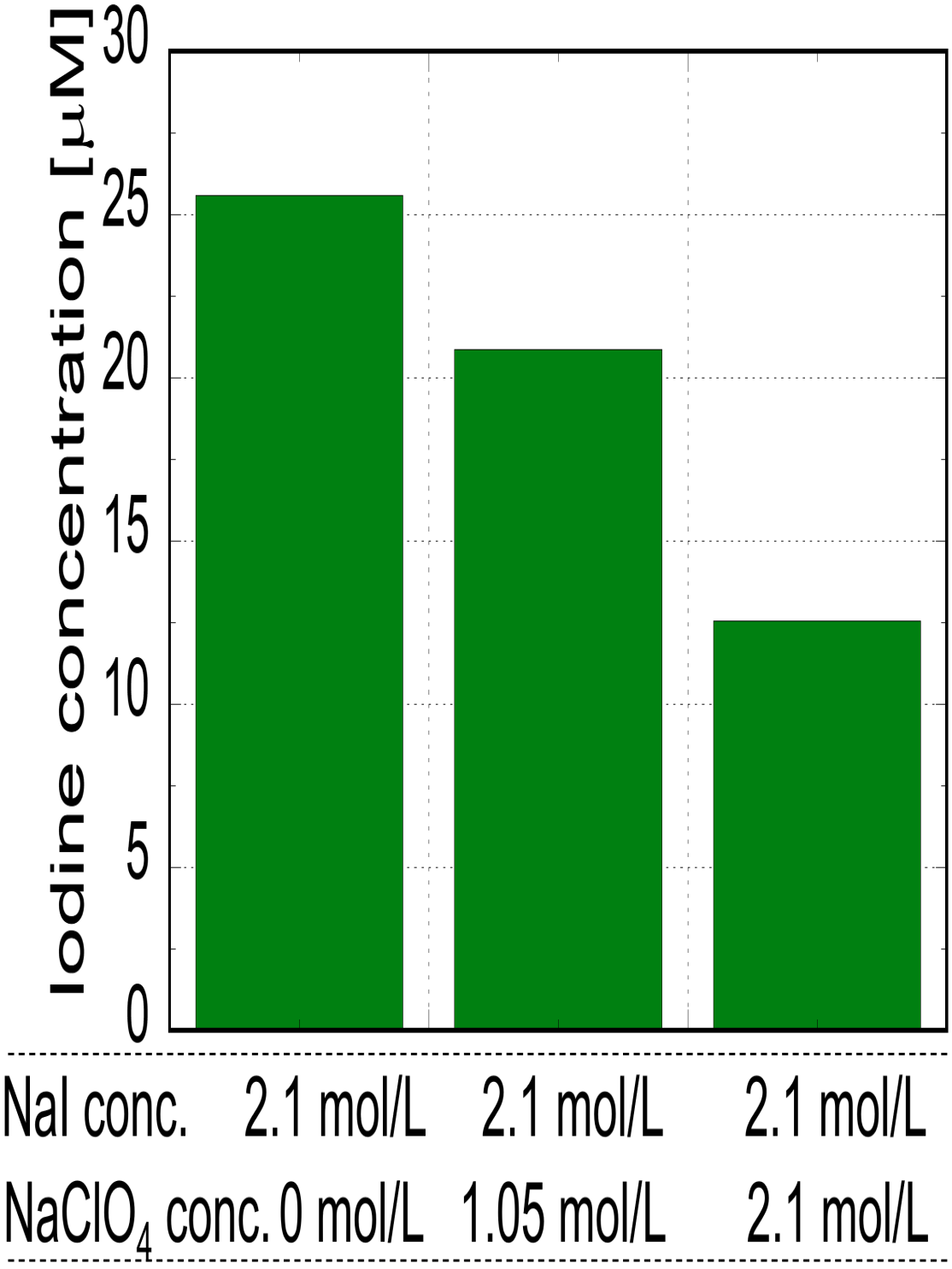

Fig. 1 Iodine concentrations when a DC argon plasma was irradiated to a mixture solution of sodium iodide and sodium perchlorate for 60 s.

#85 - Oral

The Method Of Determining Ion Mobilities In A Liquid Dielectric In A Wire-Cylinder Electrode System Based On Current Characteristics

Others

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Keywords: Dielectric Liquid, Ion Mobility, Heterocharge Layers, Current Characteristics

Abstract Text
A significant challenge in the study of electrohydrodynamic processes is the lack of knowledge of the mobility of ions in dielectric liquids. This work introduces a novel method for determining ion mobility by analyzing current waveforms generated in a wire-cylinder electrode system under an applied voltage. During current flow, heterocharge layers form near the electrodes, where ions of the opposite sign dominate the charge transport. This localized imbalance of charge carriers causes a noticeable drop in the current level, providing valuable insights into ion mobility.

The change in integral electrical conductivity is primarily influenced by processes near the wire electrode, where stronger electric fields lead to thicker ion depletion layers, combined with the inherently small cross-sectional area. By selecting the polarity of the wire electrode, it becomes possible to isolate processes where the mobility of ions of a specific charge plays a dominant role.

As part of the method, a numerical model was developed in the present work to simulate the experimental setup. The model demonstrates how key liquid parameters, such as electrical conductivity, ion mobility, and recombination coefficients, influence the formation time of heterocharge layers and the observed current drop. Importantly, computer modeling shows that, in the absence of ion injection, the mobility of ions can be determined from current waveforms.

The significant advantage of this method is its ability to measure the mobility of ions generated intrinsically within the liquid, rather than those introduced by external factors. Currently, an experimental setup is under development to investigate the possibility of determining ion mobilities using this method. Challenges related to capacitive currents and ion injection at low voltages, as observed in preliminary data, are being addressed. While the method is still in development, it shows significant potential as a tool for investigating ion mobility in dielectric liquids.

#86 - Oral

The Minimum Flow Rate Scaling Of Taylor Cone-Jets Of Highly Viscous Liquids

EHD of multi-phase flows

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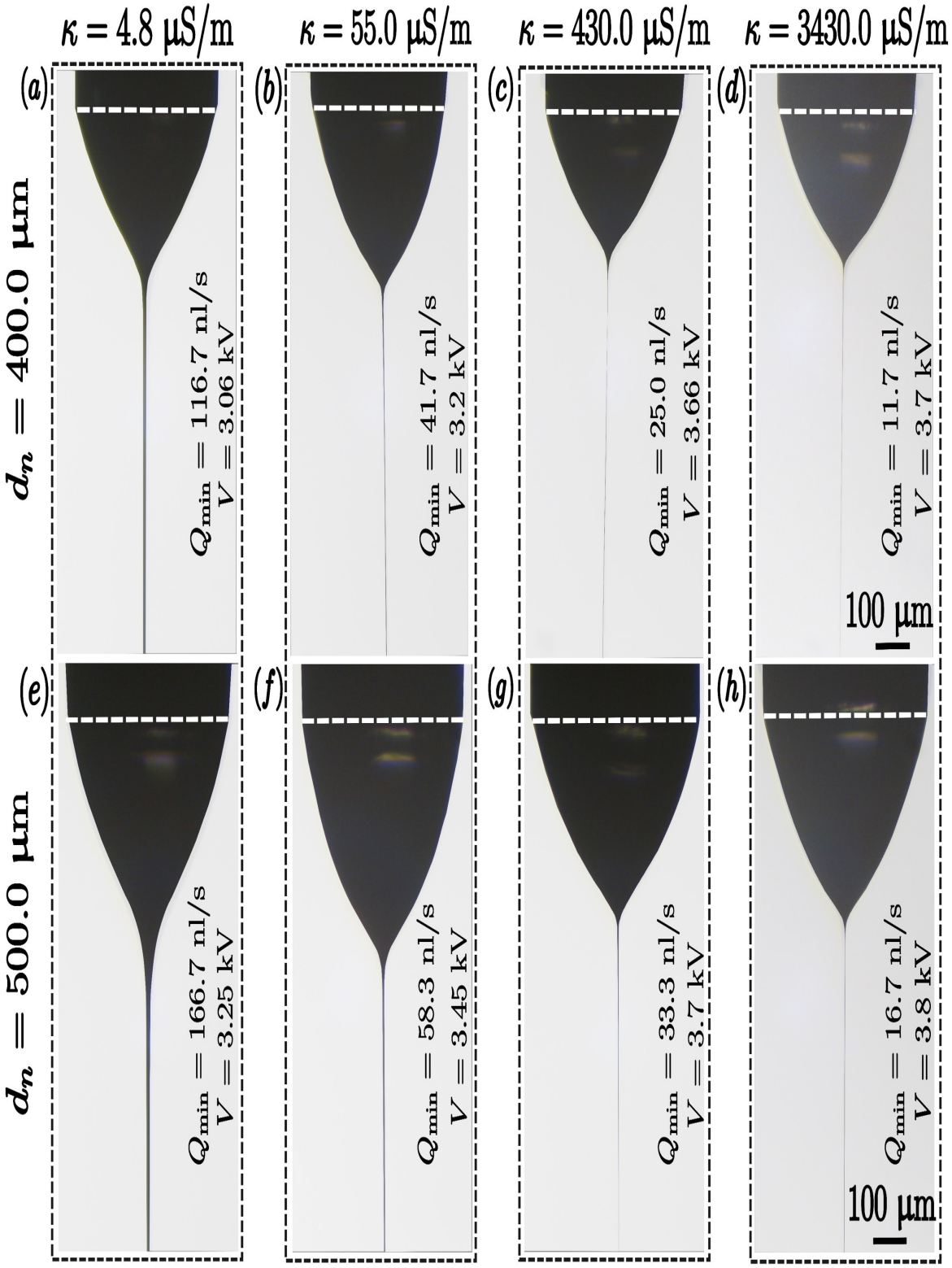
Keywords: Taylor Cone-Jet, Minimum Flow Rate, Electrohydrodynamic Jet Printing, Microfluidics

Abstract Text
Applying a high voltage to a liquid meniscus held at the exit of a metallic nozzle results in Taylor cone formation, whose tip emits a fine jet. Steady cone-jetting is essential for applications such as electrospraying, electrospinning and electrohydrodynamic jet (EHD-jet) printing. However, steady cone-jetting occurs only when the flow rate exceeds a threshold value. It is well documented that this minimum flow rate for steady cone-jetting of a less viscous liquid is independent of the nozzle diameter and depends only on the properties of the liquid. In this study, through experiments and scaling analysis, we demonstrate that the minimum flow rates of highly viscous solutions, such as salt-doped glycerol, depend significantly on the nozzle diameter, besides depending on the solution properties. We derive the scaling relations for the minimum flow rate and the corresponding jet diameter by balancing the viscous and the interfacial forces in the cone region and viscous and electrostatic suction forces in the cone-to-jet transition region. The derived scaling relations for the minimum flow rate and the corresponding jet diameter show excellent agreement with the experimental data available in the literature and our experiments for liquids with electrical conductivity ranging over five orders of magnitude. Furthermore, we also establish the regime under which the derived scaling laws hold, where the minimum flow rate depends on the nozzle diameter. Lastly, we briefly discuss the effect of viscoelastic flow behaviour on the minimum flow rate, given that electrospinning and EHD-jet printing usually employ polymeric solutions. The description of the minimum flow rate for the formation of Taylor cone-jets of highly viscous and polymeric solutions can be helpful for choosing the correct process parameters for steady cone-jetting in practical processes.



Snapshots of steady Taylor cone-jets of salt-doped glycerol solutions at the minimum flow rate condition. We infer from these experimental observations that the minimum flow rate of steady EHD-jetting of a highly viscous solution depends on both the needle size and the electrical conductivity of the solution.

#87 - Oral

Experimental Investigation Of Electrocoalescer Unit Prototype For Numerical Models Verification

EHD of multi-phase flows

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Keywords: Electrocoalescence, Two-Phase Electrohydrodynamics, Electrostatic Oil Cleaner, Water-In-Oil Emulsion

Abstract Text
During the last 10 years, a lot of numerical models were developed to describe and investigate electrical coalescence of conducting droplets suspended in insulating oil. One part of these models is based on the pair droplet interaction, while another part tries to describe a multiple droplet system. The former models provide quite exact droplet dynamics and can yield quantitatively correct results for several droplets, while fail to describe emulsion evolution under the effect of the electric field. The latter ones can be applied for the description of an emulsion behavior but are not so exact and utilize many simplifications (e.g., dipole-dipole approximation of droplet interaction). The key issue is the quantitative models verification using suitable experimental data.
The study is devoted to a collection of experimental data on emulsion evolution, which can be appropriate for thorough checking the correctness of various numerical models and conclusions made on their base. We created a lab scale electrocoalescer unit prototype with moderately uniform electric field distribution that simplifies creation and application of various computational models. The electrostatic oil cleaner was filled with transparent two-phase liquid—a water-in-oil emulsion with grape-seed oil being used for the continuous phase.
A number of video recordings were made for various values of input parameters—applied voltage, water content and droplet size distributions. Several assumptions, that were earlier made based on the numerical models, were experimentally tested. The observed experimental data can be used for the verification of computer models describing emulsion behavior under the effect of the electric field.

#89 - Oral

The Effect Of Polarity Change On An Asymmetric Cylinder-To-Cylinder EHD Device

EHD in liquids

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2. University of Balamand, Balamand, Lebanon

Keywords: Electrohydrodynamics , Hydrofluoroether-7100, Micro-Pump, Particle Image Velocimetry

Abstract Text
Since the 1960s, electrohydrodynamics (EHD) has attracted significant research interest, particularly for its potential in developing EHD micro-pumps. These pumps offer advantages such as low power consumption, absence of mechanical vibrations, and straightforward fabrication, making them ideal for space applications and other environments requiring thermal management of electronic devices. Despite these benefits, EHD pumps often exhibit lower efficiency compared to other fluid transport technologies, limiting their broader application.
A crucial factor influencing EHD pump performance is the geometry and placement of electrodes, which significantly affect electric force distribution and fluid motion. Various electrode configurations, such as blade-blade and point-blade arrangements, have been studied, each demonstrating unique impacts on current distribution, fluid velocity, and overall pump efficiency. These studies highlight the importance of optimizing electrode design to enhance pump performance.
Previous research focused on a symmetric cylinder-to-cylinder EHD configuration to ensure a conduction-dominated electric force regime, avoiding charge injection for a more controlled environment. Under these symmetric conditions, it was observed that polarity had little effect on fluid velocity and vortex size, although it mirrored vortex shape and position relative to the vertical axis.
This study extends previous findings by numerically and experimentally analyzing the effects of polarity manipulation in an asymmetric cylinder-to-cylinder system with a fixed electrode gap. The results indicate that varying polarity between asymmetric electrodes significantly alters fluid dynamics, impacting vortex morphology, location, and fluid velocity. These changes are attributed to ionic mobility ratios within the fluid and the electric field intensity between asymmetric cylinders.
By demonstrating how polarity changes in asymmetric systems influence EHD pump behavior, this work provides valuable insights for optimizing EHD pump configurations. The findings contribute to a deeper understanding of EHD systems and offer potential improvements in thermal management applications where precise fluid control is essential.

#90 - Poster

Application Of The Arbitrary Lagrangian–Eulerian Approach To Simulate Two-Phase Electrohydrodynamics Of Low-Conducting Droplets In Low-Conducting Dispersion Medium

EHD of multi-phase flows

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Keywords: Electrical Coalescence, Numerical Simulation, Air Bubble Electrodeformation, Dielectrophoretic Forces

Abstract Text
Numerical simulation of electrohydrodynamic processes in two-phase immiscible liquids is still a challenging task though a lot of models are available for such computations. One of very promising approaches—the arbitrary Lagrangian–Eulerian (ALE) method—has been successfully applied recently to simulate electrical coalescence of two electrically conducting droplets suspended in a dielectric fluid. However, the case of electrically conducting droplets is much simpler than the case of less conducting suspended medium due to the following. In the former case, electrostatic forces act only along normal direction and the surface-charge relaxation time is negligible.
The present study is devoted to corresponding modification of the ALE model and its implementation in COMSOL Multiphysics software. The new models considers the following:
- both normal and tangential projection of the electrostatics forces;
- droplet-surface charging owing to emerging ion fluxes after the electric field change or volume alteration (e.g., due to droplet electrodeformation);
- surface charge convection for rotating droplet.
The modified model was applied to simulate several specific tasks to check its correctness. In particular, the modeling of air bubble shape change under AC electric field with various frequencies was done. The model can be applied for computation of low-conducting droplets and bubbles behavior under the electric field.

#91 - Oral

Impact Of Seeding Particle Properties On PIV Accuracy In Electrohydrodynamic Systems

EHD in liquids

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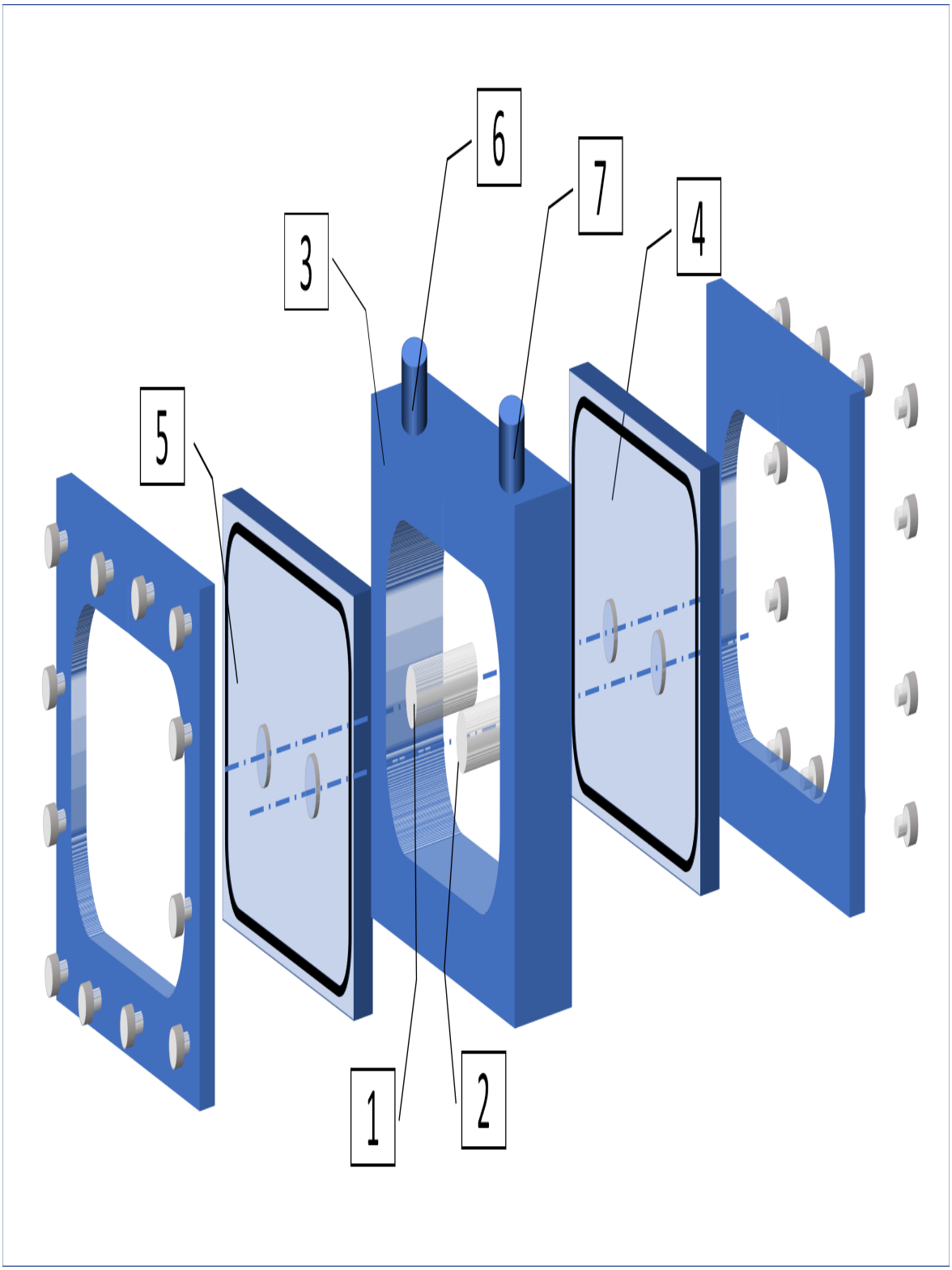
Keywords: Dielectric Liquid, Electrohydrodynamics, Particle Image Velocimetry, Seeding Particle

Abstract Text
Particle Image Velocimetry (PIV) is a widely utilized technique for visualizing fluid flows, enabling the capture of instantaneous velocity fields with a single measurement. This method requires introducing fine tracer particles into the fluid, which are illuminated by a laser source, and their motion is recorded to determine the velocity distribution. However, in electrohydrodynamic (EHD) systems, the use of these particles introduces additional challenges due to their interaction with the applied electric field. One key concern is the accumulation of electric charges on the particles' surfaces, which can alter the electric field distribution. Additionally, charged particles may travel at velocities different from the surrounding fluid, violating the fundamental assumption of PIV that the particles accurately track fluid motion. Further issues include particle clumping, filament formation, or adhesion to solid surfaces, which can hinder charge transfer in the dielectric liquid. In extreme cases, the particles may absorb all available charges, neutralizing the fluid and reducing its motion. These phenomena depend strongly on the type of fluid and tracer particles used.
In this study, five types of particles were examined: PMMA (polymethyl methacrylate), POM (polyoxymethylene), PTFE (polytetrafluoroethylene), SiO_2 (silicon dioxide), and Vestosint. Experiments were conducted on a hydrofluoroether dielectric liquid (HFE-7100) in a symmetric cylinder-to-cylinder configuration, with a DC voltage applied between the electrodes. To ensure consistent results, the repeatability of PIV measurements was evaluated across multiple experimental runs. In addition, the migration velocity of tracer particles relative to the fluid was analyzed for various particle types to understand their influence on measurement accuracy. The results demonstrated that fluid behavior varied significantly with the particle type. This indicates that the properties of the seeding particles affect the performance of the EHD apparatus. These findings emphasize the importance of selecting appropriate tracer particles to ensure accurate PIV measurements, particularly in the presence of electric fields where particle-fluid interactions can rigorously affect experimental outcomes.



Exploded view of the EHD apparatus

#92 - Oral

Finite Taylor Cone: The Impact Of The Electrospray

Electrostatics

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Keywords: Electrospray, Taylor Cone

Abstract Text
When a conductive liquid flows out of a needle under the effect of an electric field, a conical shape may be exhibited for a certain range of the the electric field strength and a jet or a spray is ejected from its apex. The first attempt to model this situation was carried out by Taylor (1964), who simplified the geometry to an infinite cone and stablished the given value of the strength of the electric field that is in equilibrium with the surface tension and the semiangle of the cone, known as the Taylor cone angle α. Later, Fernández de la Mora (1992) included in the analysis the influence of the emitted electrospray that modifies both the strength of the electric field and the cone angle, and Pantano et al. (1994) considered the shape of the electrodes and finite value of the cone volume without the spray.
In this work, we take into consideration both (1) the influence of the cone finiteness and geometry of the device, and (2) the mutual impact of the electrospray.
In fig. 1 (left), we can observe the electrode and needle (in dark blue) connected to a high voltage, the grounded counterelectrode (in dark red) and the computed shape of the cone as a result of the balance between surface tension and electrostatic stresses. The electrospray volumetric charge is also considered, although not shown. In fig. 1 (right), we have depicted the cone shape that depends on its volume and the electric Bond number. We can observe that, the Taylor cone angle is locally reproduced at the cone apex, despite its deformation far from this region.

These simulations reproduce the results by Pantano et al. (1994) and extend it to consider the influence of the electrospray.

As part of the results, we have obtained the range of feasible electric Bond number, based on the applied voltage and geometry of the device, while locally reproducing the one obtained by Taylor at the apex. It has been done for several values of the electric current carried by the electrospray, hence shedding light on how the electrospray influences the cone.

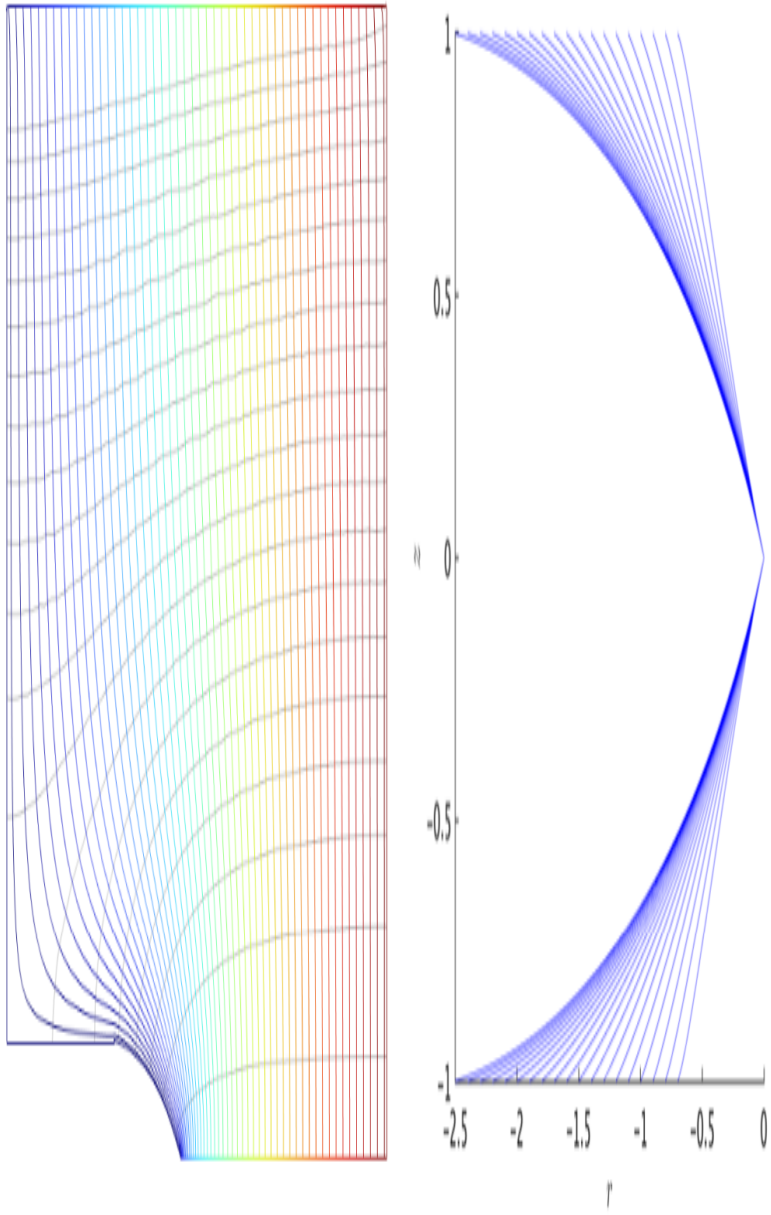

Fig. 1. (left) Sketch of electric potential (color map) and electric field (streamlines) in an electrospray device with deformable meniscus. (right) Taylor cones shape for varying electric Bond number and corresponding volumes.

#93 - Oral

Electrokinetic Effects in Cone-Jet Electrospraying: Ion Size and Solvent dependence

EHD of multi-phase flows

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Abstract Text
This study investigates the often overlooked role of electrokinetic phenomena in the cone-jet mode of electrospraying. Using numerical simulations, we analyze the influence of ion size and solvent properties on the electrospraying process, particularly at the critical transition region from cone to jet. Contrary to the simplified leaky dielectric model, our results reveal that ion characteristics impact the electrical current and jet diameter. Notably, smaller ions (¡ 1 ˚A) lead to a substantial increase in current and a decrease in jet size due to stronger ionic bonds and higher dissociation rates. We also examine the spatial distribution of charge density and species concentrations in the transition region, highlighting the complex interplay between electrokinetics, fluid dynamics, and ion transport in determining electrospray behavior. These findings underscore the need for a more comprehensive understanding of electrokinetic effects to accurately predict and control electrospray performance.

#94 - Oral

Effective control method of high Reynolds number flow around airfoil using plasma actuator

EHD in gases

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Abstract Text
Dielectric barrier discharge plasma actuators have gained prominence as active flow control devices using electrohydrodynamic force. Previous studies have shown that plasma actuators can suppress laminar flow separation around an airfoil by promoting turbulent transition. Whereas, at higher Reynolds number, turbulent flow separation occurs after the flow transitions to turbulence. In this case, there are two challenges: first, the velocity induced by plasma actuators is small compared to the mainstream flow; and second, because the separation occurs after the flow transitions to turbulence, the method that is effective for laminar separation cannot be applied. The authors explore the effective methods for controlling such high Reynolds number flows around an airfoil with turbulent separation. To achieve this objective, we consider two strategies; the first is increasing the induced flow velocity of plasma actuator by arranging the multiple elements of plasma actuators in tandem; the second is to induce a flow by plasma actuator in the opposite direction to the mainstream at the turbulent separation point, thereby forming strong large-scale vortices. In the presentation, we will discuss the usefulness of these two strategies to turbulent separation control from two-dimensional electrohydrodynamic simulation using Suzen-Huang model, which can evaluate the body force of plasma actuators effectively.

#95 - Poster

Experimental study of particle removal by dielectric barrier discharge

EHD in gases

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Abstract Text
Avoiding the adhesion and accumulation of particles on surfaces is extremely important in numerous technological and industrial applications, such as in the pharmaceutical, cement, or food sectors, where fine powdery materials are transported through pipes, or in photovoltaic power plants, where the presence of particles on the panels reduces their efficiency. Accumulated particles on surfaces can be removed using the electrostatic and electrodynamic forces that arise in electrical discharges, particularly in corona and dielectric barrier discharges. During the development of the discharge, particles become electrostatically charged and, moreover, they are subjected to the effect of the ionic wind generated by the discharge itself. Both factors decisively contribute to rapid removal of particles from the surface.
In the present work, we investigate the removal of fine CaCO3 particles from a surface using dielectric barrier discharge (DBD). The DBD reactor consisted of a FR-4 glass epoxy board, 60 mm long and 30 mm wide, on the top of which an array of 14 copper strips, 1 mm wide, were arranged in parallel separated by 3 mm. Similarly, on the lower side, 15 parallel copper strips were also distributed. Each strip on the upper side was equidistant from two strips on the lower side. Four different kinds of CaCO3 particles, with predominant particle size of 15 μm, 30 μm, 45 μm and 80 μm, were used in the experiments. When the DBD reactor is energized, the CaCO3 particles (1 g of mass) deposited on the glass epoxy board are progressively swept from the surface of the dielectric by the effect of Coulomb force and the ionic wind. To measure the efficiency of the DBD in removing the CaCO3 powder, the mass of particles ejected over time was measured using an analytical balance, with a resolution of 0.1 mg. The figure below shows the experimental results obtained when the DBD is driven by a frequency of 50 Hz. The particle size plays a determinant role in the rate of particle removal, since particles adhesion increases as particle size decreases.
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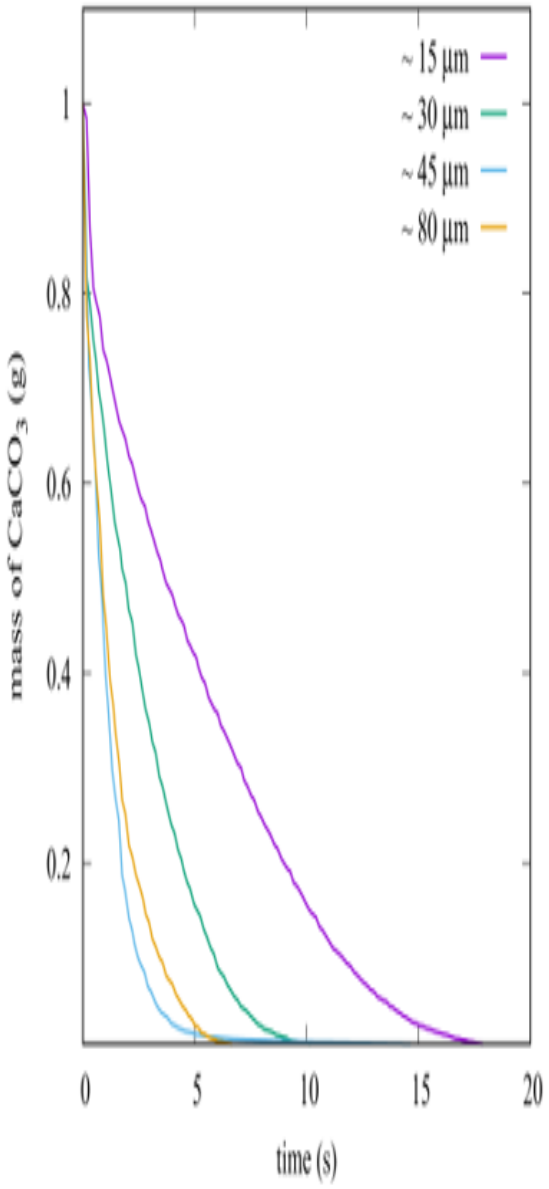

Temporal evolution of the mass of $CaCO_3$ particles using different particle sizes. DBD was operated at 50 Hz with a peak-to-peak amplitude of 18 kV.

#96 - Poster

Characteristics of single-phase gliding arc equipment with twisted electrodes and radial gas injection

EHD in gases

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Keywords: Gliding Arc Discharge, Environmental Protection, Nonthermal Equilibrium, Twisted Electrodes

Abstract Text
Gliding arc discharge is one of the newer types of atmospheric pressure discharge, published in 1989. It is currently developing important applications in exhaust gas treatment, water treatment and carbon dioxide fixation. However, the non-steady state of discharge mechanism has led to a number of difficulties. It is important to note that the discharge path rises from the lower end of electrodes and heads towards the top, then arcs extinction, but there is a considerable amount of time when the discharge path is not in existence until it re-ignites at the lower end. During arc extinction, the working gas is just passing through the electrodes and inside the discharge tube. Multi-electrode type and tornado type have been proposed to solve the problems, but all of them lead to increased structural complexity. In this study, twisted electrodes were proposed in a basic single-phase gliding arc structure to reduce the problem of non-steady state. Discharge path of the gliding arc is strongly dependent on the operating gas velocity in the shortest distance zone of electrodes, while the gas introduction other than in the downstream direction of electrode was also strongly dependent on the discharge path. The structure of the twisted electrodes with gas introduction into the radial direction of the discharge tube was a classical single-phase gliding arc, but it was found to be capable of providing a plasma volume equivalent to that of multi-electrode type.

#97 - Oral

Fully 3D Numerical Computations of the Unipolar Injection between an Hyperbolic Blade and a Plane Electrode

EHD in liquids

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Keywords: Blade-Plane Configuration, Numerical Simulation, Finite-Volume Method, Conduction Phenomenon

Abstract Text
A dielectric liquid with low conductivity can be set into motion by an external electric field. The primary driving force behind this is the volumetric Coulomb force, which acts on free charge carriers due to the electric field. There are two main sources of space charges in an isothermal liquid: the field-enhanced dissociation of ionic pairs in the bulk liquid and the injection of charges at the electrode/liquid interface. In this study, we introduce an efficient numerical algorithm based on the finite volume method for an injection-dissociation model that accounts for both sources of space charges. This numerical solver is used to simulate electrically induced flows of dielectric liquid in a hyperbolic blade-plate configuration, highlighting the differences between injection and conduction-induced flow motions. In the first part of the study, we numerically demonstrate that under high applied voltage, ions are injected from the blade and move towards the opposite plate electrode, resulting in a jet-like or plume-like motion. Conversely, when the applied voltage is low and thus injection can be negligible, the conduction mechanism leads to a hetero-charge layer around the blade electrode, inducing a motion that directs from the plate to the blade. Particular care should be paid to the fact that the two ionic species involved in the dissociation process do not necessarily have the same ionic mobility. We shall analyse the conditions that lead to a switch between conduction mechanism to injection one. We examine and highlight the conditions leading to this transition from the conduction mechanism to the injection one within the same flow. This transition is both performed and simulated within the same computation.

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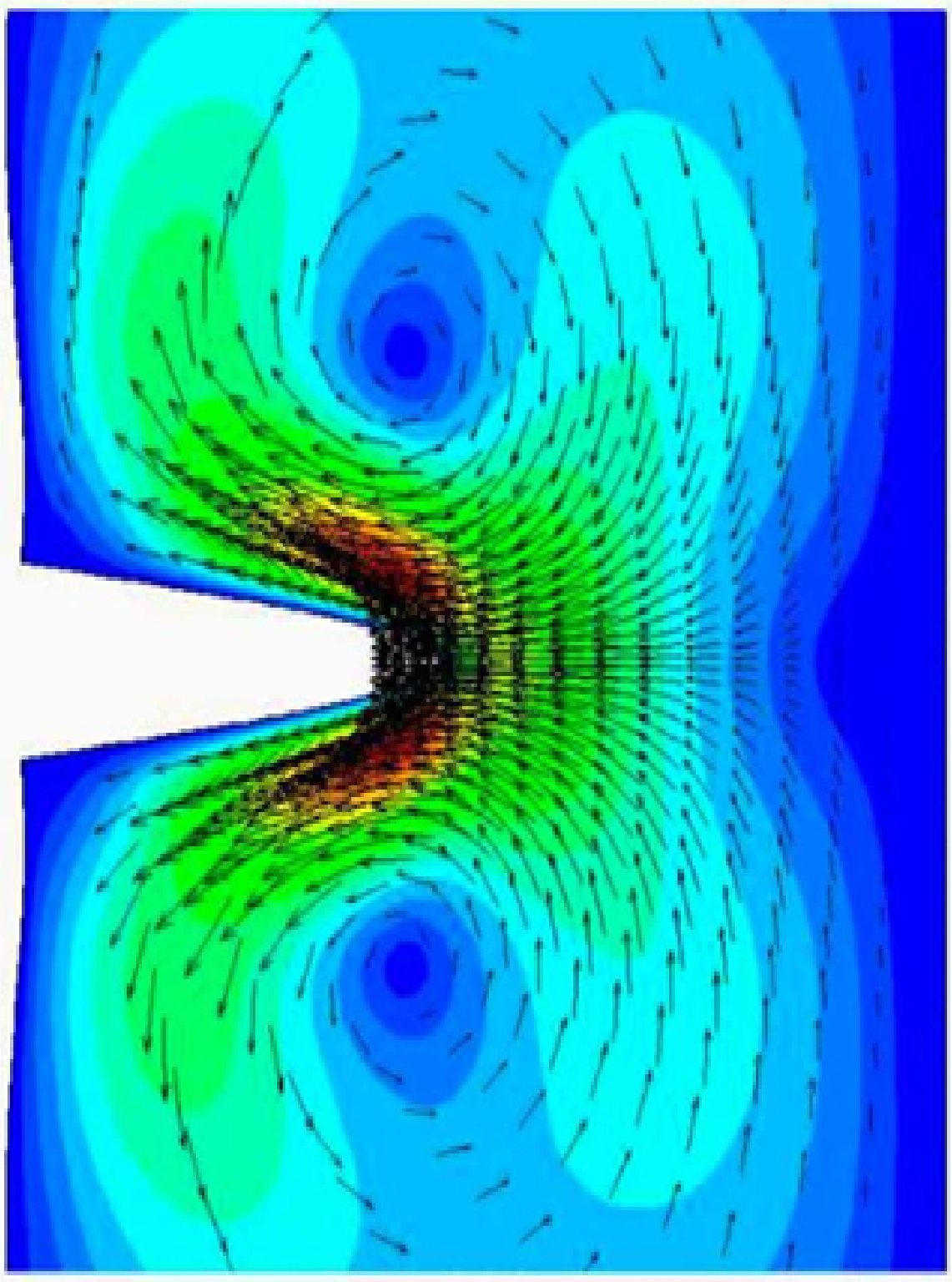

#98 - Oral

Numerical investigation of flow reversal in Electrohydrodynamic conduction : An analysis of blade-Plane configuration

EHD in liquids

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Keywords: Blade-Plane Configuration, Numerical Simulation, Finite-Volume Method, Charge Injection

Abstract Text
Electrohydrodynamic (EHD) flow phenomena in dielectric liquids, particularly in a blade-plane electrode configuration, have been extensively studied both experimentally and numerically. EHD flows in such setups arise from either charge injection or conduction mechanisms. This study focuses on the injection mechanism, which occurs when the electric field at the blade electrode exceeds a critical threshold. In this process, the blade acts as a charge emitter, while the plane electrode serves as a collector. The injected charged particles transfer momentum to the surrounding neutral fluid, creating a jet-like flow known as an EHD plume. These plumes are energy-efficient as they generate fluid motion without mass transfer in the bulk, making them advantageous over traditional methods like blowing or suction.
This type of jet flow has been investigated for various applications, including enhancing heat transfer to cool hot walls, mixing different miscible fluids, and controlling flow, among others. Wu et al (2014). Therefore, just like thermal plumes, an in-depth study of EHD plumes is crucial from an industrial perspective. Vazquez et al. (1996) conducted a comparative study of thermal and EHD plumes, analyzing axisymmetric plumes across various Prandtl numbers. Subsequent numerical studies by Vazquez et al. utilized finite element-based numerical approaches to accurately describe the EHD plumes and their characteristics. Perez et al (1995) conducted studies to analyse the dynamics and linear stability of charged jets in dielectric liquid and in 2009, Perez et al. examined the EHD plumes in a blade-plane setting, using a Finite Volume method with a TVD scheme (SMART), and discussed different flow regimes. Traore et al. (2013) numerically analyzed EHD plume flows with different blade configurations, incorporating various injection laws. They found that the blade shape and injection laws significantly impact the flow structure, particularly the transition of flow from steady to unsteady regimes.
Despite these advancements, most studies have been limited to two-dimensional (2D) simulations. However, the current study employs fully three-dimensional (3D) numerical simulations, revealing that EHD flows are inherently three-dimensional, even at moderate electrical Reynolds numbers. This finding underscores the importance of considering 3D effects to accurately capture plumes flow dynamics and stability.

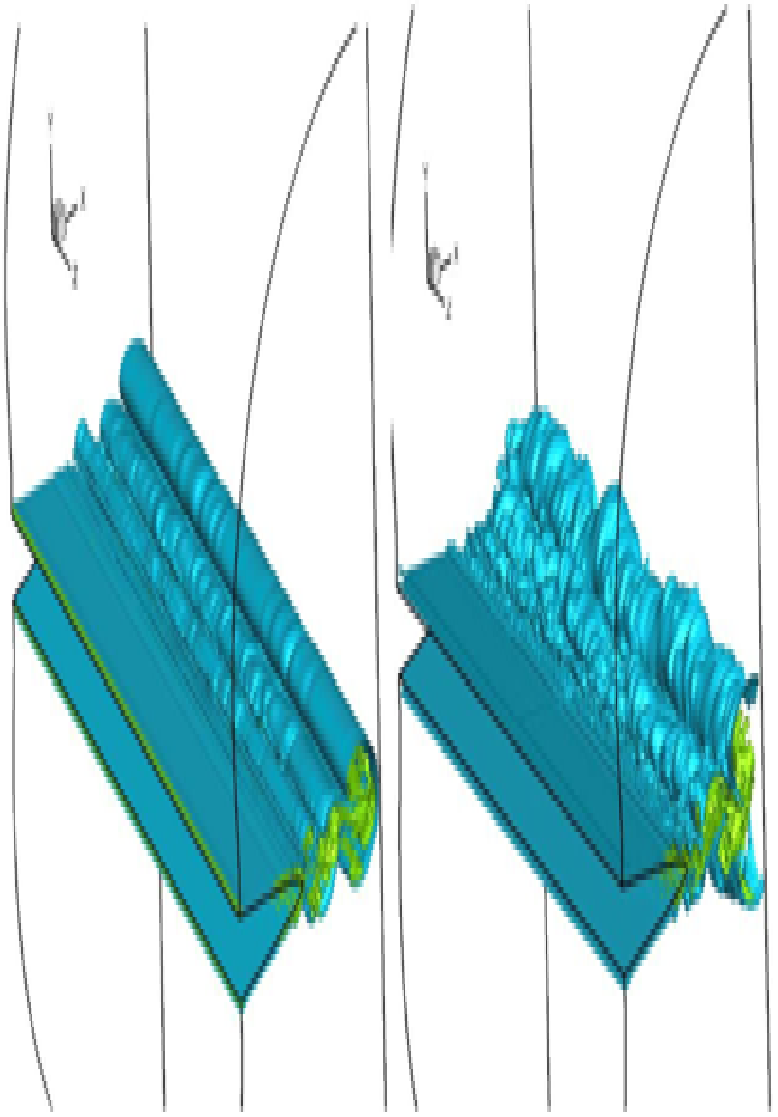

Figure 1: 3D charge density iso-surfaces (q = 0.1 (blue) and q = 0.5 (green)) at non-dimensional time 0.0017, for 1st and 3rd injection laws.

#99 - Oral

Numerical Study of Electro-Thermo-Hydrodynamic Conduction in Dielectric Liquids: Impact of Temperature-Dependent Properties and Dielectric Forces on Rayleigh-Bénard Instability.

EHD in liquids

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Keywords: Rayleigh-Bénard Instability, Heat-Transfer, Numerical Simulation, Finite-Volume Method

Abstract Text
This study focuses on the numerical investigation of electro-thermal-convection phenomena driven by the combined effects of electrohydrodynamic (EHD) conduction and a thermal gradient between two parallel plates, specifically in the context of Rayleigh-Bénard instability. The governing equations, which include the Navier-Stokes equations, the heat equation, transport equations for ionic densities, and the Poisson equation for the electric potential, are solved using the finite-volume homecode Oracle. These equations are coupled to account for the complex interactions between the electric field, ionic transport, and thermal gradients.Previous research has shown that the flow dynamics in such systems are significantly influenced by the ionic mobility of each ionic species and the liquid's permittivity. However, in most studies, the ionic mobility is often assumed to be identical for all species and independent of temperature, which limits the accuracy of the results. In this work, we address this limitation by incorporating temperature-dependent variations of both the liquid permittivity and the ionic mobility of each species into the model. This allows for a more realistic representation of the physical properties of the dielectric liquid under varying thermal conditions. Furthermore, the study examines the impact of the dielectric force and the Onsager effect on thermal convection and heat transfer. The Onsager effect, which increases the dissociation of ionic species with the electric field seems to play a critical role in modifying the flow structure and stability. By analyzing these effects, we aim to better understand how the interplay between electrical and thermal forces influences the onset and development of convection patterns. The stability of the flow is also investigated by exploring the influence of these parameters, which are closely linked to the temperature field. Our findings highlight the importance of considering temperature-dependent properties and their impact on flow behavior, particularly in systems where precise control of heat transfer and fluid motion is required. This study provides new insights into the complex dynamics of electro-thermal-convection phenomena and lays the groundwork for future research in this field.

#102 - Oral

Advancing Electrocoalescers Design: Optimizing Dehydration Efficiency for Crude Oil Emulsions

EHD in liquids

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Keywords: Electrocoalescence, Frequency, Converging Electric Field, Intensification.

Abstract Text
This paper explores design challenges and process intensification in electrocoalescers, crucial for dehydrating water-in-crude oil emulsions in the petroleum industry. Electrocoalescence-based dehydration is highly effective due to its fast kinetics, minimal internals, and tunable parameters such as electric field strength and frequency. However, processing opportunity crudes, fluctuating water cuts, and increasing refinery capacities pose significant challenges, often addressed through inefficient conventional methods.

A key focus is the effect of electrostatic boundary conditions on dehydration performance. Experimental results highlight the influence of field strength (0.3–1.0 kV/cm) and boundary configurations (insulated vs. grounded), demonstrating their impact on optimal electrode placement. The study also investigates frequency effects, showing that high-frequency fields (kHz range) enhance droplet interactions, improving dehydration.

Furthermore, a novel gradient electrocoalescers is proposed, leveraging dielectrophoretic forces to enhance water removal, particularly in low-water-cut emulsions. Results suggest superior performance when the electric field gradient aligns with gravity. Lastly, distributor placement in grid electrocoalescers is examined, revealing optimal configurations based on water cut levels, supported by RTD studies and CFD simulations.

This paper provides critical insights into electrocoalescers design, offering practical solutions for improved dehydration efficiency and process intensification in refinery operations.

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#103 - Oral

Droplet, bubble and emulsion formations in non-uniform electric field

EHD of multi-phase flows

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Keywords: Electrohydrodynamic (EHD), Electrospray, Charged Droplets, Flow-Assisted Electrospray

Abstract Text
Highly non-uniform electric field applied to a sharp nozzle or electrode induces various electrohydrodynamic (EHD) phenomena such as ionic wind (gas flow), induced liquid flow, deformation of interface, charging and break up of liquid. Ionic wind has been well-studied in electrostatic precipitator (ESP) to understand the trajectory of charged particle and in plasma actuator for flow control near the surface. When a liquid is subjected to a highly non-uniform electric field sequential break-up of ligament and droplet which eventually leads to a dispersed microdroplets. Non-uniform electric field across the two different liquid layer can also produce microdroplets. Depending on the liquid type, emulsions of water-in-oil or oil-in-water can be generated. In the presentation, fundamental of these processes and possible applications will be addressed.

#104 - Oral

Enhancement of Drying of Moist Porous Media with Electrohydrodynamics

EHD of multi-phase flows

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Keywords: Electrohydrodynamics, Drying, Corona Wind, Dielectrophoresis

Abstract Text
Industrial drying consumes about 12% of the total end-use energy in manufacturing, amounting to 1.2 quads annually in the U.S.A., which is significant given the total U.S. energy consumption of around 96+ quads per year. Approximately 0.5 quads/year, or 40%, could be saved with new drying technologies [1 and 2].
Industrial drying removes moisture from materials through evaporation, requiring more energy than just changing the phase of free water due to molecular bonding. Current drying processes are slow and energy-intensive, but novel technologies aim to increase drying rates and reduce energy use.
Electrohydrodynamic (EHD) drying for bio-based and food products has been explored [3 and 4], using a EHD corona wind generated by a high potential difference. However, this method has low energy efficiency and may not sustain the corona wind over long periods.
An alternative approach uses electrophoresis to enhance drying rates without charge injection, establishing a diverging electric field between a perforated electrode and the grounded sample[5]. This method has shown significant drying rate improvements for moist paper and food samples with negligible EHD energy consumption.
This presentation will discuss progress in EHD drying of moist porous media, focusing on its potential for energy savings and reducing the carbon footprint in the food and pulp and paper industries.
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#105 - Oral

The State-of-the-Art of Electrohydrodynamic in Thermal Management Systems – A review of application opportunities, fundamental physics and numerical models

EHD in liquids

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Keywords: Electrohydrodynamics, Thermal Management, Control, Heat Transfer, Two-Phase Systems, Thermal Storage, Drying

Abstract Text
Electrohydrodynamics (EHD) refers to the interaction between electric fields and fluids, where the resulting electroconvection induces fluid motion or enhances heat transfer. This approach offers a highly efficient, active solution for various thermal management applications, including heat transfer control, fluid pumping, and phase change fluid redistribution. EHD's key advantage lies in its ability to manipulate fluids without requiring mechanical components, making it especially beneficial for applications that require low weight and energy input. This review explores the principal applications of EHD, with a particular focus on its use in two-phase heat exchangers and thermal storage systems. It also covers its role in thermal energy systems, such as boiling, condensation, and evaporation.

In thermal storage systems, particularly those using PCM, EHD contributes by improving heat transfer by employing dynamic external electric fields to trigger electroconvection instabilities, shedding thermal boundary layers and enhancing fluid circulation and solid dendrite extraction, which leads to more efficient melting. EHD's impact is also notable in two-phase flow regimes, such as those in evaporators and condensers. In evaporators and condensers, EHD can control heat transfer by fostering fluid circulation, liquid extraction flow regime transition to reducing thermal resistance. EHD drying provides a non-thermal, energy efficient way of extracting liquid content from capillary or capillary-porous materials which is essential in heat sensitive materials of biological origin. Another advantage of EHD is its capability for intelligent thermal management through the modulation of voltage, waveform, and frequency. Adjusting these parameters allows precise control over electroconvection, enabling tailored manipulation of fluid behavior and thermal boundary layer stability, making EHD adaptable to a wide range of thermal management applications.

This review delves into the fundamental physics and numerical models behind EHD, highlighting its impact on both single-phase and two-phase systems. It also highlights experimental and numerical advancements, identifying current challenges and proposing future research directions to extend EHD's applications in drying, thermal storage, and other thermal management systems.

#106 - Poster

Numerical Simulation of Electrohydrodynamic Deformation of a Leaky Dielectric Droplet employing Arbitrary Eulerian Lagrangian (ALE) Approach using COMSOL Multiphysics

Fundamental Electrohydrodynamics

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Abstract Text
Electrohydrodynamics (EHD) drop deformation refers to the study that how a fluid responds (deformation) when subjected to an external electric field. This phenomenon occurs due to the interaction between electric field and the electric charge distribution on the droplet surface, which induces electric stress at interface thereby leads to deformation. The drop may undergo stretching, elongation, or even breakup depending on factors such as the field strength, fluid properties and drop size. Understanding EHD drop deformation has its application in such as electrowetting,inkjet printing, microfluidics and electrospinning where precise manipulation of droplet deformation is required. This study aims to explore the governing principles of drop deformation employing ALE approach using COMSOL Multiphysics software, providing insights into the role of electrostatic forces which plays a role in deformation of fluid droplets in electric field. The droplet is considered to be leaky dielectric so the electric current inside and outside induces the surface charge distribution which creates the normal and tangential stresses on interface leads to prolate and oblate deformation as shown in figures below for the parameters R,Q and λ, where R=conductivity ratio Q is dielectric constant ratio and λ is viscosity ratio respectively.Taking this formulation we can model different physical electrohydrodynamic phenomenon like drops deformation in an emulsion,electrowetting of droplets, as well as electrospinning and electrospraying application.

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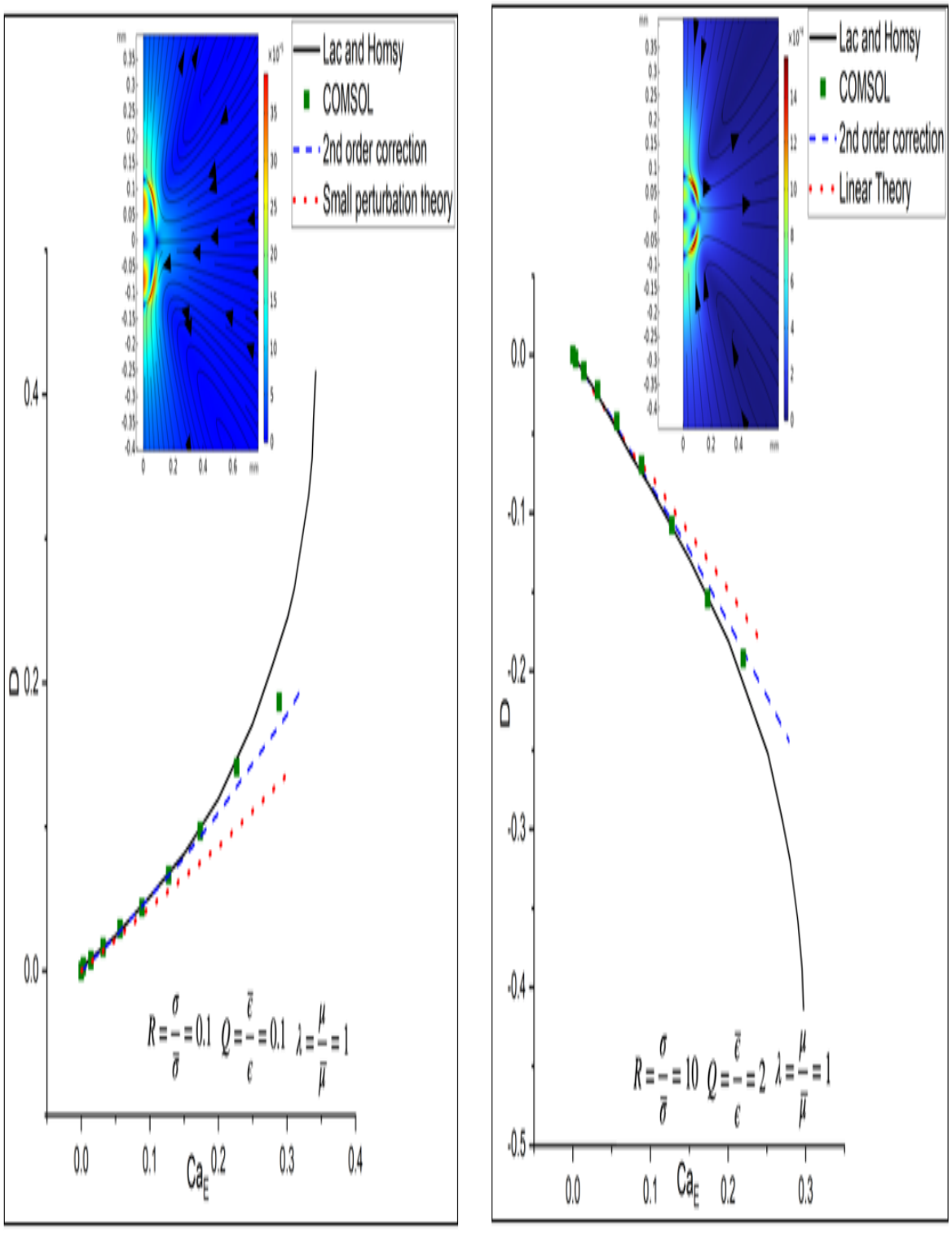

Figure Prolate and oblate deformation of droplet in electric field based on the dimensionless parameters