CENTER FOR ADVANCED RESEARCH IN DRYING

A National Science Foundation Industry/University Cooperative Research Center

Enhancement of Drying Rate of Moist Porous Media with Electric Field

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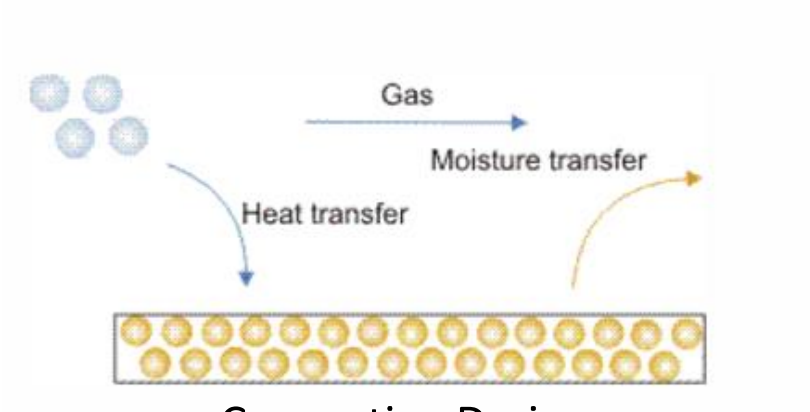
Introduction to Drying

Process heating operation	Description/example applications[12]	Typical temperature range (F)[13]	Estimated (2010) U.S. energy use (TBtu)[14]
Fluid heating, boiling, and distillation	Distillation, reforming, cracking, hydrotreating; chemicals production, food preparation	150–1000°	3,015
Drying	**Water and organic compound removal**	**200-700°**	**1,178**
Metal smelting and melting	Ore smelting, steelmaking, and other metals production	800–3000°	968
Calcining	Lime calcining	1500–2000°	395
Metal heat treating and reheating	Hardening, annealing, tempering	200–2500°	203
Non-metal melting	Glass, ceramics, and inorganics manufacturing	1500–3000°	199
Curing and forming	Polymer production, molding, extrusion	300–2500°	109
Coking	Cokemaking for iron and steel production	700–2000°	88

Characteristics of common industrial process that require process heating and estimated energy use (DOE, 2015).

Reducing drying energy by 20 percent would save 312 TBtu per year in the United States, worth $1-1.5 billion annually.

Examples of Existing Drying Methods



Convective Drying


Radiative Drying

Dielectric Heating

Disadvantages:

- Energy-intensive process
- Relatively inefficient
- Sample properties may change during drying process

Ref: http://www.thermopedia.com/content/711/
http://www.electronicdrying.com/e_drying
https://en.wikipedia.org/wiki/Dielectric_heating
https://www.esticastresearch.com/report/spray-drying-equipment-market/

Introduction to Electrohydrodynamic (EHD) Phenomena

- A clean and sustainable process for drying
- Interaction between electrical field and fluid flow field
- Coupled electrostatics and momentum equation via body forces
- Electric body forces:

$$F = qE - \frac{1}{2}E^2 \nabla\varepsilon + \frac{1}{2}\nabla\left[E^2 \left(\frac{\partial\varepsilon}{\partial\rho}\right)\rho\right]$$

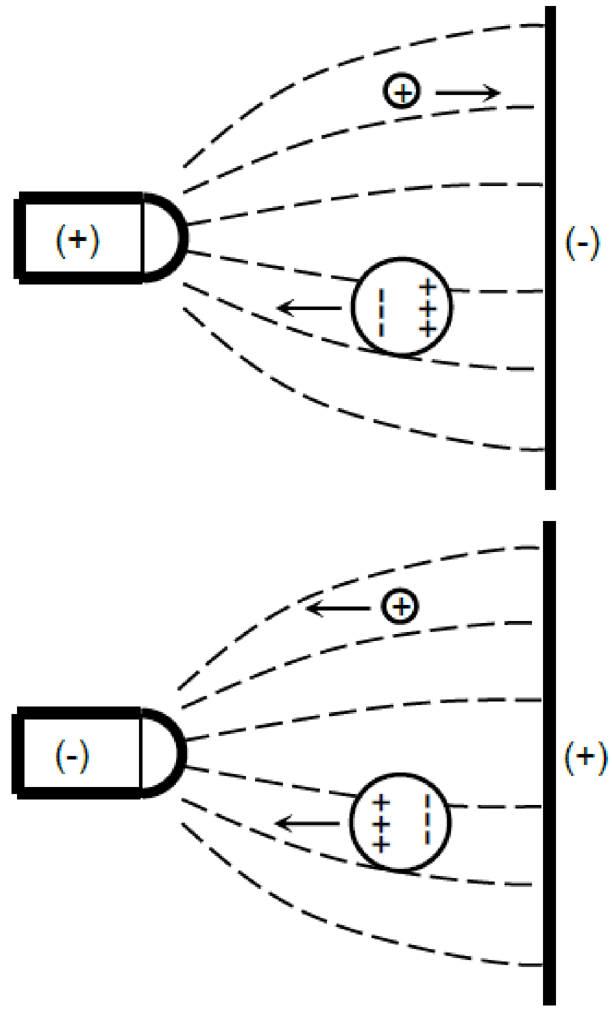
Coulomb Force

Dielectrophoretic Force (DEP)

Electrostriction Force

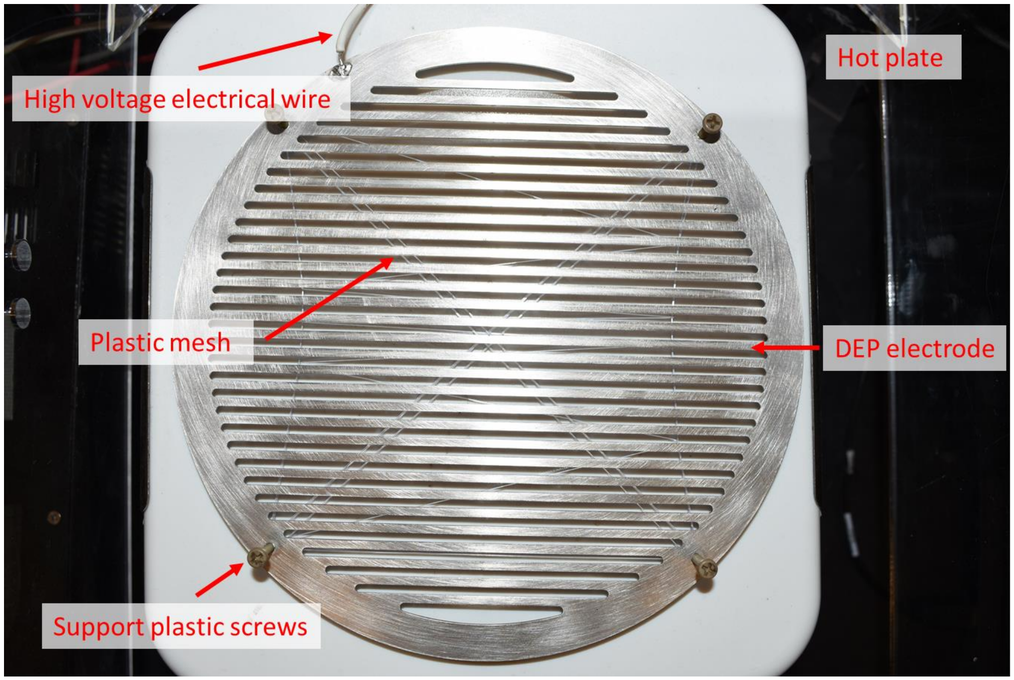
Illustration of DEP Force Phenomenon

- Dielectrophoresis is translational motion of neutral matter caused by polarization effects in a non-uniform electric field.
- Vapor phase with low permittivity will move toward low electric field.
- Liquid with high permittivity will move toward high electric field.
- Thus, extraction of vapor is feasible with DEP.
- DEP force is independent of applied potential polarity.

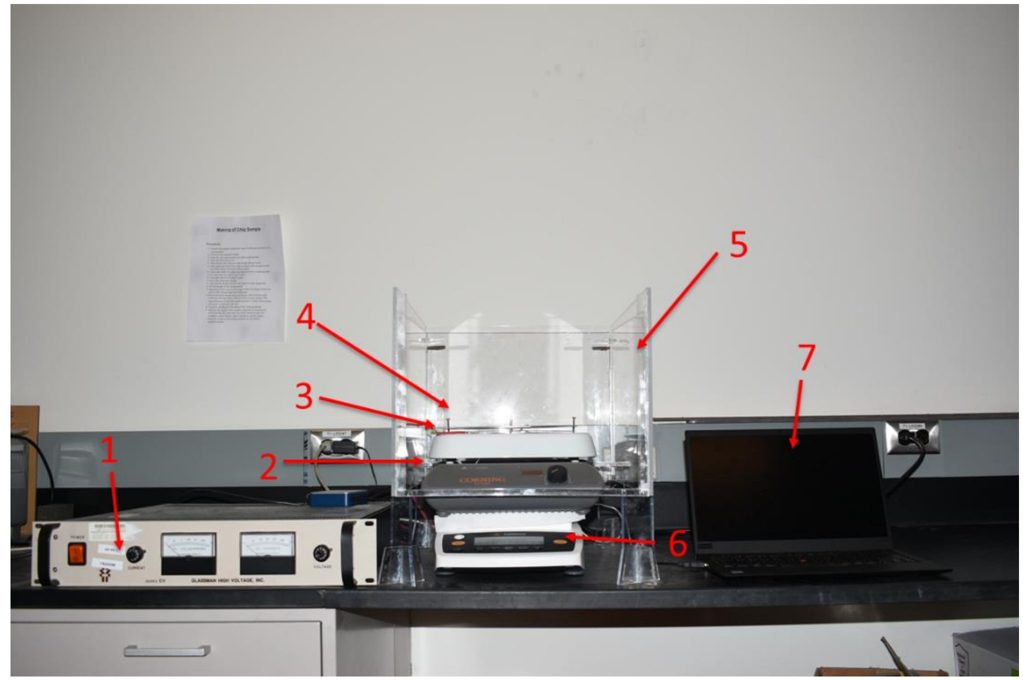


Dielectrophoresis in non-uniform AC electric field

Fabrication of DEP Electrode and Experimental Setup



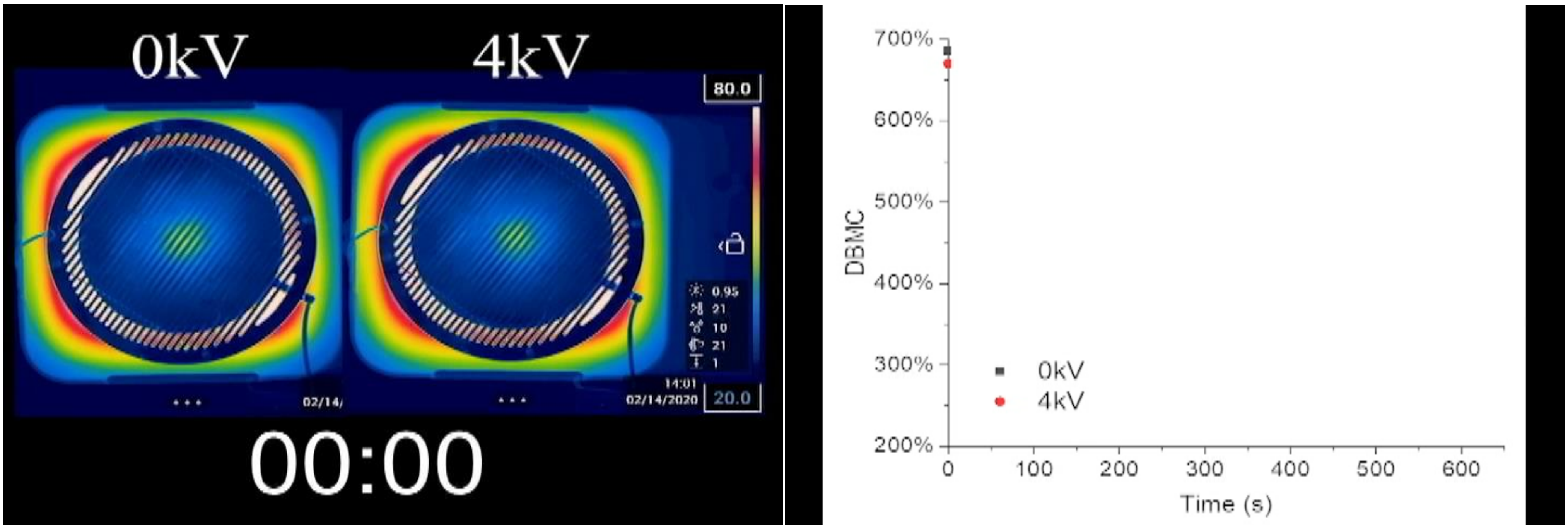
Fabrication of DEP electrode



Experimental setup for DEP drying study (1. High-voltage power supply, 2. Hot plate, 3. Ground electrode, 4. DEP electrode, 5. Drying chamber, 6. Precision microbalance scale, and 7. Data acquisition unit)

Visualization of Surface Temperature and DBMC in the Presence of DEP Mechanism

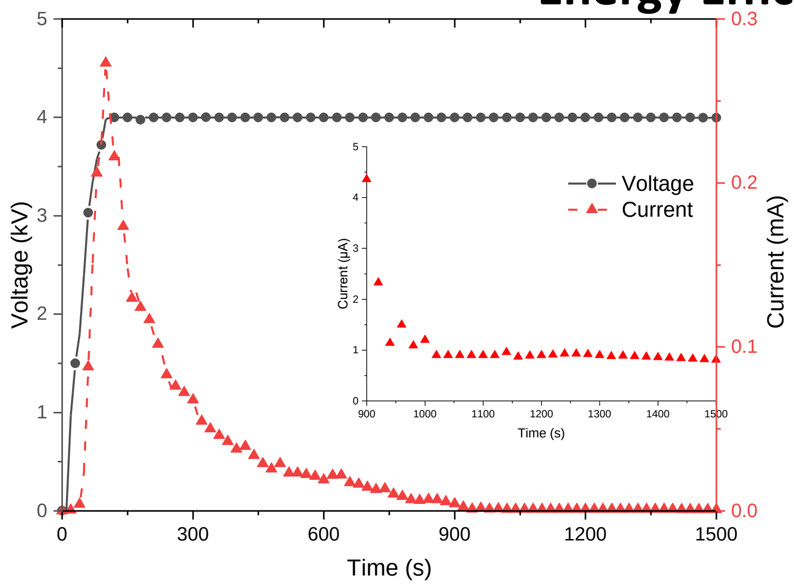
$$Dry\ basis\ moisture\ content\ (DBMC) = \frac{instantaneous\ weight\ of\ water(g)}{bone\ dried\ weight\ of\ sample(g)} \times 100\%$$



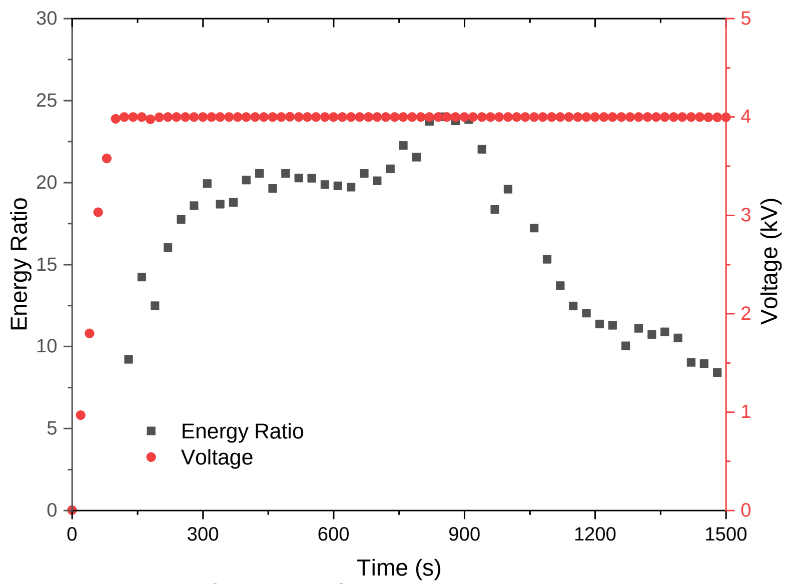
Comparison of surface temperature (Left) and DBMC (Right) evolution with hand-sheet paper sample

The sample under DEP drying achieves lower surface temperature and higher drying rate

Energy Efficiency of DEP Mechanism



Voltage and current as a function of drying time with applied potential of 4 kV



Energy ratio as a function of drying time with applied potential of 4 kV

Energy Ratio

$$= \frac{Enhanced\ evaporation\ energy}{Accumulated\ input\ electric\ energy} = \frac{(m_1 - m_2) * h_{fg}}{\int_0^t V(t)I(t)dt}$$

m_1 : The instant weight of sample under regular drying (g)
m_2: The instant weight of sample under DEP drying (g)
h_{fg}: Latent heat of evaporation (j/g)
V: Applied voltage (V)
I: Current (A)

The DEP mechanism requires low electrical power consumption thus achieves high energy efficiency.

Conclusions

- An experimental setup designed and fabricated, basic tests conducted and analyzed, **proof of concept achieved**.
- In the presence of DEP mechanism, the sample experiences **lower surface temperature** and achieves **higher drying rate**.
- The DEP mechanism requires negligible electric energy consumption and **high energy efficiency**.

Impact

- The planet is heating up fast due to increasing global warming.
- Reduce energy consumption in drying of moist porous media.
- It is anticipated to save at least 10% of total energy in drying (0.1 quads) with DEP mechanism in the United States.
- Reduce CO_2 emission of 687,830,000 kilograms.

148,601 Passenger vehicles driven for one year

77,397,322 gallons of gasoline consumed

87,720,488,356 number of smartphones charged

898,274 acres of U.S. forests in one year

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Thank you for your time!