Electronic Supplementary Material (ESI) for Lab on a Chip.

Supplementary information

AC Electric Field Controlled Non-Newtonian Filament Thinning and Droplet Formations at Microscale

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Contents

1. Methods of applying the AC electric field

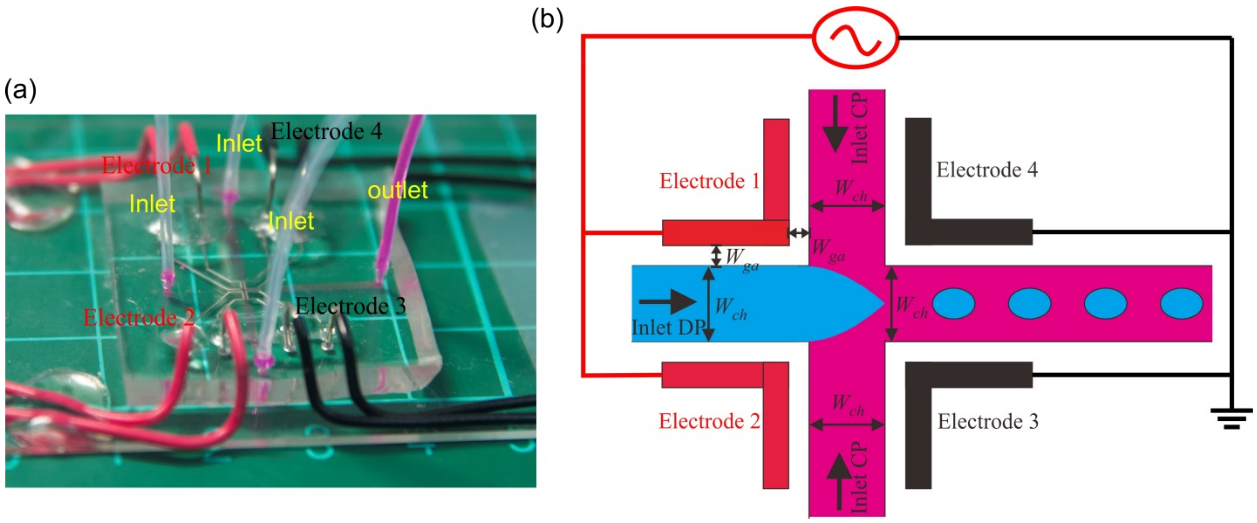

Figure S-1 Methods of applying AC electric fields through the microchannel. (a) The photo of the microchannel, (b) schematics of the electric circuit of implementing the AC electric field.

The methods of applying the AC electric field are shown in Figure S-1. As indicated both in (a) and (b), there are four electrodes all of which are connected with the electric wires. Among them, electrode 1 and 2 are connected to the high voltage amplifier where the high voltages with sine wave patterns are generated while the other two are grounded as indicated in (b).

2. Material properties:

Viscosity of the fluids

Table S-1 Viscosity of the fluids

Fluids	Viscosity (mPa·s)
Mineral oil with 5% span 80	30.0
63% w.t. Glycerol in DI water	10.5
PEO M_w=4M, 0.5% w.t. aqueous solution	Shown in main text, Figure 3

The viscosities are measured by the TA Instruments Discovery Hybrid Rheometer (DHR-2).

Interfacial tension between the fluids

Table S-2 Interfacial tension of the fluidic systems

Fluidic systems	Interfacial tension (mN/m)
PEO M_w=4M, 0.5% w.t. aqueous solution / Mineral oil with 5% span 80	18.0
63% w.t. Glycerol in DI water / Mineral oil with 5% span 80	4.9

The interfacial tension are measured by the tensiometer,model: FTA 200, using pendent droplet method.

Dielectric constant of the fluids (relative electric permittivity)

Table S-3 dielectric constant of the fluids

Fluids	Relative permittivity ε_r
Mineral oil with 5% span 80	2.8
63% w.t. Glycerol in DI water	46.3
PEO M_w=4M, 0.5% w.t. aqueous solution	891.0

The dielectric constants of the fluids are measured by filling the fluids into a self-fabricated capacitor of cylindrical shape. The capacitances with and without the fluids are measured by a precision LCR meter (Keysight E4980AL). The relative permittivity can then be calculated by the formula of $C=\varepsilon_0\varepsilon_r A/d$.

3. Calculation of the relaxation time λ for the polymer solution

We utilize the approach indicated in Eq. (8), McKinley's review [1] which uses the filament thinning process and the formula $\dot{\varepsilon}_{mid} = -\frac{2}{R_{mid}}\frac{dR_{mid}}{dt} = \frac{2}{3\lambda}$ to estimate the relaxation time. From the filament thinning process, we can calculate the $\dot{\varepsilon}_{mid} \approx -\frac{2}{60} \cdot -0.855 \times 10^3 = \frac{2}{3\lambda}$, therefore $\lambda \approx 23.4$ ms. The slope of filament thinning is obtained by the linear curve fitting of the measured data as shown in the figure below.

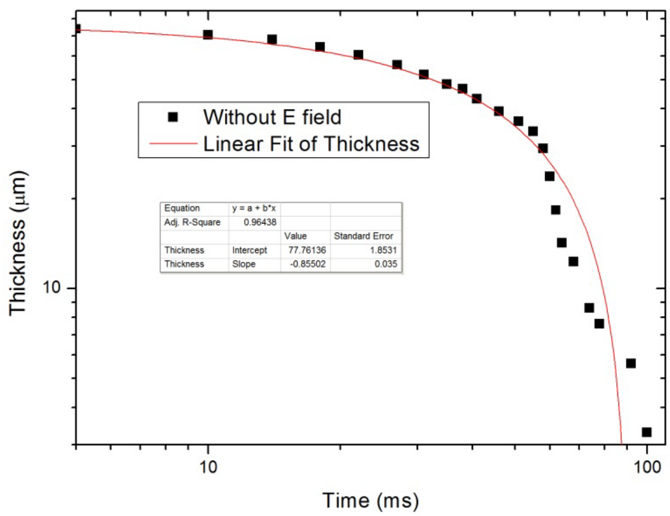

Figure S-2 Linear fitting for the slope of the filament thinning.

4. Merging of droplets under AC electric field in jetting regime

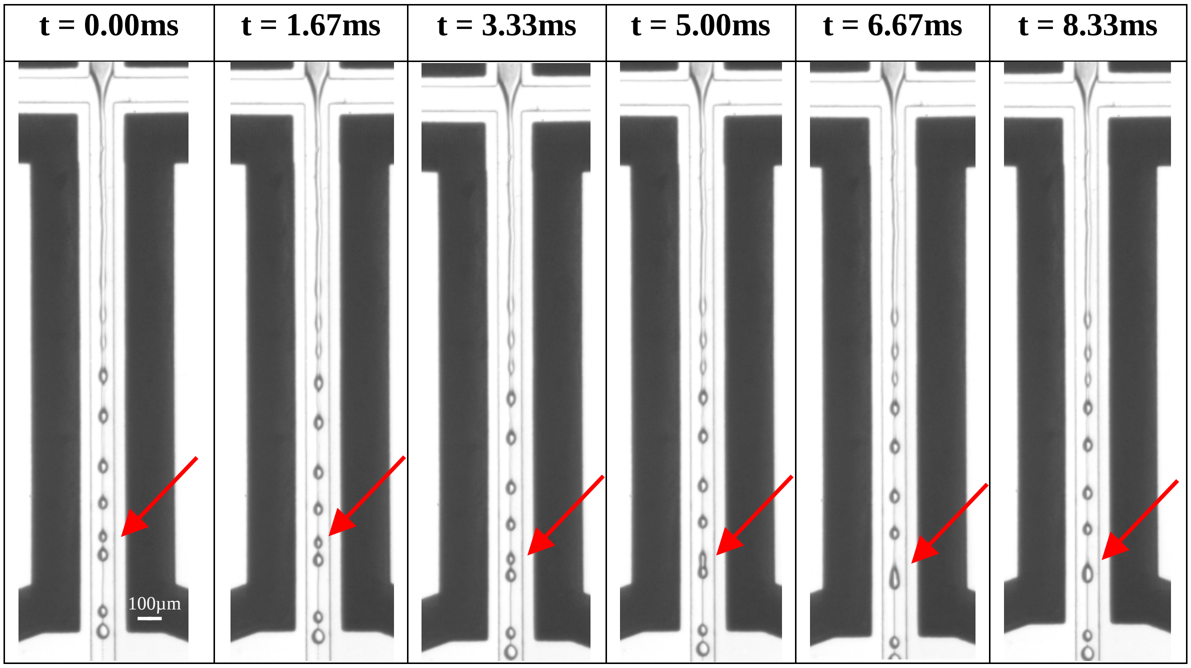

Figure S-3 Merging of droplets in jetting regime. Q_{DP}: Q_{CP}=20:160 µl/hr, applied electric field: 750 V , 5KHz.

5. Plots of droplet diameter as a function of applied voltage at various frequencies

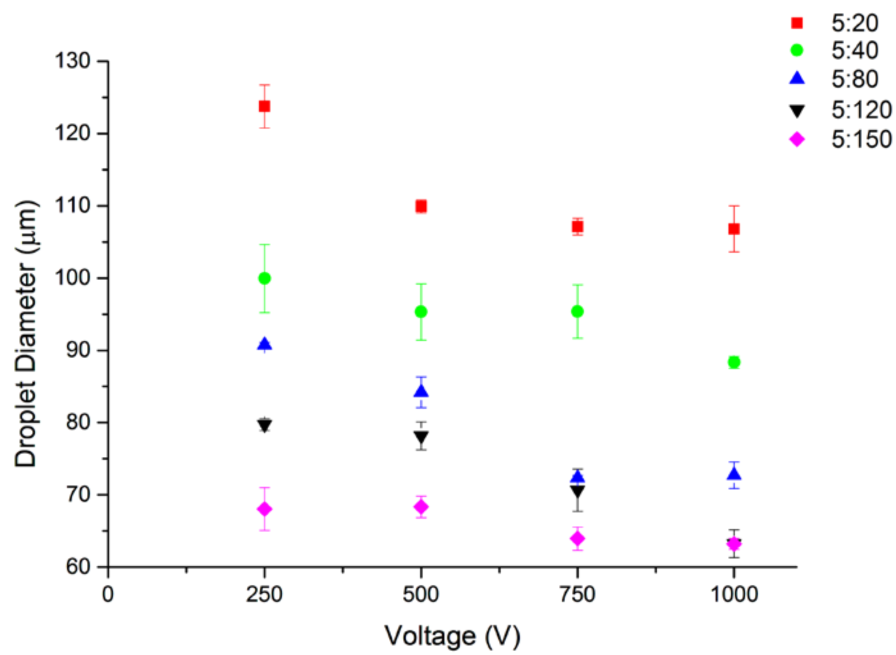

Figure S-4: Droplet diameter as a function of applied voltage at 500Hz where Q_{PEO} is 5µl/hr

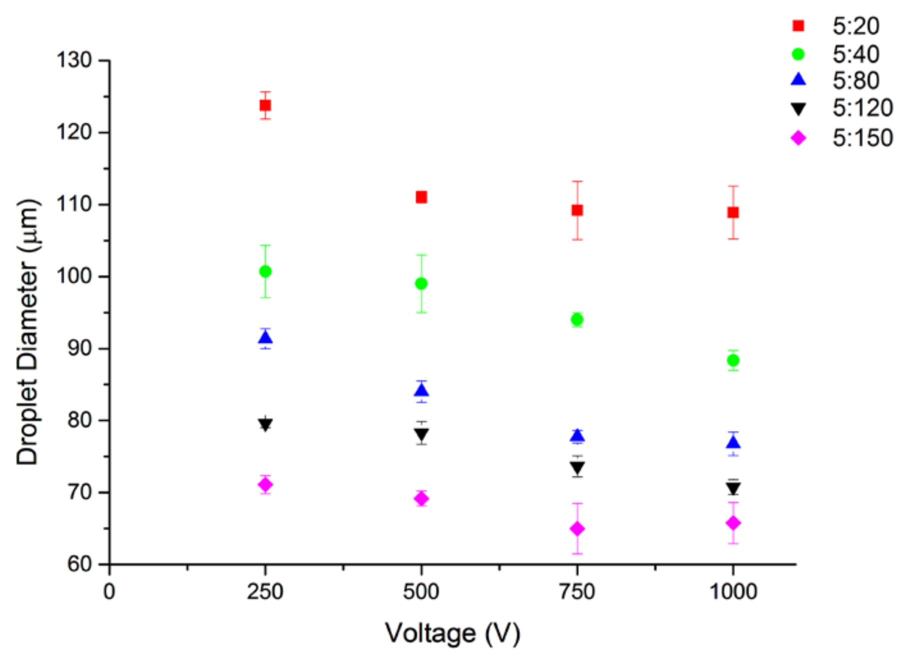

Figure S-5: Droplet diameter as a function of applied voltage at 1000Hz where Q_{PEO} is 5µl/hr

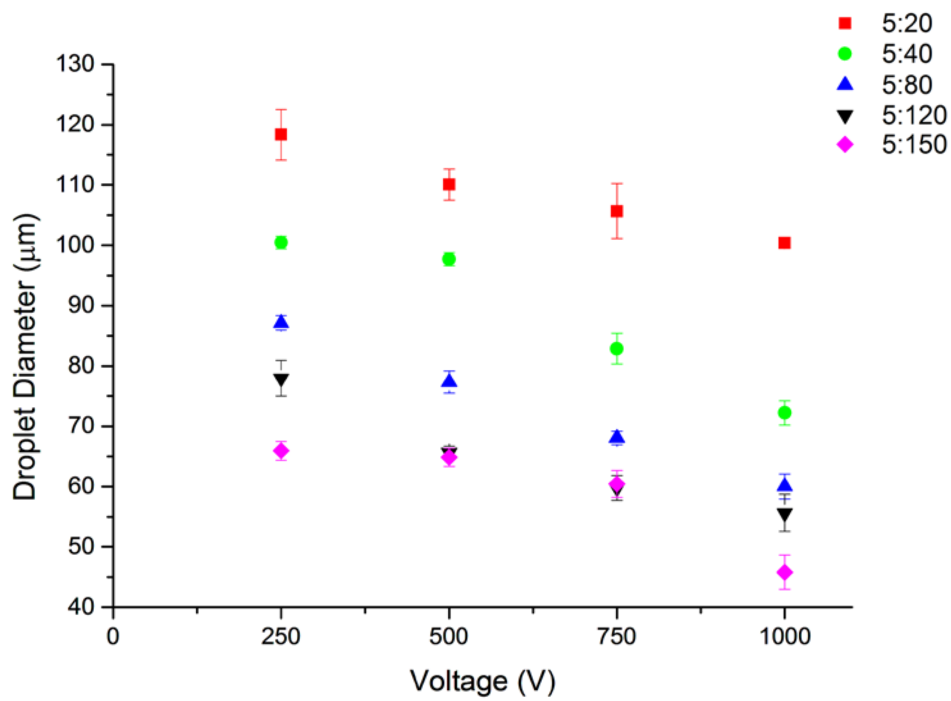

Figure S-6: Droplet diameter as a function of applied voltage at 5000Hz where Q_{PEO} is 5µl/hr

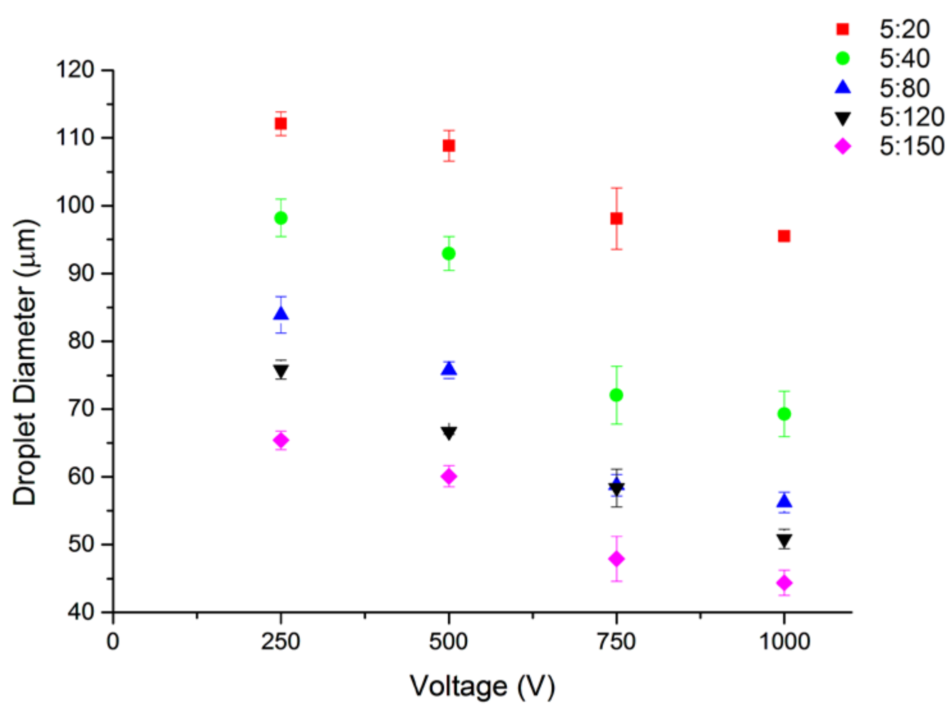

Figure S-7: Droplet diameter as a function of applied voltage at 7000Hz where Q_{PEO} is 5µl/hr

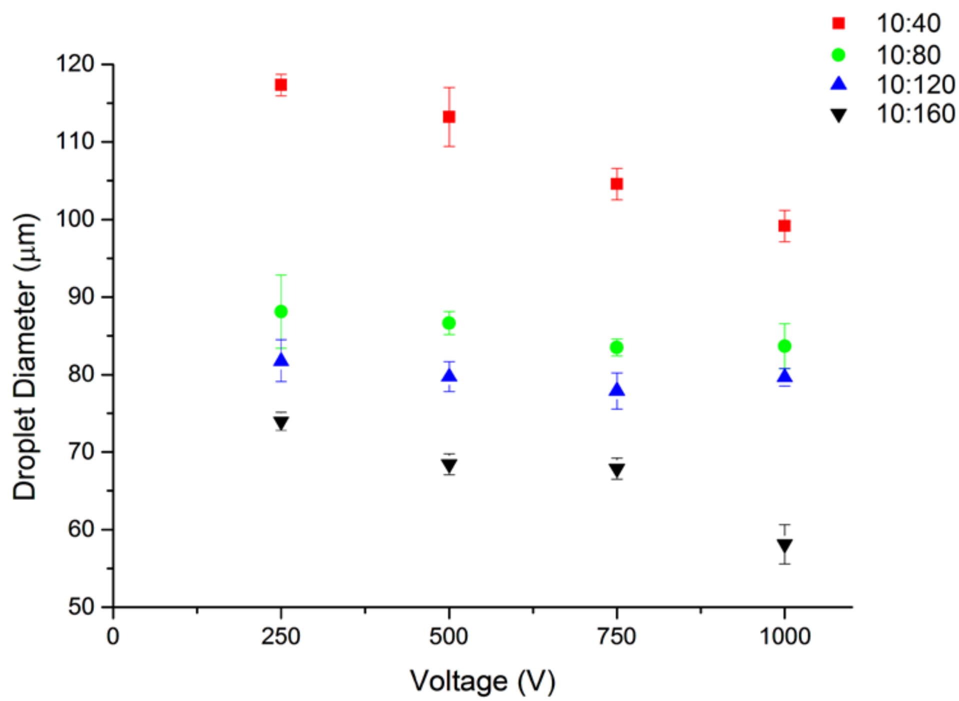

Figure S-8: Droplet diameter as a function of applied voltage at 500Hz where Q_{PEO} is 10µl/hr

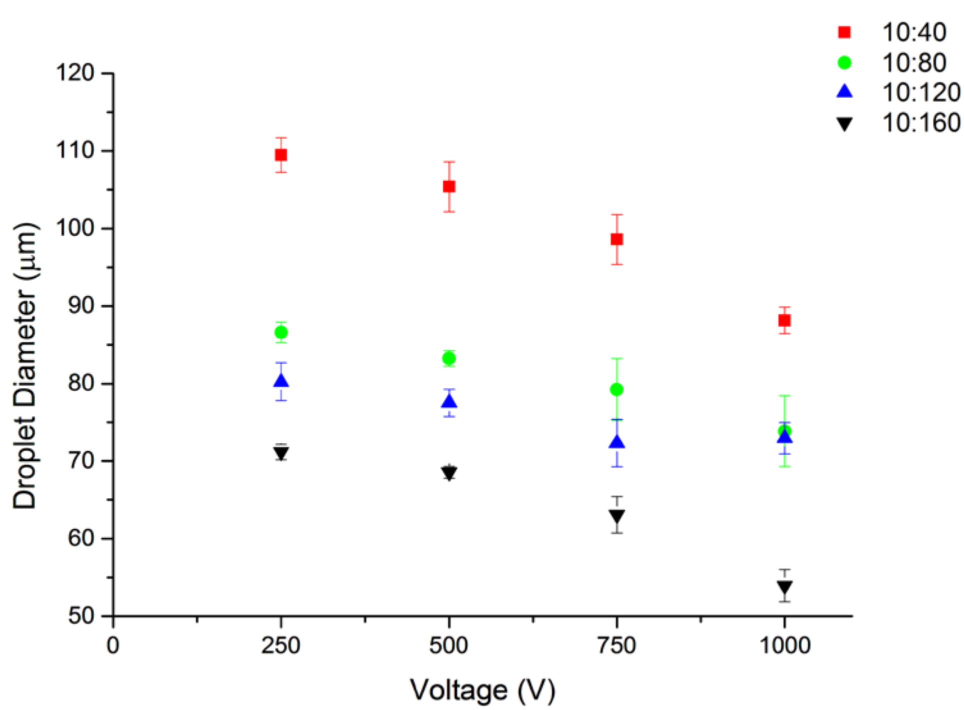

Figure S-9: Droplet diameter as a function of applied voltage at 2000Hz where Q_{PEO} is 10µl/hr

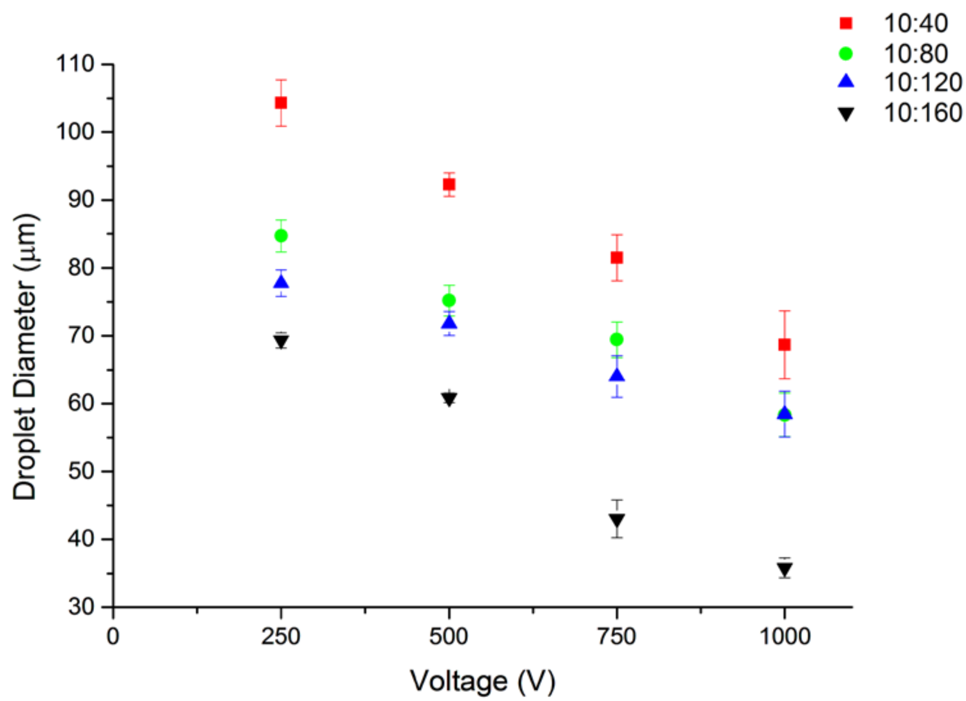

Figure S-10: Droplet diameter as a function of applied voltage at 7000Hz where Q_{PEO} is 10µl/hr

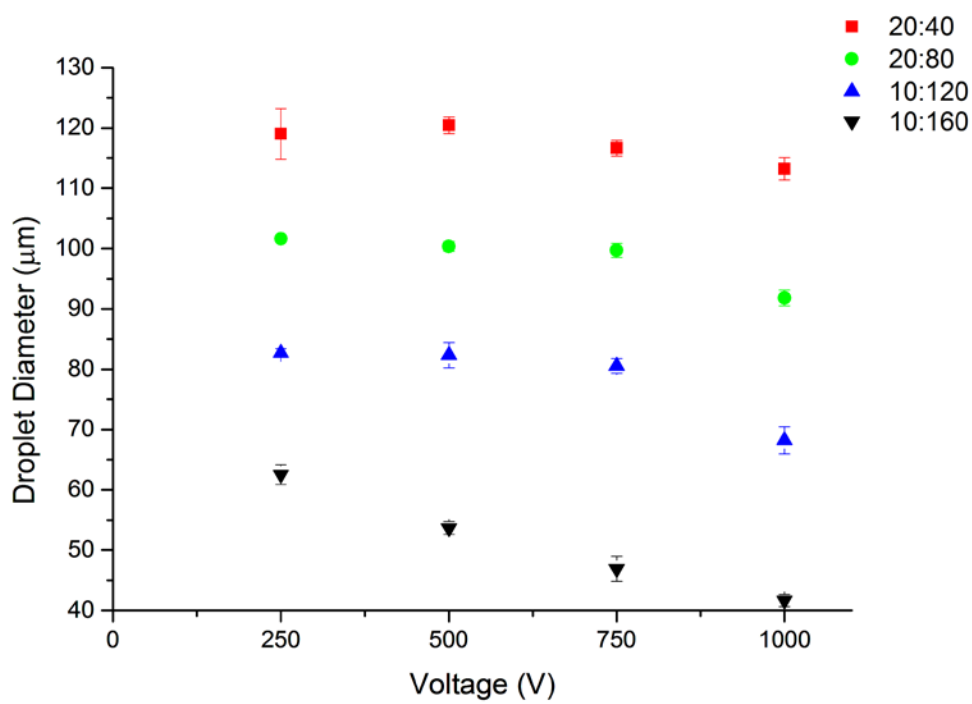

Figure S-11: Droplet diameter as a function of applied voltage at 1000Hz where Q_{PEO} is 20µl/hr

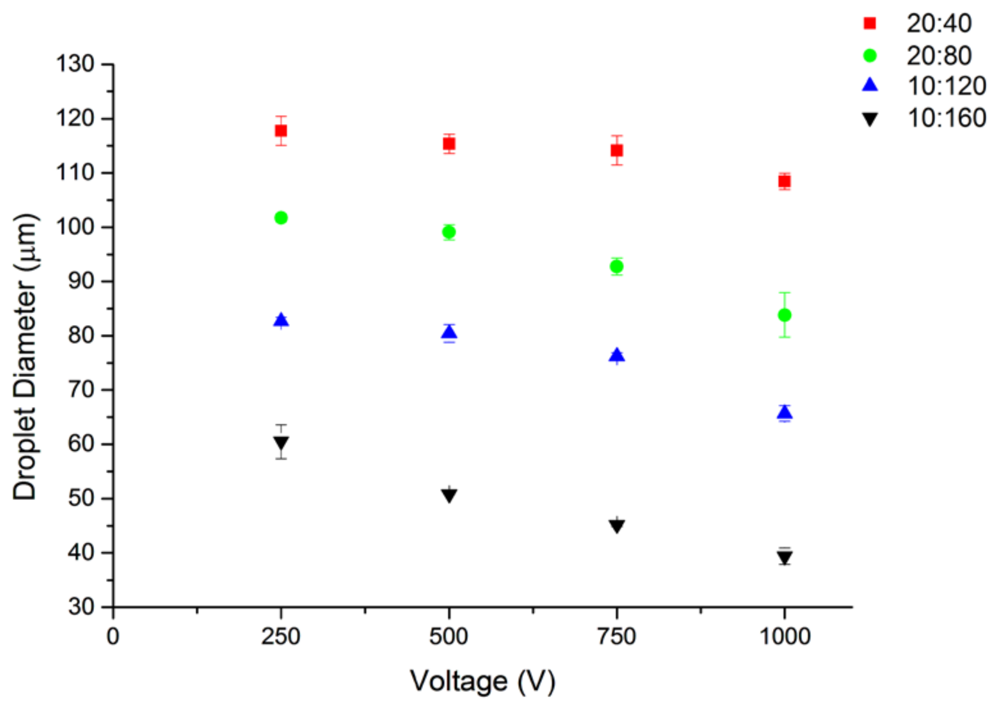

Figure S-12: Droplet diameter as a function of applied voltage at 2000Hz where Q_{PEO} is 20µl/hr

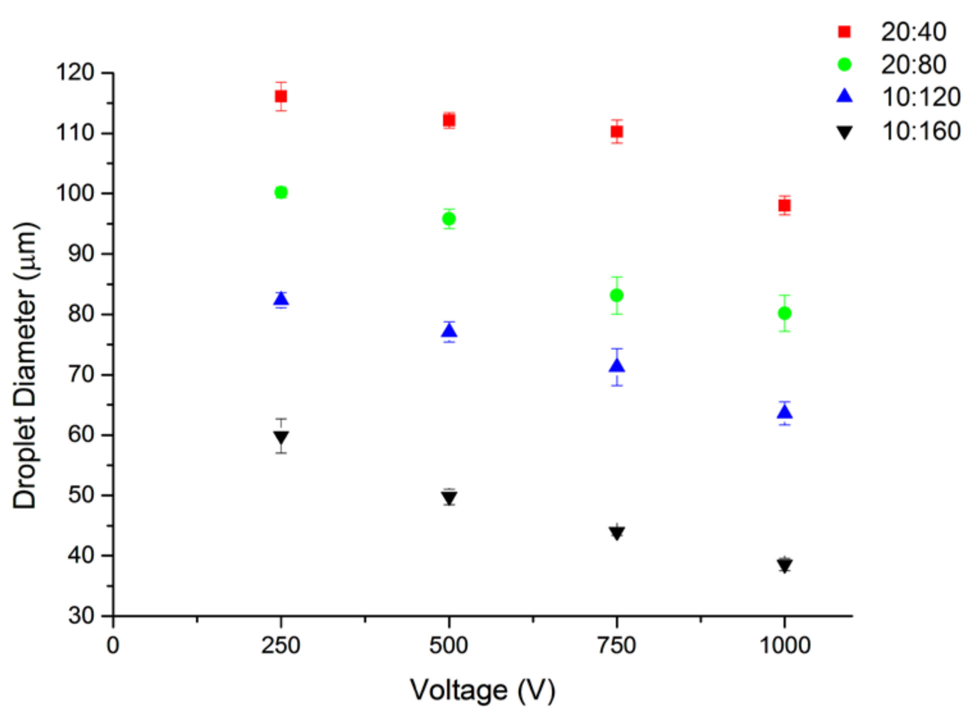

Figure S-13: Droplet diameter as a function of applied voltage at 5000Hz where Q_{PEO} is 20µl/hr

6. Plots of droplet diameter as a function of frequency at various applied voltages

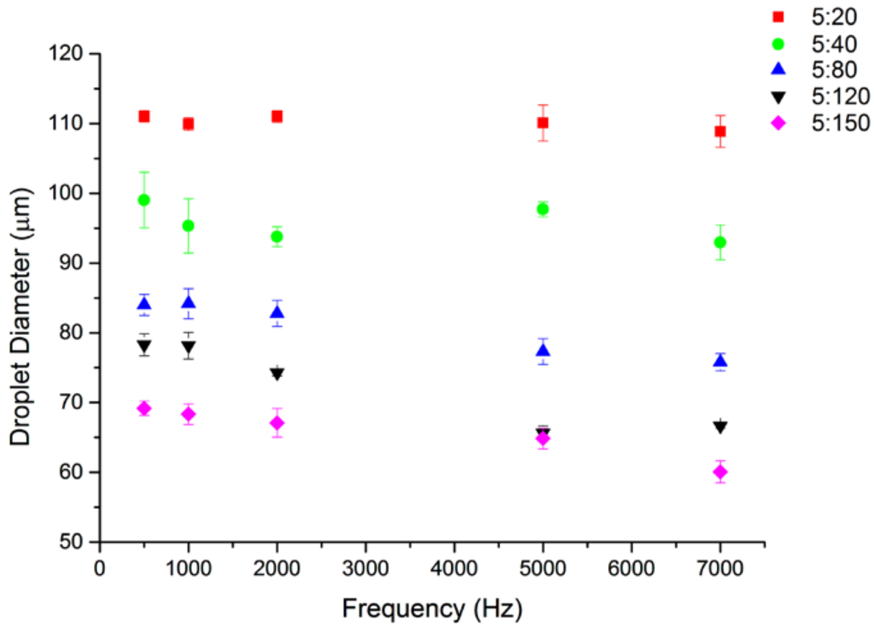

Figure S-14: Droplet diameter as a function of frequency at 500V where Q_{PEO} is 5µl/hr

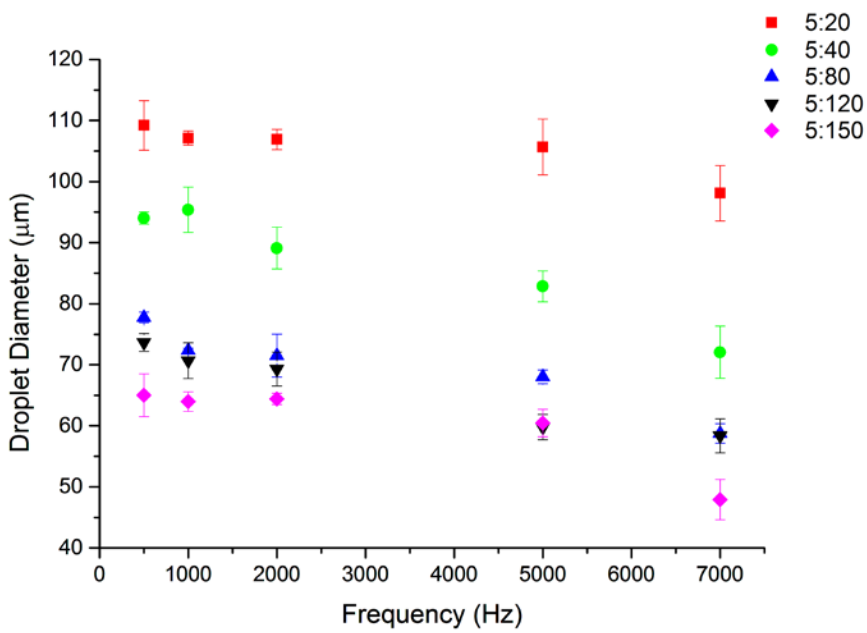

Figure S-15: Droplet diameter as a function of frequency at 750V where Q_{PEO} is 5µl/hr

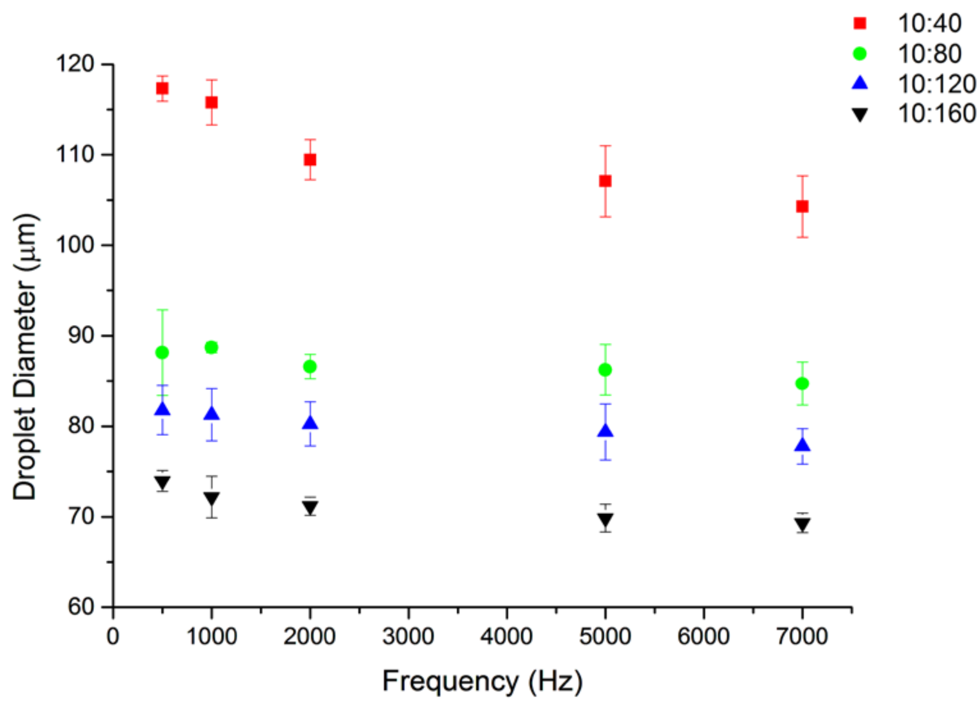

Figure S-16: Droplet diameter as a function of frequency at 250V where Q_{PEO} is 10µl/hr

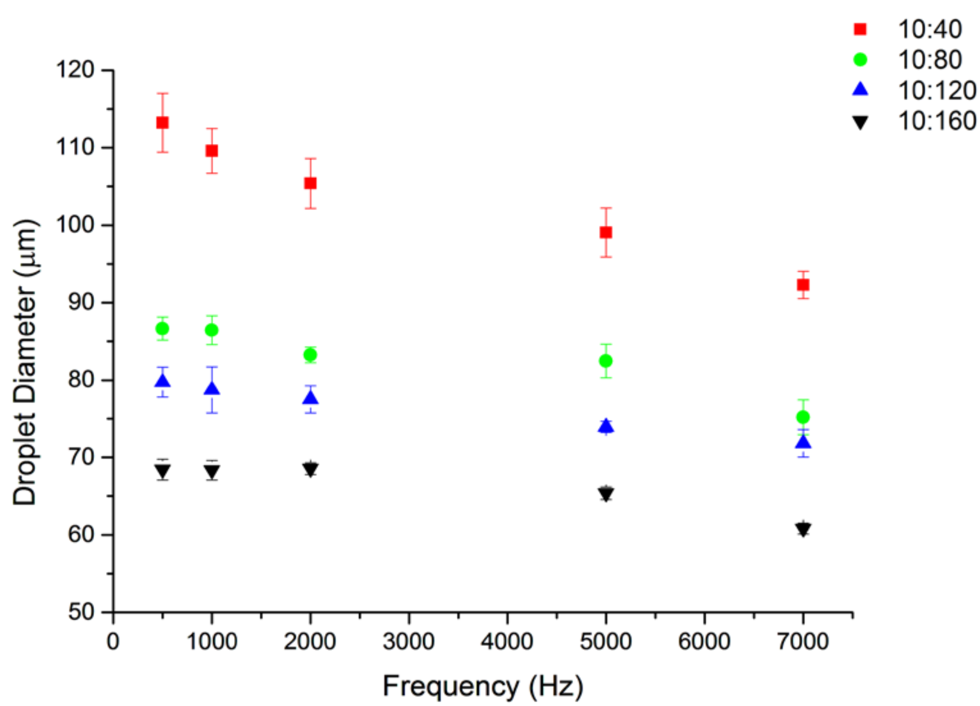

Figure S-17: Droplet diameter as a function of frequency at 500V where Q_{PEO} is 10µl/hr

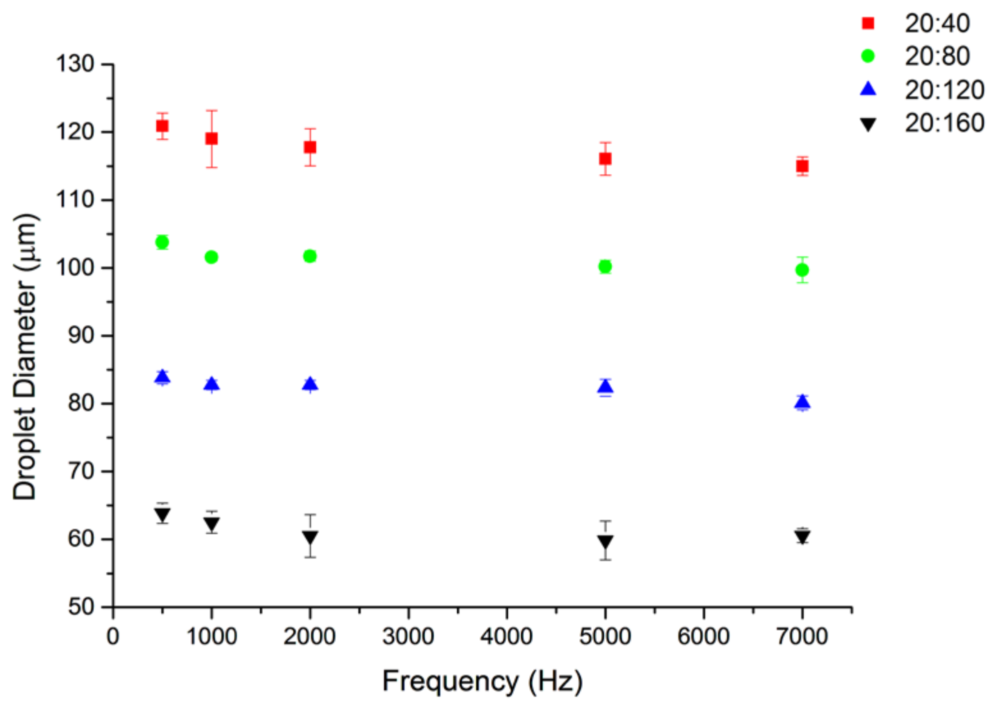

Figure S-18: Droplet diameter as a function of frequency at 250V where Q_{PEO} is 20µl/hr

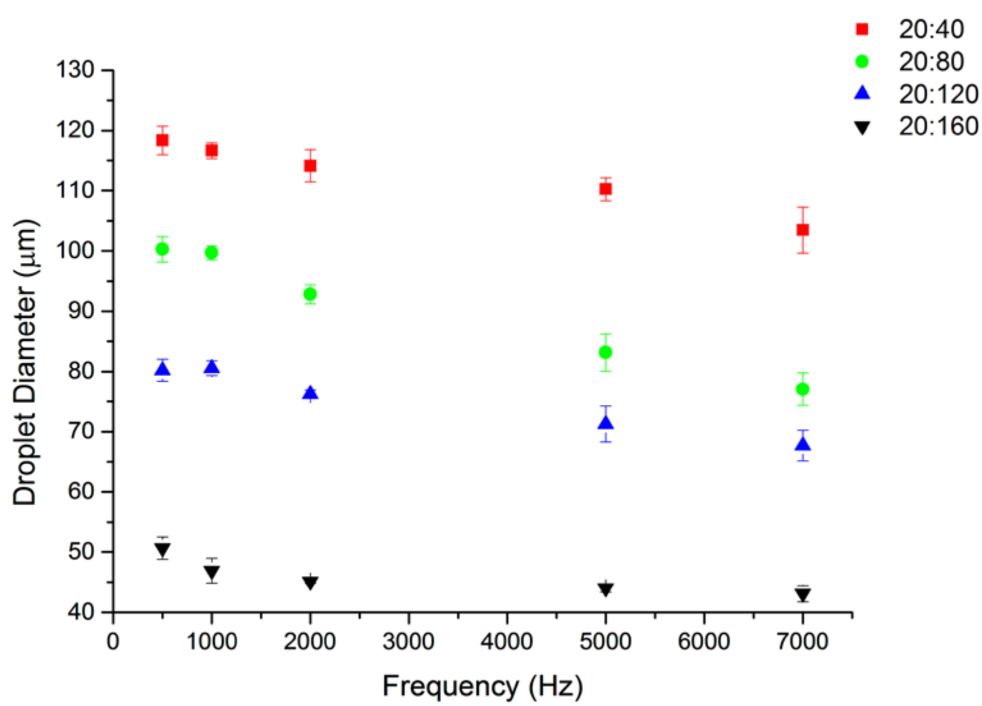

Figure S-19: Droplet diameter as a function of frequency at 750V where Q_{PEO} is 20µl/hr

7. Caption list of the uploaded videos

Table S-4 Caption list for the uploaded videos

Video Name	Caption	Capture speed (fps)
S 1-1 without e field	Non-Newtonian droplet breakup processes ***without electric*** field, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 1-2 500 V 2K Hz	Non-Newtonian droplet breakup processes under AC electric field of ***500 V 2K*** Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 1-3 750 V 7K Hz	Non-Newtonian droplet breakup processes under AC electric field of ***750 V 7K*** Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 1-4 1 KV 7 K Hz	Non-Newtonian droplet breakup processes under AC electric field of ***1K V 7K*** Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 2-1 squeezing 750V 500Hz	Non-Newtonian droplet formation in ***squeezing*** regime, under the AC electric field of 750V 500 Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 2-2 dripping 750V 500Hz	Non-Newtonian droplet formation in ***dripping*** regime, under the AC electric field of 750V 500 Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:160 µL/hr	1000
S 2-3 jetting 750V 7K Hz	Non-Newtonian droplet formation in ***jetting*** regime, under the AC electric field of 750V 7K Hz, Flow rates are $Q_{DP} : Q_{CP}$ =10:160 µL/hr	1000
S 3-1 fluorescent no field	***Fluorescent*** capturing of the non-Newtonian droplet formation, ***without electric field***, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 3-2 fluorescent 1KV 1KHz	***Fluorescent*** capturing of the non-Newtonian droplet formation, with the AC electric field of ***1KV 1K Hz***, Flow rates are $Q_{DP} : Q_{CP}$ =10:40 µL/hr	1000
S 4-1 non-Newtonian 1kv 4kHz	Droplet formation tuned by AC electric field 1K V 4K Hz: the ***non-Newtonian fluid***	1000
S 4-2 Newtonian 1kv 4kHz	Droplet formation tuned by AC electric field 1K V 4K Hz: the ***Newtonian fluid***	1000

References

1. G. H. McKinley, *Rheology Reviews*, 2005, **3**, 48.