An Introduction to Inkjet

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Outline of Presentation

- Why inkjet
- A little bit of inkjet history
- The various types of inkjet
- How droplets are generated in Drop-on-Demand inkjet
- Influence of rheology
- Influence of voltage
- Influence of pulse
- Influence of frequency
- Acknowledgements

Why Inkjet?

How many times has your office desktop printer:

run out of paper?	**Once or twice a week**
run out of ink?	**Once or twice a month**
been offline?	**Once or twice a year**
not printed the image you wanted?	**Hardly ever**

Why Inkjet?

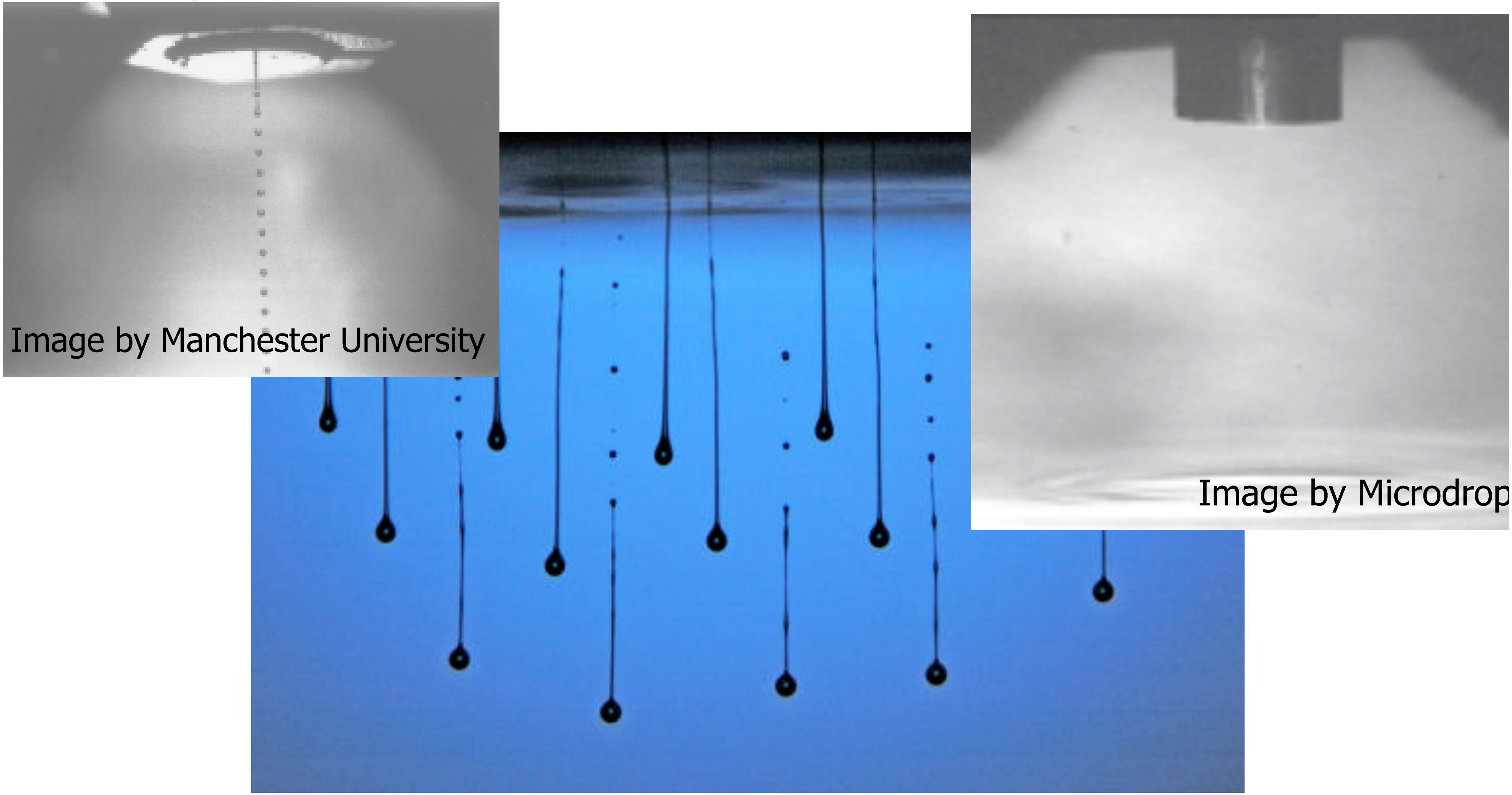


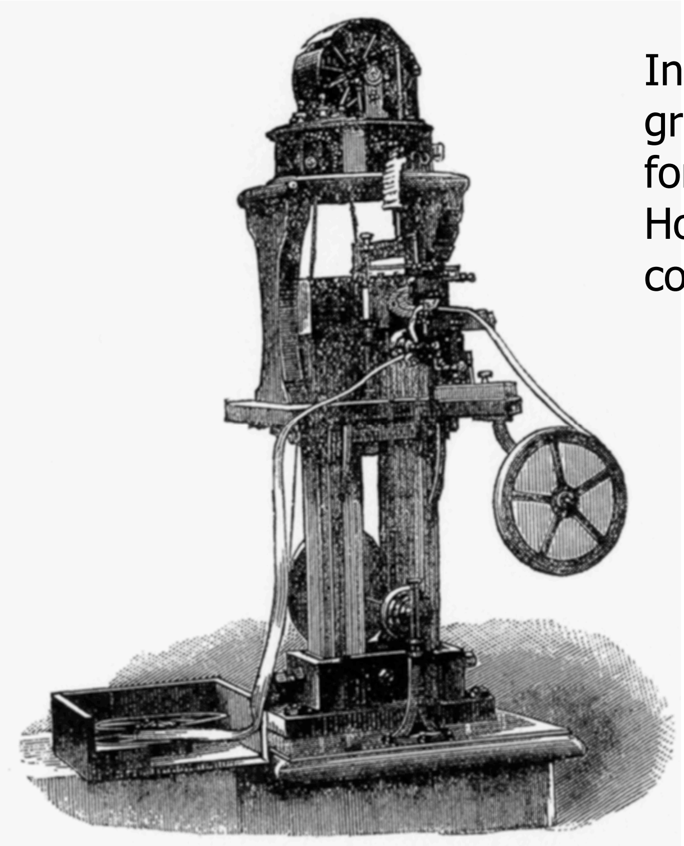
Image by Manchester University

Image by Microdrop

Image taken by Steve Hoath, http://www.ifm.eng.cam.ac.uk/pp/inkjet/default.html

Reproducible Droplets

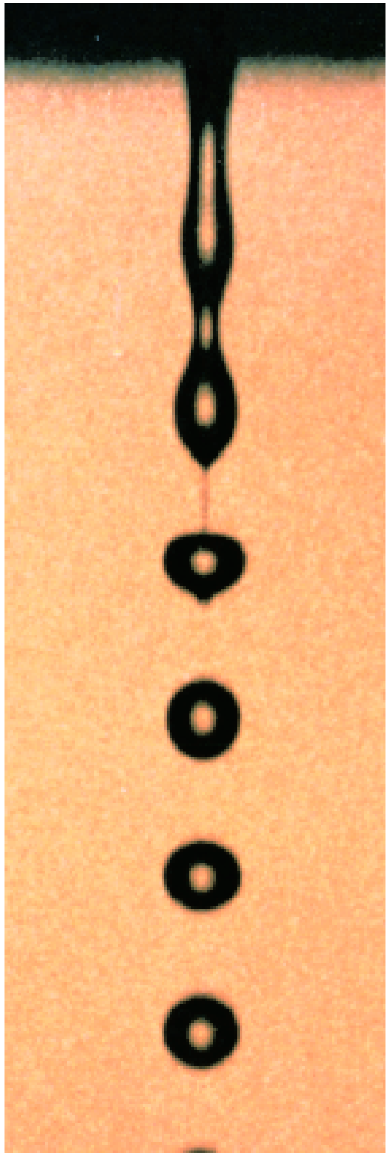
Origin of Inkjet



In 1867, William Thomson (later Lord Kelvin) was granted a patent for his proposal to use electrostatic forces to control the release of ink drops onto paper. However, his proposal did not describe a way of controlling the pattern of the droplets.

Lord Rayleigh - Fluid under pressure issues from an orifice and breaks into uniform droplets due to the amplification of induced capillary waves, which are usually due to an electromechanical device that causes pressure oscillations to propagate throughout the liquid

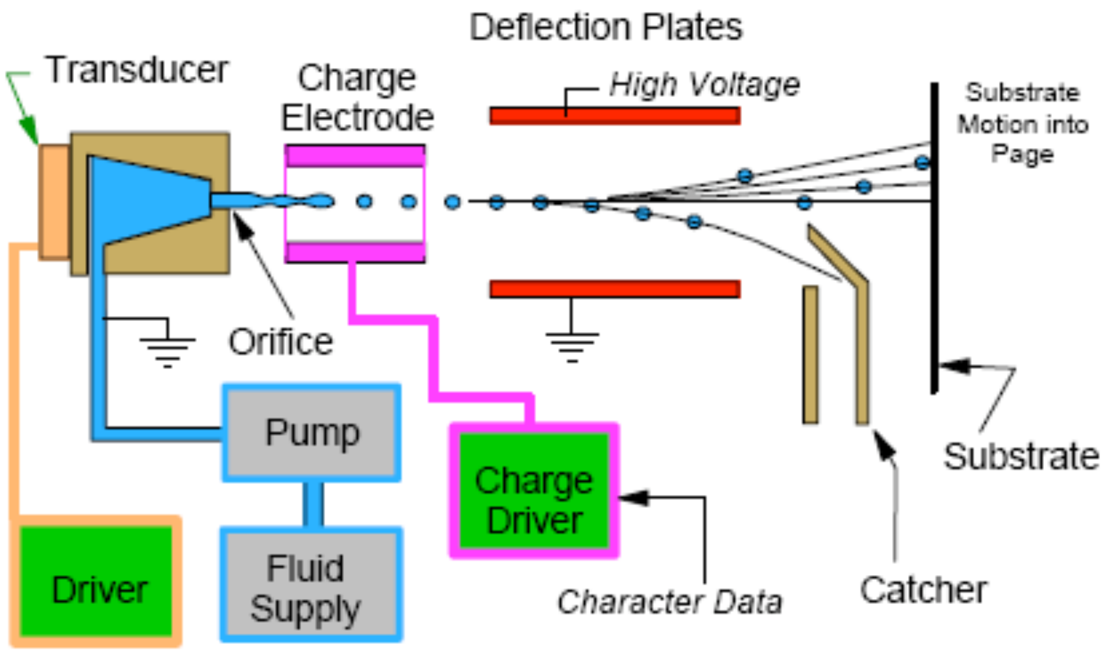
This principle is employed in inkjet devices



W. Thomson, "Improvements in Telegraphic Receiving and Recording Instruments" G.B. Pat 2,147 (1867).

Lord Rayleigh, *Proc. London. Math. Soc.;* **1878**, *10*, 4

Continuous Inkjet (CIJ)



- Droplets break off in the presence of an electromagnetic field and acquire a charge
- Droplets may then be directed by another electromagnetic field to land upon the substrate

Advantages:
Rapid droplet formation rate
No waste due to droplet recycling

Disadvantages:
Ink must be electrically conducting
Droplet recycling is a cause of contamination

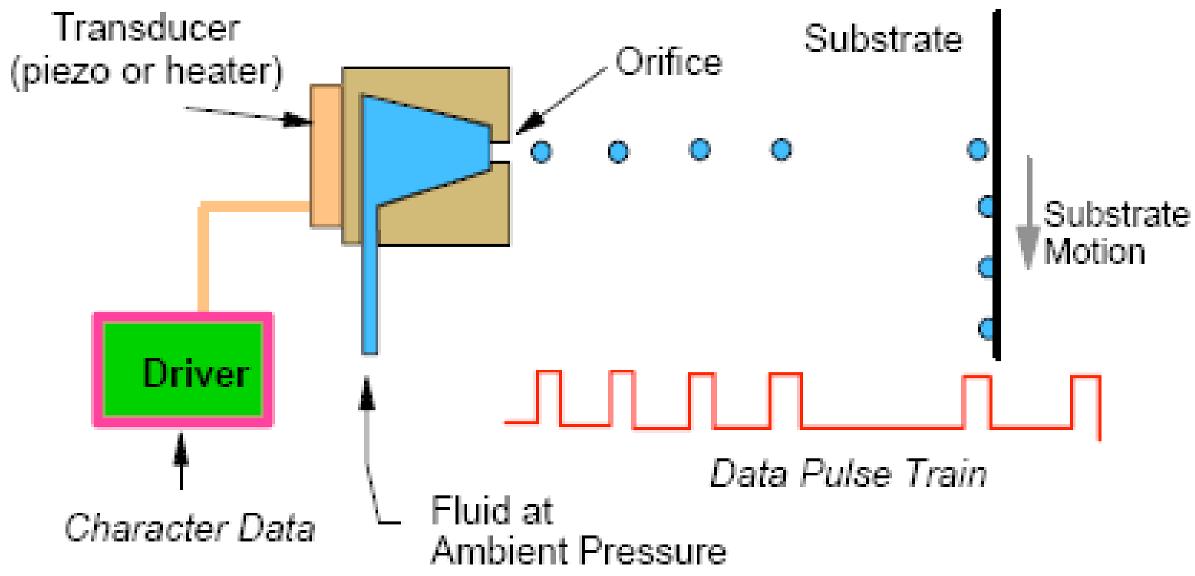
Some CIJ Manufacturers

Hitachi

Domino

Chaudhary et al. *J. Fluid Mech.* **1979**, *96*, 257: Pimbley, *IBM J. Res. Dev.* **1984**, *29*, 148

Drop on Demand Inkjet



- Drop on Demand (DOD)
Droplets are produced by pressure/velocity transients that are caused by volumetric changes, which are induced by a piezoelectric material

- Thermal Inkjet Printing (TIJ)
Droplets can also be produced by thin film resistors instead of piezoelectric transducers

Advantages:
No contamination
No waste since droplets only made when needed
Wider range of inks can be used (more so for DOD than TIJ)

Disadvantages:
Lower droplet formation rate than CIJ
Ink rheology imposes limitations

Some DOD Manufacturers

Microdrop

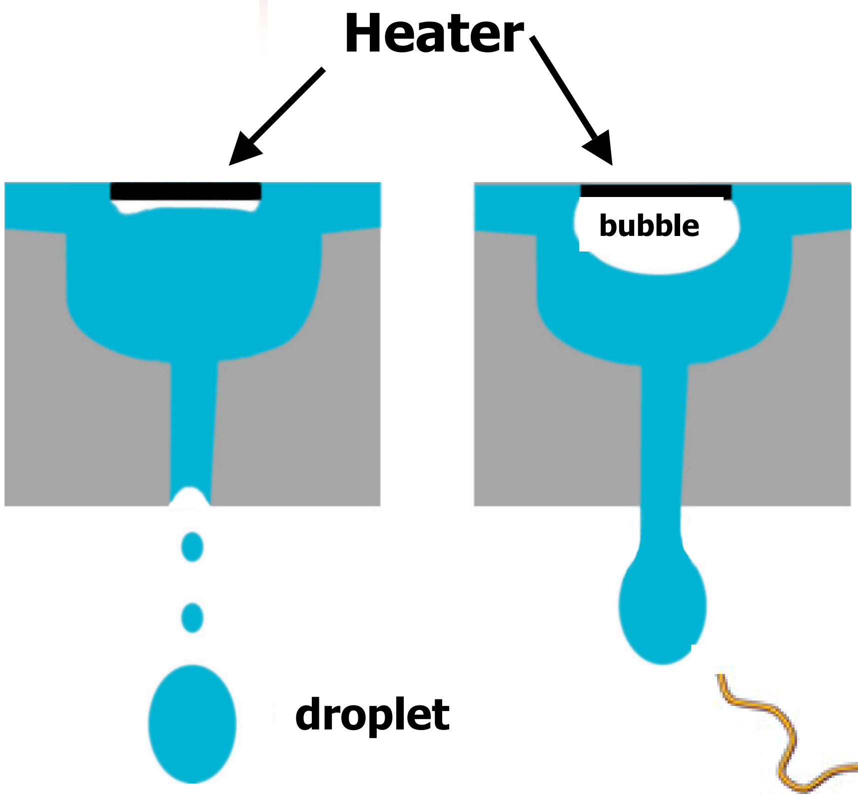
MicroFab

Fujifilm Dimatix

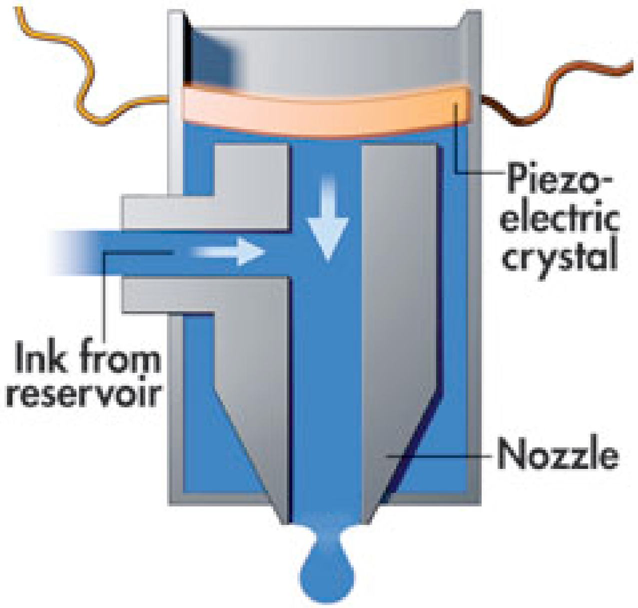
PixDro

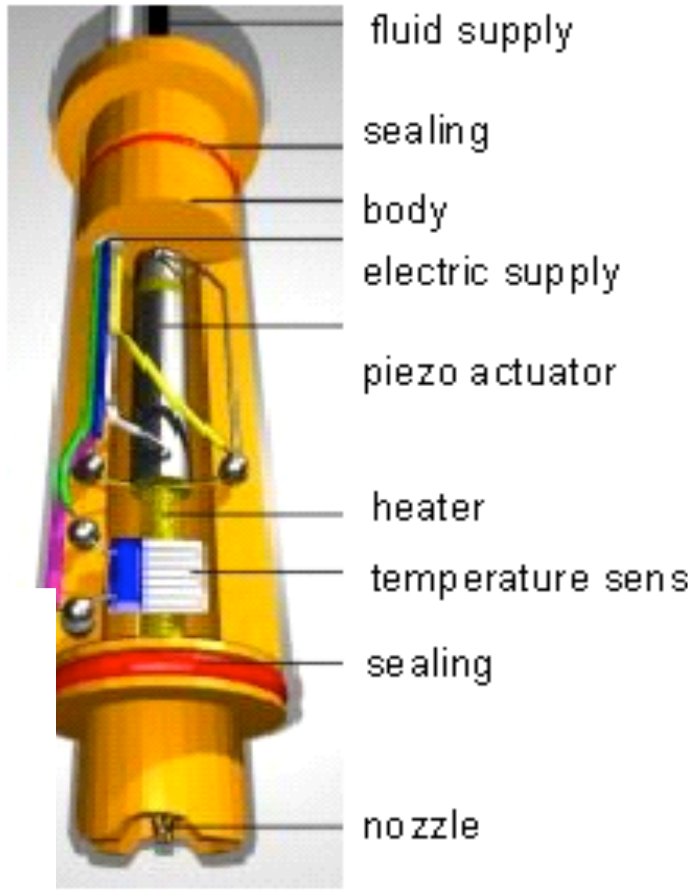
Hansell, U.S. Patent 2,512,743, **1950**

Drop-on-Demand Printheads



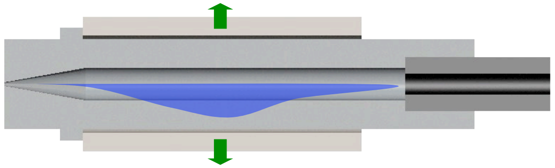
Thermal Inkjet



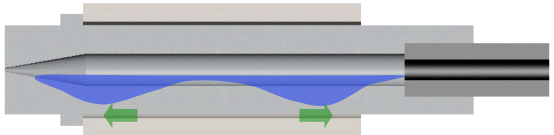


Piezo Inkjet

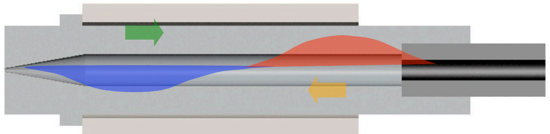
Drop ejection for DOD



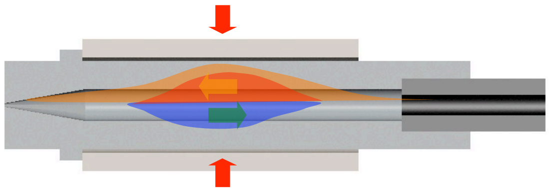
I - Piezo moves outwards



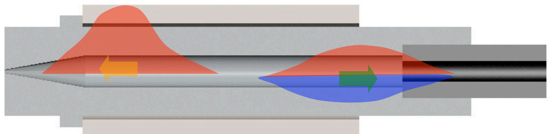
II - Negative waves travel outwards



III - Waves reflect and one reverses



IV - Waves arrive at centre when piezo contracts



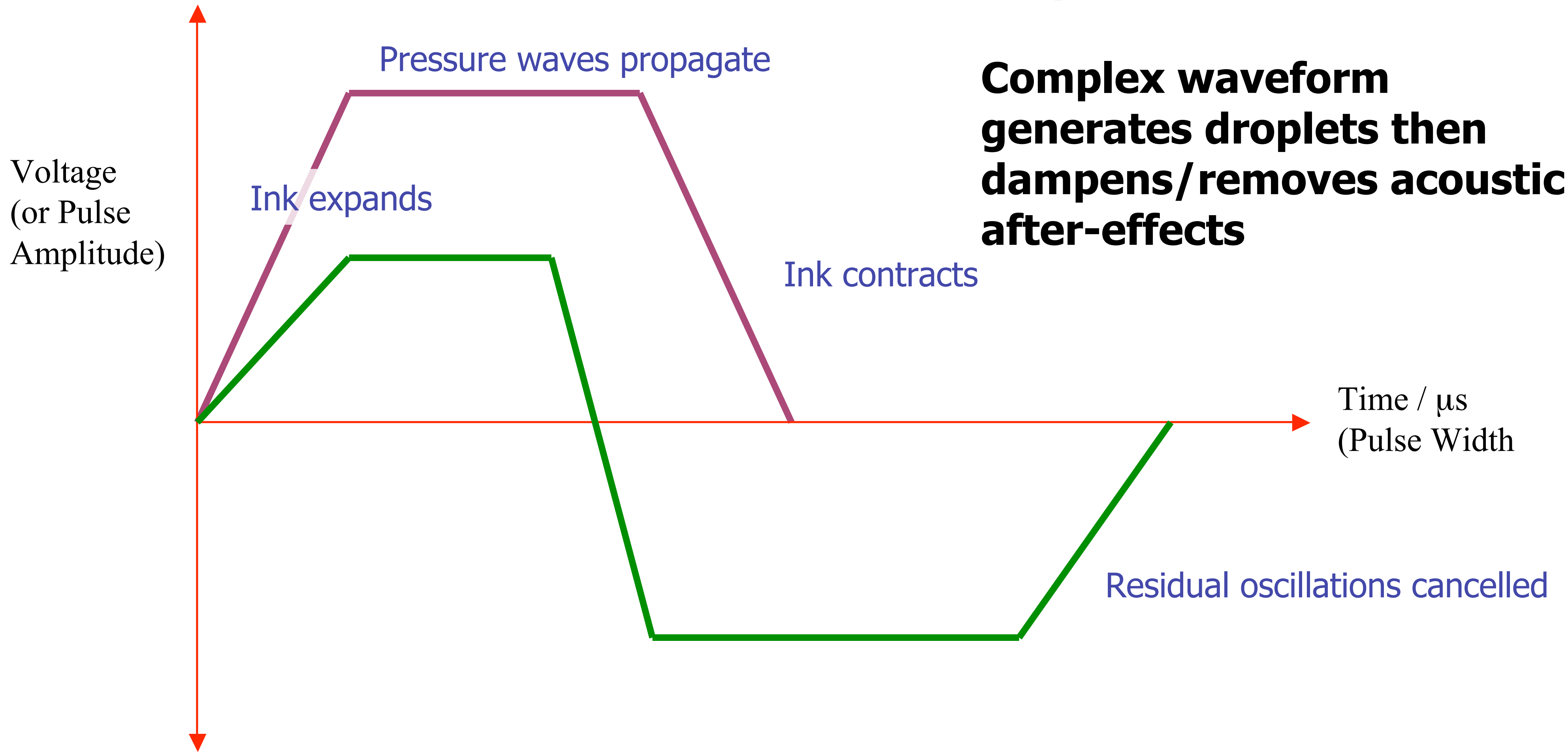
V - Wave is magnified and drop ejected

Shin, Grassia & Derby, *J. Acoust. Soc. Am.*, **2003**, *114*, 1315

Wave forms

Simple waveform generates droplets

Complex waveform generates droplets then dampens/removes acoustic after-effects



Frequency = the amount of times this waveform is repeated during a second

Ink Rheology

Viscosity

The acoustic waves which cause a droplet to be ejected are affected by ink viscosity.

The more viscous an ink is, the more the acoustic waves will be dampened. If an ink's viscosity is increased then voltage has to be increased to eject a droplet.

A benefit of a fairly viscous ink is a reduction in satellite formation.

Ink with a viscosity value between 0.5 - 40 mPa.s can be jetted. (Check with your printer vendor.)

Ink Rheology

Density

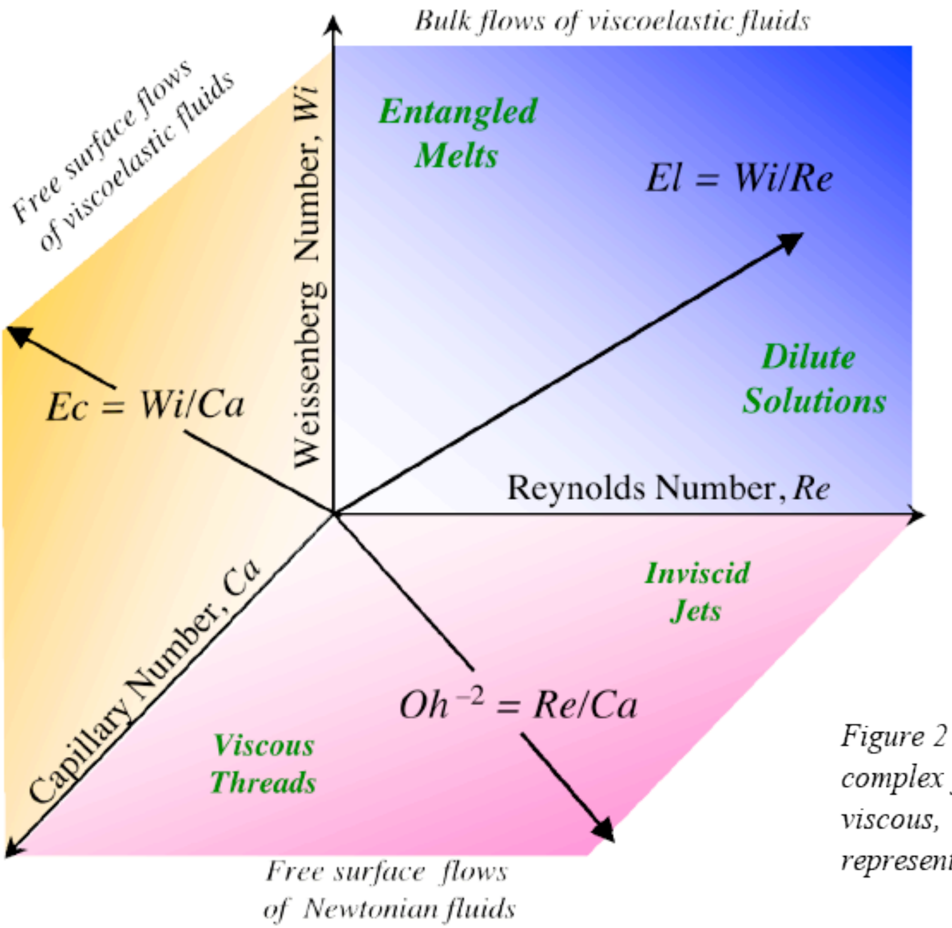
The main effect of density is on the acoustic speed, it does not affect droplet generation.

Surface Tension

An increase in surface tension will require an increase in voltage to generate a droplet. Low surface tension values can lead to bubbles forming inside the nozzle.

Ink with a surface tension value between 020 - 70 mN.m^{-1} can be jetted. (Check with your printer vendor.)

Inkjet Printing: Fluid Mechanics



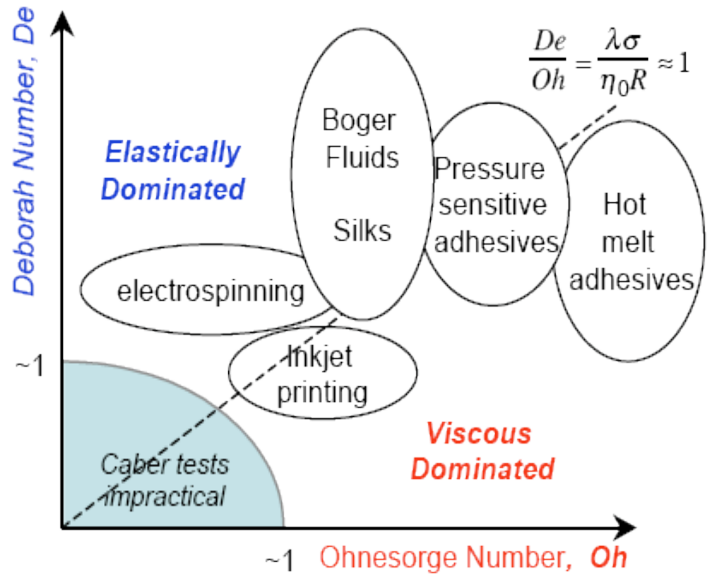


Figure 2 An 'operating diagram' for capillary self-thinning and break-up of complex fluids; organized in terms of the natural time scales for capillary, viscous, and elastic phenomena. Sketched are the loci for some common representative free surface flows of complex fluids.

Figure 1: 'Operating diagram' showing the key dimensionless parameters characterizing free surface flows of complex fluids.

Gareth H. McKinley - *Rheology Bulletin*, July 2005
https://dspace.mit.edu/bitstream/1721.1/18086/1/05-P-05.pdf

Reynolds and Weber Numbers

$$Re = \rho V L / \eta$$

$$We = \rho V^2 L / \sigma$$

ρ = density
V = fluid velocity
L = length
η = viscosity
σ = surface tension

The Reynolds number is the ratio between viscosity and inertial force

The Weber number is the ratio between surface tension and inertial force

The Z number

Fromm obtained an approximate solution to the Navier – Stokes equations to describe droplet formation:

$$\frac{\mathrm{Re}}{\mathrm{We}} = \frac{(\gamma \rho a)^{1/2}}{\eta}$$

ρ = density

γ = surface tension

η = viscosity

a = characteristic length

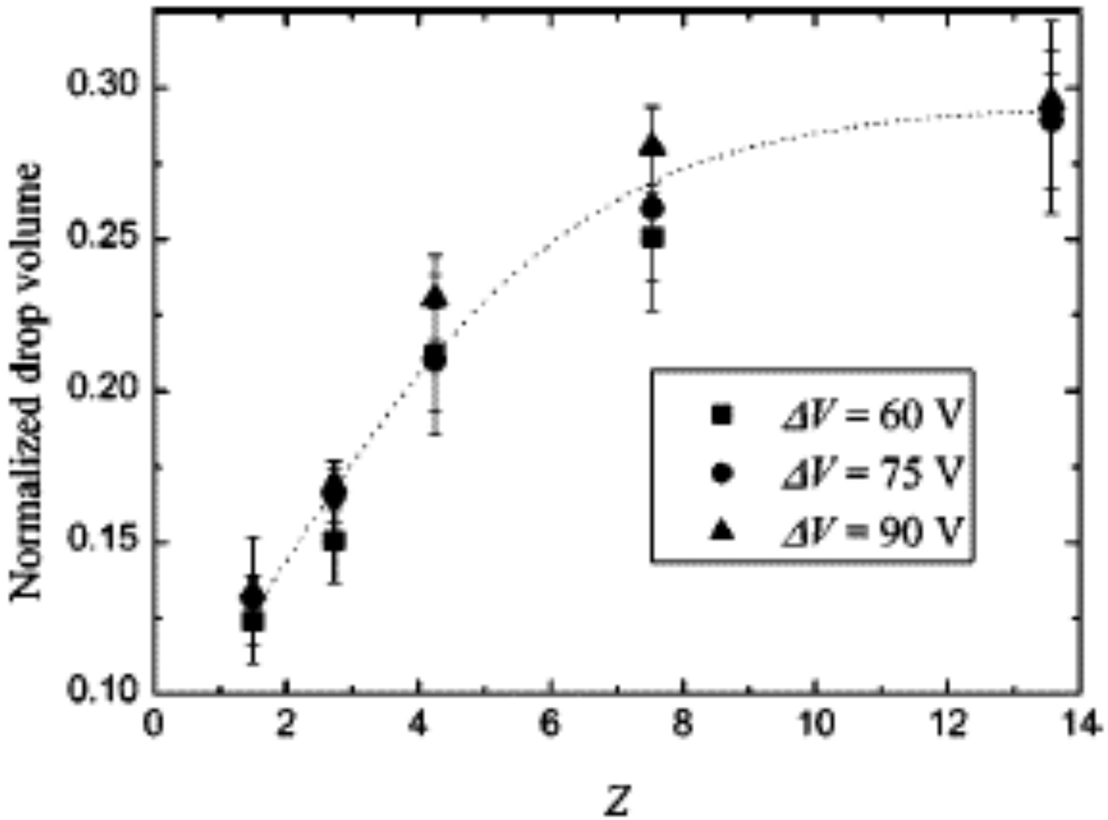
Re/We = **Z** = Oh^{-1} (Ohnesorge number)

Fromm: If Z > 2 then drop formation in drop-on-demand systems is possible

Reis et al: If 1 < Z < 10 then drop formation is possible. Lower limit is controlled by viscosity, upper limit represents satellite formation

Fromm, *IBM J. Res. Dev.* **1984**, *28*, 322 Reis, Derby *J. Appl. Phys.* **2005**, *97*, 094903

Effect of Z on Droplet Volume



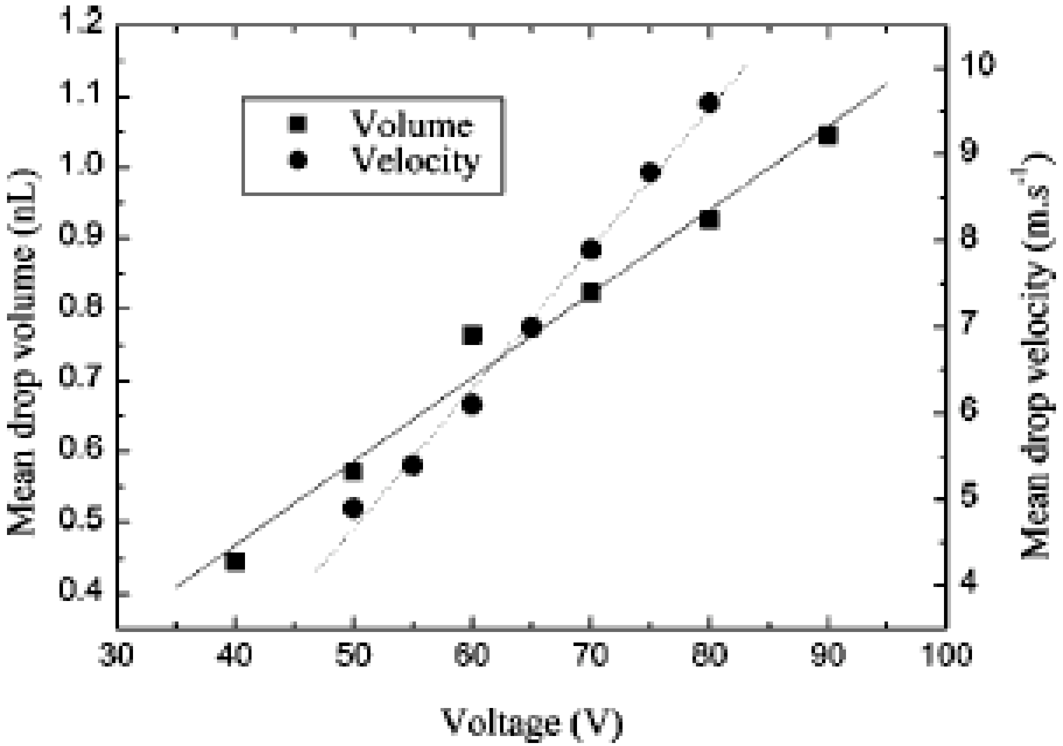
Droplet volume increases with Z as predicted by Fromm

$$Z = (d\rho\gamma)^{1/2} / \mu$$

Droplet volume is normalised to the volume displaced by the actuator at different driving voltages

Reis, Derby *J. Appl. Phys.* **2005**, *97*, 094903

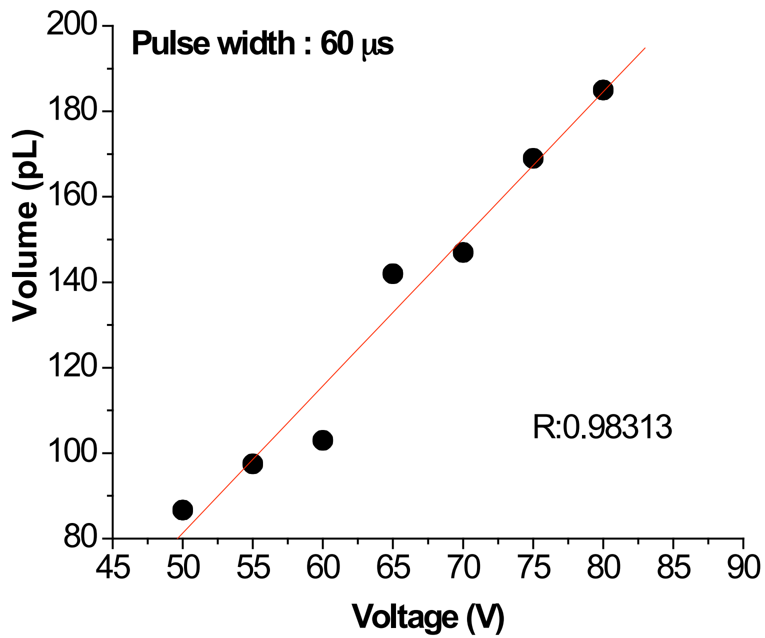
Influence of Voltage on Droplet Volume



Molten paraffin wax

Applied voltage is proportiona to droplet volume

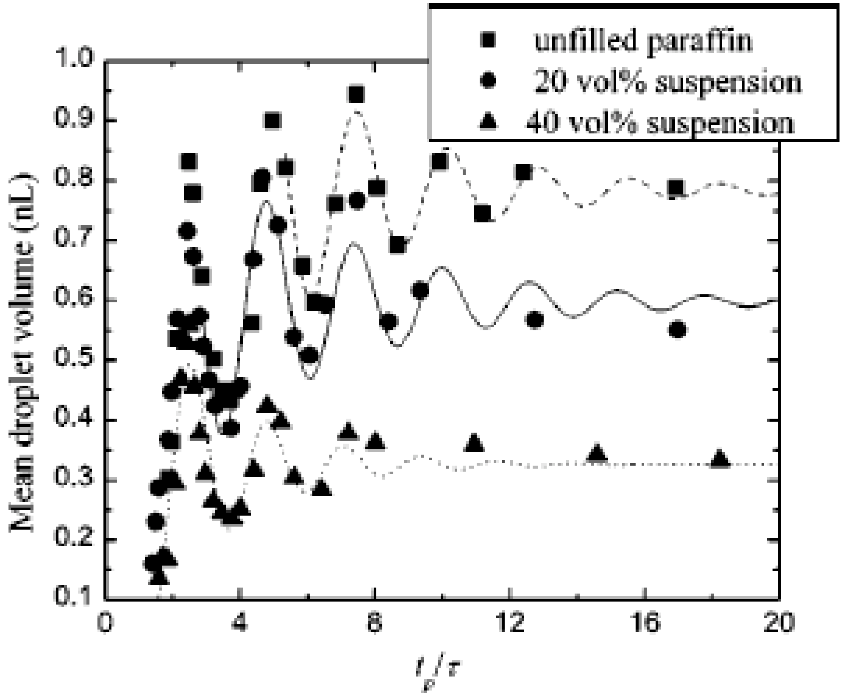
Increased Voltage = Increased Droplet Volume



Aqueous PEDOT solution

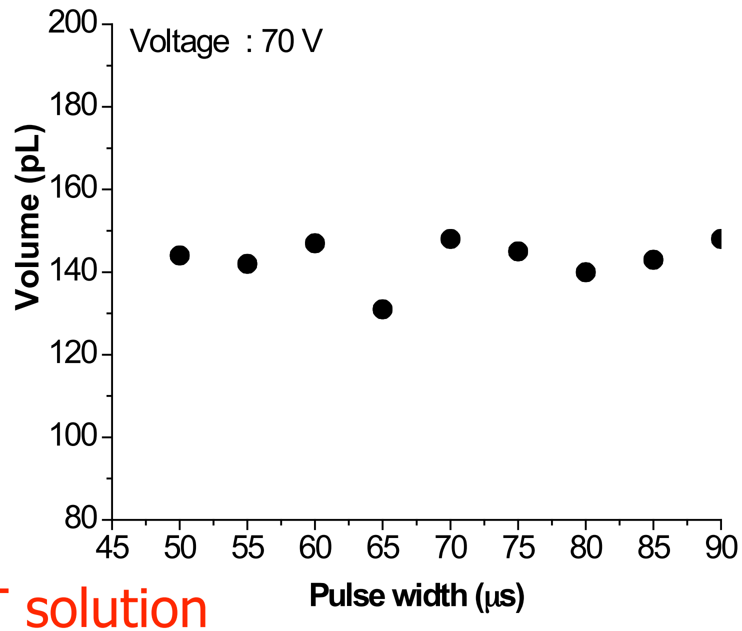
Reis, Derby, *J. Appl. Phys.* **2005**, *97*, 094903

Influence of Pulse Width on Droplet



Molten paraffin wax

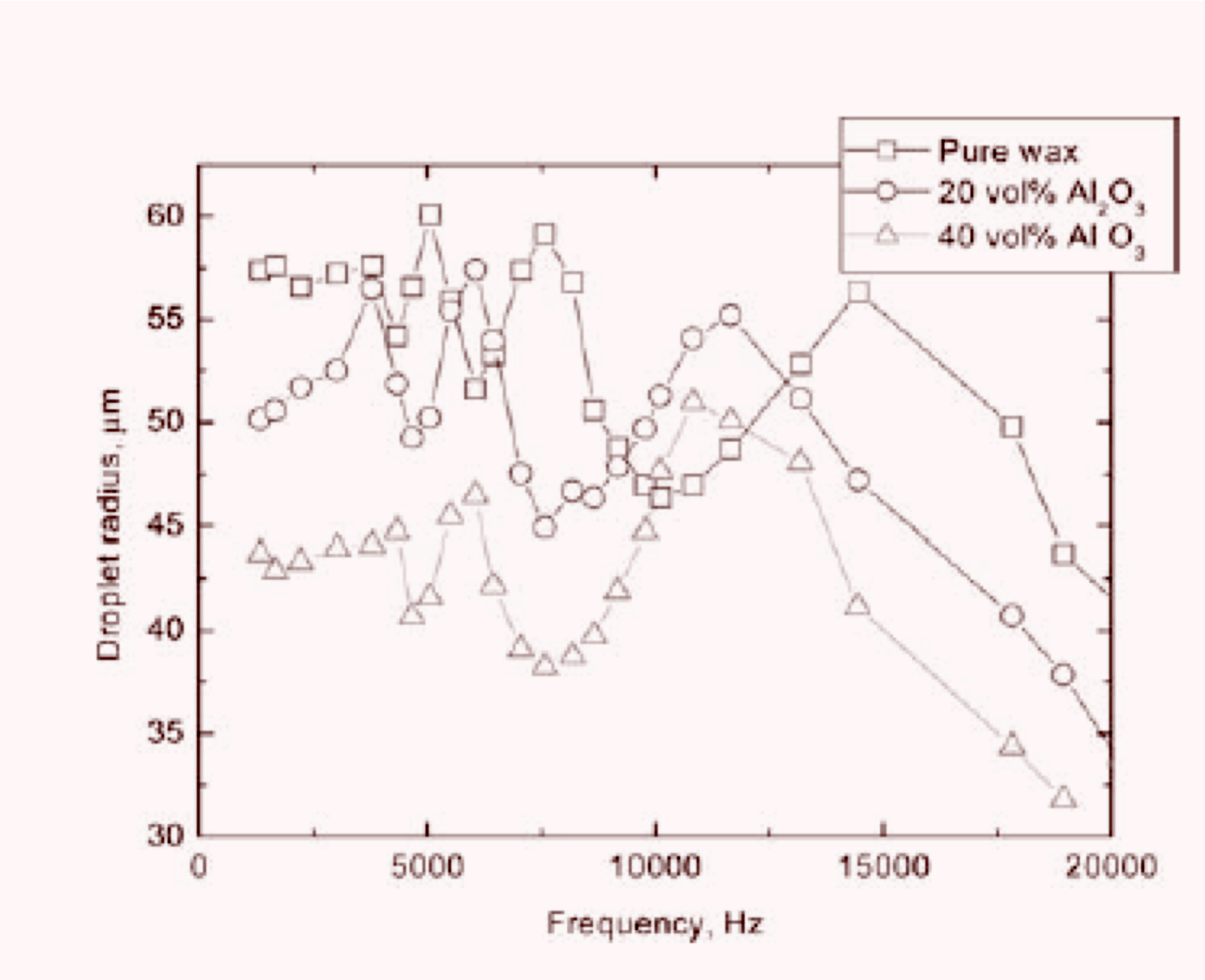
Pulse width has a complicated effect on droplet volume



Aqueous PEDOT solution

Reis, Derby, *J. Appl. Phys.* **2005**, *97*, 094903

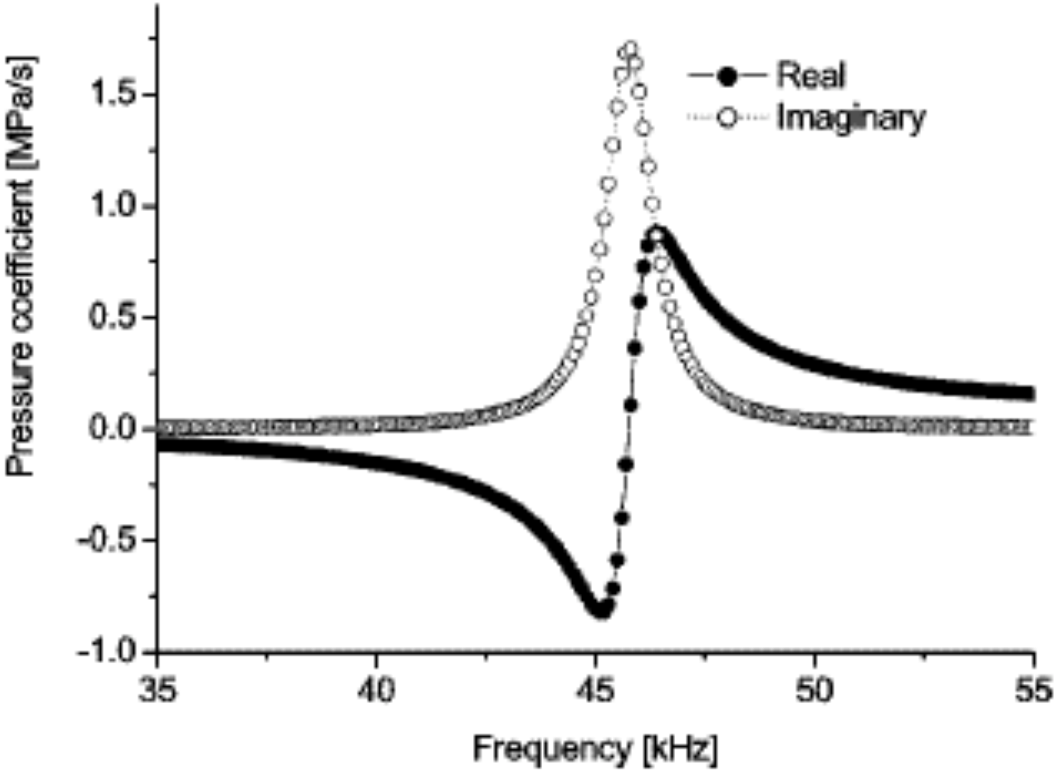
Influence of Frequency on Volume



Sinusoidal behaviour similar to that of varying pulse width.

Ainsley, Derby, *J. Mater. Sci.* **2002**, *37*, 3155

Influence of Frequency on Pressure

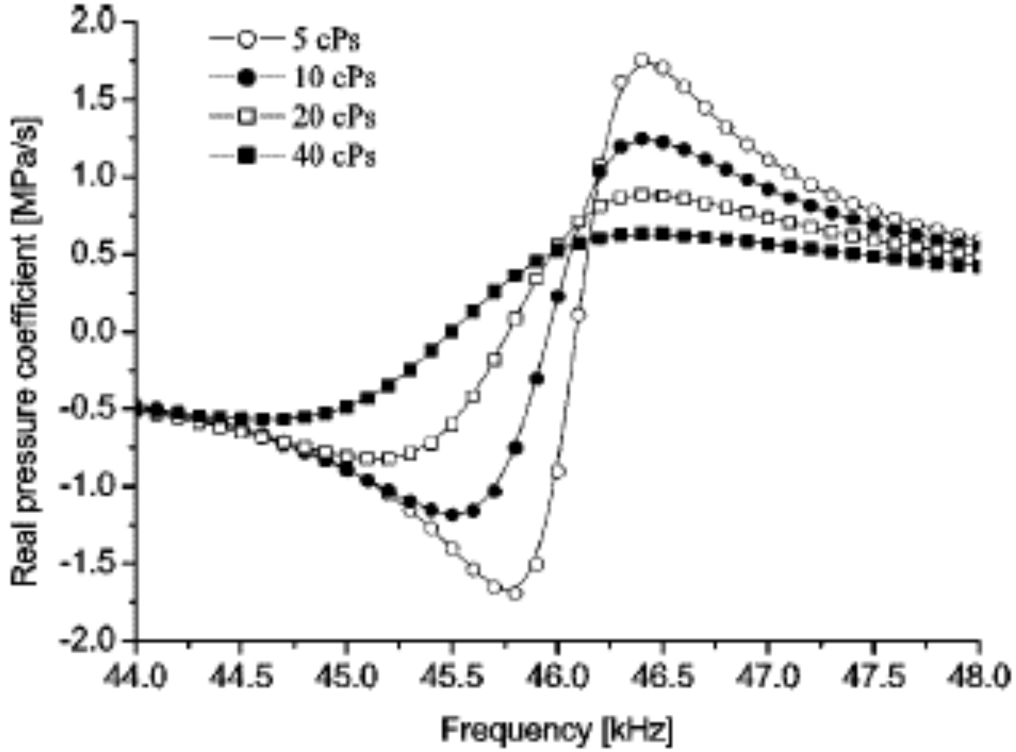


Computational results of the effect on pressure of frequency for a PZT 5A tube

(R_1 = 0.41 mm, R_2 = 0.65 mm, L = 15.33 mm)

Shin, Derby, *J. Acoust. Soc. Am.*, **2003**, *114*, 1314

Influence of Viscosity

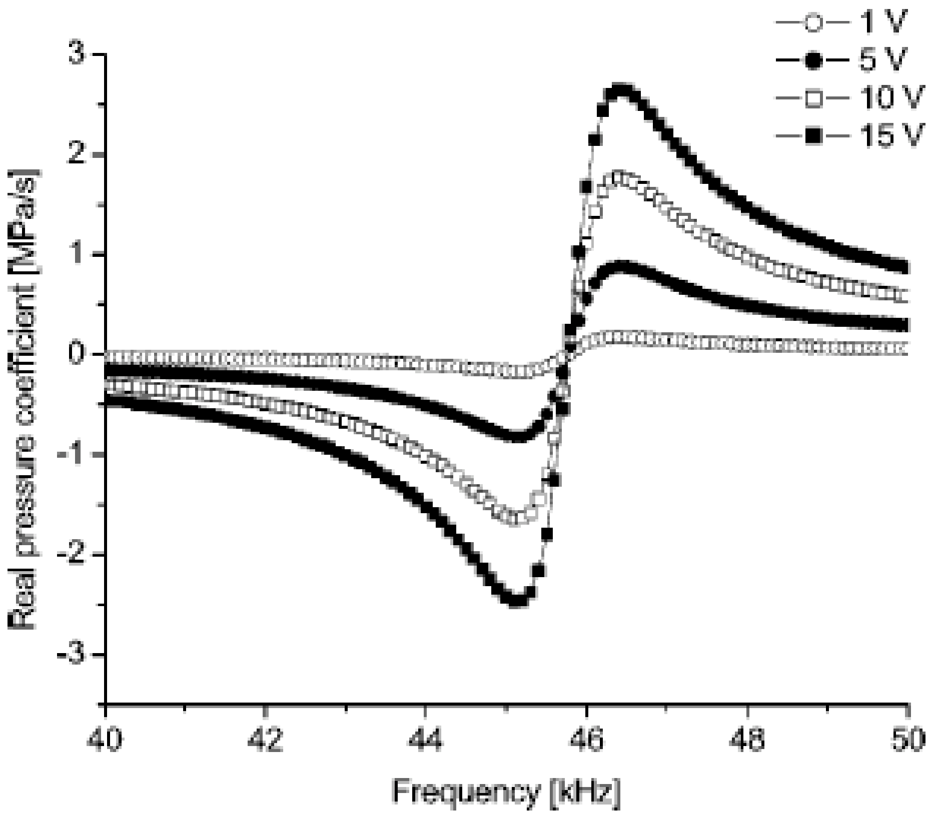


Computational results of the effect on pressure of frequency for four liquids with varied viscosity for a PZT 5A tube

(R_1 = 0.41 mm, R_2 = 0.65 mm, L = 15.33 mm)

Shin et al, *J. Acoust. Soc. Am.*, **2003**, *114*, 1314

Influence of Voltage



Computational results of the effect on pressure of frequency for four different voltages using a PZT 5A tube

(R_1 = 0.41 mm, R_2 = 0.65 mm, L = 15.33 mm)

Shin et al, *J. Acoust. Soc. Am.*, **2003**, *114*, 1314

Summary

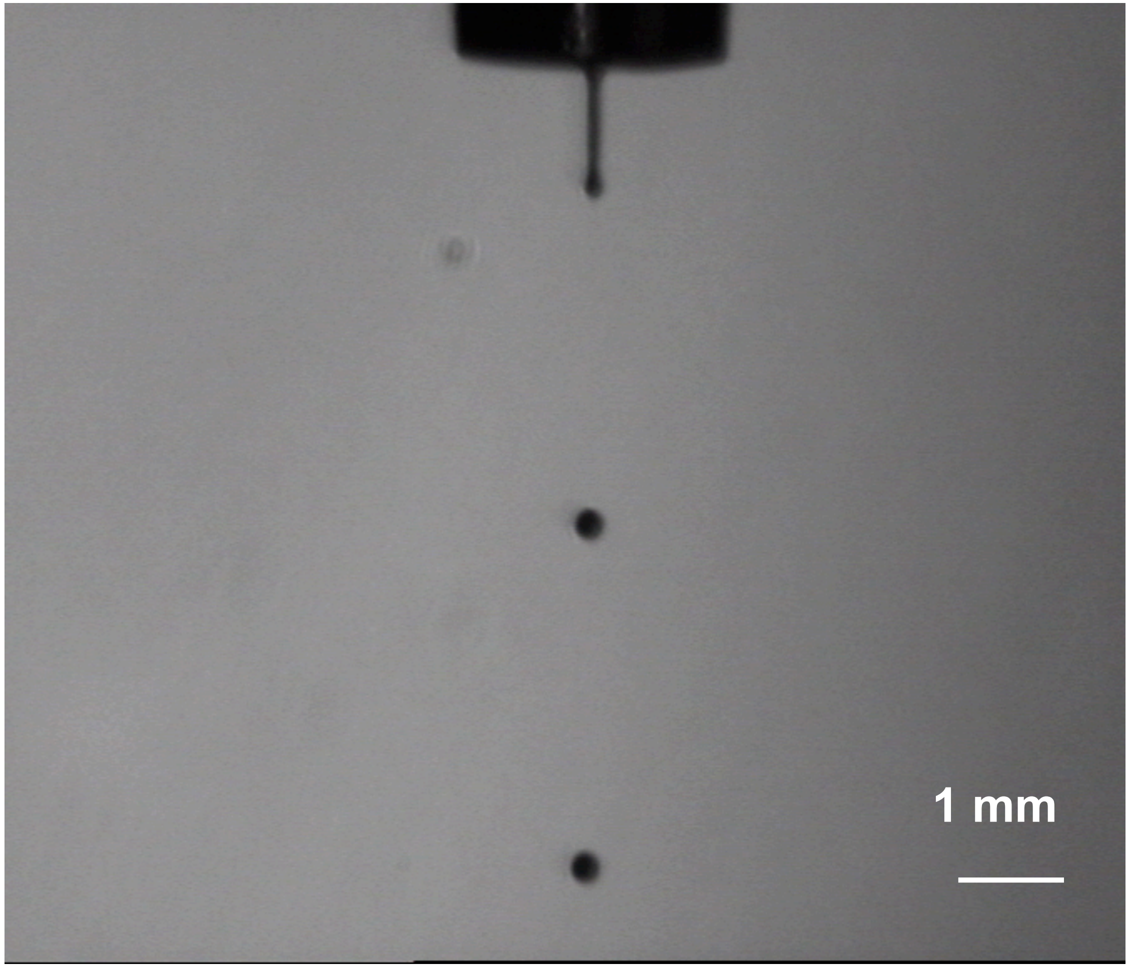
Inkjet printers are widely used, usually for small document printing runs but are increasingly being used for a wide variety of applications.

Inkjet's appeal lies in its ability to reproducibly generate uniform sized droplets.

With ink, viscosity is important. Above about 40 mPa.s jetting becomes difficult.

Droplets are generated by a voltage pulse. Typically, the larger the voltage, the larger the droplet.

Thankfully…



If you see droplets, your ink is printable.

Although, what goes on behind the nozzle is quite complicated the beauty of inkjet is that a simple visual check is all that is needed for most users - assuming your ink has the proper rheometry

Acknowledgements

- Slides 7 & 8 were based on MicroFab's Tech-note 99-01, which can be found at: http://www.microfab.com/equipment/technotes.html

- SMN, MicroDrop and Dimatix