ELECTRO-HYDRODYNAMIC SPRAYING FROM NARROW CAPILLARIES

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Steady liquid jets are often generated from a liquid-fluid interface (conductor-dielectric) when exposed to electrostatic fields. Typically a conducting liquid flows through of a capillary tube set at high voltage, and out of its end into a gaseous surrounding. Jets from highly viscous liquids, especially if non-newtonian, fly as a continuous filament towards the counter-electrode, and are the basis of "electrospinning". Lower viscosity jets on the other hand, break up forming mists of highly charged, non-agglomerating droplets. Because the drops result from the quasi-periodic breakup of a jet, they are of uniform size (stddev. ~10%). Such "electrosprays" form the basis of Electrospray Ionization Mass Spectrometry (ESI-MS) of proteins, whose success stems in part from the little analyte spent, in uL range.[1] Despite the liquid flow being low, applications closer to Nanoscience and Nanotechnology are being pursued, including electro-deposition for thin-film formation [2,3] and spray-to-nanoparticle conversion processes (chemical spray and spray-flame pyrolysis, and spray drying).[4,5]

We are interested in advancing the state-of-the art of the spray generation processes. More fundamental an issue than the low flow rates is the strong dependence between droplet size and electrical conductivity of the liquid.[6] In this connection, we have become interested in the report by Wilm & Mann that narrowing the capillary exit tip to a few microns dia. from conventional sizes of few 100 um's, causes a reduction in droplet diameter by a factor of 2 or 3.[7] We have found very scarce information on either droplet size and charge distributions, or on the fluid motions responsible for the droplet formation. We are thus carrying out a systematic investigation of this mode of atomisation from narrow capillaries, employing microscopy for the first time.

Methods: Borosilicate glass capillaries (1.0 o.d., 0.58 i.d.; mm) are pulled using a P-97 Sutter micropipette puller. The pulled ends are typically 10-17 um in o.d., 4-6 um in i.d., and are filled with pre-filtered liquid solutions (LiCl in tri(ethylene)glycol). A metal filament inserted into the liquid is connected to a 0-2kV power supply (Ultravolt 2A12). This glass tip lays horizontally on the Teflon purpose-made platen of a microscope (Kyowa ME-LUX2), fitted with a long-working distance (~8 mm) lens. ~3 mm away from the pulled tip of the capillary is a counter electrode (the open end of a stainless steel tube 3.2 o.d., 1.7 i.d. mm), or a metal frit disk 9.5 in diameter). It is connected to the p.s. ground through a nanoamp-meter. Images are focused onto a CCD camera sensor through the scope's photo tube, and captured by a computer. The capillary can be pressurized using CO_2 (99.995 %). Spraying is into room air.

Results and Conclusions: Our images provide readily interpretable patterns (despite limitations in resolution). The liquid stays anchored at the tip of the glass capillary (wetting only its exit face, and not the sides). At low values of the applied voltage V, transmitted current I grows with V while a blurry cusp forms on the meniscus. This cusp probably is the periodic oscillation of the meniscus. At higher V's, however, I suddenly increases while the blurry cusp is replaced by a dark "solid" cusp, which we interpret as emission of a steady jet. As the pressure drop P is raised, the current grows in the high conductivity solution (fig 3). With the low conductivity one, the trend is not monotonous with P (fig 4), and the stability of the meniscus is more complex in behaviour.

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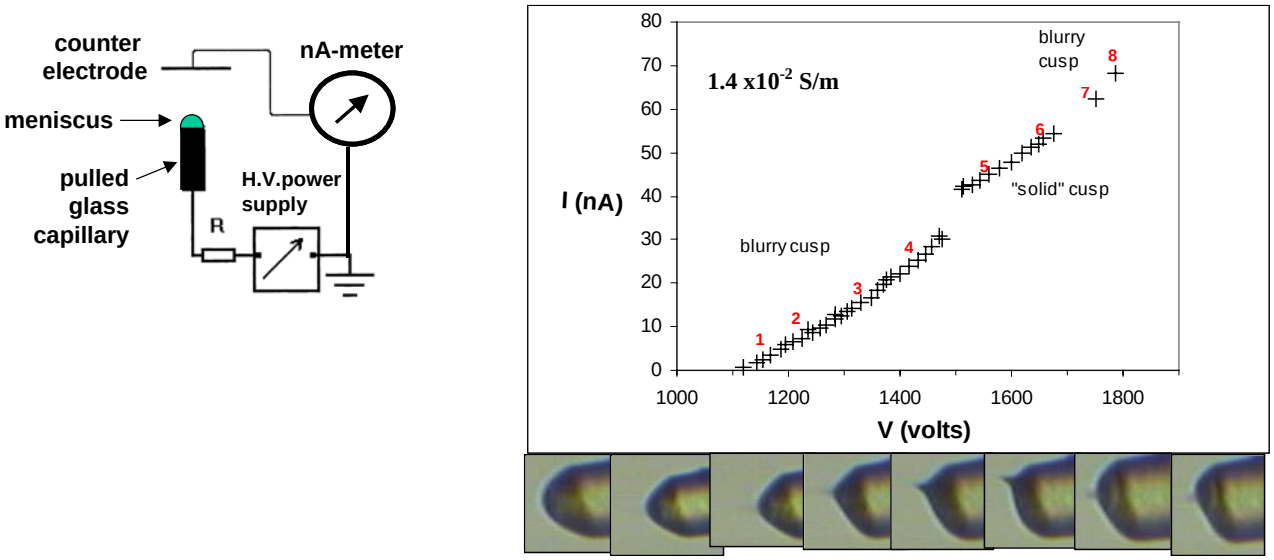
Figures: 1: Set-up schematic. 2: Transmitted current *vs.* voltage with pictures of capillary tip numbered left to right. (Capillary pressure drop P = 0 bar; counter electrode=tube.)



Figs 3 (left) and 4: Transmitted current *vs.* voltage for two different electrical conductivity solutions. (Fig.3: id=5.5 od=14. Fig.4: id=4.5 od=10, in um. Counter electrode= porous plate.)