# Pulsed corona for breaking up air bubbles in water

# Pulsed Corona for Breaking up Air Bubbles in Water

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## ABSTRACT

**The injection of gas into water, through a hollow needle, gives a stream of bubbles. These bubbles can be effectively broken up by application of HV pulses. Our experimental work shows that this mechanism works in demineralized water and even in conducting tap water if the pulses have a short rise time. Bubble diameters are as low as 50 $\mu$m. Our pulse source uses either a HV tetrode or a spark gap as switching element. Extremely small bubbles are produced at a high rate and a low power input. Applications for this method can be found in chemical process technology.**

## 1. INTRODUCTION

CHEMICAL processes such as absorption, catalytic slurry reactions *etc.* are expedited by a much enlarged surface area between gas and liquid [1]. In particular, processes involving absorption of oxygen in water are widespread. Ogata *et al.* [2] reported the formation of small bubbles in nonconducting liquids by the application of strong electric fields. Using the favorable effect of a ring-shaped electrode above the needle, we easily obtained bubble diameters down to 50 $\mu$m [3].

To enable bubble disruption in conducting liquids we apply pulse shaped voltages. For high frequencies, pulse source and water behave like a capacitive divider. The conductivity of the water subsequently leads to a fast decay of the pulse. The rise time therefore should be small compared to this decay time to reach, during a short period, the high electric field needed for bubble disruption. We use short pulses also to avoid breakdown. Sufficient time is needed however to transfer electrical energy to the bubble, which is a mechanical system. A low duty cycle for the pulses limits ohmic dissipation and electrolysis. Our pulse source uses either a HV tube to produce 3 kHz of narrow 3 A current pulses or a repetitive (20 to 80 Hz) high current capacitor discharge via a spark gap. To improve breakup, we also investigated how an insulating low permittivity spacer around the needle can increase the field strength near the needle tip.

A strong reduction of the bubble diameter when it

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leaves the needle results from the electrostatic forces across the surface of the bubble. High electric fields near the needle tip are needed and the permittivity values of fluid and gas must not be too close together. It is the same mechanism that leads to the elongation of free floating bubbles and droplets in the direction of the field [4]. For the evaluation of the complicated fields and forces near a needle tip a computer-aided analysis is needed (386PC field programs from Ansoft [5] and from IES [6]). Shock waves in the water produced by partial discharges in the mixture of gas and water around the needle tip can also lead to enhanced bubble disruption. This mechanism may become increasingly important when liquids with higher conductivities are used.

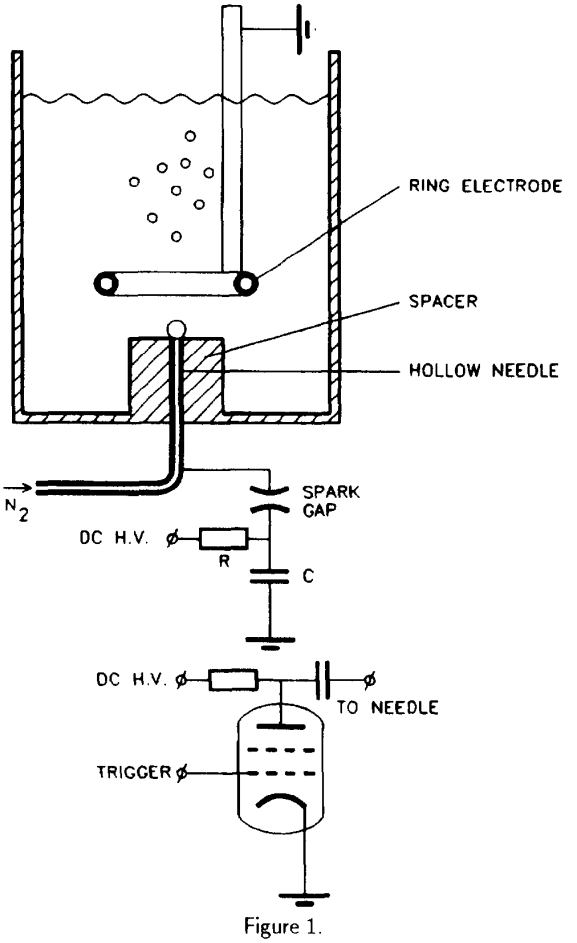


Figure 1.

The experimental setup with spark gap (top) and HV tube (bottom).

## 2. EXPERIMENTAL SETUP

Figure 1 shows the experimental setup. We use two types of pulse sources: the spark gap in the upper part of the Figure and the HV tube separately below it. The pulse source is connected to a needle with 0.6 and 0.35 mm outer and inner diameter. The needle protrudes into the PVC Perspex™ container via a 10 mm PVC spacer. In a later stage of the experiment we found that the properties of the PVC spacer deteriorate rather quickly. During a series of experiments with a polyethylene spacer, such deterioration was not found. The second electrode in the vessel is a brass ring. The water is either demineralized water with a measured conductivity $\sigma \approx 0.0003$ or tap water with $\sigma \approx 0.03$ S. Effects on the breakup process that are due to the type of gas are not expected. Therefore only nitrogen is used.

We measure the pulse voltage using a differentiating/integrating (D/I) technique [7, 8]. The sensor is a small electrode around the HV conductor to the needle. It is connected to a coaxial signal cable. The sensor's capacitance to HV in combination with the termination resistor of the cable forms a differentiator for the HV. With a passive $RC$ integrator behind the cable termination to restore the original waveform, we obtain a perfectly attenuated HV signal. The passive integrator is followed by an active stage to correctly integrate the low frequencies. Cable termination and integrator are mounted in a special EMC cabinet. The D/I measuring system has a large bandwidth, is linear, and has only one simple HV component. The excellent EMC performance is inherent to the design in two ways. The integration necessary after transport of differentiated signals strongly reduces interference signals, and since common mode currents are effectively rerouted by the special EMC cabinet, the transfer impedance to the sensitive digital measuring equipment is very low.

Since the HV tube can only pass $\approx 3$ A peak current to the capacitive load of 150 pF, the slope of the pulse at the needle is 20 kV/$\mu$s at most. The spark gap is a low impedance source that allows short rise times (40 ns). It switches spontaneously at a repetition rate fixed by the charging time of capacitor $C$ (2.5 nF), the gap width and the dc HV setting. We can represent the impedance of the water by a parallel $R_w$ and $C_w$. With a needle of outer radius $r_1$ that protrudes a distance $h$ out of the spacer we can model the impedance by a cylinder of water around the needle and a half sphere around the needle tip (the effect of the spacer is not accounted for). Thus, for tap water $R_w$ is 19 k$\Omega$ for $h = 0$ and 6 k$\Omega$ for $h = 2$ mm. For demineralized water these values are respectively 1.9 M$\Omega$ and 0.6 M$\Omega$. The capacitances are 2.8 and 6.0 pF, respectively. The calculated impedances of the needle with the water agree within 10% with measured values. We observed that during HV operation the resistance of the needle in the water is lower than the values given above. Additional dissipation by the breakup

process and partial discharges leads to a lower effective resistance.

To represent the actual capacitive load correctly as seen by the spark gap, we have to include the stray capacitances of the connection to the needle into $C_w$. The total value is therefore $\approx$ 150 pF. The decay time of the pulses is governed by $CR_w$ in case of the spark gap circuit and by $C_wR_w$ when the tube circuit is used. Due to the discharge activity around the needle the actual decay can be faster.

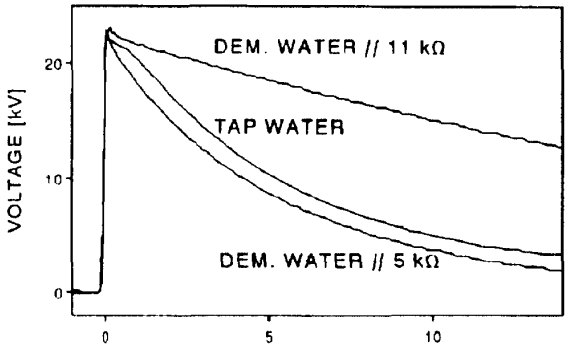


Figure 2.

Measured HV pulses when a resistor is in parallel with the demineralized water to simulate the behavior of tap water (spark gap circuit).

## 3. ELECTRICAL CIRCUIT AND BREAKUP

Both circuits can produce high pulses in demineralized water (18 kV peak pulse voltage at a charging voltage of 20 kV). We observe intense bubble breakup in this case. The spark gap is needed to produce breakup in tap water. Figure 2 gives the measured wave shapes for the spark gap circuit. A resistor is connected in parallel with the demineralized water to simulate the circuit properties of tap water. We decreased the resistance to observe at what value breakup is prevented. A resistor of 11 kΩ still allows breakup but at 5 kΩ the effect disappears completely. Since the voltage plot for tap water without a parallel resistor is not far above the curve of demineralized water in parallel with 5 kΩ, the capabilities of the present pulse source are close to the limits for breakup with tap water.

## 4. BREAKUP PROCESS AND FIELD GEOMETRY NEAR THE NEEDLE

The electrostatic pressure difference at the interface from water (1) to gas (2) is [4]

$$\Delta p = \frac{1}{2}\varepsilon_o(\varepsilon_1 - \varepsilon_2)\left[E_{\parallel}^2 + \frac{\varepsilon_2}{\varepsilon_1}E_{2\perp}^2\right] \qquad (1)$$

The field components tangential and normal to the bubble surface are denoted by the subscripts $\parallel$ and $\perp$.

An extra pressure difference (from medium (1) to (2)) results from the electrostriction term of the Maxwell stress tensor

$$\Delta p = \frac{1}{2}\varepsilon_o(\varepsilon_2 - 1)\left[E_{\parallel}^2 + E_{2\perp}^2\right] \qquad (2)$$

Since $\varepsilon_2 - 1$ in Equation (2) is much smaller (medium 2 is a gas) than $\varepsilon_1 - \varepsilon_2$ in Equation (1) ($\approx 79$), the effect of electrostriction is negligible. Combining Equation (1) with a numerical 2D field calculation, we can determine the forces on a bubble attached to the needle tip. This procedure was verified for dc voltages applied to a needle without a spacer in ethanol [3]. The measurements show that a voltage of 1 kV at the needle pushes the bubble into the liquid when the diameter has grown to 1.6 mm; at 3 kV this is 1.0 mm. When no voltage is applied the diameter would be 2.7 mm. The numerical calculations agree within 7% at 1 kV and within 40% at 3 kV with the measured values. At higher voltages much smaller bubbles are found but the errors increase considerably. Corona effects (not included in the simulation) may explain these differences.

Experimentally we found that a favorable geometry of spacer and needle contributes considerably to the intensity of breakup. Due to its relatively low permittivity, the presence of the spacer in the water causes a field strength near the needle tip that is much higher than in the situation with only water surrounding the needle.

Computer calculations (Figures 3 and 4) for the present situation and for a needle tip far above the dielectric clearly illustrate this principle.

## 5. RESULTS AND CONCLUSIONS

Photographs of bubble disruption with the spark gap circuit and the needle tip at the spacer surface are shown in Figures 5 (demineralized water) and 6 (tap water). Figure 7 is a photograph of bubbles escaping from the needle when no HV is applied.

We can summarize some conclusions as follows. Intense bubble disruption is obtained in water by using HV pulses. Bubble breakup at high conductivities of the liquid requires short pulse rise times. Bubble diameters in water are as low as our detection limit of 50 $\mu$m.

Our pulse source is sufficiently effective to cause bubble breakup in tap water at a power input to the needle of 15 W.

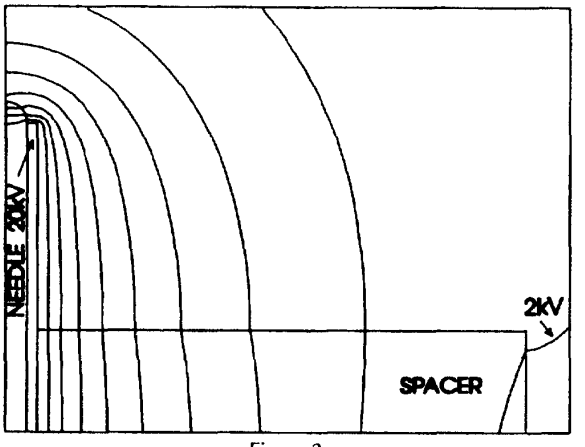


Figure 3.

Calculated equipotentials for a needle protruding 2 mm out of the spacer. The geometry has cylindrical symmetry with the axis located at the left border of the window. The 2 kV equipotential lies close to the edge of the spacer.

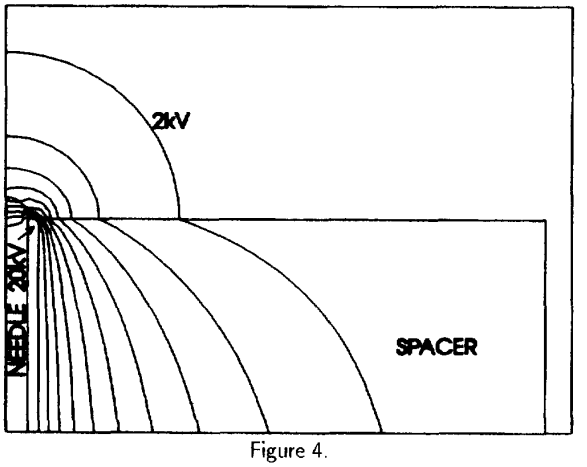


Figure 4.

Calculated equipotentials for a needle flush with the spacer. The 2 kV equipotential is much closer to the needle than in Figure 3. This indicates that the $E$-fields near the needle are considerably higher than in the case of Figure 3.

A geometry with the needle tip at the surface of a dielectric spacer is very advantageous but can be further improved. A spacer made of polyethylene or PTFE maintains this advantageous field geometry during prolonged exposure to water and HV pulses. The material PVC deteriorates rather quickly.

Electrostatic forces explain the diameter reduction of the bubbles, but at voltages $> 3$ kV additional effects, presumably corona, have to be taken into account.

At high pulsed voltages the shock waves that develop as a result of partial discharges possibly form a powerful mechanism for bubble disruption.


Figure 5.

Photograph of bubble breakup in demineralized water during HV pulse operation. The arrow indicates the diameter of the spacer.

Applications are in the fields of environmental protection *e.g.* absorption of oxygen for waste water treatment; chemical process technology, hydrogenation processes in petroleum plants; biotechnology, and catalytic slurry reactions.

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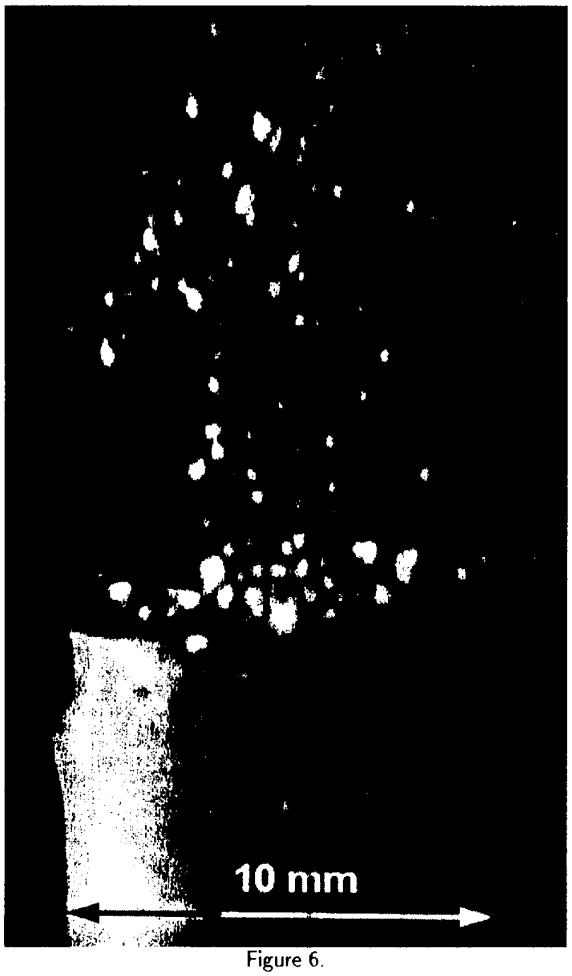


Figure 6.
Photograph of bubble breakup in tap water during HV pulse operation.


Figure 7.
Photograph of bubble breakup when no HV is applied.

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