A rotating suspended liquid film as an electric generator

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We have observed that a rotating liquid film generates electricity when a large external electric field is applied in the plane of the film. In our experiment suspended liquid film (soap film) is formed on a circular frame positioned horizontally on a rotating motor. This devise is located at the center of two capacitor-like vertical plates to apply external electric field in X-direction. The produced electric energy is piked up by two brushes in Y-direction of the suspended liquid film.

We previously reported that a liquid film in an external electric field rotates when an electric current passes through it, naming it the liquid film motor (LFM). In this letter we report that the same system can be used as an electric generator, converting the rotating mechanical energy to an electric energy. The liquid film electric generator (LFEG) is in stark contrast to the LFM, both of which could be designed in very small scales like micro scales applicable in lab on a chip. The device is comparable to commercial electric motors or electric generators, but there is a significant difference in their working principle; in an electric motor or generator the Lorentz force is the driving force, while in an LFEG the Coulomb force is the deriving force. So in despite to usual electric generators, this generator does not use a magnetic field and is purely electrical, which brings a similarity to bio mechanisms. We have investigated the characteristics of such a generator experimentally. This investigation sheds light on the physics of Electrohydrodynamics on liquid films.

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Understanding the behaviour of liquids under applied electric fields is an important fact with many current applications ranging from medical use in Lab on a chip to commercial use with electro-wetting and electro-spraying etc. In addition, many Electrohydrodynamical phenomenon are regarded as special experiments in which many properties of the fluid can be investigated. In the case of a suspended liquid film, it has been shown that suspended films of liquid crystals behave as a Phenomenological model for cell membranes. Suspended liquid films show an Electroconvection behaviour when subjected to an electric current.

We have previously introduced a device calling it the liquid film motor (LFM). The device is consisted of a two dimensional frame on which a suspended liquid film is formed, connected to a pair of electrodes which conduct an electric current with a current density of \( \vec{J} \). Two parallel metal plates are placed which makes an electric field of \( \vec{E} \) normal to the current. When current passes through the film and external electric field is applied, impressively the film starts to rotate. It was shown that the velocity of rotation is precisely controllable with the product of the two electric fields, and the direction of rotation strictly obeys a right hand rule (\( \vec{E} \times \vec{J} \)).

In 2008, many attempts have been made to explain the dynamical mechanism and the physical reason of rotation in the LFM. In 2009 Shiryaeva et al. performed calculations to explain this phenomenon using classical Electrohydrodynamics. In 2011 Liu et al. proposed a controversial theory about the dynamical mechanism, mentioning that the rotation is induced because of the continuous competition between the establishment of the coherent domains in water by the external field and its destruction by the electric current. In 2013 we performed experiments to examine the prediction of Liu et al. regarding the AC liquid film motor and we showed that in the case of different frequencies the state of rest which was predicted in the theory did not occur and the vibration threshold does not exist i.e. vibration is observed in any electric field strengths. Overall we conclude that still the main physics behind these phenomena is not well known.

In this letter we construct a different experiment, treating the previous liquid film motor differently. The device treats as a generator, i.e. it converts the rotating mechanical energy to electrical energy. The device works as well with an AC external electric field. This phenomenon is a reverse phenomenon compared to to what we have
reported on LFM.

Looking for the physics behind this phenomenon, we could simply conclude that LFEG behaves the inverse of LFM. If we apply an electric current on a suspended liquid film subjected to an external electric field it rotates, and if we rotate the liquid film it generates electricity.

FIG. 2. \( I - V \) Characteristics of the liquid film electric generator in different angular velocities. \( E_{ext} = 1kV/cm \).

FIG. 3. Generated voltage as a function of the external field in different angular velocities.

The setup consists of a circular frame attached and centred to an electric motor to rotate it. A liquid film is formed on the frame and two wires of diameter 10\( \mu m \) are dipped in the film to conduct the current through. When an external field was applied and the film was rotating, a potential difference and electric current could be observed along the wires. To obtain the electrical characteristics of the generator, the system was attached to a variable load resistor ranging from 100\( M\Omega \) to 1\( G\Omega \) and the voltage difference between the first 100\( M\Omega \) was measured using a high input impedance of 10\( 14 \Omega \) (Keithley 602). By testing the voltage across the system in different load resistances the I-V characteristics of the generator is obtained for different angular velocities as plotted in figure(2). Also the output voltage of this device for different angular velocities is plotted as a function of external electric field (Fig 3). The created voltage is in direct relation with the direction of external electric field and the angular velocity of the film i.e. reversing it’s direction of rotation the voltage reverses and increasing it’s velocity increases the output voltage. The same relation was observed with the external electric field.

In conclusion, the liquid film electric generator (LFEG) is in contrast to the liquid film motor, both of which work with the same principle. The reversible physical phenomenon behind this little device helps us a great deal to understand the Electrohydrodynamic behaviour of liquid films, which is applicable in many areas such as mixing, washing and micro-pumping in Lab on a chip.