LDV measurements of liquid velocity induced by charge injection in Diesel oil in a blade-plane-slit geometry

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Abstract. When applying a high potential to a blade or a pin immersed in an insulating liquid, ions are injected from the electrodes into the liquid. Several researches have been made on blade-plane geometry and important results have been already issued. In this paper, we test a blade-plane geometry with a two-plate system creating a slit in front of the blade and for which the fluid flow produced by the injected ions is modified by the slit. The electric current is also different from the one obtained with a simple blade-plane geometry. We first present the evolution of the injected current as a function of the applied voltage. Then we study the characteristics of the injection of charges and particularly the threshold of both voltage and electric field. We finally present a Laser Doppler Velocimetry (LDV) study of the flow.

1. Introduction
In ElectroHydroDynamics (EHD), it is well known that the velocity of a fluid can be easily modified by electrical systems that are very attractive because of their little energetic consumption. The injection of electric charges into a liquid is an example of electrical phenomenon (electroconvection) that can be used to make a fluid circulate. When applying a high enough voltage between a blade and a plane immersed in an insulating liquid the ions injected from the active electrode bring the fluid to move and to form a so-called “charged plume”. This charged plume is generally composed of an about 100 μm diameter central zone containing almost all the charges [1] and of a peripheral zone where the viscosity forces dominate the electrical ones. The injection is always controlled by the space charge density which limits the electric current.

Experimental devices that use EHD properties to bring a fluid to move are very common. In this article we focus our attention on EHD pump systems. A large number of them have been already studied in [2] and [3]. In this article we use the ion-drag pump system [4] and our purpose is to work with Diesel oil on an EHD pump based on blade-plane and blade-slit geometry.

Tobazeon [5] and Haïdara [6] have already studied the blade-plane geometry for which the injection of ions had produced charged plumes with values of the velocity up to 10 cm/s. In this study we first work on Diesel oil with blade-plane geometry and then with a two-plate system designed in order to create a slit facing the blade. We study the influence of this latter geometry on the charged plume by LDV velocity measurements.

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2. Experimental setup

The test cell is mainly composed of a $20 \times 20 \times 10 \text{ cm}^3$ glass aquarium filled with Diesel oil in which the electric device is totally immerged. A schematic diagram of both systems is shown in figure 1. The electric device of the blade-slit geometry is constituted of a sharpened blade of stainless steel (used as an active electrode) mounted in front of a two-flat-plane electrodes of duralumin. One can easily see the blade facing the slit between the two plates in figure 1-b. Different configurations have been tested for different positions $d$ of the blade and different gaps $H$ between the two plates. The electrode gap was at most 8 mm and the radius of curvature of the blade tip was about 7 ± 2 µm.

![Figure 1. Electrical devices.](image)

The potential difference ($0 – 30 \text{ kV}$) was supplied by a Spellman SL10 generator and the electric current was measured with a Meterman 37XR multimeter ($\pm 0.01 \mu\text{A}$). The kinematic viscosity $\nu$ of the Diesel oil was 10 cSt at 20 $^\circ$C and its specific mass $\rho$ and relative permittivity $\varepsilon$ at the same temperature were respectively 850 kg/m$^3$ and 2.2. The 5 cm long blade was mounted on a moving support facing the plane electrodes.

3. Electrical characteristics

In a first experiment we measure the electric current for increasing values of the applied voltage from zero to $25 – 30 \text{ kV}$ in order to check whether or not we have injection. The characteristics for two types of Diesel oil are examined. The Diesel oil of type I has a classical behaviour [6] [7] and the two well-known regimes can be observed in figure 2: the quasi-ohmic regime ($I = A \cdot V^\alpha$) for $V < V_{th}$ and the injection regime ($I = a \cdot V^{1/2}$) for $V > V_{th}$, $V_{th}$ being the threshold voltage of the injection phenomenon. For a type I Diesel oil $\alpha \approx 2.9$ which is a conventional value for a mineral oil in a blade-plane geometry. The threshold voltage depends on the distance between the electrodes, the radius of curvature of the blade tip and of course the characteristics of the insulating liquid.

The electrical behaviour of the type II Diesel oil is different from the one of type I (figure 2): only one regime can be observed. A more complete electrical study on different types of Diesel oil should be performed in order to understand this particularity. All the following experiments have been carried out with type I Diesel oils.

![Figure 2. Current-voltage characteristics for different values of the potential (Device 2 with $H = 5 \text{ mm}$ and $d = 4 \text{ mm}$).](image)

![Figure 3. Current-voltage characteristics for blade-plane and blade-slit configurations ($d = 10 \text{ mm}$ for both devices).](image)
Figure 3 shows a comparison between the electrical characteristics of both geometries (Devices 1 and 2). Different gaps between the two plates are tested with Device 2 for a fixed value of $d$. All the characteristics obtained with Device 2 have a similar quasi-ohmic part. In the injection regime, the current is more important with Device 2 than with Device 1 whereas $H$ is not a significant parameter. This is probably due to the presence of the slit which modifies the fluid flow. This phenomenon was observed for various distances and various radii of curvature.

![Diagram of Device 1 and 2](image)

(a) Global view of Device 1  
(b) Zoom on the blade tip in Device 1

**Figure 4.** Distribution of the electric field calculated by numerical simulation.

Previous works have shown that the electrical injection is characterized by the presence of an injected space charge that maintains a constant value of the electric field on the blade tip. This electric field $E_{th}$ is a threshold of the phenomenon [7]. We have estimated the threshold field with Ansoft Maxwell software. The threshold experimental value of the voltage is applied to the blade and the plane is grounded. As $V_{th}$ is the voltage at which injection starts, we consider that the space charge can be neglected for $V \leq V_{th}$. Figure 4 presents the distribution of the electric field calculated by a numerical simulation for $d = 10$ mm in Device 1. The threshold electric field value on the blade tip is about $E_{th} \approx 0.4$ MV/cm. Simulations have been made on all experimentally tested cases presented in figure 3. The same value of $E_{th}$ was always obtained.

4. Laser Doppler Velocimetry (LDV) measurements

The LDV method has been adapted to a Diesel oil flow generated by the injection of electric charges from a metallic blade between two duralumin plates. A seeding of 0.5 µm diameter SiO$_2$ particles was finally chosen after several tests. The direct velocity measurement performed with the LDV system allows us to examine the role of the EHD motion in the charge transport more quantitatively.

![Diagram of LDV measurement](image)

**Figure 5.** Schematic streamlines inside and outside the slit.

**Figure 6.** Evolution of the horizontal velocity in 3 different sections (1, 2, 3) inside the slit.
The injection of ions generates a unique flow from the blade through the slit (from the right to the left in figure 5) which divides into 2 flows after the slit up and down all along the plates (B and C in figure 5). This separation causes an opposite flow in the central zone by viscous friction. Figure 6 is a zoom of the velocity field inside the slit (A in figure 5). From section 1 to section 2, the central axis velocity $V_x$ increases to reach 0.6 m/s.

![Figure 7. Horizontal and vertical velocities in three sections between the two plates (5 mm slit).](image)

The fluid flow observed through section 1 is composed of two flows. The first one comes from the upper side of the blade and the second one from the lower side of it. These two flows form the two pseudo parabolic shapes visible on the velocity profile $V_y$ in section 1. In section 1 a central small peak is also visible on the velocity profile $V_y$. This peak is a consequence of the charge injection phenomenon which induces the motion of the flow. This acceleration produced by the electric charges concentrated in the centre of the plume carries on a few millimetres. Then the velocity reaches 0.6 m/s in the centre of the flow (section 2). Because of the fluid incompressibility, the vertical velocity $V_y$ is directed from the walls of the slit to the central axis as seen in sections 1 and 2. From section 2 to section 3, the central velocity starts to decrease. This deceleration is due to the expansion of the charges and the viscous friction. Immediately after the exit of the slit, the flow splits into two flows, up and down, because of the grounded electrodes.

5. Conclusion

In this paper, we studied the behaviour of a Diesel oil flow under the influence of an electric field with a blade-plane-slit geometry. The measurements of the current and velocity profiles show the influence of the geometry of the device on the quantity of injected charges. In fact, the injected current increases when a slit is performed on the plate even if the threshold field remains at a constant value. The velocity can reach 0.6 m/s with a flow separation just after the exit. We can also notice that the type of the Diesel fuel should not be ignored because it has a remarkable effect on the injected current.

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