STREAMING CURRENT OF A ROTARY ATOMIZER FOR ENERGY HARVESTING

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ABSTRACT

We present the experimental results of an energy conversion system based on a rotary atomizer and the streaming current phenomenon. The advantage of using a rotary atomizer instead of a channel or membrane micropore as in conventional pressure-driven approach is that the centrifugal force exerted on the fluid on a smooth and large surface will avoid clogging. Here we successfully obtain a high output power up to 1.7 miliwatts. This to our knowledge is the first time electrical power is generated in a rotary atomizer system.

KEYWORDS: Streaming current, Energy conversion, Rotary atomizer, Centrifugal force, Charged droplet

INTRODUCTION

Recently, energy harvesting from streaming current in micro/nanofluidic systems has been investigated intensively. The approach of researchers in the field primarily focuses on the use of pressure-driven flow (PDF) in a micro/nanofluidic channel [1] (Fig. 1a). In MicroTAS 2012, Xie presented an approach using pressure-driven liquid microjet flow through a micropore in a two-phase system [2]. This method partly prevented the conduction current, hence obtaining high energy conversion efficiency. In this work instead of using pressure driven flow, we use a rotary atomizer to propel the liquid by the centrifugal force. The advantage of using rotary atomizer is that the centrifugal force exerted on the fluid on a smooth and large surface will not only avoid clogging the channel or membrane micropore but also produce a high electrical output power. We also introduce a coupling method which helps to successfully prevent the conduction current phenomenon as shown in next sections.

THEORY

When a glass surface is in contact with water, it bears a negative charge due to the dissolution of surface silanol groups. In the adjacent liquid, an electrical double layer (EDL) will be formed with a net positive charge in which the charges can be transferred if the liquid is driven by an external force. Fig.1a shows the conventional single-phase PDF system, where an applied pressure difference between the micro/nanofluidic channel ends induces a downstream flow of counterions in the diffuse part of the EDL at the channel walls. This leads to the formation of an electrical current, the so-called streaming current (I_s). The downstream accumulation of ionic charges creates an electrokinetic (streaming) potential which acts to drive a current in the opposite direction to the streaming current, called the conduction current (I_c). The net current which is the difference between streaming current and conduction current can be directed to an external load to generate electrical power. Fig 1b shows the configuration of our new two-phase streaming current system based on glass rotary atomizer and demineralized water. Here, the conduction current is eliminated by a coupling method, namely (i) the creation of air isolated micrometer-sized charged droplets in an air gap between the solution phase on the rotating glass plate and the charged collector; (ii) a metal shielding ring connected to electrical ground to prevent the electrical field formed between collector and grounded electrode at the fluid supplier acting on the water on the rotating glass plate.

![Figure 1](image_url)

**Figure 1:** (a) Single-phase conventional pressure driven flow; I_s: streaming current, I_c: conduction current; (b) Schematic view of our new approach using centrifugal force in a two-phase system.

EXPERIMENTAL

The experimental set-up and parameters are shown in Fig. 2 and Table 1. Demineralized water (DI water) is gravitationally supplied continuously from a supplier bottle where the water pressure is kept constant by using an over-
flow valve. Upon contacting the center of the rotating glass Petri dish, the centrifugal force drives the water radially toward the plate edge where it disintegrates into droplets due to Rayleigh instability. Driven by inertia, these droplets continue their journey toward and land on the aluminum collector. Electrically, the charges in the mobile part of the EDL on the Petri dish surface are transferred into the flying droplets and then electrochemically converted to an electron current at the aluminum collector. This electrical current then passes through a load resistor connected to ground finally generating electrical power. We denote the electrical current through the load resistor as $I_2$. Current is supplied from the grounded electrode at the fluid supplier and denoted as $I_1$. A small amount of charged droplets will also land on the shielding ring. This electrical current is denoted as $I_3$. The current $I_1$, $I_2$ and $I_3$ are measured using Keithley instruments, namely Keithley models 2410, 6485 and 6487.

**Table 1: Water and other experimental setup parameters**

<table>
<thead>
<tr>
<th>Water properties</th>
<th>Symbol</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>$\rho$</td>
<td>$10^3$</td>
<td>Kg/m$^3$</td>
</tr>
<tr>
<td>Flow rate of the water supplier</td>
<td>$Q$</td>
<td>2.7</td>
<td>cm$^3$/s</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Other properties</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of the glass Petri dish</td>
<td>$d$</td>
<td>5</td>
<td>cm</td>
</tr>
<tr>
<td>Distance between Petri dish and</td>
<td>$d_1$</td>
<td>10</td>
<td>cm</td>
</tr>
<tr>
<td>the charged collector</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance between Petri dish and</td>
<td>$d_2$</td>
<td>0.15</td>
<td>cm</td>
</tr>
<tr>
<td>the shielding ring</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance between the upper and</td>
<td>$d_3$</td>
<td>0.4</td>
<td>cm</td>
</tr>
<tr>
<td>the lower part of the shielding</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ring</td>
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</tbody>
</table>

![Figure 2: Our rotary atomizer for energy conversion set-up components.](image)

**RESULTS AND DISCUSSION**

Figs. 3a and 3b shows the electrical currents $I_1$, $I_2$, $I_3$ with ((a), $I_3 > 0$) and without ((b), $I_2 = 0$) the use of the shielding ring. The current $I_1$ represents the sum up of streaming current and conduction current ($I_1 = I_s - |I_c|$). The current $I_2$ equals $I_1$ minus losses of charged droplets.

Without the shielding ring, the current $I_1$ and $I_2$ both decrease with the increase of load resistor values and $I_2$ is approximately equal to $I_1$. Here, the increase of load resistor values leads to the increase of the target potential and thereby increases the conduction current, hence reducing $I_1$ and $I_2$.

It is obvious that the shielding ring prevents the reduction of the current $I_1$ which remains constant for load resistors up to $R = 1900$ Mohm (target potential up to 2 kV), though at the cost of an increasing loss $I_3$. With load resistor values higher than 1900 Mohm, $I_1 \geq I_2 + I_3$ and we assume current is lost to other processes such as to electrical breakdown at high target voltage ($V > 2.5$ kV).

Also when no load resistor is used, an increase of both $I_1$ and $I_2$ is seen in case the shielding ring is used when compared to the case without shielding ring. We hypothesize that this is caused by the change of the electrical potential at the location of the grounded ring from strongly positive in its absence to ground potential when present. In the former case a strong conduction current will be generated, decreasing $I_2$, while in the latter case the conduction current will be much smaller.

The generated target voltage ($V = I_1R$) and output power ($P_{out} = VI_2$) in both cases, with and without shielding ring are depicted in Figs. 3d and 3c. The maximum output power we can generate at the present stage is 1.7 miliwatts which is the highest output power known in literature related to energy conversion system based on streaming current phenomenon [3].

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Figure 3: Measured current versus resistor values with (a) and without (b) the shielding ring. Output power and output voltage with (d) and without (c) the shielding ring. The rotational speed of the motor (ω) is 729 rad/s.

The energy conversion efficiency of the system (χ) is defined by the ratio between the electrical output power and the mechanical input power. At first approximation, we take the input power is equal to the kinetic energy (P_k) of the water leaving the edge of the rotating glass plate.

\[
χ = \frac{P_{out}}{P_{in}} \approx \frac{P_{out}}{P_k} = \frac{I^2 V}{\frac{1}{2} \rho Q R^2 \omega^2}
\]

According to eq. (1), the efficiency of our system at maximum output power is calculated and equal to 0.15%.

CONCLUSION
We successfully generate a high electrical output power of 1.7 miliwatts using a glass rotary atomizer and streaming current phenomenon. The conduction current is successfully eliminated by a coupling method using an air gap and a metal shielding ring. To our knowledge, this is the first time energy generation using a rotary atomizer generator has been studied, either experimentally or theoretically.

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REFERENCES

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