Journal of Physics: Conference Series **776** (2016) 012100 doi:10.1088/1742-6596/776/1/012100

Study of EHD flow generator's efficiencies utilizing pin to single ring and multi-concentric rings electrodes

Sumariyah[1,3 a],Kusminarto[3,b] ,A. Hermanto[3] and P. Nuswantoro[3]
1Physics Department, Faculty of Science and Mathematics, Diponegoro University, Indonesia
2Center for Plasma Research, Faculty of Science and Mathematics, Diponegoro University, Indonesia
3Physics Department, Faculty of Mathematics and Natural Sciences, Gadjah Mada University, Indonesia

E-mail: asumariyah@undip.ac.id

Abstract. EHD flow or ionic wind yield corona discharge is a stream coming from the ionized gas. EHD is generated by a strong electric field and its direction follows the electric field lines. In this study, the efficiency of the EHD flow generators utilizing pin-multi concentric rings electrodes (P-MRE) and the EHD pin-single ring electrode (P-SRE) have been measured. The comparison of efficiencies two types of the generator has been done. EHD flow was generated by using a high-voltage DC 0-10 KV on the electrode pin with a positive polarity and electrode ring/ multi-concentric rings of negative polarity. The efficiency was calculated by comparison between the mechanical power of flow to the electrical power that consumed. We obtained that the maximum efficiency of EHD flow generator utilizing pin-multi concentric rings electrodes was 0.54% and the maximum efficiency of EHD flow generator utilizing a pin-single ring electrode was 0.23%. Efficiency of EHD with P-MRE 2.34 times Efficiency of EHD with P-SRE

1. Introduction

Electrohydrodynamic (EHD) flow and is also called ion wind or the electricity wind is a stream coming from the ionized fluid generated by a strong electric field and the direction of flow follows the direction of the field lines. EHD flow prospects in the industry are quite large, as be applied for printing patterns of micro/nano size [1]. The study of EHD flow used as the coolant carried out by Alamgholilou[2] and Shin[3]. The applications of EHD flow for the textile finishing is done by Joshi [4], Guljarani[5] and Zhao[6] and EHD as a drying apparatus is conducted by Singh[7] and Dinani[8]. Devices that use EHD flow has many advantages such as power required is quite low.

Various attempts have been made to improve the efficiency of energy EHD flow generators such as by modifying the electrode configuration, for example electrode configured needle-arrayed electrodes combined with a plate fin heat sink by Huang[9] and six stages in series. As for increasing the number of pin electrodes for EHD pumps has been conducted by Zhang[10]. Configuring wire electrodes and a semi-cylindrical contour shaped electrodes of the cooling system has been done by Kim[11]. Electrode Configuration of the needle to parallel plates for cooling the device by Shin[3].

Research methods in this paper are the same as methods of our previous research.They are determining the maximum angle of EHD flow [12], modeling of electric potential distribution in the zone of EHD flow [13], Measurement of the velocity of EHD flow [14] and determination of Ion Mobility in EHD Flow Zone [15].

Theoretical examination of the EHD Flow

In the experimen the value of the velocity of EHD flow **u** which is the output of generating system of EHD is proportional to the voltage between electrodes V and is comparable to the root of the current I (Robinson, 1967) as indicated by the equation:

$$`\mathbf{u} \propto V \propto I^{1/2} \tag{1}$$

According to the law of conservation of energy:

$$\frac{\rho_g S d\mathbf{u}^2}{2} = \int_0^d q\mathbf{E}dz \tag{2}$$

With ρ_g is mass density of air (kg m^{-3}), S is a ring electrode surface area and q is the density of the charge (C m^{-3}). Substitution Gauss law to equation (1) and integrate it to find:

$$\mathbf{u} = \sqrt{\frac{\varepsilon_0}{\rho_g}}\mathbf{E} = \sqrt{\frac{\varepsilon_0}{\rho_g}}\frac{V}{d} \tag{3}$$

Where ε_0 is the dielectric permittivity of vacuum. If the threshold voltage of corona discharge V_0 considered, relationship of velocity of EHD flow **u** with voltage shown by the equation:

$$\mathbf{u} = \sqrt{\frac{\varepsilon_0}{\rho_g}}\frac{V - V_0}{d} \tag{4}$$

Energy efficiency is defined as:

$$\eta = \frac{\frac{d}{dt}\left(\frac{1}{2}m\mathbf{u}^2\right)}{P} \tag{5}$$

where m is the mass of air (kg), **u** is the velocity of EHD flow and P is electric power (W). Meanwhile, according to Timothy [16], relationship of velocity of EHD flow and electrical power shown by the equation:

$$\mathbf{u} = \frac{2^{1/3}\varepsilon_0^{1/6}}{(S\mu)^{1/3}\rho^{1/2}}P^{1/3} \tag{6}$$

where μ is the ion mobility and ρ is a density of the air. Substitution of equation (6) into the equation (5) resulting the equation:

$$\eta = \frac{\frac{d(\frac{1}{2}mu^2)}{dt}}{u^3}\frac{2\varepsilon_0{}^{1/2}}{S\mu\rho^{3/2}} \tag{7}$$

With derivating the air mass (m) with respect to time in equation (7), equation (8) is found

$$\eta = \frac{\rho S u^3}{2u^3} \frac{2\varepsilon_0{}^{1/2}}{S\mu\rho^{3/2}} \qquad (8)$$

2. Research Methods

Two configurations of the EHD flow generator are studied, they are a pin-multi concentric ring (P-MRE) and pin- single ring electrode (P-SRE) which is as the control of measurement. Pin electrodes made of stainless steel sewing needle with a diameter of pointed end 0.09 mm. Multi concentric ring electrodes consist of 3 concentric ring electrodes are arranged concentrically interconnected. The third ring of the electrode constituent having diameters in each of 8 mm, 16 mm and 24 mm. In a single ring electrode, the diameter is 24 mm. All electrode metal rings with the same width and thickness, respectively 2 mm.The composition of the generating system of EHD flow in this study includes P-MRE, P-SRE, (high voltage power, set voltage and current measurement tools and a set of measuring tools EHD flow velocity). The air can come from the top and out of the bottom, as shown in Figure.1

The EHD flow generated by installing a high voltage DC 10 KV on the electrodes of the corona discharge system with a positive polarity on the pin electrodes and a negative polarity on the ring/ the multi-concentric ring. A high-voltage probe 1000: 1 was used to measure the high voltage, which is connected to the CRO and the ion current was measured using a multimeter. Measure the velocity of EHD flow, Hot-Wire Anemometer was placed perpendicular the pin electrode direction with distance was 15 mm.

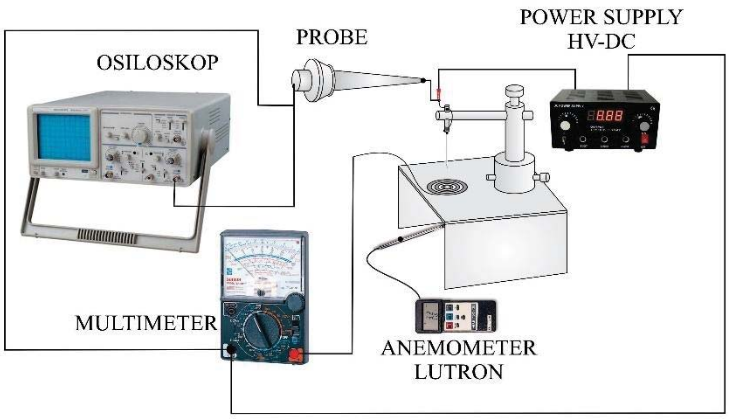

Figure 1. The Composition of a Generating System of the EHD Flow

3. Results and Discussion

Velocity of EHD Flow

Graph of velocity of EHD flow as a function of voltage (characteristics **u**-*V*) with some distance between the electrodes (*d*) fixed for the electrode configuration of pin-multi concentric rings (**uT**) and pin-single ring (**uS**) is shown in Figure 2.

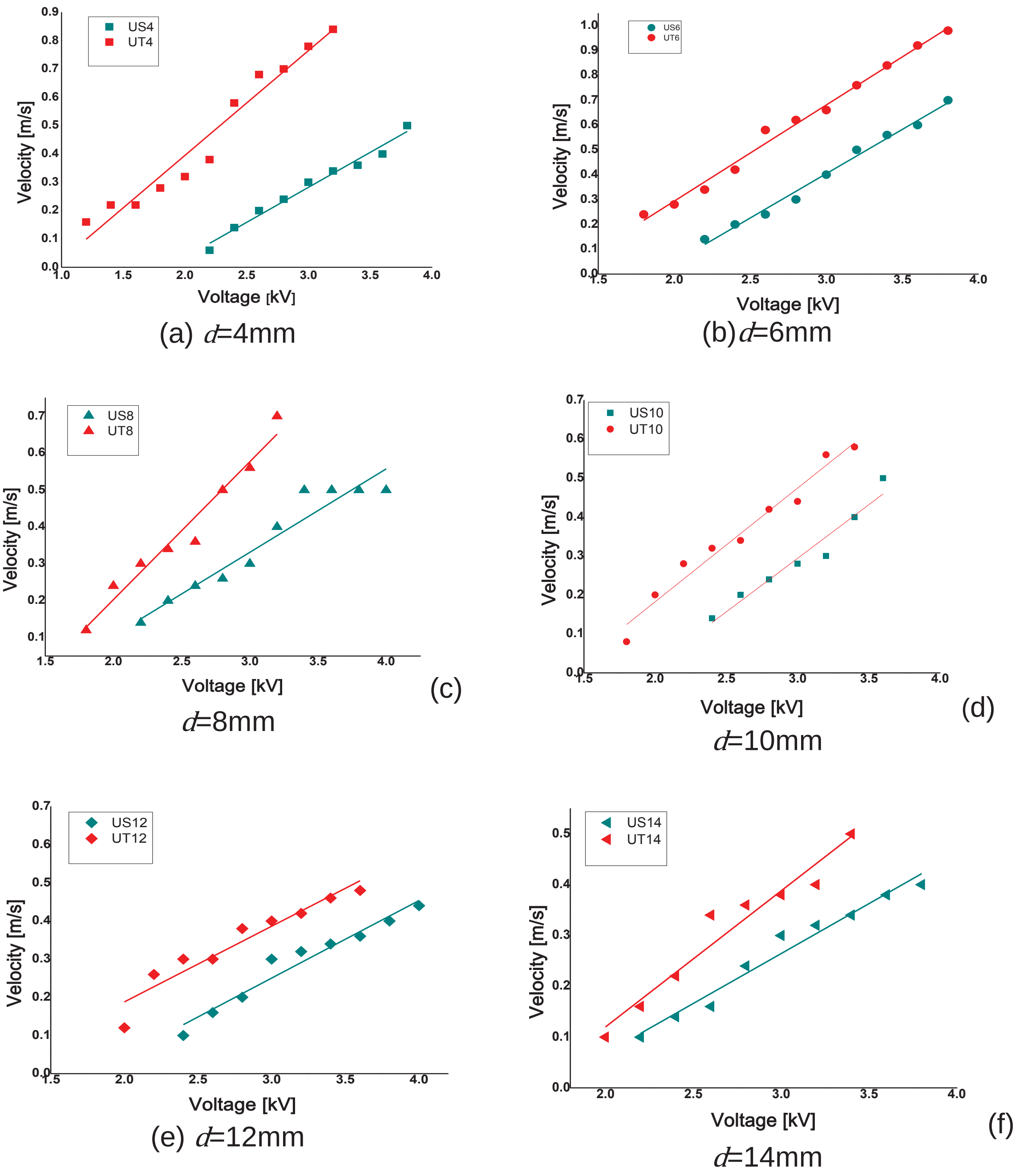

Figure 2. Characteristics u-*V* of (a) pin-multi concentric rings electrodes (*ET*) and (b) pin-single ring electrode(*ES*).

In Figure 2, It can be seen that in all the distance between the electrodes (*d*), the velocity of EHD flow increase with increasing the applied voltage. Our results are in agreement with a theory where a relationship between the applied voltage and the velocity of EHD flow is a linear function. The theoretical formulation is shown in the equation (3). This equation indicates that $\mathbf{u} \propto V$

Furthermore, in Figure 2. with the same distance inter-electrodes, we found that the velocity of EHD flow for **uT** is always greater than the velocity of EHD for **uS**. This is due to the electric field density of corona discharge with pin-multi concentric rings electrodes is greater than the electric field density of corona discharge with pin-single ring electrode. Electric field flux density led to increasing space charge of ions. The ions in its movement in drift region collide with neutral air molecules. It is very high collisions frequency. There is great momentum transfer from positive ions to the molecules of gas. In consequence, in the drift region, EHD flow will be produced with high velocity.

Energy Efficiency of generator system of EHD flow

Graph of maximum energy efficiency of the EHD flow generator (η) for various distance between the electrodes (d) respectively 4 mm, 6 mm, 8 mm, 10 mm, 12 mm, 14 mm as function of voltage (V) by using the pin-multi concentric rings electrodes and pin-single ring electrode as shown in Figure 3(a) and Figure 3(b).

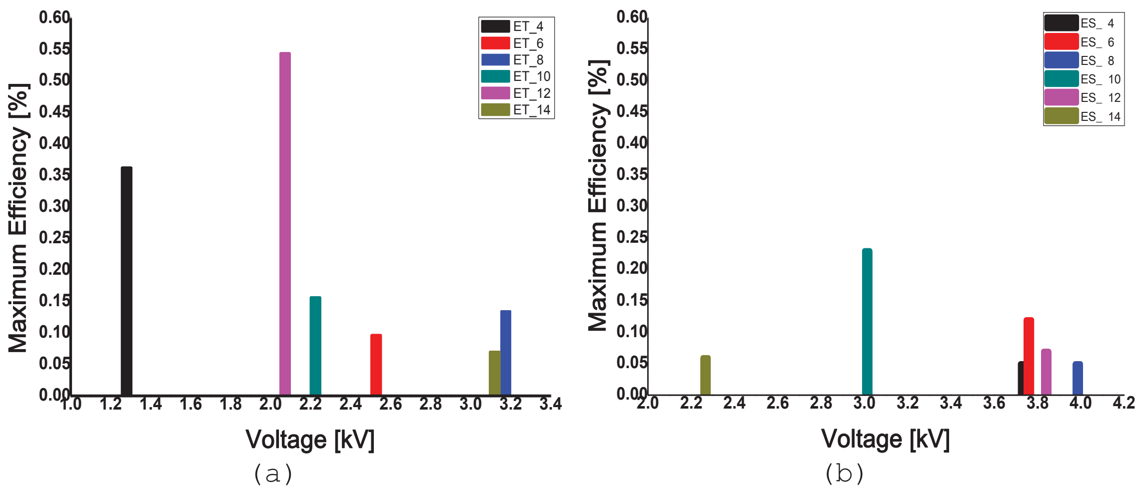

Figure 3. Chart of energy efficiency of EHD Flow Generator utilizing (a) pin-multi concentric rings electrodes (*ET*) and (b) pin-single ring electrode(*ES*).

Figure 3 (a) shows that the greatest value of the energy efficiency (0.54%) of the system generator EHD flow with pin-multi concentric rings electrodes on the voltage V = 2.0 kV, with a distance between the electrodes d = 12 mm. In Figure 3.(b), we can see that the greatest value of the energy efficiency (0.23%.) of the system generator EHD flow generator system with pin-single ring electrode on the voltage V = 3.0 kV, with a distance between the electrodes d = 10 mm.

4. Conclusion

At the same distance, we found that velocity of EHD flow with pin-multi concentric rings electrode configuration **uT** is always obtained greater than the flow of the electrode configuration EHD-pin single ring **uS**. The efficiency of the system generator of EHD flow with a pin-multi concentric rings electrodes is greater than the efficiency of system generator of the EHD flow with a pin-single ring electrode.

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