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Influence of Electrode Wire Structure on Corona Wind in a 2-D Rectangular Duct Flow (Numerical Analysis)

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Abstract

This study aims to numerically investigate the influences of number and arrangement of electrode wires on occurrence of Corona wind in a two-dimensional rectangular duct. The gap between electrode and ground wires is varied in the normal and flow directions. High electrical voltage and air flow velocity are performed at 15 kV and 0.35 m/s (Re~2200), respectively. The results show that electric fields are highly dense in the region between electrode and ground wire. In addition, electric field intensity increases significantly when the gap becomes smaller. Moreover, these results affect characteristics of Corona wind. When the gap becomes closer, diameter of Corona wind becomes smaller but swirling is more violent. With more electrode number, electric field intensity is higher and this leads circulating flow to be more complicated.

Keywords: Electric fields, Electrode Wire Structure, Corona wind

1. Introduction

Drying process is very important for agricultural countries. Conventional drying techniques usually involve the bulk gas flow of air; however they are normally low in efficiency of energy utilization [1]. An alternative method to improve the drying efficiency is utilizing a combined hot-air flow and electric field drying method, so-called Electrohydrodynamic drying.

Corona wind or ionic wind generates a secondary bulk flow with utilizing electric fields creating Coulomb force on air flow. As shown in Fig.1, with applying high voltage to an electrode, charged ions move along electric field lines to the electrode plate and collide with air molecules which then form the secondary bulk flow. As a result, the momentum transfer of gas is enhanced.

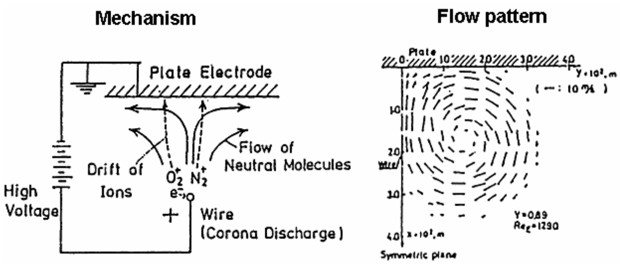

Fig.1 Mechanism of corona wind [2].

Enhancement of heat and mass transfer with electrohydrodynamic (EHD) flow is extensively studied by many researchers. They have paid much attention in a development of hot-air drying by cooperating the conventional method with the electric fields [3-6]. Ahmedou et al. [7] investigated the EHD enhancement on the drying process. The results showed that when cross air velocity was low, the ionic wind leaded to an enhancement of the drying rate. Kasayapanand [8] studied heat transfer enhancement using electrohydrodynamic technique for channel installing several electrode bank arrangements. The results showed that the electrode bank arrangement which obtained the best heat transfer performance was expressed incorporating with the optimum electrode distance ratio. Moreover, the heat transfer enhancement was also depended on the number of electrodes per length and the channel dimensions. Chaktranond et al. [9] studied enhancement of heat and mass transfer in a convective drying of single- and double-layered porous packed bed. It is made clear that the convective heat transfer coefficient and drying rate were enhanced considerably with influence of Corona wind on flow above the packed beds. An increase in temperature due to the capillary pressure difference in the double-layered packed bed was more pronounced comparing to that in the single-layered bed. Besides, in the double-layered cases, the drying rate of fine-coarse packed bed was much higher than that of coarse-fine packed bed. Saneewong Na Ayuttaya et al. [10] studied influence of positioned electrode arrangement on heat and mass transfer in unsaturated porous media during an Electrohydrodynamic drying process. This research was focused on the effects of the number and gap of the wire electrode longitudinal distance between electrodes and ground wires. The results showed that the drying kinetics increase had been strongly when gap was shortest and the number of electrode wires increased.

The present study numerically investigates the influences of vertical arrangement and number of electrodes in a two - dimensional rectangular duct. The model considers three different vertical locations where multiple electrodes are aligned in flow direction. Then, effects of number of electrodes in flow direction are investigated. The results concerning to the effect of electric field and streamline on the characteristics of Corona wind are also discussed.

2. Computational model

Model for simulating corona wind is shown in Fig.2. In simulations, electrode and ground are assumed as a point. Ground is located on x = 0.34 m, and y = 0.075 m. Distance between electrode and ground points in the vertical and horizontal directions is denoted as H and L, respectively. Dimensions of duct are 0.15 m (high) and 0.64 m (long).

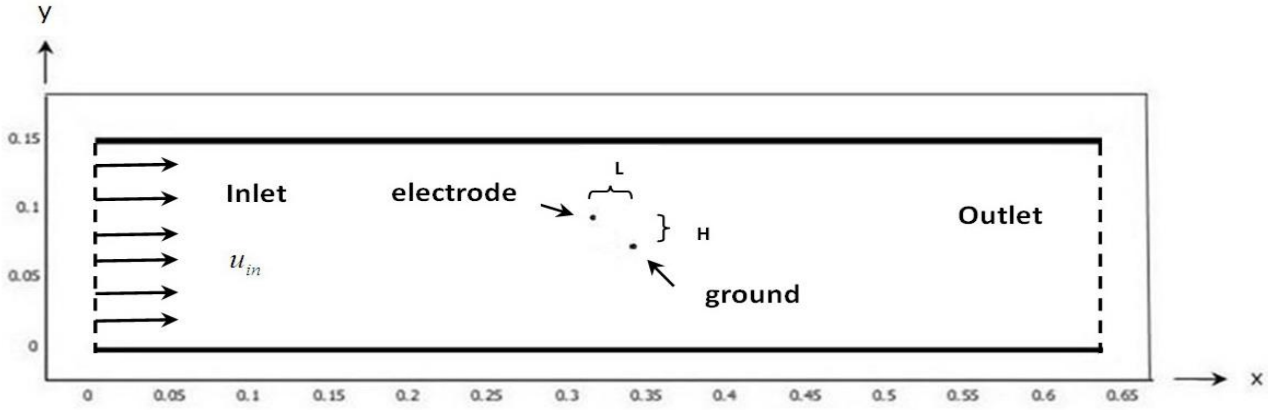

Fig.2 Computational model.

The equation system is solved with the finite element method. Lagrange quadratic elements are chosen as the basis functions with triangular shape of 3,000 elements as shown in Fig. 3

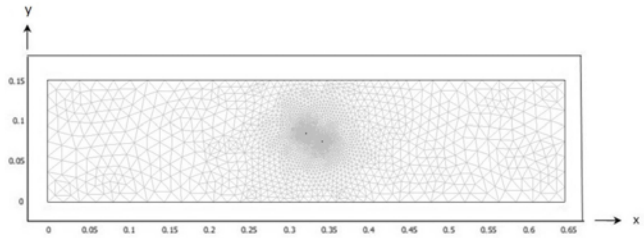
Fig.3 Grid system.

Motion of fluid flow is computed through continuity and Navier-Stokes equations,

$$\nabla \cdot \vec{u} = 0\,, \tag{1}$$

$$-\nabla \vec{P} + \mu \nabla^2 \vec{u} + \vec{F}_E = 0\,, \tag{2}$$

where $\vec{u}$ is velocity vector of fluid, *t* is time, $\vec{P}$ is pressure, ρ is density, and μ is viscosity of air. $\vec{F}_E$ is the electrophoretic force or Coulomb force acting on the free charges in an electric field, which is calculated by Maxwell's equation, i.e.

$$\vec{F}_E = q\vec{E}\,, \tag{3}$$

$$\vec{E} = -\nabla \vec{V}\,, \tag{4}$$

$$\nabla \cdot \varepsilon \vec{E} = q\,, \tag{5}$$

where $\vec{E}$ is electric field intensity, ε is dielectric permittivity, $\vec{V}$ is electric potential, *q* is electric charge density. Boundary conditions of the simulation are shown in Table 1.

Table 1. Boundary conditions.

	$u(m/s)$	$V(kV)$	$q(C/m^3)$
Electrode	$u_{wire} = 0$	$V_{wire} = 15$	$q_{wire} = 1$
Ground	$u = 0$	$V = 0$	$q = 0$
Inlet	$u = u_{in}$	$\partial V/\partial x = 0$	$\partial q/\partial x = 0$
Outlet	$\partial u/\partial x = 0$	$\partial V/\partial x = 0$	$\partial q/\partial x = 0$
Upper wall	$u = 0$	$\partial V/\partial y = 0$	$\partial q/\partial y = 0$
Lower wall	$u = 0$	$\partial V/\partial y = 0$	$\partial q/\partial y = 0$

3. Results and discussions

In all simulation cases, airflow enters the inlet of duct with a uniform velocity of 0.35 m/s (Re ~ 2200), where ρ is 1.059 kg/m^3, and μ is 2.05 $\times 10^{-5}$ kg/m.s. Electrical voltage is applied at 15 kV.

3.1 Electric fields

The similar electric field are observed when we consider *L* =2, 4, 6 and 8. So Fig.4 shows the electric fields of an electrode and a ground, where *L* = 2 cm and *H* = 0 cm. The direction of electric fields is from electrode to ground. In addition, the fields are highly dense in the region between electrode and ground. Due to high gradient of voltage potential, this causes electric field intensity to be strong in this region. As shown in Fig.5, when the gap (L) becomes smaller, electric field intensity (E) increases significantly.

3.2 Effects of elevation (*H*) on Corona wind

Fig.6 shows streamlines of air in various H. Obviously, elevation of electrode affects the characteristics of Corona wind. When H = 0 as shown in Fig.6 (a), circulating flow is not be observed. Fluid and electrohydrodynamic velocities in flow direction are approximately the same. While $H \neq 0$, circulating flow takes place around ground point. This is because the magnitude of shear flow due to difference of fluid velocity and electrohydrodynamic force performs on uncharged air flow. Electrohydrodynamic force is much larger than fluid inertia force. This causes shear flow to become stronger, resulting in circulating flow. In Fig.6 (b), the flow is circulated under the region between electrode and ground. The maximum velocity of streamline is appeared above the vortex. In Fig.6 (c), the circulation, on the other hand, occurs above the region and the maximum velocity is appeared below the loop.

A comparison of velocity field along the rectangular duct flow for various vertical positions from the ground is shown in Fig.7. The maximum velocity when H = 0 is less those of $H \neq 0$. The similar maximum velocity are observed when we consider H =1 and H = -1.

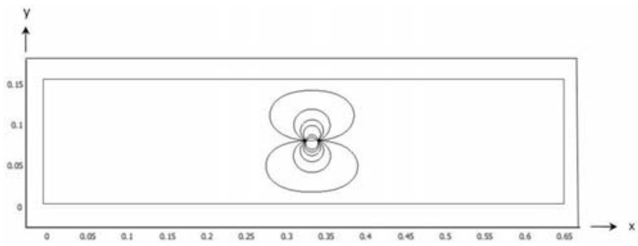

Fig.4 Electric fields when L = 2 and H = 0 cm.

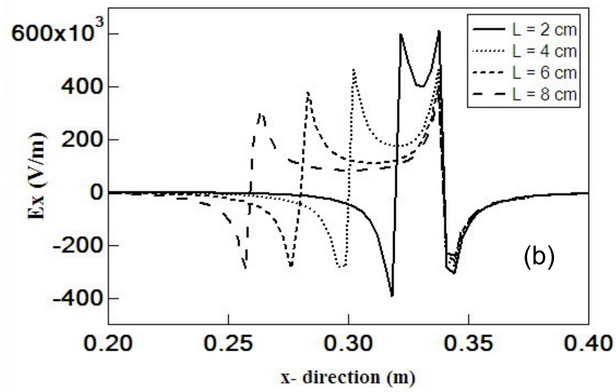

Fig.5 Electric field intensity in x direction when L = 2 - 8 cm.

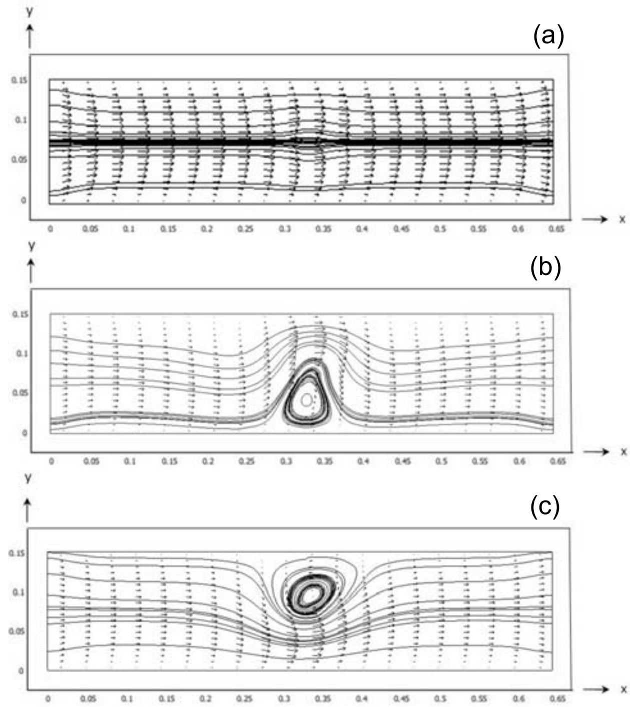

Fig.6 Streamlines of fluid in various H; (a) H= 0 cm (b) H = -1 cm (c) H = 1 cm.

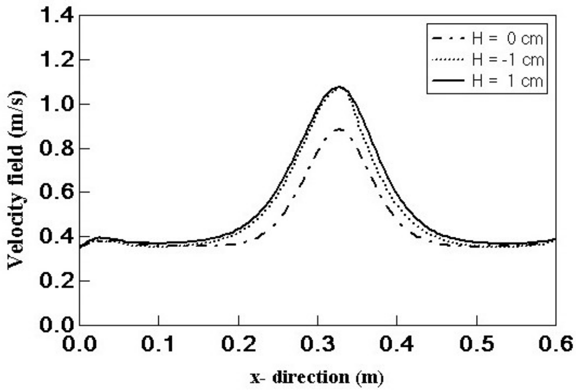

Fig.7 Velocity field in x-direction in various H.

3.3 Effects of gap (L) on Corona wind

In order to observe effects of gap (L), elevation (H) is fixed at H = 1. Fig.8 shows that when the gap (L) becomes closer, size of circulating flow becomes smaller. Strength of circulating flow is presented by vorticity (ω), as shown in Fig.9. Vorticity increases when the gap (L) becomes smaller, i.e. $\omega \propto L^{-1}$

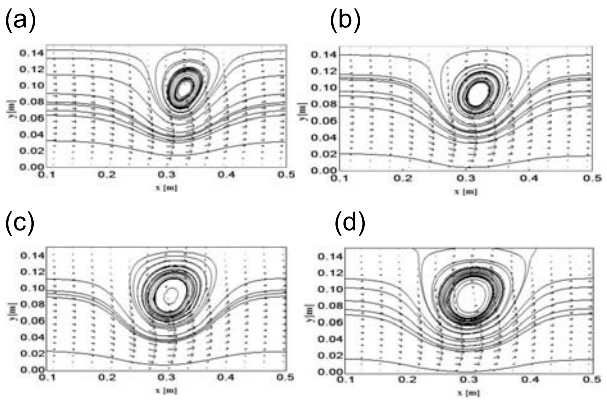

Fig.8 Sizes of circulating flow in various gaps; (a) L = 2, (b) L= 4, (c) L = 6, and (d) L = 8 cm.

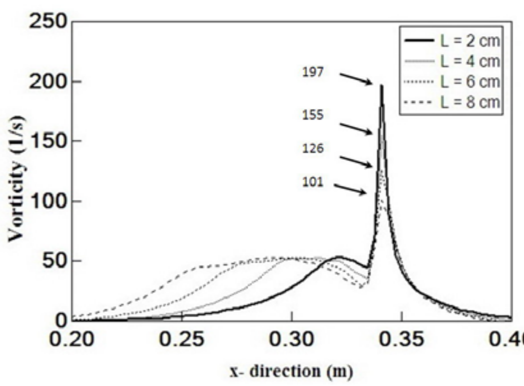

Fig.9 Vorticities in various gaps (L).

The characteristics of vorticities of Corona wind of various electrode gaps are illustrated in Fig.10. It can be seen that the closer gap encourages more violent vorticity.

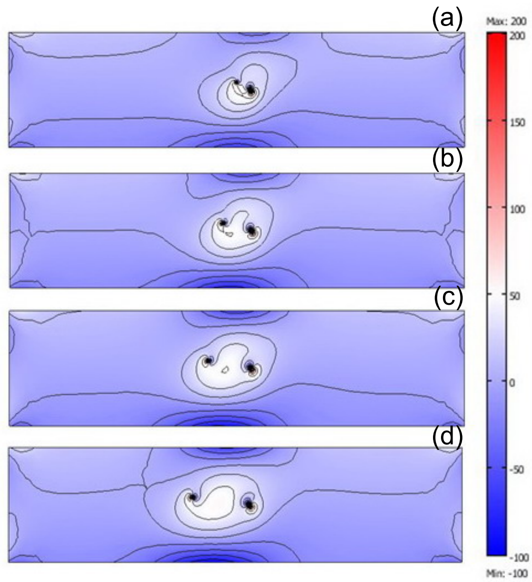

Fig.10 Vorticities of contour plot in various gaps; (a) L = 2, (b) L= 4, (c) L = 6, and (d) L = 8 cm.

3.4 Effects of multiple electrodes

In case of multiple electrodes, positions of electrode points are shown in Fig.11. Spacing between electrodes is 2 cm, and gap between ground and a closing electrode is 2 cm, and H is fixed at 1 cm. All electrodes are laid in the flow direction.

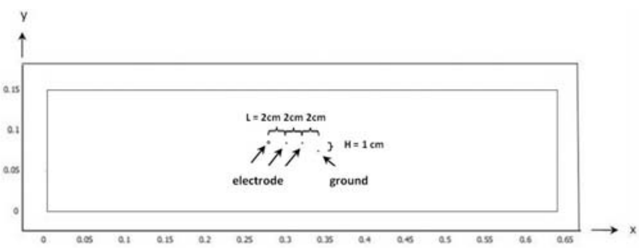

Fig.11 Positions of electrode points.

The effects of multiple electrode points on the electric fields and electric field intensity are shown in Fig.12 and 13, respectively. Increase of the electrode number causes the electric fields and electric field intensity. Electric fields are wider and denser. Due to high gradient of electric potential, the maximum magnitude of electric field intensity takes place between electrodes and ground. Therefore, high shear flow more induces the neutral airflow, resulting in enhancement of circulating flow, as shown in Fig.13 and 14.

As shown in Fig.15 and 16 positions of the maximum velocity and the maximum vorticity are different from the case of single electrode point. This is because high gradient of electric potential takes place in the different positions. As a result, characteristics of circulating flow are more complicated.

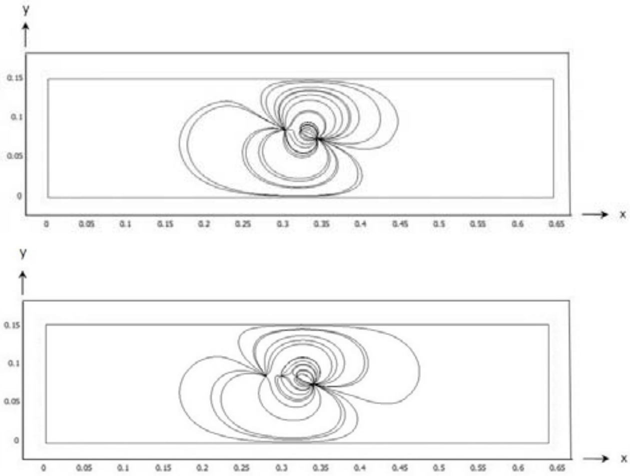

Fig.12 Electric fields; (a) *n* = 2, and (b) *n* = 3.

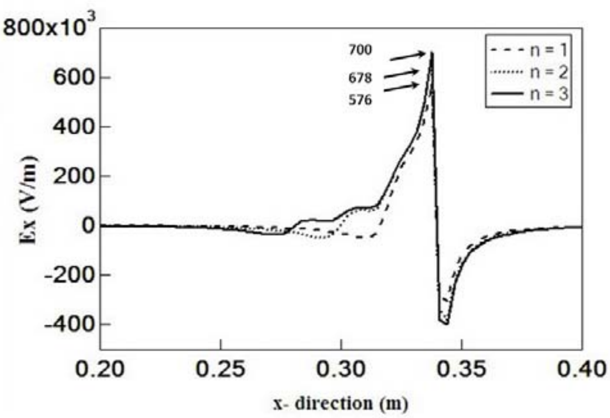

Fig.13 Electric field in direction

when *n* = 1, 2, and 3.

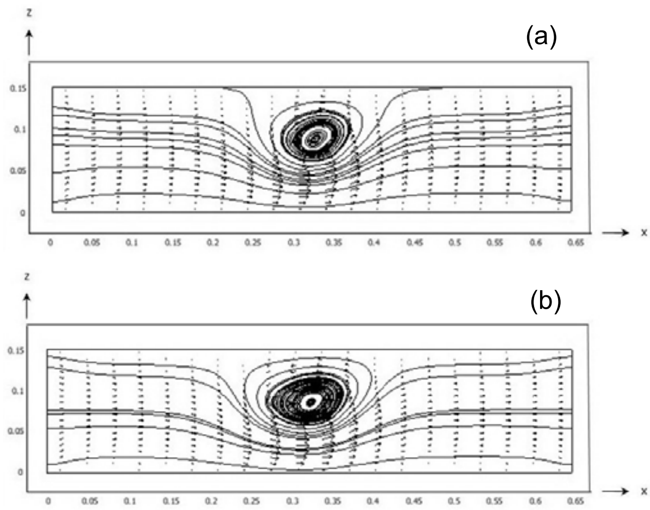

Fig.14 Streamlines of air flow in various *n*;

(a) *n* = 2, and (b) *n* = 3.

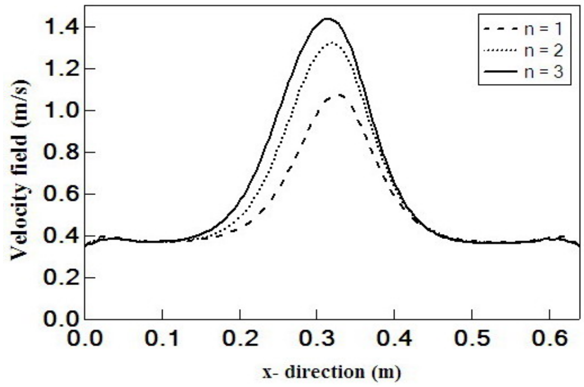

Fig.15 Velocity field in *x*-direction in various *n*.

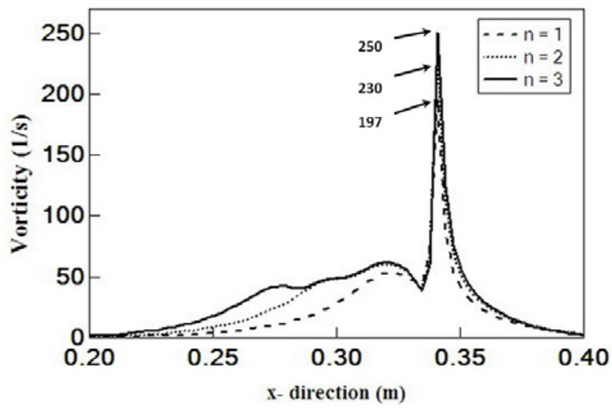

Fig.16 Vorticities in *x*-direction. in various *n*.

The contour plot of vorticities is showed in Fig.17. It can be observed that increase the number of electrodes leads to larger vorticity which promotes more complicated circulating flow.

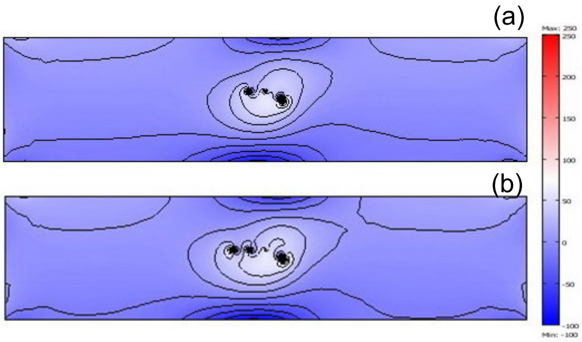

Fig.17 Vorticities of contour plot in various *n*. (a) *n* = 2 ,and (b) *n* = 3.

4. Conclusions

Numerical simulation is carried out to study the influences of the number of electrodes and the arrangement of electrodes inside the rectangular duct flow on the characteristics of Corona wind. The conclusions are obtained as follow:

(1) Distance between electrode and ground wires (*L*), affects the electric potential, where its high gradient creates high Coulomb force onto airflow. With smaller distance, Coulomb force becomes stronger, resulting in higher strength of vorticity. Inversely, when the distance (*L*) is larger, circulating flow is larger but is weaker.

(2) Due to effect of shear flow, occurrence of circulating flow is suppressed electrode and ground wires are laid on the same elevation (*H* = 0) and velocity of fluid and electrohydrodynamic velocities are not much different. In addition, distance in different elevation ($H \neq 0$) influences the circulating flow position as well as the position of maximum flow velocity, i.e. on the upper and lower parts of channel.

(3) Electric fields are more increased and denser when the number of electrodes is increased. This causes the gradient of electric potential to be more increased. With this result, more electric force creates more strength of shear flow. Consequently, circulating flow, as well as vorticities, becomes larger and stronger.

5. Acknowledgement

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6. References

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