LATTICE BOLTZMANN SIMULATION OF INDUCED FLOW BY MEANS OF LOW-TEMPERATURE PLASMA

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Summary Lattice Boltzmann simulations were performed to examine induced flow due to low-temperature plasma generated from plasma actuators on free surfaces and inside channels. The effect of actuator separation distance on the velocity flow profile, maximum velocity and flow rate (in channel flow) were examined. It was found in channel flow that channel height determines largerly the flow rate and its flow direction. Increasing the plasma voltage has a negative effect on flow rate due to the generation of larger and stronger flow vortex.

INTRODUCTION

Flow control methods have been studied extensively and most of the methods can induce gas or fluid flow by changing the shape of the geometry. Another approach is to create plasma discharge on the surface so as to control actively the boundary layer. Malik et al. [1] studied boundary layer control on plain surfaces via corona-discharge plasma and found that plasma can reduce the drag for an incoming flow. The difference between plasma flow control and other method is that one may employ plasma actuators to achieve control simply by adjusting its input power. Another advantage is that plasma actuators can actively drive air flow without an incoming flow.

Many experiments have been performed using surface plasma actuators on wingspans [2, 3]. It was found that unsymmetrical array of electrodes along wingspan will bring thrust, while symmetrical array will bring drag. This phenomenon was explained as a result of mass transportation and vortex structure as the latter was induced by a body force. Plasma actuator has been used to enhance the lift [4] and as a plasma synthetic jet actuator [5]. The actuator produced a zero-net mass flux jet on actuation and could be applied in adverse pressure gradient separation control or suction devices.

Numerical simulation of flow generated from surface plasma actuators has also been performed. Roth [6] considered body force as a result of net charge and electric field. Suzen and Huang [7] attempted to solve the Navier-Stokes equation using body force as a source item. A preliminary Lattice-Boltzmann study on active boundary layer flow control by means of a low-temperature surface plasma has been performed [8]. Results reveal interesting effects of various surface plasma parameters on active boundary layer flow control. Here, we provide our LBM simulation [9] on induced flow as a result of low-temperature surface plasma.

RESULTS AND DISCUSSION

Two Surface Plasma Actuators on a Free Surface

Figure 1(a) shows our model when two plasma actuators are placed on a free surface with the following parameters: t = 0.01 cm, d = 0.0 cm, L = 0.5 cm and y = 0.01 cm. In our simulation, we assume that there is no fluid flow (u = 0) in the air region. Figure 1(b) shows the calculated velocity distribution for a separation distance sd = 0.4 cm. We found that the main region for air acceleration is in the vicinity near the dielectric surface. Air becomes more accelerated on the top of the first embedded electrode, while u_{max} appears on the top of the second embedded electrode. When $y > 1.5$ cm, the distance away from a free surface, the effect of surface plasma on flow velocity becomes less obvious. Figure 1(c) shows the velocity profile after the flow has been stabilized at three different locations.

Two Symmetrically Placed Surface Plasma Actuators in a Channel

From the previous simulation, we found that surface plasma actuator can drive the flow, but only in the vicinity near the dielectric surface flow. Here, we model two plasma actuators inside a channel and the actuators are placed symmetrically so that air can be driven with the possibility to have an superimposed effect. This model is illustrated schematically in Fig. 2(a). Two surface plasma actuators were placed symmetrically in the channel with the same parameters: t = 0.01 cm, d = 0.0 cm, L = 0.5 cm and y = 0.01 cm. h is height of the channel and is schematically represented in Fig. 2(a). In our simulation, we assume that the entrance flow velocity is zero. As the channel height h increases, the flow direction changes. The reason for this phenomena is that channel height has an effect on the distribution of charge density and on the dilation of vortex. This vortex causes mixing on the air flow instead of driving the flow. Figure 2(b) is the flow field at h = 1.2 cm.

Figure 2(c) shows the flow rate at different h values. For the purpose of flow rate calculations, we define the channel width as 1 cm. When flow rate is positive, air flows from left to right, while negative flow rate implies air flows from right to left.

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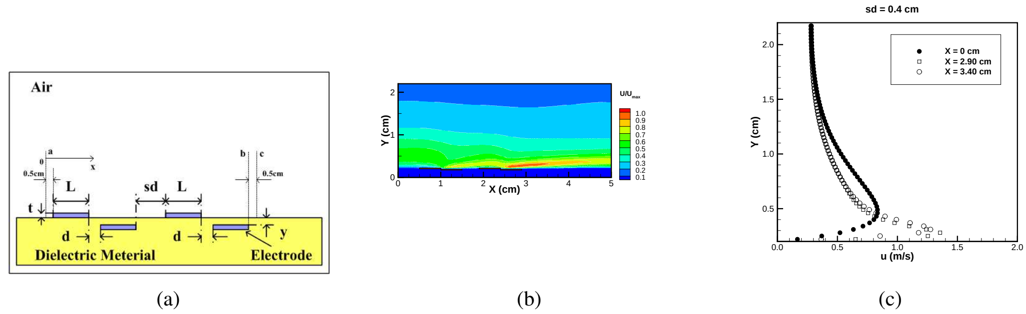

Figure 1. (a) Schematic of two plasma actuators placed on a free surface. (b) An example of velocity distribution over surface plasma actuators for a separation distance sd = 0.4 cm. (c) Velocity profile after the flow has been stabilized at three different locations.

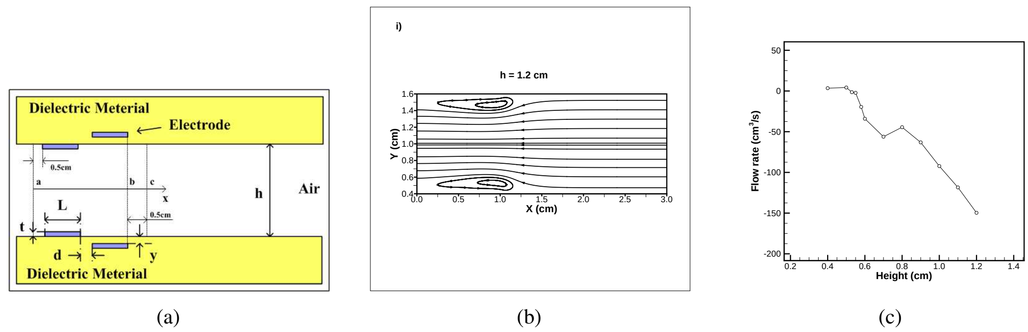

Figure 2. (a) Schematic of symmetrically placed surface plasma actuators in a channel. (b) Instantaneous flow field in a channel at sd = 1.2 cm subjected to an input voltage of 2500 V using t = 0.01 cm, L = 0.5 cm, d = 0.0 cm and y = 0.01 cm. (c) Flow rate as a function of channel height.

The way the flow rate changes is the same as that in the velocity profile. Flow rate varies only slightly as h changes from 0.4 cm to 0.5 cm. From h = 0.5 cm to 0.6 cm, we have three data points: h = 0.53 cm, 0.55 cm, and 0.58 cm. We found that the flow direction changes at an h value between 0.5 cm to 0.53 cm. From h = 0.55 to 0.7 cm, flow rate increases, while, at h = 0.8 cm, flow rate decreases suddenly. Between h = 0.8 to 1.2 cm, the flow rate increases again. We examine the relationship between channel height h, voltage and flow rate and found that higher voltage implies smaller flow rate for all h values examined. It is more obvious at h = 1.2 cm. This can be understood as follows: higher voltage causes larger vortex and, as a result, mixing is enhanced but not flow rate.

CONCLUSIONS

We have examined the effect of various separation distance between two plasma actuators on the velocity profiles and maximum velocity of an induced flow on a free surface, by means of a Lattice Boltzmann Method. It was found two surface plasma actuators can significantly increase the velocity of an induced flow. We also employed symmetrically placed plasma actuators in channels to study induced flow. It was found that channel height controls both flow rate and flow direction. Higher voltage induces smaller flow rate due to the generation of larger vortex.

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