International Journal of ChemTech Research
CODEN (USA): IJCRGG, ISSN: 0974-4290, ISSN(Online):2455-9555
Vol.9, No.12, pp 636-646, 2016

Measurements of Thrust and Flow Velocity of Plasma Discharge on Dielectric Surface

Thamir H. Khalaf[1]*, Inaam M. Abdulmajeed[1], Mohammed J. Jader[2]

Department of physics/ college of science/ University of Baghdad/ Iraq
Department of LASER physics/ college of science for women/ University of Babylon/ Iraq

Abstract : This research presents investigations of Dielectric Barrier Discharge (DBD) (Plasma Actuators), experimental methods used to calculate the induced body force for three types of dielectrics (PMMA, HDPE and Teflon) were used as plasma Actuators with two type's electrodes (Copper and Aluminum). The measurements of the thrust were produced which is then associated with a control volume analysis on data obtained by using laser Doppler anemometry (LDA) method. For the direct measurements, the influence of variable the actuator types which the induced flow acts is also investigated. The results from these tests showed that the dielectric type is most effective at higher voltages with the measured force increasing.
The PMMA dielectric was found to have a strong influence on thrust generation as compared to the other dielectrics tested. However, the power supplied to actuator manifests itself primarily as heat generation with no noticeable thrust measured.
PMMA plasma actuator has good flow velocity up to 24 m/s at 1mm dielectric thickness. The actuator thrust was higher, approximately up to 54 mN/m with copper electrodes at 9kV AC applied voltage and 8kHz frequency in 2mm dielectric thickness.
Keyword : plasma actuator, flow velocity, discharge plasma, thrust of plasma actuators.

Introduction

Ingeneral, the dielectric barrier discharge (DBD) plasma actuator consists of an asymmetric electrodes arrangementseparated by adielectric medium. The application of an alternating, highvoltagesignal results in a surface-mode discharge along thedielectric. The expansion of the discharge along the dielectric surfaceresults in a charge deposition[1].

The aerodynamic has importance of the induced body force from these actuators were first publicized in 1995 . Roth et al. was among the first to utilize the DBD actuator to manipulate the boundary layer on a flat plate over a range of freestream velocities .Roth used it for airflow applications in 1998. It is now the most used discharge for air flow control. Typically, it can generate an electric wind with velocity up to about $8ms^{-1}$.[2]The resent results by B. J. Pafford in (2013)[3], shown that induced velocity of the pulsed wall jet is measured using a Laser Doppler Anemometry, the measurements show that the pulsed arc creates a high-velocity pulsed wall jet that extends 40 mm above the airfoils surface and has an induced velocity of 15 m/s greater than the unaltered air flow over the airfoil, with peak velocities of 32 m/s.

The laser anemometry has a unique intrinsic response to fluidvelocity absolute linearity. Themeasurement is based on thestability and linearity of optical electromagnetic waves, which formost practical purposes can be considered unaffected by otherphysical parameters such as temperature and pressure[4].

This paper focuses on characterizing some limitations of the aforementioned direct and control volume inferred experimental techniques used to measure the net, The first part induced thrust for a basic single dielectric barrier discharge (SDBD) actuator. The thrust is indirectly determined from actuator efficiency analysis. The second part of flow control and velocity measurement by using Laser Doppler Anemometry (LDA) techniques.

2. Experimental arrangement

2.1 Plasma actuator setup

A DBD plasma actuator consists of two electrodes separated by a dielectric barrier. When a high voltage, alternating current is applied, the local air is ionized. The ions collide with the surrounding neutral particles so as to transfer their momentum to the air. Therefore, the plasma actuator can be thought of as imposing a localized body force to the surrounding air [5]. The aim of using this electric wind is in most cases to accelerate the airflow tangentially and very close to the wall in order to modify the air flow profile within the boundary layer. This configuration is shown in Figure (1).

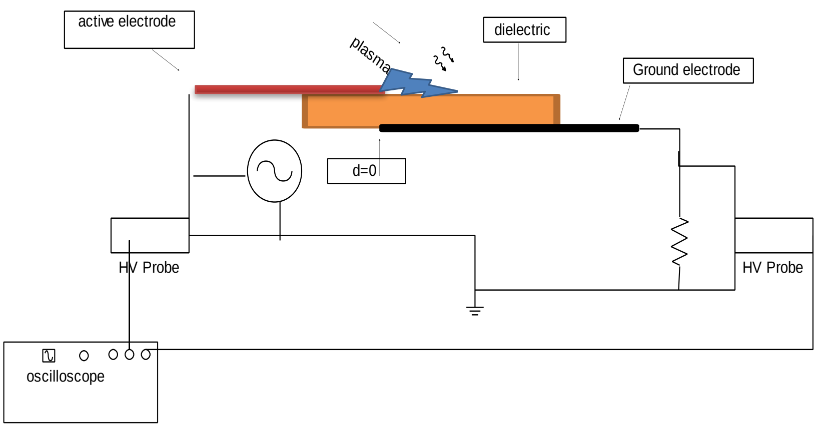
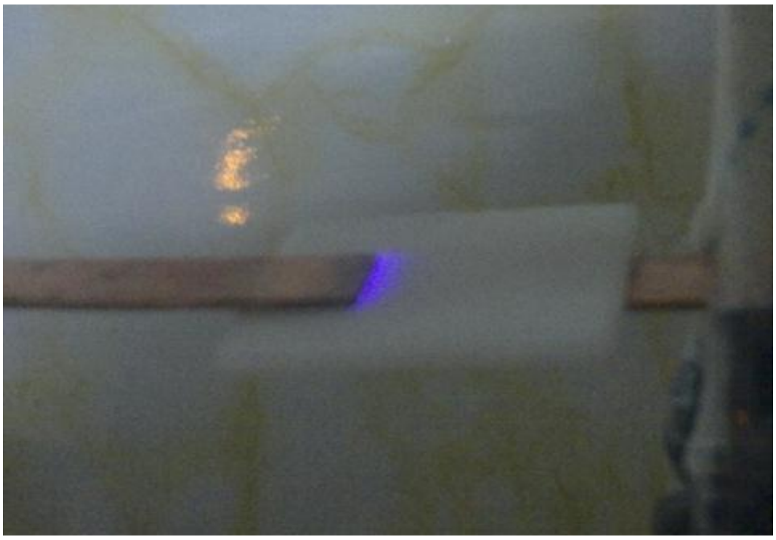


Figure (1): Plasma Actuator experimental setup.



Figure(2): Photograph for plasma discharge in DBD actuator.

The experimental setup consists of AC high-voltage device and dielectric polymer material placed between two opposite electrodes, dielectric dimensions (area) (3×3)cm^2, active electrode lengthof 1cm andgrounded electrode length of 2cm , width is1cm and electrodes thickness of 1 mm connects to theresistance10MΩ beforethe ground earth.

Two High voltage probe were used, Attention ratio (1000:1) volt, AC high voltage probe [made in Taiwan] with two digital multimeters and TWINTEX digital Oscilloscope, TSO 1202, 200MHz, 1GSa/s connected with high voltage probe for actuator electrodes.

The voltage in an AC circuit is representing the following equation[6]:

$V = v_m \sin(wt \pm \varphi)$ .... (1)

Hence, v_m is maximum voltage, φ is phase angle.

The consumed electrical power of plasma actuator can be calculated from the relation[7]:

$P_{av} = \frac{1}{T}\int_0^T I(t).V(t)dt$ ………………………….(2)

$P_{av} = \frac{\tilde{V}^2}{|Z|}\cos(\varphi)$ ……………………(3)

$P_{av} = \tilde{I}^2|Z|\cos(\varphi) = \tilde{V}\tilde{I}\cos(\varphi)$ …………………….(4)

Hence cos φ is power factor representing cosine of angle between voltage and current in AC circuits, the input power for actuator circuit is given by:

$Pi = P_o + P_{lost\ or\ stored}$ ……………………….(5)

The power dissipated by the resistor at any instant of time can be found by simply substituting the time, In resistance state , $\varphi = 0$, The average (real) power in the equation (3) becomes :

$P_{av} = \frac{\tilde{V}^2}{|Z|}$ ……….……………(6)

Three types of polymers used in current experiment (Poly methyl methacrylate (PMMA), High density polyethylene (HDPE) and Teflon) to get actuators optimization in set of variables parameters for discharge diagnostic at constant conditions.

The actuator efficiency was depended set of parameters such as(dielectric thickness, dielectric type, electrode type and applied voltages) to get maximum force production on dielectric surface , also horizontal distance influence was noted between the electrodes at frequency value of 8 KHz with AC high voltage (3,5,7 and 9) KV at same conditions in all of states.

The efficiency η is definedas the ratio between the produced power $P_{out}$and the consumedpower P_{in}., the results of the efficiency calculations are depicted in Ref.[8]:

$\eta = P_{out.} / P_{in.}$ ………………………(7)

Since the plasma actuator is operated as a flow control device, it is important to compare the pure electrical quantities with the fluid mechanical results. The actuator thrust is a convenient measure to quantify the effectiveness of a plasma actuator, as emphasized Enloe et al[9] or Thomas et al[10]. Experimentation of the temporal evolution of force production is a rather challenging topic, as demonstrated by Enloe[9].

Efficiency of force production may be defined as the mount of force produced for given power input, as given by the equation (8). A force power diagram in presented in setFigures, such as a plot has already been shown by Gregory et al[11] and subsequently led to the dimensioned coefficient of the so-called force (production) efficiency (Ferry &Rovey)[12].

$\eta = \frac{F}{P_A} = \frac{F/L}{P_A/L}$ ………………………..(8)

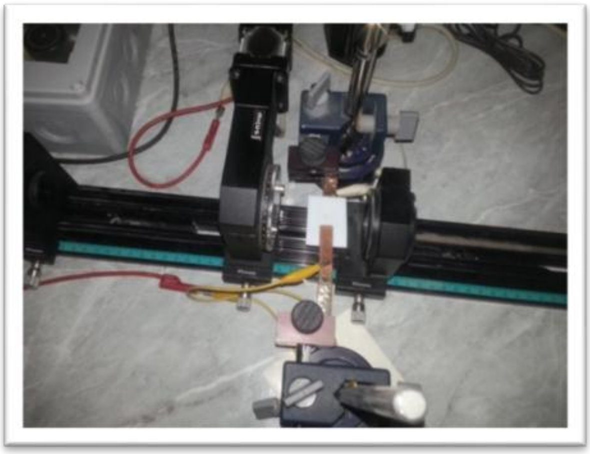
Hence, *F/L* is actuator force and P_A/L is consumed power per unit length.

2.2-Measurements of plasma flow velocity by Laser Doppler Anemometry

Laser Doppler Anemometry (LDA) technic is used to measure of plasma flow velocity for plasma actuators. LDA experiment was used in this work (made in Germany), figure (3) shown that LDA experimental setup, its dependent Doppler signal generate by scattering particles using the spatial overlap of two laser beams. Laser Diode light with wavelength of 650nm is divided into two parallel beams by beam splitter. A convex lens focuses both beams in one spot at which the beams intersect in an angle, depending on the beam separation and focal length of the lens. A rotating acrylic disc is placed in this focal plane. Particles distortions at the disc surface pass through the beams‟ crossing point and generate light scattering. This LDA signal is collected on a photo diode. The intensity profile of the LDA signal is displayed as a function of time and can be Fourier transformed for Doppler frequency analysis.

The split beam of laser light source by the beam splitter into two beams, and it crossed these two beams at an angle ∝. At the intersection of two laser beams to form interference fringes as aborted in the following figure system.

(a)



(b)

Figure (3.): Photographs of LDA experimental setup, (a) experimental setup for measurements of plasma flow velocity,(b) cross section of plasma actuator to the current experimental.

The interference fringes can be used to measure the flow velocity: in gas (plasma) or in a flowing medium, scattering particles are either present or introduced. When passing through the fringe system, these particles scatter the light. The scattered intensity I(t) is modulated with the frequency fs, which depends on The fringe spacing Δx and on the velocity component v of the particle perpendicular to the fringe.

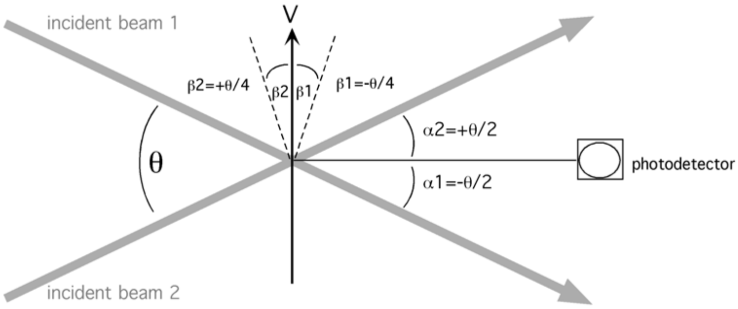


Figure (4): The beat frequency[13].

As an example, consider the geometry depicted in Figure (4) with using to the equation (9),the frequency shift for first beam is given by following equation (10)[13]:

$f_{D1} = (2v/\lambda)\ \mathrm{Cos}\ (-\theta/4)\ \mathrm{Sin}\ (-\theta/4)$ ....(9)

The frequency shift for second beam is bright or dark zones where

$f_{D2} = (2v/\lambda)\ \mathrm{Cos}\ (+\theta/4)\ \mathrm{Sin}\ (+\theta/4)$ ....(10)

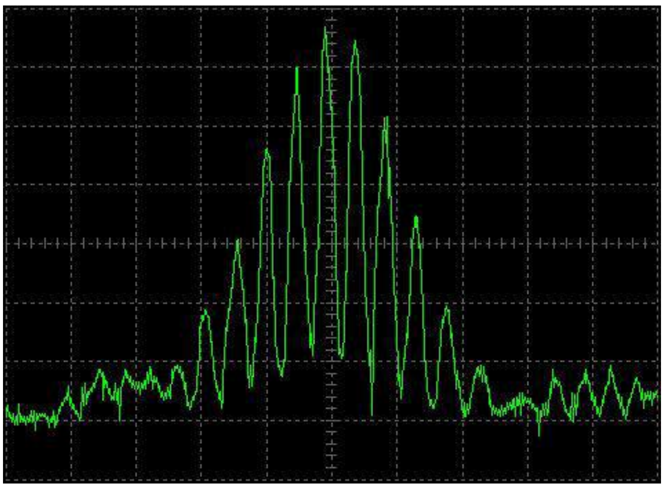
The fringe spacing, d_f, is the distance between sequential

$d_f = \frac{\lambda}{2\mathrm{Sin}(\frac{\theta}{2})}$............(11)

As a particle crosses the fringe pattern, the intensity of the scattered light varies withthe intensity of the fringes. Thus, the amplitude of the signal burst varies with time scaled$_f$/v, where v is the velocity component perpendicular to the fringe pattern, and perpendicular to the bisector of the two incoming beams. The frequency of theamplitude modulation is thus,

$v/d_f = \frac{2v}{\lambda}\ \mathrm{Sin}\ (\frac{\theta}{2})$ ....(12)

$\left|\frac{f_{D1}-f_{D2}}{2}\right| = \frac{2v}{\lambda}\ \mathrm{Cos}\ (\frac{\theta}{4})\ \mathrm{Sin}\ (\frac{\theta}{4}) = \frac{2v}{\lambda}\ \mathrm{Sin}\ (\frac{\theta}{2})$ ....(13)



Figure(5): scattering wave signal during passage in plasma flow.

Figure(5) shows the scattering wave signal during passage in plasma flow**.** For many single scattering centers individual signals arise with random amplitude and phase distribution, which overlap to a strongly fluctuating sum signal. The frequency fs can be determined by suitable numerical analysis.

3-Results

3.1-**Thurst measurements**

The thrust results in this study, its presented in Figure (6),Hence, the resulting force F/L was presented as a function of several discharge specific quantities. Forinstance, and shown the actuator force as function of the operating voltage. Its good agreementwith the results of Thomas et al. [9], Produced higher plasma actuators power in the event of (PMMA/Cu) was about (54mN/m) and the relation of plasma actuator thrust as a function to applied voltage is approximately perfect linear (R^2=0.9893) as shown in Figure (6).

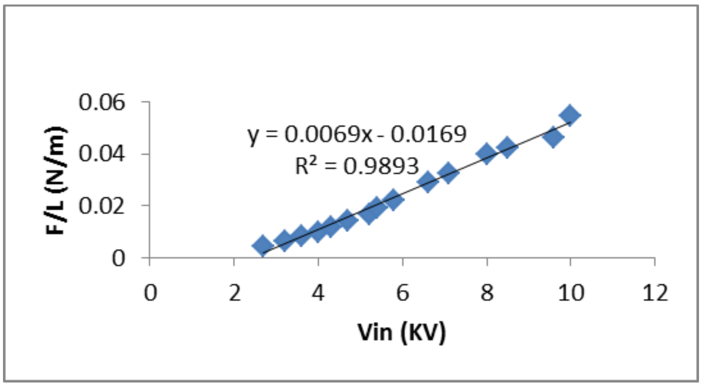


Figure (6): Plasma actuator force F/L as a function of applied voltage in PMMA with Copper electrodes at frequency 8KHz.

High density polyethylene actuator force has measured using copper electrodes in Figure (7) hence, its was about (10 - 33) mN/m with linear behavior (R^2=0.9674) ,also, its consider good actuator.

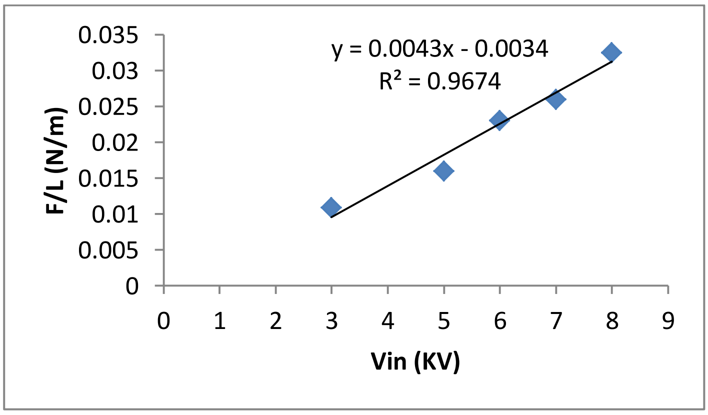


Figure (7): Plasma actuator force F/L as function of applied voltage in high density polyethylene with copper electrodes at 8kHz frequency.

Teflon actuator representing in Figure (8) with good linear relation, actuator thrust up to (46.2mN/m) at applied voltage (9KV) with a suitable stability.

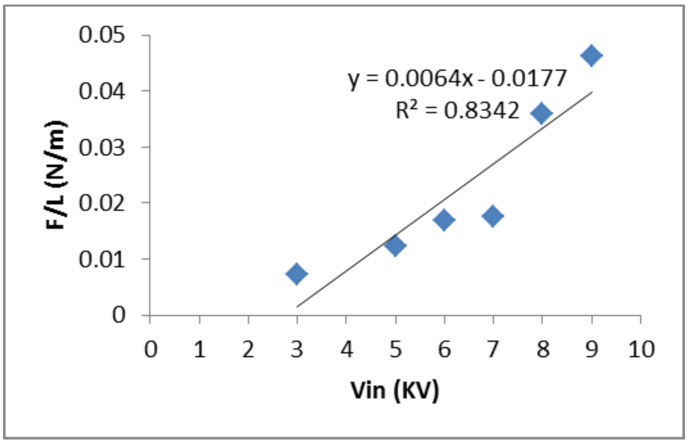


Figure (8): Plasma actuator force F/L as function of applied voltage in PTFE (Teflon) with copper electrodes at 8kHz frequency.

In Figure (9), the PMMA actuator thrust was about (32mN/m) with Aluminum electrodes at frequency 8KHz. The behaver semi linear approximately from straight line relationship (R^2=0.927).

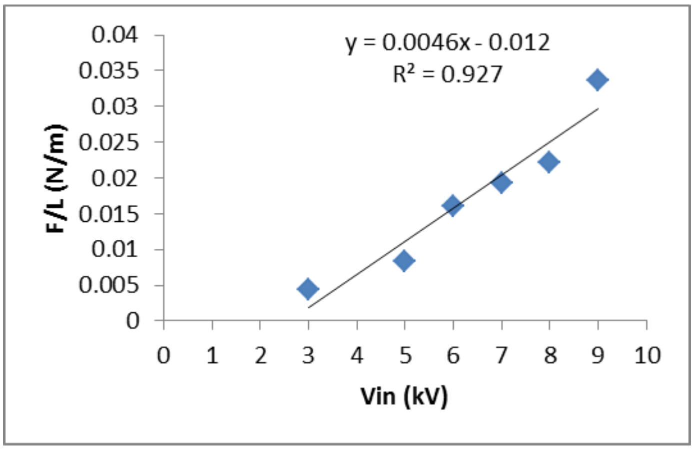


Figure (9):Plasma actuator force F/L as function of applied voltage in PMMA with Aluminum electrodes at 8kHz frequency.

In Figure (10), denote thrust value in high density polyethylene with Aluminum electrodes at frequency 8kHz. Its lower comparison with each actuators about (4-29 mN/m), and not good actuator comparison with PMMA actuators. in Figure (11), Teflon plasma actuator thrust up to 29mN/m with linear relation (R^2=0.83902).

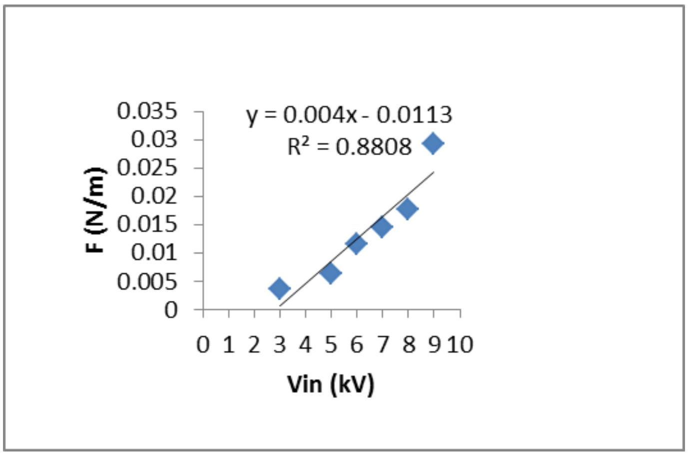


Figure (10): Plasma actuator force F/L as function of applied voltage in high density polyethylene with Aluminum electrodes at frequency of 8kHz.

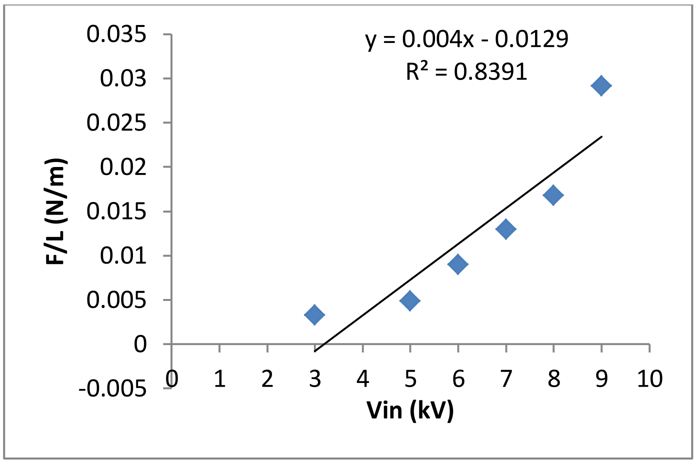
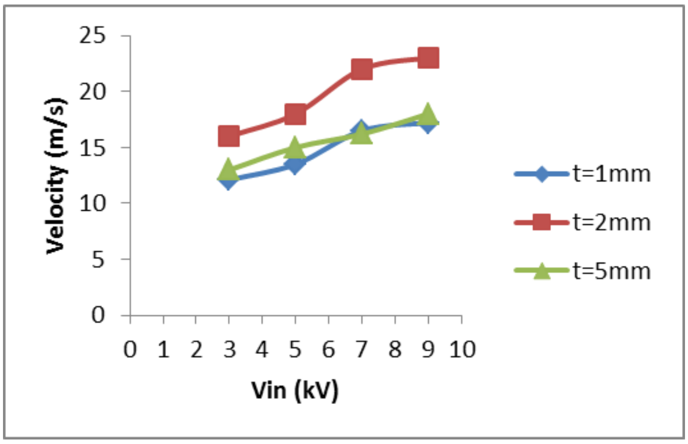


Figure (11):Plasma actuator force F/L as function of applied voltage in PTFE (Teflon) with Aluminum electrodes at 8kHz frequency.

3.2- Flow Velocity Measurements

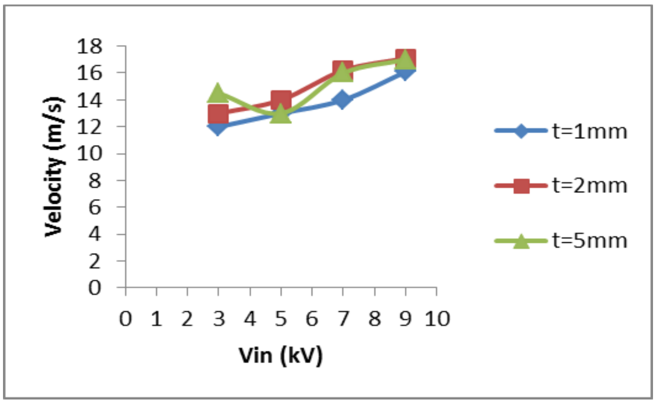
In current experimental, the plasma flow have been measured from the optical method (LDA) for three different thickness (1,2,5 mm) of dielectric material and applied voltages at constant frequency 8KHz. Two types of electrodes and three types of insulators (PMMA, High Density polyethylene (HDPE) and Teflon) showed that to measure of plasma flow velocity.

These velocities varied with applied discharge voltage on polymer, the results showed a difference in the flow velocity in each case. The best speed of the flow in the events of PMMA actuator with copper electrode and appropriate evidence of this to get the best actuator force when the plasma flow velocity is approximately between (16-24 m/s) as maximum value at 2mm thickness, also, the velocity approximately from (12-17m/s) at (1,5 mm) thickness shown in Figure (12).



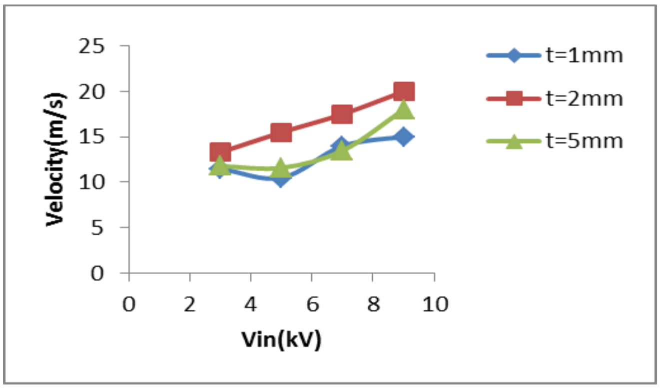
Figure(12): The flow velocity as a function of applied voltage in PMMA actuator with copper electrodes at 8kHz frequency.

In Figure (13) representing to the results of flow velocity in high density polyethylene actuator with copper electrodes, it’s shown that the velocity include between 14 to 17 m/s as maximum value at 5mm dielectric thickness, and minimum value in 5 KV up to 11 m/s also, it’s have velocity between 12 to 16 m/s at 1mm thickness with applied voltages.



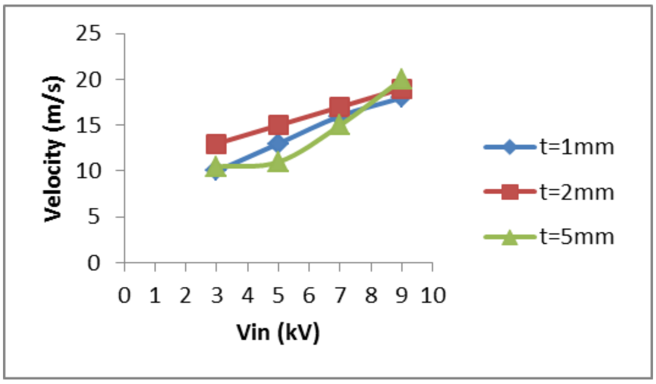
Figure(13): The flow velocity as a function of applied voltage in high density polyethylene actuator with copper electrodes at 8kHz.

Teflon actuator with copper electrodes has measure of velocity, higher value at 2mm thick (12-20) m/s and lower values at 1mm includes between 11 to 16 m/s.

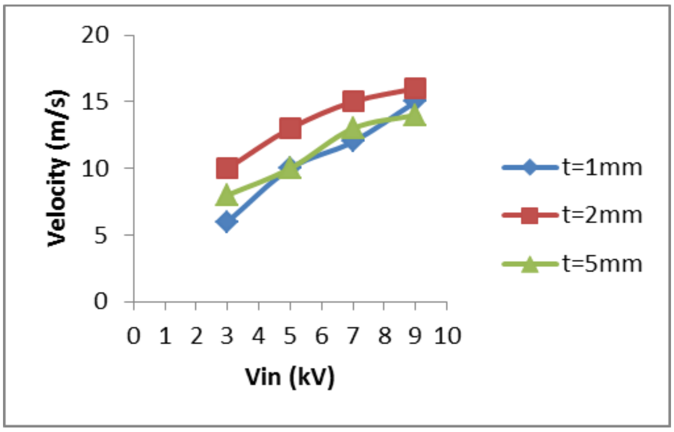


Figure(14): The flow velocity as a function of applied voltage in Teflon actuator with copper electrodes at 8kHz frequency.

In figure (15) representing to PMMA actuator with Aluminum electrodes. The results have lower values comparison with copper electrodes, hence, it was include approximately between (10-20) m/s at 5mm thickness, whoever, from 12.5 to 18 m/s at 2mm thickness and 10 to 17 m/s at 1mm thickness. These differences of velocity values are occur expected for agreement or not agreement for each of polymer structure ponds oscillator with applied voltage frequency and impactin output power. The maximum value of velocity in Figure (15) at 2mm of Teflon thickness, hence up to 16m/s at 9KV.

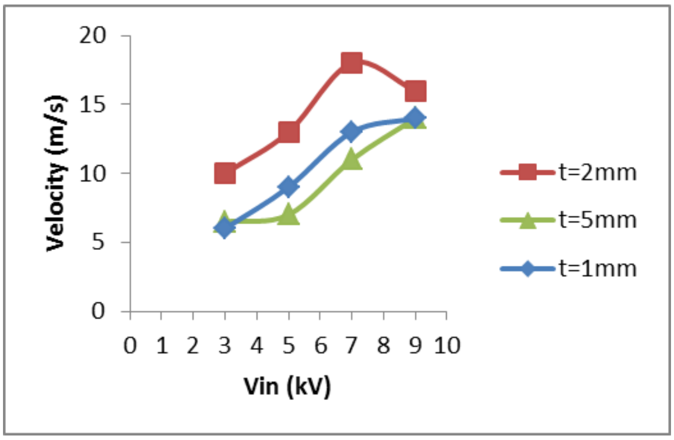


Figure(15): The flow velocity as a function of applied voltage in PMMA actuator with Aluminum electrodes at 8kHz frequency.



Figure(16): The flow velocity as a function of applied voltage in high density polyethylene actuator with Aluminum electrodes at 8kHz frequency.

Figure (17) gives the measured velocity for Teflon actuator with Copper electrodes. Its clear that the of velocity was lower with Aluminum electrodes about of 10 to 18 m/s at 2mm and 6 to 13 m/s at (1,5 mm) thickness.



Figure(17): The flow velocity as a function of applied voltage in Teflon actuator with Aluminum electrodes at 8kHz frequency.

A difference between actuators power of the plasma depending on each of the dielectric and the electrodes types, at different applied voltages at the frequency of 8 kHz, Produced higher plasma actuators power in the event of (PMMA / Cu), was about (54mN/m) as in Figure (6), and velocity 24m/s shown in Figure (12). As well as the lower value of strength were observed with each of Teflon, polyethylene with the electrodes of Aluminum was up to (30 mN/m), as shown in Figure (16), Figure (17). The reason for the difference in the disparity of force to parameters group including such as dielectric constant and the nature of polarization inside the dielectric under effect of high voltage at 8KHz frequency, as well as the nature of the strength of the bonds and their frequencies. It produces the greatest ability in the case of broad reach of the state of the resonant frequency between the source and molecular bonds of polymers[14].

References

1. R. Durscher , S. Roy, "Evaluation of thrust measurement techniques for dielectric barrier discharge actuators", Exp. Fluids 2012, 53:1165–1176.
2. Roth, J. R."Electrohydrodynamically induced airflow in a one atmosphere uniform glow discharge surface plasma", 25th IEEE Int. Conf. Plasma Science, Raleigh, NC, (1998).
3. B. J. Pafford, B.S., "Investigation of Magnetohydrodynamic Plasma Actuators for Aerodynamic Flow Control", Thesis, M.S. University of Texas at Austin, (2013).

4. K. D. Jensen "Flow Measurements", Dantec Dynamics Inc. 200 Williams Dr Ramsey, NJ 07446, USA, Vol. XXVI, No. 4 (2004).
5. M. Debiasi, L. Jiun-Ming "Experimental Study of a DBD-Plasma Driven Channel Flow" AIAA, 954-(2011).
6. G.Sun, W. Liu, C. Li and R. Zhang, "On the mechanical efficiency of dielectric barrier discharge plasma actuators", applied Physics Litters 98, 221504, (2011).
7. BOYLESTAD, "Introductory Ciruct Analysis", book, Tenth Edition, 2010.
8. N. Benard, E. Moreau, "Electrical and mechanical characteristics of surface AC dielectric barrier discharge plasma actuators applied to air flow control"Exp Fluids 2014, 55:1846-1851.
9. Enloe, C. L., McLaughlin, T.E., VanDyken, R. D., Kachner, K. D., Jumper, E. J., and Corke, T. C., "Mechanisms and Responses of a Single Dielectric Barrier Plasma Actuator: Plasma Morphology," AIAA Journal, 2004, 42(3):589-594.
10. Thomas C. Corke ,Martiqua L. Post and Dmitriy M. Orlov "Single Dielectric Barrier Discharge Plasma Enhanced Aerodynamics : Physics, Modeling and Applications" Experiments in Fluids,(2009).
11. Gregory, J. W., Enloe, C. L., Font, G. I., and McLaughlin, T. E., "Force Production Mechanisms of a Dielectric-Barrier Discharge Plasma Actuator," AIAA 2007-185, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, Nevada, 2007.
12. J. W. Ferry, "Thrust Measurement of Dielectric Barrier Discharge Plasma Actuators and Power Requirements for Aerodynamics Control" , M.SC. Thesis, Missouri University of Science and Technology, (2010).
13. Durst, F., A. Melling, and J. Whitelaw. Principles and Practices of LaserDoppler Anemometry. Academic Press(1981).
14. A. Kareem, N. A. Alrazak, K. H. Aljebori, A. M. Aljeboree, H. L. Algboory and A. F. Alkaim, Removal of methylene blue dye from aqueous solutions by using activated carbon/ureaformaldehyde composite resin as an adsorbent, International Journal of Chemical Sciences, 2016, 14, 635-648.

*****