OPTIMISATION OF GAS EHD PUMP WITH NOZZLE DOWN STREAM

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ABSTRACT

With the application of high voltage between sharply curved electrode and blunt electrode, the air near sharply curved electrode ionizes. The ions formed are accelerated towards blunt electrode due to electric field. In the process they collide with electrically neutral molecules and transfer their momentum completely as the collision is assumed to be elastic. This results in motion of air which is called ionic wind or corona wind or Electrohydrodynamic wind. Electrohydrodynamics (EHD) refers to the study of this interaction of fluid motion and electric field.

Keywords: Electrohydrodynamics, Corona discharge, Ion drag pump,Gas pump,Ionic wind

1. INTRODUCTION

With the application of high voltage between two asymmetric electrodes; one highly curved electrode as emitting electrode and one of low curvature as collecting electrode, current is developed by ionising air near emitting electrode to create plasma. This is due to high potential near emitting electrode owing to its high curvature and this process is called corona discharge. Net effect is that ions, of the same polarity as that of corona discharge, are drifted to other electrode. A space charge is formed between electrodes. The movement of ions is obstructed by electrically neutral air molecules causing transfer of momentum from ionic space charge to air bulk. Therefore, the Coulomb force acting on the ions becomes an electric body force on air molecules. The resultant air motion has been termed "corona ", "electric", "ionic", or "ion-driven" wind and recently terminologically defined as "Electrohydrodynamic (EHD) gas flow" (Zhao and Admiak, 2005 &.Moon et al., 2009).

An EHD gas pump is a device which produces unidirectional ionic wind. Attempts are being made to use corona discharge as driving mechanism for a gas pump. Though voltages are high the current involved is low which reduces power consumption. The EHD gas pump has no moving parts making maintenance easy which is an added advantage. By overcoming technological challenges and with significant advancement this technology can be implemented in various applications in future. This calls for more research to broaden the understanding of EHD.

During the last several decades many studies have been conducted on EHD and

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its applications in a variety of fields, such as aerodynamics, heat and mass transfer (Leger and Moreau, 2002, & Lai and Sharma, 2005). EHD Gas pumps can be used in Electronic and Microelectronic devices. Possibilities of controlling flow and Hypersonic flows using EHD is also explored (Macheret et al., 2004). Its feasibility as Microsatellite propulsion system for future is yet to be investigated. Researchers are exploring this promising technology for near space propulsion systems (Young and Keith, 2009). Researchers are also trying to control air intake in an aircraft using dielectric barrier discharge (Leonov and Yarantsev, 2006).

2. LITERATURE REVIEW

In recent years there has been increase in EHD research around the world. Leger, 2001 and Moreau et al., 2008, have successfully demonstrated the application of EHD in aerodynamics. They experimentally showed that flow can be attached to the plate by activating corona discharge over the plate. They also investigated the effect of humidity on behaviour of discharge current as a function of the applied electric field. Cooling of integrated circuitry can be enhanced by using ionic winds (Go et al., 2007). Figure 1 illustrates the change that will occur in the boundary layer profile with the application of corona discharge which augments the heat transfer.
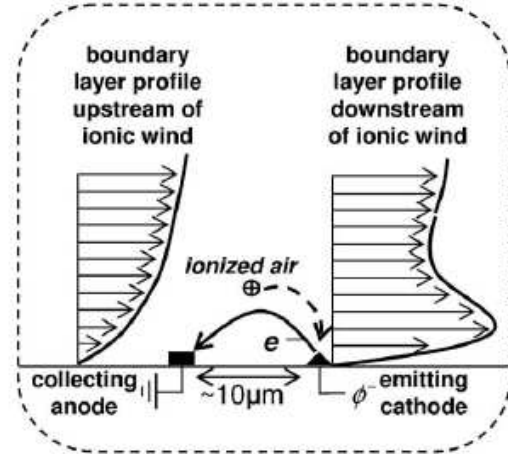

Figure 1: Illustration of boundary layer change due to ionic wind

Although higher voltage produces higher velocities, the high electric field intensity causes avalanche discharge (spark), reducing the effectiveness of the EHD pump. Takeuchi and Yasuoka, 2009, conducted experiments with thin wire and rod configuration to avoid sparks jumping across sharp edges. They were successful in producing volumetric flow rate of 43 L/min. Results show that it is better than a DC fan for CPU cooling. However, the velocities produced were low compared to other electrode configurations.

They also related Reynolds number based on rod electrode (Re_r) and EHD number (IEEE-DEIS-EHD, 2003) as $Re_r=(EHD_r)^{0.5}$

$$Re_r = \frac{\langle U \rangle \times d_r}{\nu_g}$$

$$Ehd_r = \frac{Id_r^3}{\rho_g \nu_g^2 \mu_t A_r}$$

Where   \<U\> is average flow velocity

d_r is dia of rod elctrode

v_g is kinematic viscosity of air

I is time averaged discharge current

µ is mobilityof ion in gas

The above EHD number formula is dimensionless parameter, recommended by IEEE-DEIS-EHD Technical Committee.

EHD number was also used by Lai and Sharma, 2005, who worked on enhancing EHD based drying. It is an important number for researchers who are engaged in Electrohydrodynamics. It was equivalent to the dimensionless parameter by Sadek and Fax, 1972 and it is defined as square root of force ratio (ion drag force / inertial force) and can be expressed as

$$EHD\ no. = \sqrt{\frac{\epsilon}{\rho}\left(\frac{V-Vo}{su}\right)}$$

Where   € is permittivity of gas
     ρ is gas density
     s is spacing between electrodes
     u is air velocity
     V is applied voltage
     V_0 is threshold voltage (which is determined by plotting square root of current against applied voltage and extrapolating to zero current level)

Lai and Sharma, 2005 and IEEE-DEIS-EHD, 2003 defined EHD number based on the initial work of Yamamoto.and Velkoff, who in their paper referred the number as N_{EHD} and it was not named as EHD number which we use today and as found in IEEE-DEIS-EHD. According to Yamamoto N_{EHD} is ratio of EHD Reynolds number to Reynolds number,

which when simplified becomes ratio of characteristic velocity to flow velocity.

$$N_{EHD} = \frac{EHD\ Re}{Re}$$

$$= \frac{U_e}{U}$$

$$U_e = \sqrt{\frac{IL}{\rho\mu_i A}}$$

The IEEE-DEIS-EHD recommended EHD number is a function of current only is derived from N_{EHD} which is function of current as well as flow velocity. N_{EHD} should explain physics of EHD as compared to EHD number. In our investigation we have considered both numbers. we have not yet arrived at a conclusion. As it is seen in above equations that N_{EHD} is a more powerful number to explain physics. So it should be given more priority.

Brown and Lai, 2009, studied EHD pumps of different diameters of 38.1 mm and 63.5 mm. They noticed some unknown behaviour in bigger diameter tubes. It was speculated that recirculation cells are formed in the tube. They used four emitting electrodes placed equidistant around the inner surface of the tube and grounding plate along the circumference and their work shows that velocity profile is uniform in smaller tubes and it is clear

that velocity at the centre is lower for higher diameter tubes because the collecting electrode is near the inner wall of the tube.

Moon et al ,2009, utilized a ring and a needle at its centre as one electrode to improve the efficiency of plasma induced flow. But the collecting electrode used was a ring which is similar to that in the study by Brown and Lai, 2009, and it is expected to have the same disadvantage of producing annular flow.

A very high velocity can be seen in computational work by Zhao et al.,2005, in pin-plate or pin-grid configuration with plate/grid being cathode shows that ionic wind velocity reaches up to 10 m/s near the plate/grid with 11 KV. Moreau et al.,2008, studied ionic flow in cylindrical tubes with needle as anode and mesh as cathode. In their experiments, for an optimum configuration, velocity of 8 m/s is measured at the exit. Their experiments also show that positive corona produces more velocity than negative corona. This was not observed in Takeuchi's work. This may be due to use of needle as emitter electrode as compared to Takeuchi's wire electrode.

J.S Chang et al., 2009, investigated mechanism of electrohydrodynamically induced flow in wire-non parallel plates of length of 60 cm. He observed that there is an optimum angle at which maximum velocity is produced and the flow recirculation is enhanced with increase in angle between the plates. However the extent of applicability of these findings to the presented work is uncertain till further research.

Even though a few studies on various configurations have been conducted, no literature is available on dependence of ionic wind properties on the geometry of electrodes. Present work is focused on finding a relation between the velocity and the geometry as well as finding a way to maximise the velocity. It is done by choosing electrode configurations which allow continuous change of geometric properties.
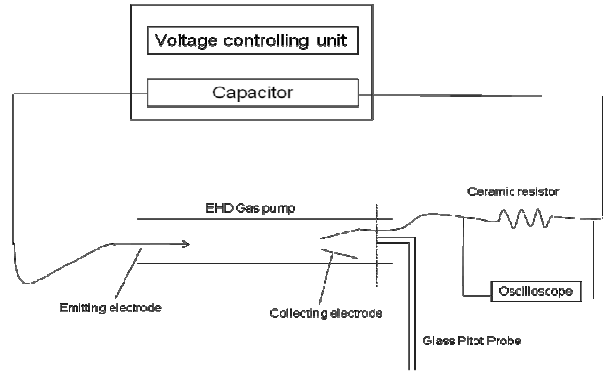
3. EXPERIMENTAL SET UP

A schematic diagram of EHD gas pump and flow measurement experimental apparatus are shown in Fig 2. In this experiment air at atmospheric pressure and room temperature was used as working fluid. The discharge is obtained from a capacitor based high voltage power supply which can supply a voltage up to a maximum of 50 KV. A micro manometer (DPM, model TT 570s) (see Fig 3a) connected to glass pitot tube (see Fig 3b) mounted on traverse was used to measure velocity at the exit of tube. Pitot tube is placed close to the collecting electrode so it should be made up of any insulating

material. Glass was used to meet this purpose. The velocity is measured at 45 mm from the end of collecting electrode.

Measurement of current is very important as parameter like EHD number is function of electric current. A resistor is place between collecting electrode and high voltage source as shown in Fig 2. Current and voltage can be measured across the resistor using oscilloscope. The resistor used should be a ceramic resistor with at least 5 W rating and with a resistance of at least 10 KΩ. Ceramic resistors can withstand the high temperatures generated because of high voltage supply. Resistors other than ceramic resistors fail with the application high voltage and give inaccurate data.

An electrode was selected which is expected to overcome the deficiencies of electrodes available in literature. The emitting electrode should be as sharp as possible and collecting electrode should be blunt. Due to more ionisation near the sharp electrode, flow is induced from sharp electrode to blunt. After conducting experiments axisymmetric conical foil as collecting electrode and needle as emitting electrode was found to be a promising one.

Fig 2: Schematic diagram of the experimental set up

The EHD gas pump is made up of three tubes, two glass tubes and one acrylic tube (see Fig 3c and 3d). When assembled together it acts as a single tube with internal diameter of 20 mm. The emitting electrode is attached to Styrofoam which is held in the glass tube. Holding the collecting electrode which is in conical form is little difficult. To solve this problem an acrylic tube having a slot in radial direction was made. Then the conical electrode is glued to acrylic strip which enter this tube through the slot provided. Now two glass tubes one longer than the other enter the acrylic tube on either side. The longer glass tube holds the emitting electrode.
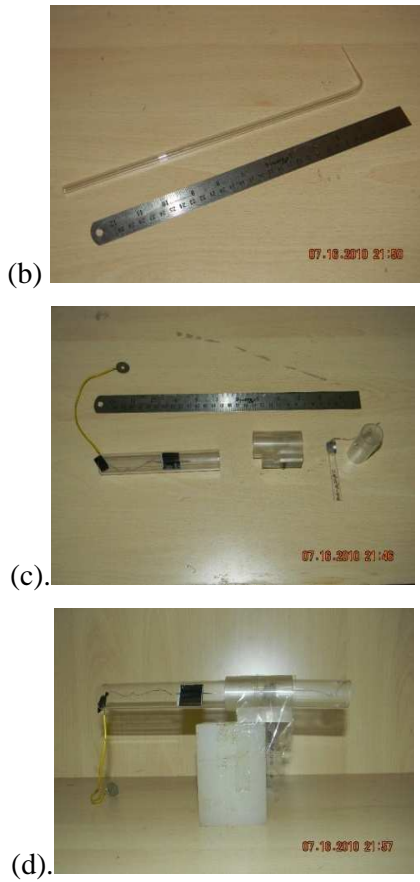

(a)

(b)

(c).

(d).

Figure 3:(a)Micromanometer (b)Pitot probe (c) Unassembled EHD gas pump (d) Assembled EHD gas pump

4. RESULTS AND DISCUSSION

After conducting experiments it was found that velocity induced in EHD pump depends on the shape and configuration of the electrode. A new variable based on geometry of electrode is introduced to understand the phenomenon better.

To understand the geometry dependence a length scale is proposed and can be understood by simple demonstration below in Fig 4. Consider a line AB subtending an angle on a point O. Figure 4 shows another line BC subtending same angle at O. The new line BC should be such that the line joining its midpoint and the point O, divides BC into two symmetrical halves. It can also be understood as the image (i.e. BC) of AB as viewed from the point O.
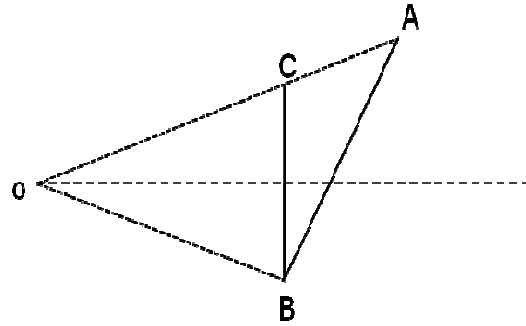
Figure 4: Projection of line on a point

A new variable called Electrode geometry factor, EGF, is proposed and is defined as the ratio of the surface area as viewed from the tip of the needle to the actual surface area of the cone (see Fig 5).

Electrode geometry factor, EGF =

$$\frac{surface\ area\ of\ cone\ with\ slant\ height\ \ lp}{surface\ area\ of\ cone\ with\ slant\ height\ \ l}$$
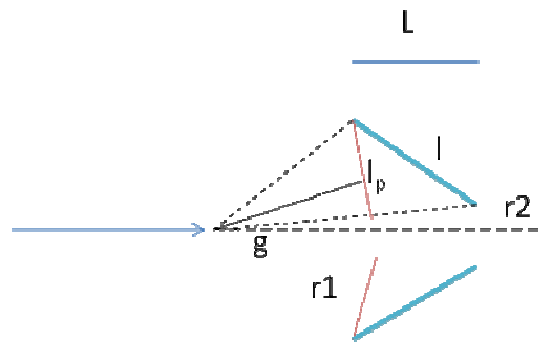

**Figure 5**: Schematic diagram of cone and its projected cone

Where r_2 is smaller dia of conical foil
r_1 is bigger dia of conical foil
L is length of electrode
G is gap between the electrodes
2α is cone angle

Experiments were conducted with two cones of axial lengths 5 mm and 10 mm in a tube of 20 mm diameter with regular cone and inverted cone configurations. as shown in Fig.6 Velocity is measured across the tube diameter, to obtain average velocity at various gap distances between electrodes and up to a maximum gap of 25 mm.
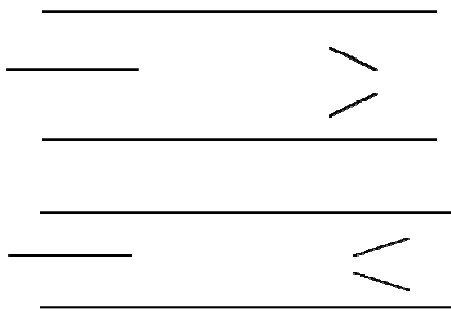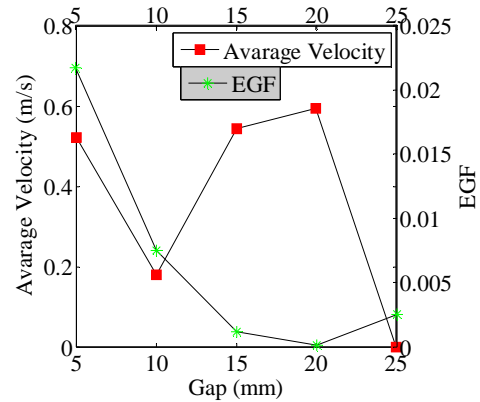
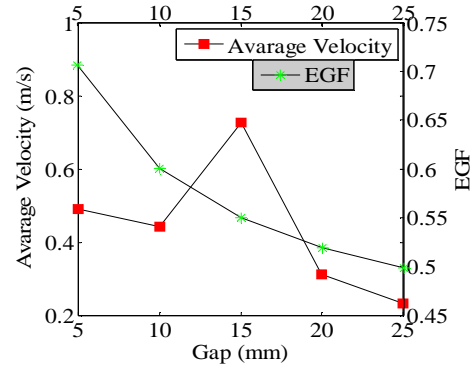(a) Regular configuration

(b) Inverse configuration

Figure 6 : Electrode Configurations in EHD pump

The Fig.7 shows the variation of average velocity and EGF with increase in gap. It is observed that as gap is increased the average velocity increases to reach peak velocity and then it starts decreasing, which is due to decrease in electric field strength. This can be seen in the plots except for the cone with L=10 mm in regular configuration, in which the decrease
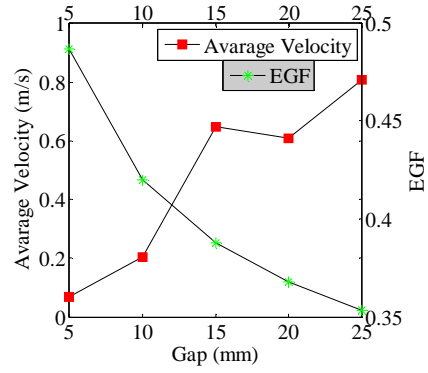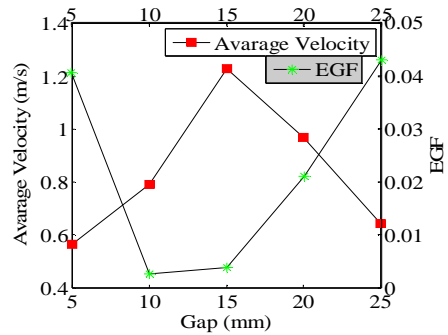
(a) L=10 mm Regular cone configuration

(b) L=10 mm Inverse con configuration

(c) L=5 mm Regular cone configuration

(d) L=5 mm Inverse cone configuration

Figure 7: Variation of Average velocity and EGF with gap

might start when gap between the electrodes is increased more than 25 mm. The geometry and the definition of EGF tell us that EGF decreases continuously in regular configuration whereas in inverse configuration it decreases and increases.

It is evident from the Fig.7 that orientation of the collecting electrode influences the flow velocity. Above plots show that velocity is maximum in cone with L=5 mm in inverse configuration. Fig 8 shows the relation between the number N_{EHD} and average velocity induced in the EHD pump. Maximum velocity is achieved when N_{EHD} is low. The relation between the average velocity and EHD number is shown in Fig.9 which shows that the higher the EHD number the higher is the velocity.
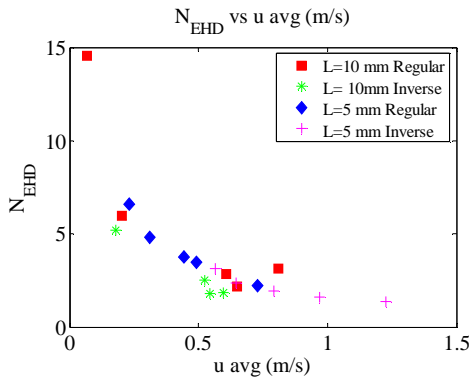

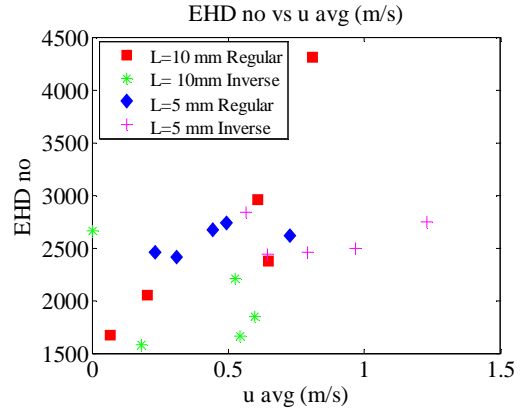**Figure 8:** N_{EHD} vs Average velocity

Figure 9: EHD number vs Average velocity

The Fig 10 below shows N_{EHD} as a function of EGF and Fig 11 shows EHD number as a function of EGF. It shows that regular configurations are more widely spread where as inverse configurations are concentrated.
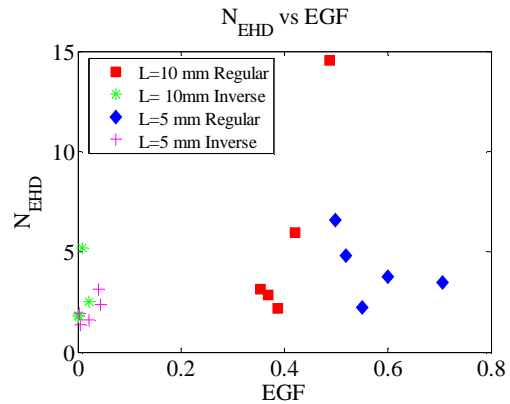
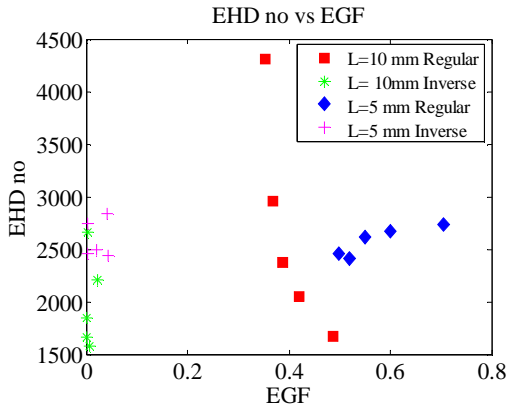

Figure 10 : N_{EHD} vs Average velocity
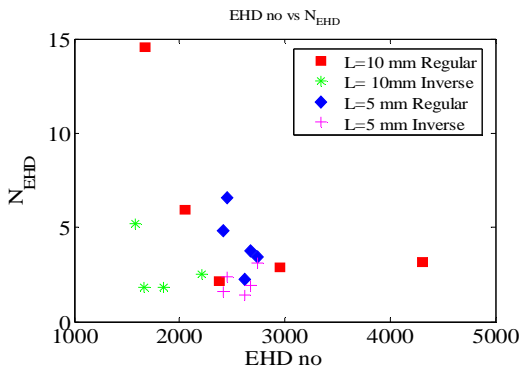
Figure 11: EHD number vs Average velocity

Figure 12 : $N_{EHD \ vs \ EHD \ Number}$

Fig12 below shows the realtions of N_{EHD} and EHD number. The results clearly show that both numbers may not have same significace and need not explain same physics. So apart from EHD number as recommended by IEEE-DEIS-EHD Technical Committee., N_{EHD} should be studied without any modifications to it.What physics these numbers explain is still under investigation. We recommend to have a rethink on dimentionless numbers for EHD before applying them directly in research.

Effect on average velocity with Nozzle downstream of EHD pump

Experiments with different geometrical configurations of cone showed higher average velocities for inverse configurations with shorter axial length after establishing this result, effect of nozzle downstream was studied. Nozzle with exit diameter of 1cm was integrated to EHD pump downstream and same experiments were repeated. Higher average velocities were recorded for EHD pump with nozzle downstream. It was also observed higher peak velocity and higher average velocity occurred at different optimum gaps for EHD pump with nozzle downstream as compared to EHD pump without nozzle.Figure 13 shows result of regular cone in EHD pump with nozzle and without nozzle. Higher average velocity value of 2.2 m/s at 10mm gap can be seen in EHD pump with nozzle as compared to EHD pump without nozzle where maximum value is 2.1 m/s at 15mm gap .
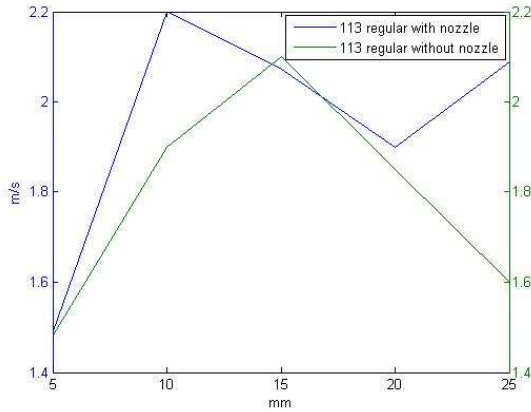
Fig 13 Avg velocity, vs. gap for regular cone without nozzle & with nozzle (higher average velocity of 2.2 m/s at 10mm for EHD pump with nozzle as compared to 2.1 m/s at 15mmgap in EHD without nozzle can be seen. This highlights higher average velocities with nozzle downstream)

As per conservation of mass and by continuity equation, after integrating nozzle of exit diameter of 1cm downstream EHD pump velocity recorded should increase to almost four times as compared to without nozzle, but this was not observed as can be seen in figure 13.EHD performance goes down in terms of efficiency with addition of nozzle downstream.

5. CONCLUSION

Experiments with regular and inverse conical configurations as collecting electrode for EHD pumps with and without nozzle shows variation of average velocity with gap & its dependency on configuration and orientation of electrode (a new non dimensional parameter called Electrode Geometry Factor (EGF). Average velocity behaves inversely with the newly proposed parameter, EGF.

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