Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 17 Issue 5 Version 1.0 Year 2017
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Numerical Analysis of Electrical Characteristics in a Squared Channel EHD Gas Pump

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GJRE-F Classification: *FOR Code: 090699*

NUMERICALANALYSISOFELECTRICALCHARACTERISTICSINASQUAREDCHANNELEHDGASPUMP

Strictly as per the compliance and regulations of:

Numerical Analysis of Electrical Characteristics in a Squared Channel EHD Gas Pump

Rezaur Rahman [α] & Dr. A.K.M Monayem Hossain Mazumder [σ]

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I. Introduction

When a gas discharged from the place where geometry confines the gas ionizing processes to high-field ionization regions around an active electrode [1](Goldman, A. Goldman, and Sigmond, 1985). The American Standards Association defines "Corona is a luminous discharge due to ionization of the air surrounding a conductor around which, exists a voltage gradient exceeding a certain critical value" [2](What is Corona? Hubbell Power System, 2004).

So far two types of flow generated per the working principle. One is displacement type and another one is a dynamic type[3] (Laser and Santiago, 2004) which distinguishes between the reciprocating and continuous flow [4](Chen, 2005).

Corona discharge mainly occurred with two asymmetric electrodes, one of its very sharp on curvature shape (needle, pin or wire) and another one has a very curvy geometry (rod or plate). The curved electrode contains a very high charge potential which is created by supplying a very high voltage from an outer source. By creating a plasma state, the electrode with high curvature ionized the nearest gas molecules which tend to migrate to the ground low curved electrode and this procedure is fully controlled by Coulomb force. Coronas can be either positive or negative. The voltage supplied to the curved electrode determines whether it is positive or negative. If the voltage supplied to the electrode is positive the corona discharge is positive otherwise it is negative if the supplied voltage is negative.

The ionized ions generate thrust on the other molecules near them by creating a collision while they try to move to the ground plate (low curved electrode). This continuous migration process creates a bulk flow, which is called ionic wind or corona wind (Fig 1).

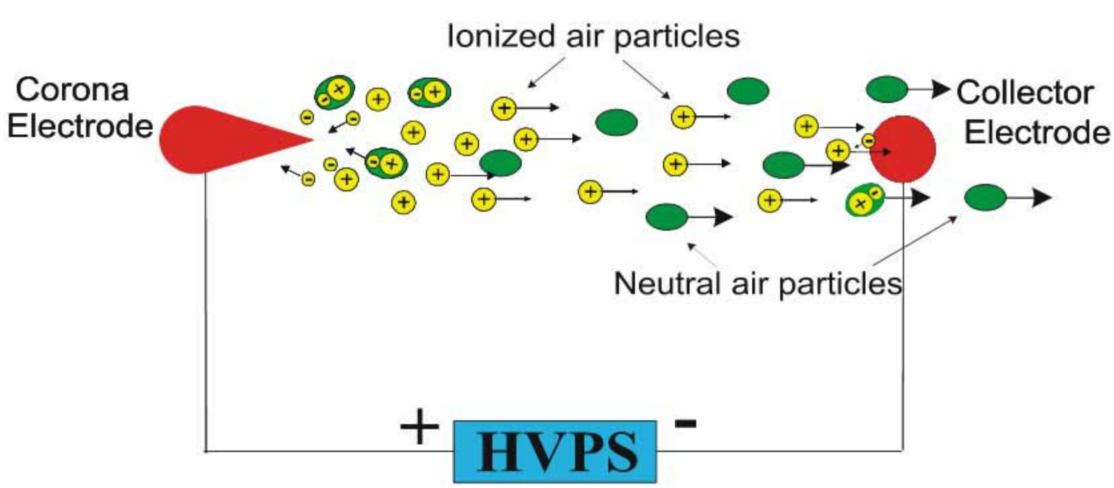

Figure 1: A basic schematic diagram for Corona wind generation with corona discharge[5](Genuth, 2013).

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II. Experimental Setup

The main design parameters followed here is the same as[6] (Mazumder and Lai, 2014), two stage EHD pumping procedure, but for this type of study, we only consider a single stage model. A glass box is the main structure where the other apparatuses are mounted. This box also works as a passage to the EHD flow which is induced after providing very high voltage and reaches the initial limit. Other main two parts of this setup are a conductor (emitter pin) and ground plate.

In this study, the whole design procedure is done using PTC Creo Parametric 3.0 m010. The main glass box is taken with an inner dimension of 4 in by 4 in by 12 in. The thickness of the glass is 0.25 inches. The conductor is made with copper material of 20 GA which gives this wire a diameter of .032 inches. The Ground plate thickness is 0.025 inches. The emitter pin is also made with the same copper wire and their length is 1.0 inches from the top to the ground plate. Whole conductor setup is attached to the glass box just 1.0 inches below the top of the box see fig 2.6. The gap between the conductor and ground plate is 2.5 inches that also concludes that the pin end point to the ground plate beginning is 1.5 inches (Fig 2.6), this gap is necessary to achieve the successful EHD pumping. Three types of the ground plate, as well as three types of conductor setup, are used in this study. The ground plate with a height of 0.5 inch, 1.0 inch and 2.0 inch and conductor with 4 pins, 12 pins, and 28 pin emitters are considered and designed for this numerical analysis process.

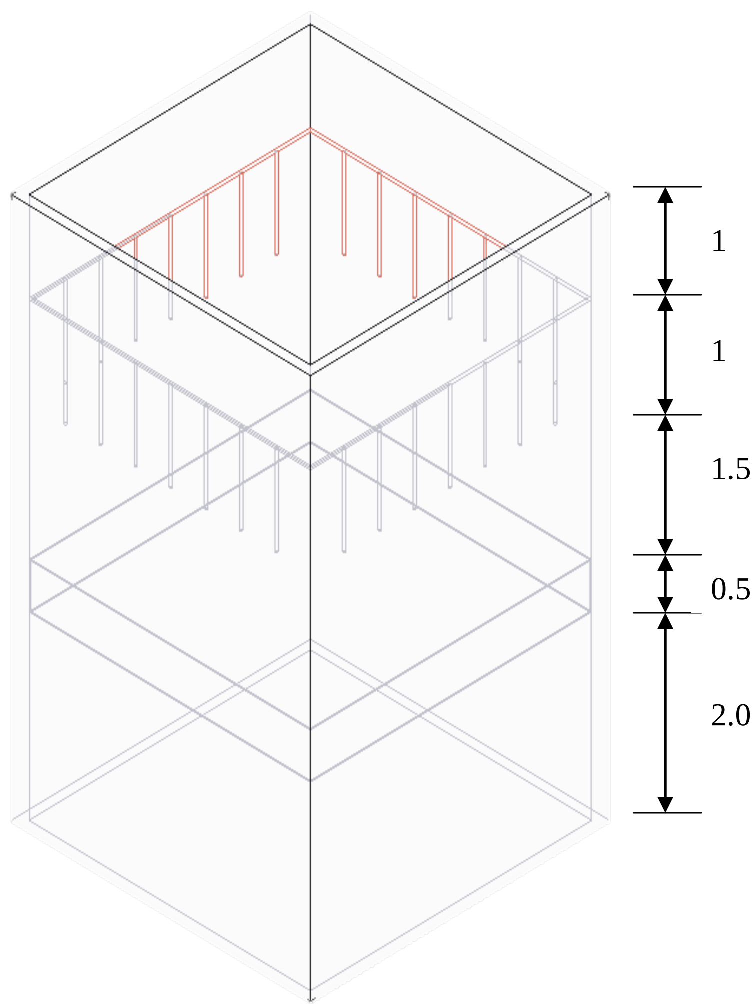


Figure 2: Schematic figure of 28 pin conductor setup with a 0.5-inchgroundplate.

Cases of study
4 pin conductor with 0.5 inch of groundplate.
4 pin conductor with 1.0 inch of groundplate.
4 pin conductor with 2.0 inch of groundplate.
12 pin conductor with 0.5 inch of groundplate.
12 pin conductor with 1.0 inch of groundplate.
12 pin conductor with 2.0 inch of groundplate.
28 pin conductor with 0.5 inch of groundplate.
28 pin conductor with 1.0 inch of groundplate.
28 pin conductor with 2.0 inch of groundplate.

III. Theory and Simulation Set Up

The electrostatic theory is derived from Gauss's Law and from Faraday's law of induction. Gauss's Law shows that the net electric flux passing through any closed surface is equal to the net positive charge enclosed by that surface. This derives that in differential format

$$\nabla \cdot D = \rho \tag{1}$$

Here D (x, y) is the charge density. We also know that the charge density can be pulled out by multiplying the relative permittivity ε_r, ε_o is the permittivity of free space, 8.854 × 10^{-12} F/m and Field Intensity E. So, we can conclude with another equation:

$$D = \varepsilon_r \cdot \varepsilon_o \cdot E \tag{2}$$

With the help of Faraday's law of induction, it is known that

$$E = -\nabla \cdot \phi \tag{3}$$

Where ϕ (x,y) is the electric potential.
So, the final field equation is

$$\nabla \cdot (\varepsilon_r \cdot \varepsilon_o - \nabla \cdot \phi(x, y)) = -\rho \tag{4}$$

This is the equation that the electrostatic field simulator solves using the finite element method.

To analyze the results a datum line is created by Maxwell just in the middle of the model with a total height of 6-inch top to bottom. This datum line is used to create the data plots after finishing the simulation process. Also, parameters like force, torque, and matrix distribution are set up on each part of the model to get the final output after final pass in the simulation process. An empty box is created just in the middle of the main canal to cover the highest maximum volume to get a visual of voltage, charge, electric field distribution after completing the simulation work.

Solution setup is the main part before starting the solution, where we can put the percentage of error, we will allow in this particular study with the number of passes allowed. Here we put the percentage of error allowed is 0.5 % with a number of passes 10 for all cases. So, the Maxwell software will perform the passes till it reaches the error percentage allowed. If we put the whole procedure in a flow chart we can conclude with the below flow chart.

IV. Results and Discussion

Electric Field Intensity

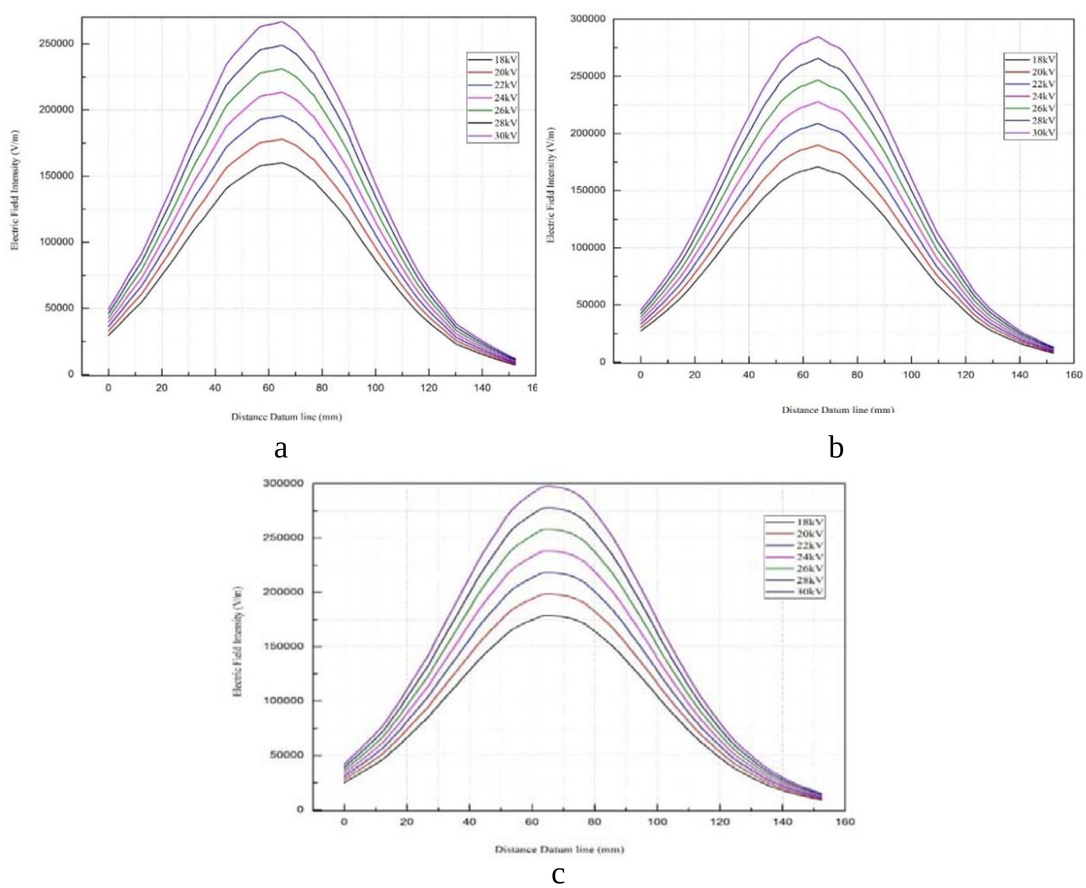
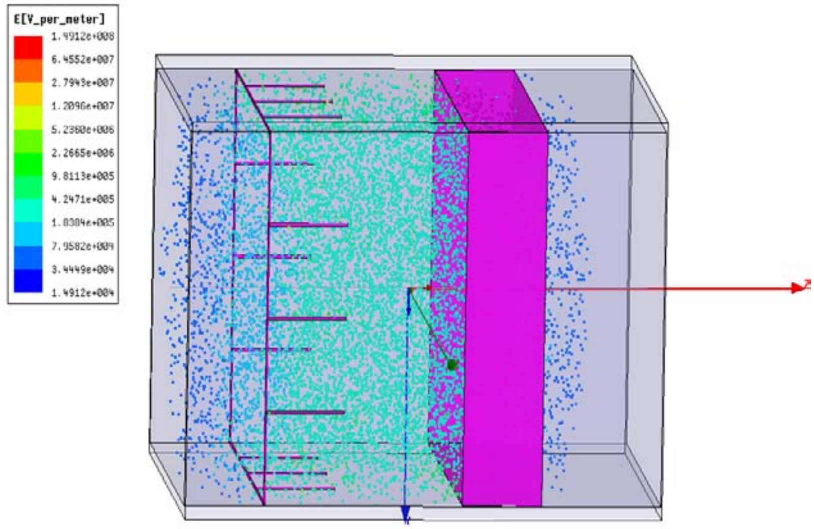
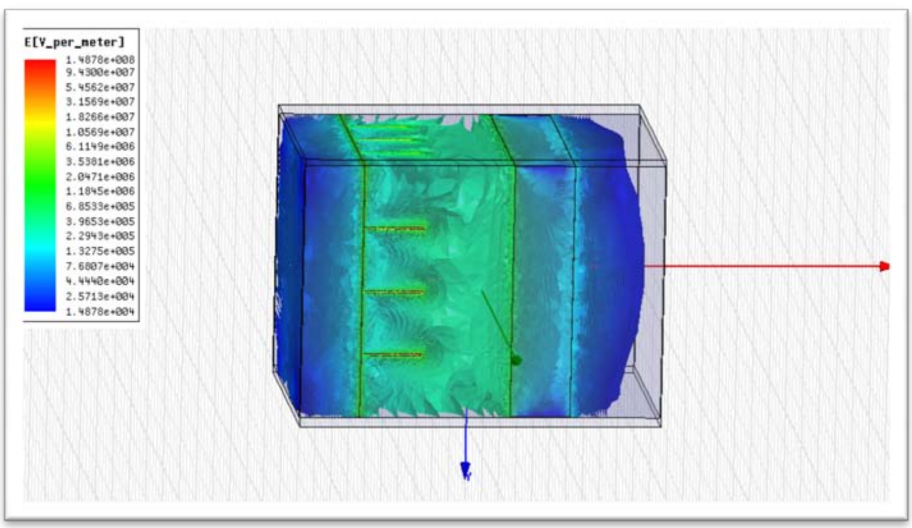


Figure 3: Electric field intensity (v/m) distribution with 0.5-inch ground plate along the datum line (a) for 4 pin emitter (b) for 12 pin emitter (c) for 28 pin emitter

The use of the different height of ground plate poses different lines in the graph which also represents the change of electric field intensity. The replacement of ground plate with larger width shows a greater range of field intensity with the same amount of voltage input.



a



b

Figure 4: Electric field intensity distribution in for 12 pin, 1.0-inch ground plate 24 kV applied voltage (a) Cloud view (b) Isovalsurface view

From figure 4 observation, which the same setup in field overlay with a much detail view, it is found the air near the conductor pin have greater field intensity than the air on the top and bottom of the passage. Also, the highly intense field layer is also found on the top on the ground plate. The top part of the ground plate portion remarkably carries high electrical field intensity though the input voltage in this portion is 0 kV. It indicates that the charged ionic air near the conductor jumps to the ground plate. The migrated air particles are causing the ionic wind and the flow of fluid medium in the canal.

V. Highest Field Intense Position

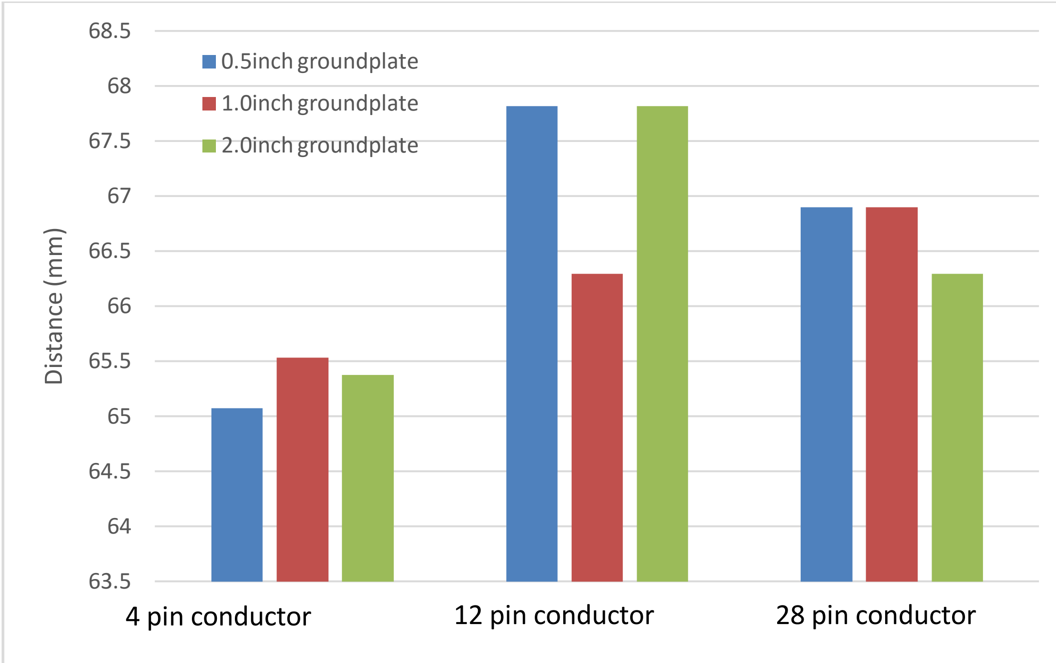


Figure 5: Highest field intensity points from the top of the channel

For each type of Ground plate setup, it is created single case, so for 0.5-inch, 1.0-inch and 2.0-inch ground plate 3 types of pin combination taken each time to build 3 fields of study. For 0.5-inch ground plate the far most position found for 12 pin conductor set up and closest found for 4 pin conductor. 1.0-inch ground plate setup showed interesting data that both 4 and 28 pin setup have the same point of highest intensity, but both of them went far from the point they have for 4 pin setup, 12 pin setup in this case lacked behind from both of them and created the point nearest to the top with an increase from 0.5-inch ground plate setup. 2.0-inch ground plate with 4 pin conductor has far most and 28 pin conductor closest points of electric field. So, it can be concluded from table 4.1 that the far most point found for the 1.0-inch ground plate with 4 and 28 pin conductor setup.

VI. Forces on Test Region

It is already discussed that the test region is created inside the channel and the material is assigned as Air to see the impact inside the channel which also worked as a working fluid domain. The table 4.2 indicates that the forces in X-axis for 4 pins are always negative and comparatively larger than 12 pin and 28 pin conductor. As the concern is the forces acting in the positive Z-axis direction as it has the potential to create the force which can drive the fluid from top to bottom of the channel. For 4 and 12 pin the Z direction force is larger, but it is negative, which means a very poor or negative potential to create the flow in the Z direction. Found forces here are very low compared to the forces created in other parts of the experimental domain. For each pin set up for every direction despite their positivity forces increase with the increase of voltage applied. The maximum total force found in the 12 pin conductor setup which is 230 μN. As the forces in X or Y or Z axis found negative in different cases which mean the force is not exerting on the outside of the channel it basically creating a collision within the region. For 4 and 12 pin the X and Z axis force pushing inwards whereas the Y axis forces are exerting on the region wall.

Table 1: Force distribution for 0.5-inch ground plate in test region

Voltage	F_{xv} Force (μN)	F_Y Force (μN)	F_Z Force (μN)	Total Force (μN)	Conductor Typed
18	-59.437	26.893	-12.602	66.444	4 Pin Conductor
20	-73.379	33.201	-15.558	82.029	
22	-88.788	40.174	-18.825	99.255	
24	-105.67	47.81	-22.404	118.12	
26	-124.01	56.11	-26.293	138.63	
28	-143.82	65.075	-30.494	160.78	
30	-165.1	74.703	-35.006	184.57	

18	-6.3726	81.071	-16.404	82.959	12 Pin Conductor
20	-7.8674	100.09	-20.252	102.42	
22	-9.5195	121.11	-24.505	123.93	
24	-11.329	144.13	-29.163	147.48	
26	-13.296	169.15	-34.226	173.09	
28	-15.42	196.17	-39.695	200.74	
30	-17.702	225.2	-45.568	230.44	
18	-49.719	-19.857	1.1611	53.55	28 Pin Conductor
20	-61.381	-24.515	1.4335	66.111	
22	-74.271	-29.663	1.7345	79.994	
24	-88.389	-35.301	2.0642	95.2	
26	-103.73	-41.43	2.4226	111.73	
28	-120.31	-48.049	2.8096	129.58	
30	-138.11	-55.158	3.2253	148.75	

VII. Conclusion

The present study has investigated the electrical characteristics of a square channel single stage EHD pump. Three types of conductor (4, 12, 28 pin) are created and each conductor have three (0.5-inch, 1.0-inch and 2.0-inch) ground plate set up with the glass channel. A lost voltage always found for every applied voltage in a conductor. The pattern of the charge distribution, electric field distribution and energy distribution are same along the datum line. All the simulations are converged within the selected maximum number of pass and energy error percentage (0.5 %). Tetrahedral meshes are created by the adaptive meshing system in each validation pass. For the same number of pins if the width of ground plate is increased the percentage of ionized air is increased. For the same ground plate width, it is found that the ionized air is increased if the pin number in conductor increased. The electric field intensity is increased by the increment of the conductor pin number and width of ground plate.

The far most point of highest electrical field intensity is the 1.0-inch ground plate with 4 and 28 pin conductor setup. The position of the highest value of electric field gradually decreases from the top the channel if the pin number is increased for 0.5-inch ground plate setup. Highest field intensity is found nearest for 12 pin conductor with a 1.0-inch ground plate and for 2.0-inch ground plate nearest field intensity created for 28 pin conductor.

Forces acting on Ground Plate, Conductor and Channel are increased with if the applied voltage is increased, which are independent of the width of ground plate, but also larger range of forces are found with the increase of pin number. The experimental domain forces are very low compared to the forces. Forces are increased when applied voltage increased despite their direction.

This study has opened a lot of opportunities to work on different shapes of sizes of EHD pump as the electric field potential and forces are measured successfully. This same simulation can be tied up with ansys fluent. This can be effective to find the flow pattern and flow velocity directly from the ionized air. Any kind of dielectric fluid can be analyzed in micro scale.

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