Evaluation of the Relative Effect of Geometric Parameters on Performance of an Electro-hydrodynamic Air Moving Device

Michael Sean June
Dept. of Mechanical Engineering
Christian Brothers University, Memphis, TN
phone: (1) 910-321-3409
e-mail: mjune@cbu.edu

Adam Henson, Aaron Griffin
Dept. of Engineering and Technology
Western Carolina University, Cullowhee, NC

***Abstract*—Electro-hydrodynamic air moving devices have many potential advantages, but are typically overlooked due to performance and efficiency concerns. Optimizing performance and efficiency by varying geometric parameters has been the subject of many papers. The current work identifies the most significant geometric parameters such as electrode material, electrode shape, distance between electrodes, number of ionization sites, and quantifies their significance with a DOE analysis. It was found that collector material, shape and distance between electrodes were significant as expected. Not expected, was the result that number of ionization sites was not significant.**

I. Introduction

Electro-hydrodynamic air moving devices have many potential applications. Due to a lack of moving parts, and given the absence of a mechanical impeller, a wider array of shape and size options are possible. With nearly silent operation and potential longer service life, these devices are an attractive option for cooling of LED lighting and smaller electronics. One of the major drawbacks of this technology is the low efficiency and performance compared to conventional rotary air moving devices (AMDs). Enhancement of both performance and efficiency has been the subject of several studies. Contemporary work on the geometric parameters which affect the performance of needle/cylinder type AMDs begin with Rickard et al. [1,2]. The current work is based on a needle and cylinder geometry described by Rickard [1,2], and June [3,4].

Several researchers have described optimization of the needle and cylinder performance in terms of static pressure, airflow and efficiency [5,6]. Attempts to quantify the effects of varying geometric parameters, on performance and airflow are not well represented in the literature. The current work is a novel application of a statistical design of experiments (DOE) to assess and quantify the relative importance of geometric and electrical parameters, namely applied voltage, needle to cylinder distance, cylinder length, cylinder material, collector shape (cylindrical, conical, parabolic), number of stages, and number of ionization sites.

II. PROCEDURE

A. Design of Experiments

A Design of Experiments was conducted using Minitab software, and checked using the Statistical Toolkit in Excel. A high and low value for each parameter was chosen, testing was conducted as described below, and the data collected was entered into Minitab and Excel, which calculated the results. A desired confidence level of 95% was chosen, giving a criterion for comparison of 0.05 (1 - 0.95 = 0.05). Any calculated p-value above 0.05 would be considered to have an insignificant effect (level of confidence < 95%). Figure 1 shows an example of a test matrix, the results of which were compared using ANOVA as part of the DOE procedure.

	10 mm			15 mm			20 mm	
	-	+		-	+		-	+
	Copper	Aluminum		Copper	Aluminum		Copper	Aluminum
	1.04	1.12		1.12	1.19		0.8	1.064
7,500 V	0.99	1.08	10,000 V	1.12	1.16	10,000 V	0.8	1.05
	1.02	1.11		1.09	1.18		0.78	1.03
	1.66	1.71		2.01	2.09		1.87	2.08
10,000 V	1.63	1.68	15,000 V	1.99	2.06	17,500 V	1.84	2.07
	1.65	1.69		1.99	2.09		1.86	2.05
	Cylindrical	Conical		Cylindrical	Conical		Cylindrical	Conical
11,000 V	1.79	2.09	15,000 V	2.27	2.52	17,500 V	2.08	2.63
	1.75	2.09		2.23	2.52		2.05	2.59
	1.76	2.06		2.26	2.49		2.04	2.61
13,000 V	2.31	2.58	18,000 V	2.62	3.15	20,750 V	2.43	3.14
	2.29	2.54		2.61	3.11		2.38	3.14
	2.29	2.57		2.58	3.12		2.41	3.12
	4-Stage	8-Stage		4-Stage	8-Stage		4-Stage	8-Stage
8,500 V	1.39	1.42	10,000 V	1.27	1.28	10,000 V	1.01	0.99
	1.36	1.38		1.24	1.22		0.98	0.99
	1.39	1.41		1.25	1.25		1.01	0.97
	2.02	2.03		1.79	1.77		1.81	1.81
11,500 V	1.99	1.98	13,000 V	1.77	1.74	16,000 V	1.79	1.79
	2.01	1.99		1.78	1.76		1.8	1.76

Fig. 1. Test Matrix. An example of one group of geometric configurations of the various experiments is shown along with voltages used in these tests. Emitter to collector distance is shown on the top line.

High values of voltage were chosen as maximum voltage obtainable before arcing was observed for each geometry, and low values were the lowest voltage that led to reasonably detectable results. Various collector shapes were tested, with collectors 3-D printed using carbon filled PLA material from Proto-Pasta. Cylindrical was chosen as the "low" value, while the conical shaped collector was chosen as the "high" value. Cylindrical, conical, and parabolic profiles were tested and shown in Figure 2.

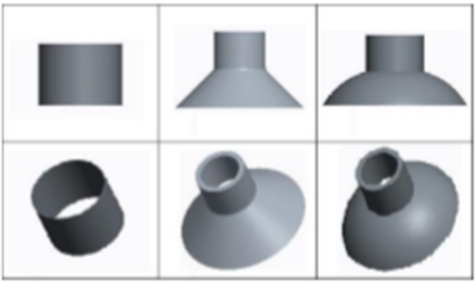

Fig. 2. Collector Shapes. Shown from left to right are cylindrical, conical, and parabolic profile collectors tested. Only cylindrical and conical were compared in the DOE.

For the cylindrical profile, aluminum, copper, and 3-D printed carbon filled PLA collectors of similar size were tested and compared in two separate DOEs. Figure 3 shows aluminum, copper and 3-D printed cylindrical collectors.

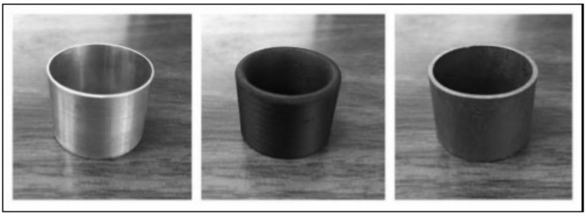

Fig. 3. Collector materials. Shown from left to right are aluminum, 3-D printed graphite/PLA, and copper collectors tested.

For the apparatus used in this study, common sewing needles were used as emitters. The number of ionization sites was equal to the number of needles used as emitters. Figure 4 shows an apparatus used to hold emitters and collectors. This particular apparatus allowed for testing of multiple stages.

Fig. 4. Emitter/Collector pairs. Conical collectors are shown with integral emitters. In this configuration, every other device would be charged negative with remaining units charged positively giving alternating positive and negative coronas.

B. Flow Bench Testing

Testing of the AMDs was conducted using a flow bench as described by June [4]. Power was supplied to the AMDs with an Acopian NO20HA1.5M high voltage DC power supply, set up to produce a negative corona.

III. RESULTS

Results of the DOE are shown in Table 1. As expected, Voltage was a significant factor in the performance of the devices under test. With the exception of numbers of ionization sites, and number of stages, all parameters commonly investigated were significant.

TABLE 1: THIS IS AN EXAMPLE OF A TABLE

PARAMETER	P	SIGNIFICANCE
VOLTAGE	<<0.05	SIGNIFICANT
EMITTER/COLLECTOR DISTANCE	<<0.05	SIGNIFICANT
COLLECTOR MATERIAL	<<0.05	SIGNIFICANT
COLLECTOR SHAPE	<<0.05	SIGNIFICANT
NUMBER OF STAGES	>0.05	INSIGNIFICANT
NUMBER OF IONIZATION SITES	>0.05	INSIGNIFICANT

IV. CONCLUSION

With the exception of the number of ionization sites, the results were as expected, the parameters evaluated had a significant effect on performance. The unexpected result was that the number of ionization sites was below the 95% confidence level chosen, and by that criterion insignificant. Number of stages was also insignificant, but on the basis of flow-rate, this was expected. One would expect air moving devices stages in series to have similar volumetric airflow rates as the single AMD, however increased static pressure should be observed, as stages are added. In this case, neither airflow nor pressure was observed increasing. This was likely due to the fact that the AMDs were not enclosed and static pressure could dissipate between stages. Further work is being conducted with enclosed and staged AMDs. Preliminary results show expected increase in pressure. More work needs to be conducted to determine if the results of the DOE show that the number of ionization sites was actually insignificant or simply of secondary significance. Previous results have showed an increase in airflow and efficiency with increase in number of ionization sites. Additionally, of great interest to this team is the effect of collector material and shape. 3-D printing affords the opportunity to create optimized geometries which would be impractical with other manufacturing techniques. The material composition and properties may also have an effect on performance and efficiency which will be the subject of further investigation.

References

[1] Rickard, M., Dunn-Rankin, D., Weinberg, F., Carelton, F., Characterization of ionic wind velocity, J. Electrostat. 63 (2005) 711

[2] Rickard, M., Dunn-Rankin, D., Weinberg, F., Carelton, F., Maximizing ion-driven gas flows, J. Electrostat. 64 (2006) 368

[3] June, M.S., Kribs, J., Lyons, K.M., Efficiency of Electrostatic Air Moving Devices, J. Electrostat, 68 (2010) 419-423

[4] June, M.S., Kribs, J., Lyons, K.M., Measuring Efficiency of Positive and Negative Ionic Wind Devices for Comparison to Fans and Blowers, J. Electrostat, 69 (2011) 345-350

[5] Jewell-Larsen, N.E., Tran, E., Krichtafovitch, I.A, Mamishev, A.V., Design and optimization of electrostatic fluid accelerators, IEEE Trans. On Dialectr. Electr.Insul., 13 1 (2006) 191-203

[6] Moreau, E., Touchard, G., Enhancing the mechanical efficiency of electric wind in corona discharges, J. Electrostat, 66 (2008) 39-44