A Comparative Study of Experimental and Simulation Results of Sieving Electrostatic Precipitator

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***Abstract*—Sieving Electrostatic Precipitator is a novel technology in the field of electrostatic precipitation where woven wire meshes are used for both particle charging and collection. Existing research shows that Sieving Electrostatic Precipitator is capable of capturing submicron particles more efficiently than conventional Electrostatic Precipitator. In order to improve this efficiency, it is important to optimize the spacing between the wire meshes, as well as the mesh size. This paper aims to investigate the efficient particle charging of Sieving Electrostatic Precipitator through experimentally obtained V-I characteristics of the electrical discharge, as influenced by the spacing between the wire meshes. The experimental data are presented and discussed on the basis of simulation results on electric field distribution, as affected by precipitator geometry, obtained with the aid of the boundary element method (BEM) electrostatic simulation software Fieldscale Charge^{TM}.**

Keywords: Electrostatic Precipitator, Corona, Simulation, Breakdown voltage, Wire mesh, V-I characteristics, Electrical discharges

I. INTRODUCTION

The spacing between discharge and grounded electrode plays an important role in the process of electrostatic precipitation. Many studies have been conducted to optimize the electrode spacing of conventional Electrostatic Precipitators (ESP) with respect to the size, shape, and operating condition [1,2,3]. However, no research has been found that attempted to optimize the spacing between discharge and grounded mesh of Sieving Electrostatic Precipitator (SEP), which is a recently developed technology in the field of elec-

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trostatic precipitation. The precipitation process of novel SEP technology is different than that of conventional ESPs [4,5]. In SEPs, airflow direction is perpendicular to the wire mesh, thus it is parallel to the electric field vector. Therefore, migration velocity is not a big factor on electrode spacing in SEPs like conventional ESPs [6]. However, resistivity of dust plays an important role in SEPs, as closer spacing between discharge and grounded mesh may create back corona [7]. High resistivity dust particles increase the possibility of back corona, which may decrease the operating voltage resulting in instable ESP operation [6,7]. Therefore, high intensity of corona current is desired in order to maximize the particle collection efficiency and improve ESP performance [6,8]. In SEPs this can be achieved by optimizing the spacing between discharge and grounded mesh.

Sieving Electrostatic Precipitator can be operated in both conventional ESP temperature of 150 °C [5,9] or at the gasification temperature which is above 400 °C [5,10,11]. This study aims to investigate V-I characteristics found experimentally at room temperature with different spacing between discharge and grounded mesh of a particular mesh size, and to compare these results with the simulation results obtained with the aid of the boundary element method (BEM) electrostatic simulation software Fieldscale Charge^{TM}.

II. EXPERIMENTAL SETUP

Experiments were conducted by the first author during the period of his dissertation research project at the Ohio University lab [1,5]. Experiments were performed in a non-conductive lexan box of 6x6 in. 10x10 SS304 wire mesh with 0.02 in. wire diameter 0.08 in. open area and 64% opening were used for both discharge and grounded mesh. The grounded mesh was kept fixed and the charged mesh had the option to move back and forth to make required spacing between charged and grounded mesh. The charged mesh was connected with a TR set of 28 kW capacity with maximum operating voltage 70 kV and maximum operating current 400 mA. Applied voltage and current were measured at the particular spacing between charged and grounded mesh. Applied voltage was started at 15 kV and incremented with 5 kV after recording the corresponding value of current. Applied voltage was incremented until the spark over voltage was reached. Sparkover voltage was recorded. The experiment was repeated to reach the stable operating condition near the sparkover voltage. At a particular spacing once the stable operating condition was achieved, the voltage and current were recorded to analyze the V-I characteristics. The experimental setup is shown in Fig.1. All these experiments were conducted at room temperature.

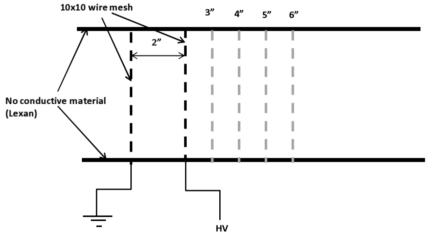


Fig. 1. Experimental setup of measuring spacing effect in SEP.

III. EXPERIMENTAL RESULTS

Experimental results of V-I measurements are summarized in Table 1, where it is shown that corona current increases with the increase of voltage and drastically changes when it reaches close to sparkover voltage. The maximum stable operating voltage and current for each spacing were recorded. TR set's maximum operating voltage, 70 kV, was achieved with 6 inch electrode spacing without having any sparkover voltage. Therefore, due to the limitation of the TR set capacity, stable operating condition at maximum voltage was not achieved with 6 inch spacing. However, V-I measurement was recorded and is shown in Table 1. The result shows that the maximum stable corona current 1.3 mA was achieved with 5 inch spacing at 65 kV. All these results, the V-I characteristics with respect to spacing are plotted and shown in Fig. 2. The plot shows that for the same applied voltage the corona current is higher for a smaller electrode spacing, while the current is highest for 5 inch spacing in a stable operating condition. Similar observations are obtained from the plot of the corona power with respect to the applied voltage (Fig. 3).

TABLE 1: VOLTAGE AND CURRENT READINGS FOR DIFFERENT VALUES OF ELECTRODE SPACING

Applied voltage (kV)	Current (mA)				
	2 in. spacing	3 in. spacing	4 in. spacing	5 in. spacing	6 in. spacing
15	0.07				
20	0.12	0.07			
25	0.55	0.15	0.07		
30		0.28	0.13	0.07	
35		0.59	0.22	0.13	0.10
40		0.80	0.40	0.20	0.13
45			0.60	0.31	0.20
50			1.00	0.52	0.35
55			1.30	0.70	0.50
60				0.95	0.65
65				1.30	0.85
70					1.1

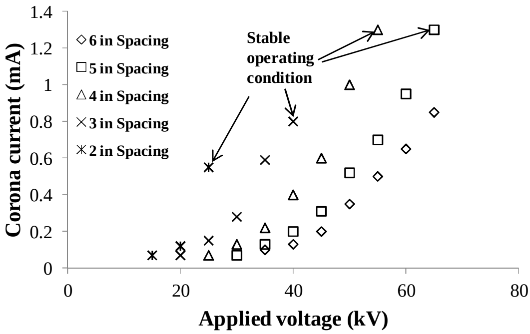


Fig. 2. V-I Characteristics for different values of electrode spacing

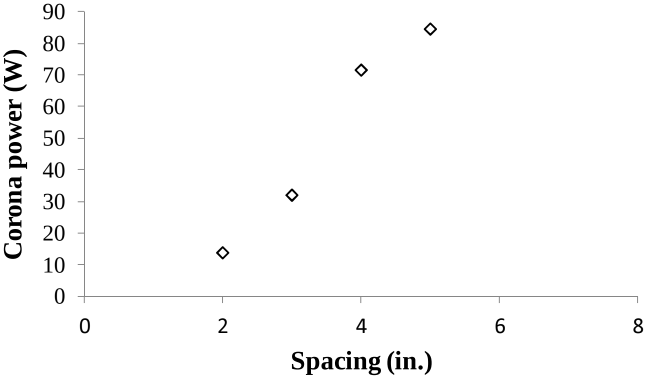


Fig. 3. Corona power at maximum applied voltage with stable operating condition for different values of electrode spacing

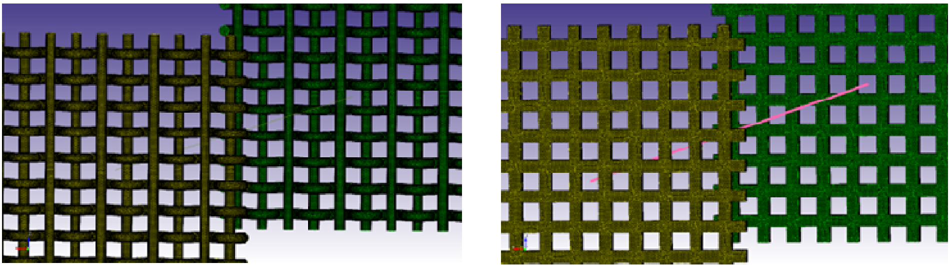
IV. SIMULATION SETUP

Simulation results on electric field distribution, as affected by precipitator geometry, were obtained with the aid of electrostatic simulation software Fieldscale Charge^{TM}. The algorithmic acceleration in Fieldscale Charge^{TM} was achieved with the fast multipole method (FMM) in conjunction with boundary element method (BEM).

In order to reduce the complexity of the actual model that was to be simulated, some simplifying assumptions were carefully considered:

i. Open area was assumed to be rectangular (Fig. 4).

The validity of this assumption is demonstrated in Fig. 5. It is shown that the electric field distributions (per unit of applied voltage, 1 V) of these two models do not differ significantly; actually, the difference of E_{middle} (the electric field value at the middle of the spacing between the two wire meshes) between the two models was found to be rather minimal (~1.2%).



(a) Actual model.

(b) Simplified rectangular model.

Fig. 4. 10x10 wire mesh with parameters: open area = 0.0041 in., wire diameter = 0.0026 in., spacing = 0.4929 in. (a) Actual model, (b) Simplified rectangular model.

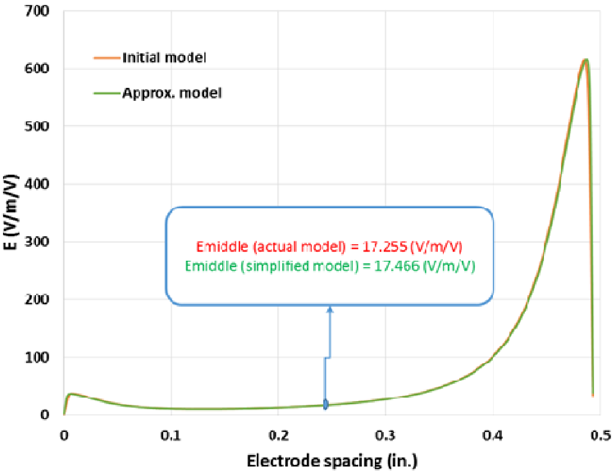


Fig. 5. Electric field distribution of the actual (Fig. 4a) and simplified model (Fig. 4b), as obtained by simulations with Fieldscale Charge^{TM}.

ii. The size of the discharge and grounded electrodes (wire meshes) was reduced.

As shown in Fig. 6, for increasing electrode size E_{middle} increases converging to a specific value that corresponds to the actual model (Fig. 4a). It is obvious that good accuracy (deviation < 0.33%) is observed for electrodes having a width two times larger than the spacing between them (Fig. 6).

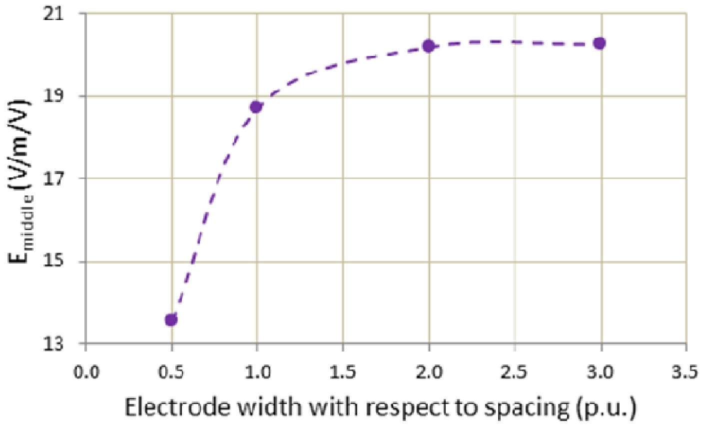


Fig. 6. Variation of the electric field value at the middle of electrode spacing, E_{middle}, with electrode width (shown with respect to electrode spacing). Mesh size = 10x10, wire diameter = 0.02 in., open area = 0.08 in. (64%) and spacing = 2 in.

As the above simplifying assumptions were proved not to significantly affect the simulation results, they were both adopted in simulations results shown hereafter. Simulations have been performed by discretizing the models with approximately 300,000 triangular elements; this value was proved to be sufficient, as when 3 million elements were used the change in the electric field values was negligible (deviations < 0.1%).

V. SIMULATION RESULTS

Fig. 7 shows the electric field distribution obtained along two different paths, being both perpendicular to the electrodes, but differ in their ending points: one path ends at the middle of the open area, while the other ends at the crosses of the wire meshes. It is obvious that the electric field values of these two paths are identical at the middle of the spacing between the electrodes, but, as expected, they differ significantly at the regions in the vicinity of the electrodes.

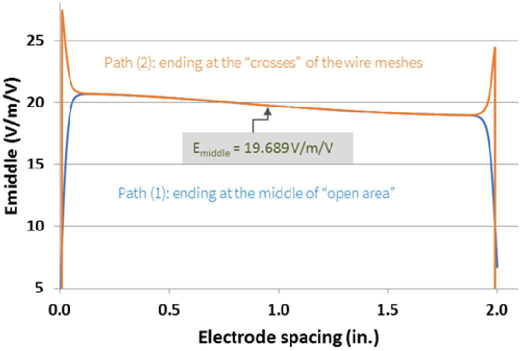
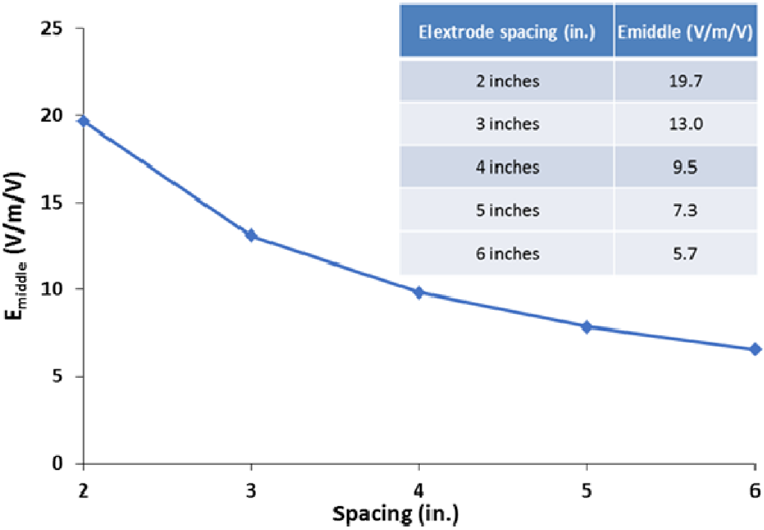


Fig. 7. Electric field distribution along two different paths between the electrodes. Mesh size = 10x10, wire diameter = 0.02 in., open area = 0.08 in. (64%), spacing = 2 in.

Fig. 8 shows the computed E_{middle} for all the experimental cases of varying electrode spacing per unit of applied voltage (1V). Electric field values are shown to decrease with increasing spacing, with a decreasing rate being lower as the electrode spacing decreases.



Elextrode spacing (in.)	Emiddle (V/m/V)
2 inches	19.7
3 inches	13.0
4 inches	9.5
5 inches	7.3
6 inches	5.7

Fig. 8. E_{middle}, as obtained by Fieldscale ChargeTM, with respect to electrode spacing. Mesh size = 10x10, wire diameter = 0.02 in., open area = 0.08 in. (64%).

VI. CORRELATION BETWEEN EXPERIMENTAL AND SIMULATION RESULTS

Table 2 summarizes the computed electric field values, E_{middle}, for the experimental cases of varying electrode spacing, by using the applied voltage levels used in experiments. These values are plotted in Figure 9. As expected, E_{middle} increases with the applied voltage, but with a rate that depends on electrode spacing, being higher for the smallest electrode spacing (2 in.) that was examined.

TABLE 2: E_{MIDDLE} VALUES OBTAINED THROUGH SIMULATIONS FOR THE EXPERIMENTAL CASES.

Applied voltage (kV)	E_{middle} (V/m)				
	2 in. spacing	3 in. spacing	4 in. spacing	5 in. spacing	6 in. spacing
15	295.3				
20	393.8	262.2			
25	492.2	327.8	245.7		
30		393.3	294.8	235.7	
35		458.9	344.0	275.0	229.1
40		524.4	393.1	314.3	261.9
45			442.2	353.6	294.6
50			491.4	392.9	327.3
55			540.5	432.2	360.1
60				471.5	392.8
65				510.7	425.5
70					458.3

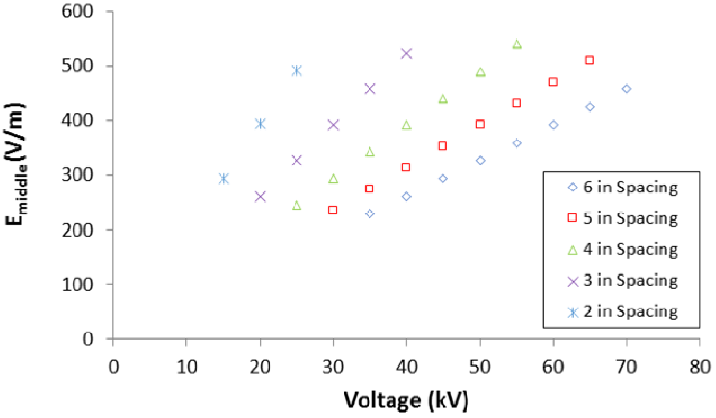
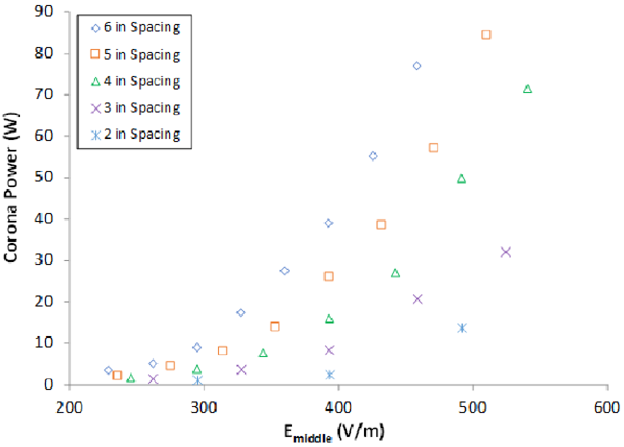
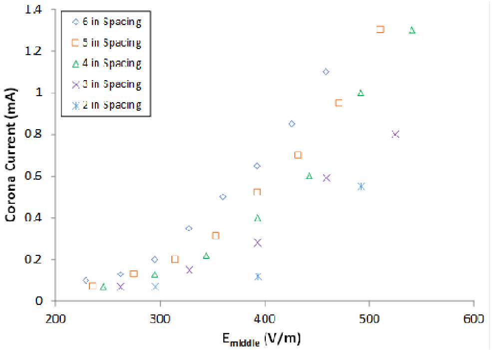


Fig. 9. E_{middle} obtained through simulations for the experimental cases.

In Fig. 10 the measured values of corona current and corresponding power are plotted against E_{middle} values obtained through simulations. For a fixed E_{middle} value the corona current and the corresponding power are higher for the largest electrode spacing (6 in.). These two quantities increase with increasing E_{middle}, that is, with increasing applied voltage or decreasing electrode spacing (Fig. 9).



(a)



(b)

Fig. 10. Measured values of (a) corona current and (b) corona power as a function of E_{middle} obtained through simulations.

VII. CONCLUSIONS

- Performance of Sieving Electrostatic Precipitator, as influenced by the electrode spacing, has been investigated both experimentally and through simulations.
- Experiments have shown that the same applied voltage corona current and the corresponding power are both higher for a smaller electrode spacing, while for 5 in. spacing the highest value of current at the stable operating condition has been observed.
- Electric field values of the experimental configurations have been obtained through simulations performed with the aid of electrostatic BEM simulation software Fieldscale ChargeTM.
- Simulations have shown that electric field values at the middle of the distance between the electrodes, E_{middle}, increase with the applied voltage, but with a rate that depends on electrode spacing, being higher for the smallest electrode spacing (2 in.) that was examined.
- Corona current and power increase with increasing E_{middle}, whereas for a fixed E_{middle} they are higher for the largest electrode spacing (6 in.) that was examined.

REFERENCES

[1] U. Khaled and A. Z. Eldein, “Experimental study of V–I characteristics of wire–plate electrostatic precipitators under clean air conditions,” Journal of Electrostatics, vol. 71, no. 3, pp. 228–234, Jun. 2013.

[2] A. Z. E. Dein and K. Usama, “Experimental and Simulation Study of V–I Characteristics of Wire–Plate Electrostatic Precipitators Under Clean Air Conditions,” Arab J Sci Eng, vol. 39, no. 5, pp. 4037–4045, May 2014.

[3] C. Buccella, “Computation of V-I characteristics in electrostatic precipitators,” Journal of Electrostatics, vol. 37, no. 4, pp. 277–291, Aug. 1996.

[4] H. Pasic, “Electrostatic sieving precipitator,” U.S. Patent 6 878 192, B2, April 12, 2005.

[5] Z. H. Khan, “Bench- and pilot testing of sieving electrostatic precipitator” Ph.D. dissertation, Dept. of Mech. Eng., Ohio Univ., Athens, OH, 2007.

[6] C. Golkowski and M. Chojnowski, “The role of electrode spacing in the performance of the electrostatic precipitator,” Journal of Electrostatics, vol. 14, no. 3, pp. 339–348, Dec. 1983.

[7] M. Jędrusik, A. Świerczok, and A. Jaworek, “Collection of low resistivity fly ash in an electrostatic precipitator,” J. Phys.: Conf. Ser., vol. 418, no. 1, p. 12069, 2013.

[8] [8] B. Navarrete, L. Cañadas, V. Cortés, L. Salvador, and J. Galindo, “Influence of plate spacing and ash resistivity on the efficiency of electrostatic precipitators,” Journal of Electrostatics, vol. 39, no. 1, pp. 65–81, Jan. 1997.

[9] Z. H. Khan and H. Pasic, “Capturing fine particulates with sieving electrostatic precipitator,” ESA Annual Meeting 2005, Alberta, Canada, June 21-24, 2005.

[10] Z. H. Khan, K. Zanganeh, and C. Salvador, “Experimental study of Dielectric breakdown of refractory board materials for application in high-temperature Sieving Electrostatic Precipitator,” ESA Annual Meeting 2012, Cambridge , Canada, June 12-15, 2012.

[11] K. Zanganeh, Z. H. Khan, et al, “Hot sieving electrostatic precipitator,” U.S. Patent 8 679 225, B2, March 25, 2014.