Influence of Nozzle Arrangement on Fiber Mat Deposition in Multi-Nozzle Electrospinning: Simulation and Experimental Approach

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Abstract

Electrospinning is a widely adopted technique for fabricating nanofibers with applications spanning biomedical scaffolds, filtration, sensors, and energy storage. To enhance productivity, multi-nozzle electrospinning systems have been developed; however, interactions between adjacent jets can alter the electric field distribution, affecting fiber formation and deposition characteristics. This study presents both experimental and simulation analyses to investigate the influence of nozzle number and arrangement on fiber mat deposition in a multi-nozzle electrospinning setup.

Experiments were conducted using a polyethylene oxide (PEO) solution under an applied voltage of 15 kV, a constant tip-to-collector distance of 15 cm, and a controlled flow rate of 0.2 mL/h per nozzle. Nozzle configurations ranged from single-nozzle to five-nozzle setups, with systematic variations in nozzle spacing. The nozzles were labeled from the center outward to assess positional effects on initiation voltage and deposition area. Electric field simulations, performed using COMSOL Multiphysics with the electrostatics interface of the alternate/direct current module, complemented the experimental measurements by elucidating field distribution patterns.

Results showed that increasing the number of nozzles led to a reduction in electric field strength per nozzle due to mutual interference, thereby requiring higher initiation voltages to achieve stable jet formation. This effect was most pronounced at the central nozzle, while outer nozzles experienced higher field strengths and lower initiation voltages. Wider nozzle spacing effectively mitigated interference, reducing the voltage requirement. Fiber production rates and overall deposition areas increased with the number of nozzles, with the total deposition area nearly doubling from 49 cm^2 for the single-nozzle setup to 92 cm^2 for two-nozzle configurations. In multi-nozzle arrangements, outer nozzles consistently produced larger mats than inner nozzles, particularly in five-nozzle setups where reduced inner spacing led to smaller central deposition areas.

This combined experimental and computational study demonstrates that optimizing nozzle number and spacing is critical to balancing production efficiency and deposition uniformity in multi-nozzle electrospinning. The findings provide valuable insights for scaling up nanofiber production while maintaining fiber quality, offering practical guidance for designing high-throughput electrospinning systems in industrial applications.

Keywords

Multi-nozzle electrospinning, electric field interference, fiber mat deposition, COMSOL simulation, nozzle spacing.