From Waste to Flame-Derived Carbon Catalyst: A Novel Approach via Electrospray Deposition

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Abstract
This study proposes a scalable method for producing carbon-based catalyst films via flame synthesis and electrospray deposition. The resulting porous, superhydrophilic films show uniform morphology and high deposition efficiency. Flame-derived carbon inks exhibit stable electrospraying behavior and performance comparable to commercial materials, supporting their potential in clean energy applications like hydrogen production and fuel cells.

Introduction
Renewable hydrogen production is gaining traction as a key solution in the shift to a low-carbon energy system, with alternatives like biomass reforming and water electrolysis replacing fossil-based hydrogen sources. Fuel cells, which efficiently convert hydrogen into electricity, are also emerging as critical clean energy technologies. Carbon-based materials are promising catalyst supports due to their low cost, high efficiency, and porous structure, which offers abundant active sites. Functionalization with noble metals, such as platinum or gold, further enhances catalytic activity [1]. In line with circular economy goals, urban mining – especially the recovery of platinum and gold from spent automotive catalyst and waste of electronic and electric equipment – offers a sustainable and cost-effective alternative to traditional mining. Catalytically active carbon powders can be produced through flame synthesis, a scalable, bottom-up method that allows control over particle morphology by tuning the operating conditions [2].
This study presents a novel approach for producing carbon catalyst film (CCF) via electrospray deposition [3]. The film is used to improve the separation of the catalyst in liquid phase reactors. The influence of deposition parameters such as voltage, flow rate, and needle-to-substrate distance on the cone-jet stability, film morphology and structural integrity is analysed to preliminarily assess the potential use of CCF in catalytic applications.

Materials and Methods
Figure 1 illustrates the experimental setup for CCF production. Carbon powders were synthesized using a flat laminar premixed ethylene-air flame stabilized on a water-cooled McKenna burner. The carbon-to-oxygen ratio (C/O) was set to 0.85. The resulting carbon was collected directly from the burner stabilization plate. The simplified carbon ink was prepared by dispersing flame-derived carbon powders in ethanol (5 mgC/mL), with 20 wt.% polyvinylpyrrolidone (PVP) added as a

stabilizing surfactant. The suspension was ultrasonicated for two hours to ensure uniform dispersion. Electrospraying was performed using a stainless-steel needle and a grounded aluminum collector, with ink delivery controlled by a syringe pump.

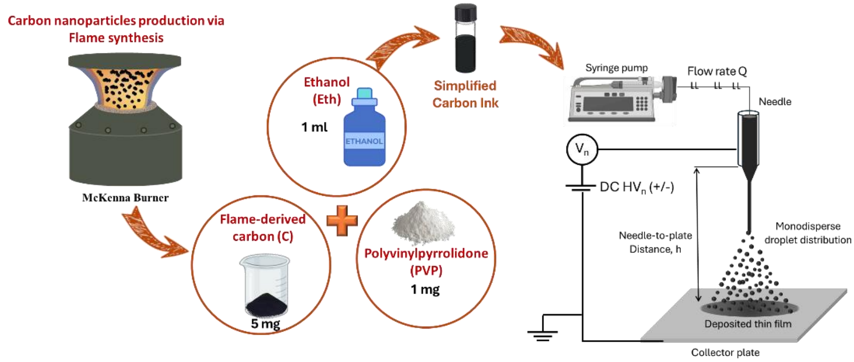

Figure 1. Sketch of the experimental setup for CCF production via flame synthesis and electrospray deposition

Electrospraying regimes were identified by visual observation of the liquid meniscus at the needle tip. Once the stability domain was mapped, selected conditions within this window were used to deposit carbon-based films. The resulting films were characterized by scanning electron microscopy (SEM) to assess film morphology.

Results and Discussion

Figure 2 shows the stability domain obtained for the flame-synthesis derived carbon ink at two different needle-to-plate distances.

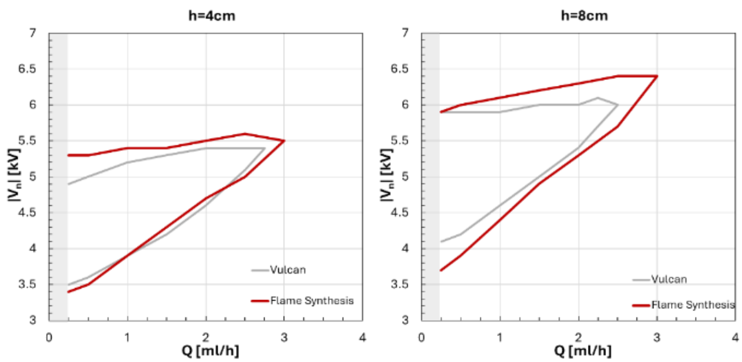

Figure 2. Stability domains at different needle-to-plate distances, 4 cm (left) and 8cm (right) for the flame-made carbon ink (red). Reference: commercial carbon in grey.

Figure 2 illustrates that cone-jet stability is the highest at low flow rates, with the voltage window narrowing as flow increases until a critical limit is reached. While increasing the needle-to-collector distance raises the required voltage, it has minimal effect on the maximum flow rate. At 8 cm, flame-derived ink supports higher flow rates than commercial alternatives, indicating better throughput. Optimal deposition was achieved at 1 mL/h and 8 cm, producing dry, porous films with good structural integrity and surface exposure. Figure 3 presents SEM images of the deposited film at various magnifications.

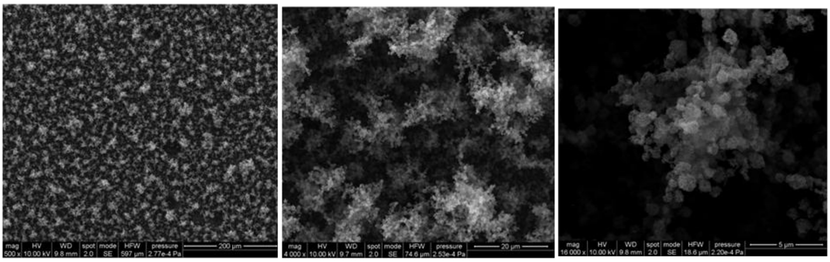

Figure 3. SEM Images with different magnifications: from left to right) 500x, 4000x, 16000x (Q=1 mL/h; h=8 cm).

Figure 3 shows that the deposited film has a granular, densely packed, and well-structured morphology, with interconnected particles forming a porous, network-like architecture. The particles appear uniformly distributed, contributing to the rough and textured surface of the film.

Conclusion

This work presents a sustainable and scalable approach for producing carbon-based catalysts from waste materials via flame synthesis and electrospray deposition. The resulting films exhibit a porous, granular structure with superhydrophilic properties, indicating high surface functionality, supporting their potential use in catalytic applications.

Acknowledgements

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References

[1] Nguyen, X.T., Kitching, E., Slater, T., Pitzalis, E., Filippi, J., Oberhauser, W., Evangelisti, C.: Aqueous Phase Reforming by Platinum Catalysts: Effect of Particle Size and Carbon Support. *Catalysts*. 14, (2024).

[2] Sirignano, M., Russo, C., Ciajolo, A.: One-step synthesis of carbon nanoparticles and yellow to blue fluorescent nanocarbons in flame reactors. *Carbon*. 156, 370–377 (2020).

[3] Castillo, J.L., Martin, S., Rodriguez-Perez, D., Higuera, F.J., Garcia-Ybarra, P.L.: Nanostructured porous coatings via electrospray atomization and deposition of nanoparticle suspensions. *J Aerosol Sci*. 125, 148–163 (2018).