Optimizing Size Distribution of Carbon Spheres to Enhance Polymer Composite Performance

Robert A. Rosario, Emily Morales Arroyo, Myrialisses Ortiz, Analaura Díaz, Idalia Ramos, José Sotero-Esteva, University of Puerto Rico at Humacao

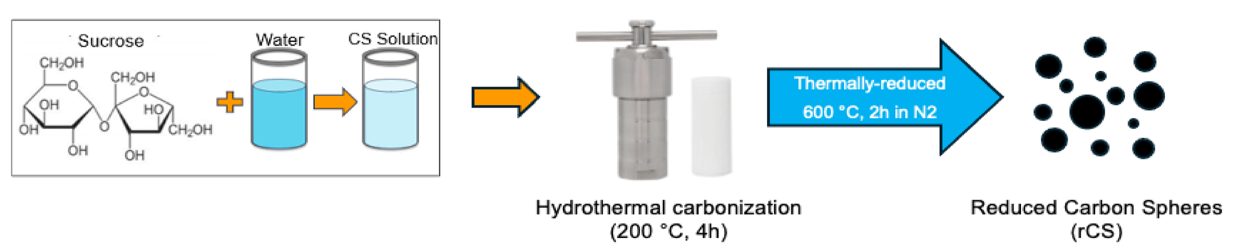
Background

- Carbon/polymer composites are valuable for applications ranging from energy storage to electronics.
- Uniformity in carbon sphere size is crucial for optimal device performance.
- Separation by size by means of mechanical sieving such as the use of membranes is prone to clogging.
- Literature reports the successful use of two similar microfluidic devices, the *pinched flow fractionator* (PFF)[1] and a *microchannel with a series of symmetric sharp corner structures* (CSCS)[2], for the separation of micro particles by size for medical and materials application.

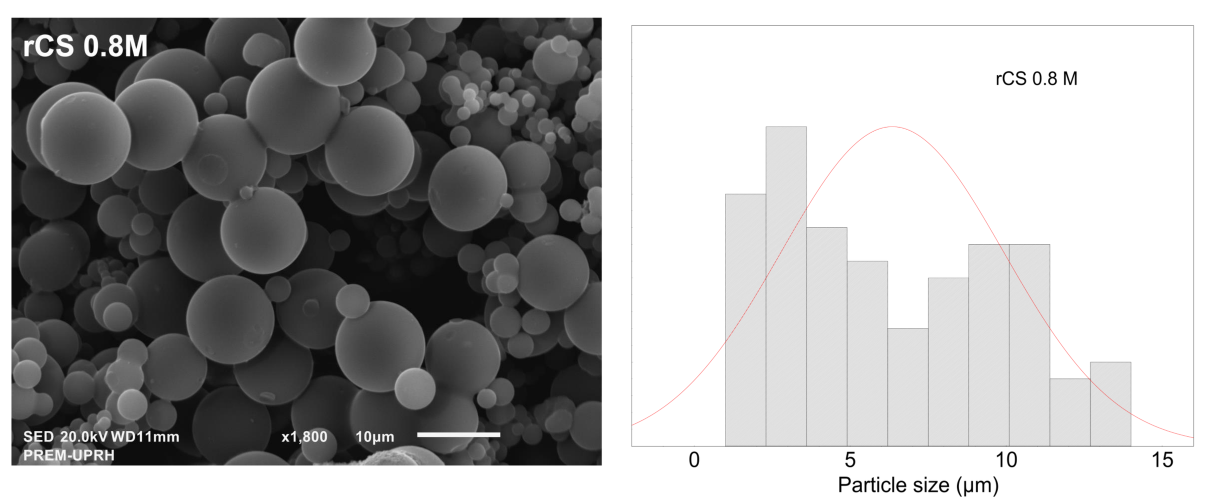
This study explores the use of a 3D-printed fluidic device which is a hybrid of these two devices for efficient particle separation of sub-micrometer particles, with a focus on carbon sphere/polymer composites.

Methods

Carbon Spheres Synthesis

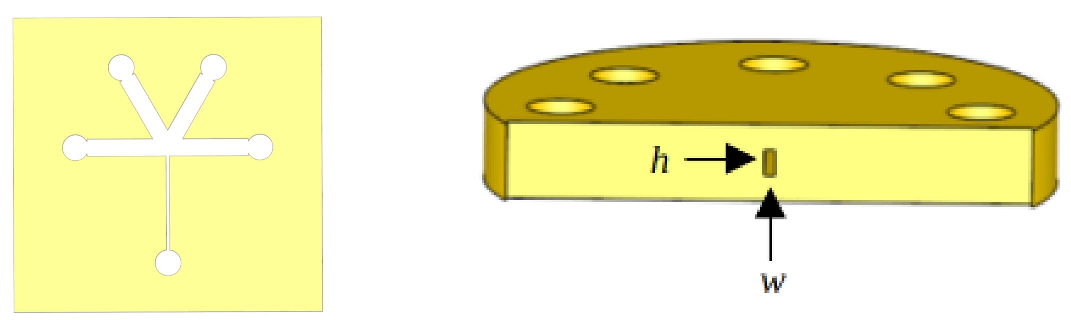


Hydrothermal carbonization of sucrose method used to produce carbon spheres.



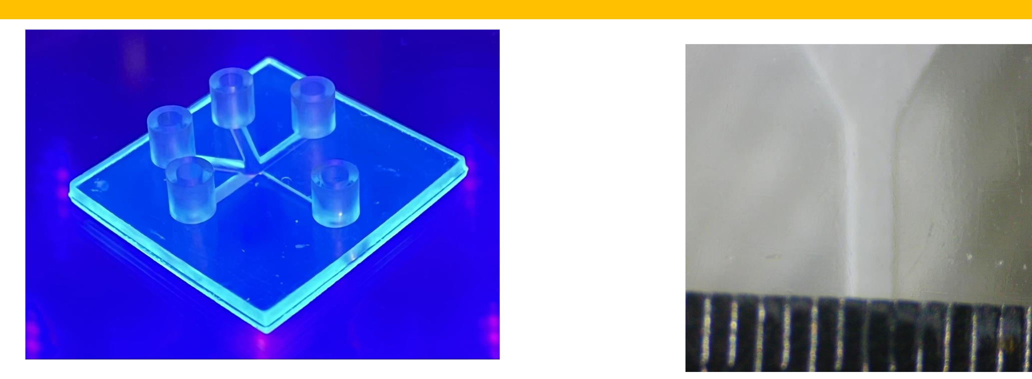
SEM image of reduced carbon spheres prepared with 0.8 M sucrose solution and the distribution of their diameters..

Fluidic Device



- The tested device, similar to a PFF, features four outlets but only one inlet which makes it similar to the CSCS.
- A python script using the CAD-Query library was used to design the fluidic device.
- The number of outlets, widths and length of channels is easily configurable for future optimization.

Manufacturing Method



(Left) A microfluidic device was 3D-printed using an ANYCUBIC Photon Mono 4 with clear Water-Wash Resin. **(Right)** The inlet channel at the split point. Each line represents 0.005 inches (total width: ~0.254mm).

Acknowledgments

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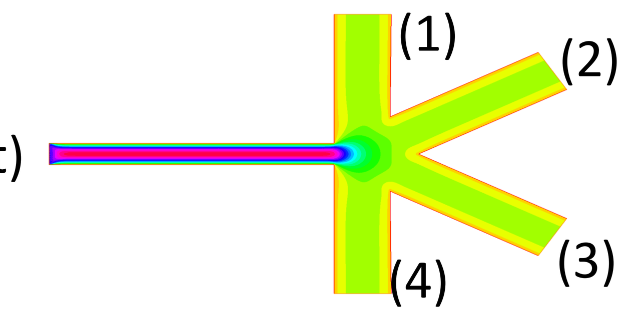
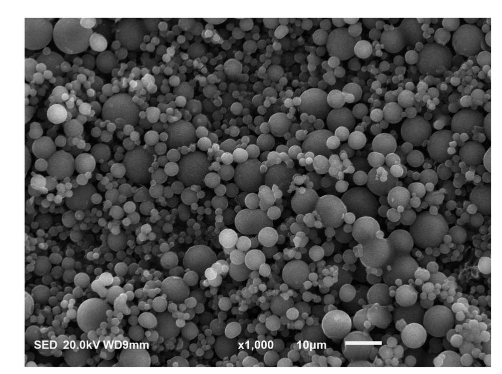
Simulations

Simulation of the fluid throughout the channels

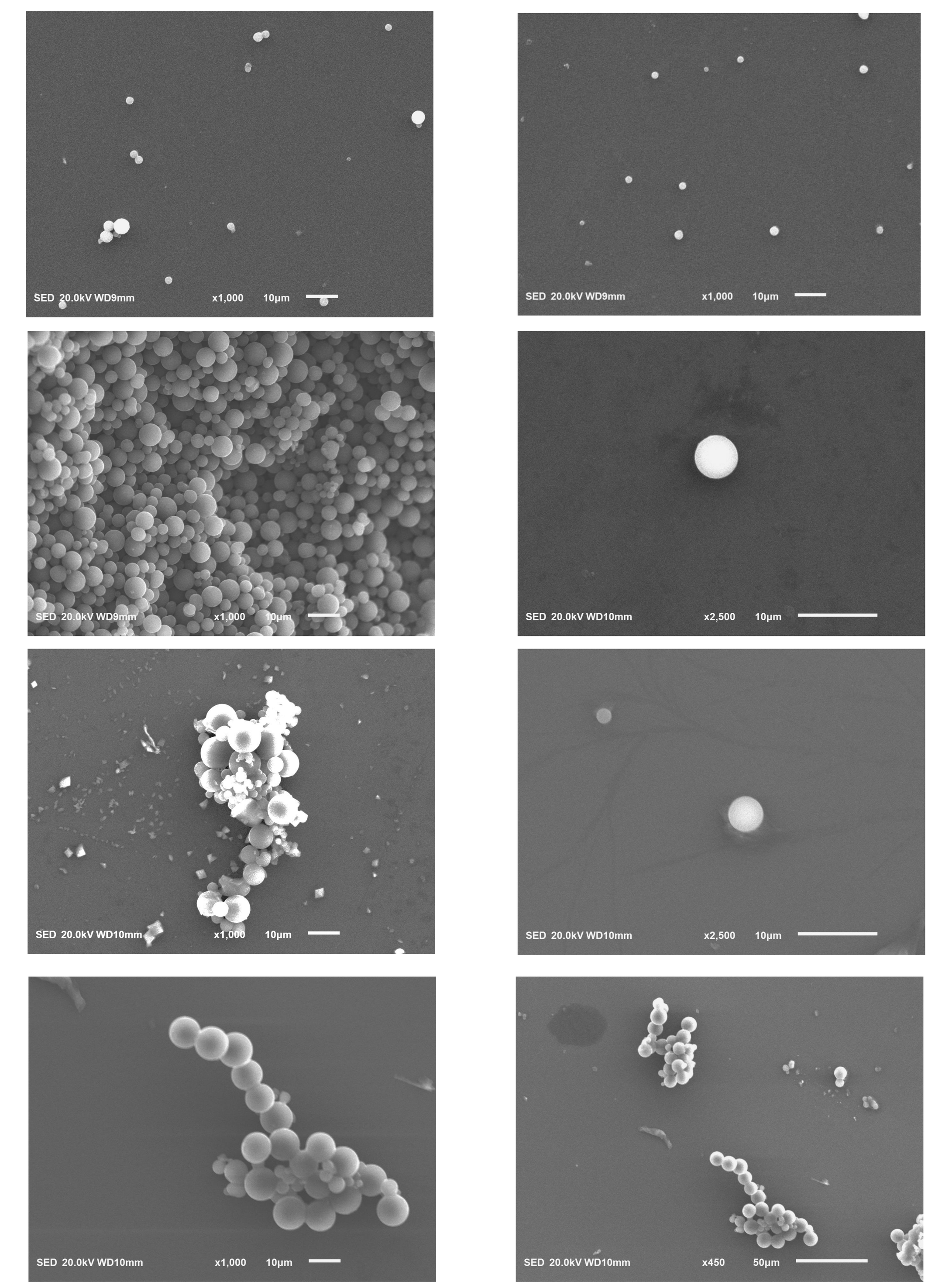
- A Finite Elements Method simulation was performed with using FreeFEM.
- Incompressible fluid modeled using Navier-Stokes equations.
- Conclusion: fluid flow along outlets occurs at similar velocities.



Results and Conclusions



Inlet
Diameters up to ~10µm



Outlet 1
Less and dispersed spheres
Diameters ~2-3µm

Outlet 2
Large number of spheres
Diameters up to ~7µm

Outlet 3
More waste
Diameters up to ~10µm

Outlet 4
More uniform size
Diameters ~10µm

After testing several microfluidic models and dispersion methods for the spheres (DI water alone or DI water with varying concentration of surfactants), the best results were achieved with a one-inlet, four outlet design and the spheres dispersed in DI water. Tests using samples of 0.8 M carbon spheres, with diameters of up to 10 µm, show preference for Outlet 2. While the majority of particles were observed exiting through this outlet, larger spheres (~10 µm) predominantly appeared in Outlets 3 and 4, whereas smaller spheres (2-3 µm) tend to pass through Outlet 1.

According to the cited literature, a CSCS-based device is expected to separate smallest particles through outlets 1 and 4 and largest through outlets 2 and 3. Our results are not consistent to those cited. Further research is needed.

References

1. Yamada, M., Nakashima, M., & Seki, M. (2004). *Analytical chemistry*, 76(18), 5465-5471.
2. Ashrafizadeh, S. N., Zare, M., and Khatibi, M., *Chem. Eng. Process.* 2024, 110087.