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Koen Kwak
Northwestern University
Antonia Akoto-Yeboah
The Ohio State University
Blaine Lee
The Ohio State University
Pelagia-Iren Gouma
gouma.2@osu.edu

The Ohio State University

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Electrospun Cellulose Acetate Mats Mimic Nature for Oil–Water Sorption and Separation

Koen Kwak, Antonia Akoto-Yeboah, Blaine Lee, & Pelagia-Irene (Perena) Gouma[a]

[a]*Department of Materials Science and Engineering, The Ohio State University College of Engineering, Columbus, OH*

ABSTRACT
Oil contamination presents persistent environmental challenges, motivating the development of effective sorbents from alternative and sustainable materials. This study investigates electrospun cellulose acetate (CA) mats for oil sorption, examining the effects of polymer composition, precursor concentration, and electrospinning throughput. Pure CA and CA/polyvinylpyrrolidone (PVP) composite mats were fabricated and evaluated using gravimetric measurements and ultraviolet–visible (UV–Vis) analysis. Pure CA exhibited substantially greater oil sorption than the CA/PVP composite, while increasing CA concentration from 10.0% to 15.0% produced the greatest improvement in oil uptake. The 15.0% CA formulation achieved an average gravimetric oil-sorption capacity approximately three times that reported for conventional polypropylene sorbents. Standard and high-throughput electrospinning of 10.0% CA yielded comparable performance, supporting the scalability of the fabrication process. Inspired by the Salvinia effect, in which specialized aquatic fern surfaces combine water repellency with air retention, these CA mats integrate high apparent water repellency and oil uptake within a single material produced through a single-step process. This approach demonstrates the potential of electrospun CA as a scalable biomimetic sorbent for oil–water separation, translating complementary biological functions into a practical fibrous architecture.

KEYWORDS
Cellulose acetate; Electrospinning; Oil sorption; Oil–water separation; Salvinia effect.

INTRODUCTION

Oil contamination of aquatic environments remains a significant environmental challenge because petroleum hydrocarbons can persist in ecosystems, especially after the use of surfactants, while threatening wildlife, and disrupting marine food webs.[1,2] The ecological consequences of large-scale spills are well documented. Following the 1989 Exxon Valdez oil spill, populations of killer whales, sea otters, and several seabird species experienced substantial mortality, with some populations exhibiting reduced health and reproductive success more than two decades later due to persistent oil contamination in nearshore habitats. Similarly, the 2010 Deepwater Horizon spill resulted in long-term adverse effects on marine mammals, including impaired health and reproduction in bottlenose dolphins.[2] These events demonstrate that the impacts of oil contamination can extend far beyond the initial spill, underscoring the importance of developing efficient and sustainable oil-remediation technologies.

Various remediation strategies have been developed to mitigate oil contamination in aquatic environments, including physical recovery, chemical treatment, and sorption-based approaches. Physical methods such as containment booms and skimming are commonly implemented during oil spill response to limit oil spreading and recover surface oil. However, these techniques are often limited by environmental conditions, as their effectiveness decreases under high sea states, strong currents, and when oil becomes dispersed or emulsified in the water column.[3,4] Additional approaches, including in situ burning and chemical dispersant application, can accelerate oil removal but present limitations associated with incomplete removal, potential toxicity, and the generation of secondary environmental impacts.[5,6] Similarly, solidification techniques and shoreline containment strategies have been investigated but may introduce challenges related to recovery efficiency and ecological disturbance.[7,8]

Among the available remediation strategies, sorbent-based approaches have attracted significant attention due to their ability to selectively remove oil from contaminated water through absorption and adsorption mechanisms. Sorbent materials offer advantages including simple application, high oil affinity, and effectiveness in recovering residual oil that remains after conventional cleanup methods.[9,10] However, many commercially available oil sorbents are derived from synthetic polymers, such as polypropylene (PP), which exhibit acceptable oil uptake but present sustainability concerns due to their petroleum-based origin and limited biodegradability.[9] The degradation and fragmentation of PP materials can contribute to persistent plastic and microplastic pollution in aquatic environments, providing additional motivation for the development of biodegradable sorbent alternatives.[9,11] Consequently, increasing interest has been directed toward the development of renewable and biodegradable sorbent materials capable of maintaining high oil absorption performance while reducing environmental impact.

Cellulose-based materials have emerged as promising alternatives due to their abundance, low cost, and tunable surface properties for pollutant removal applications.[9] In particular, electrospinning enables the fabrication of CA mats composed of interconnected nanofibers with high porosity and surface area, characteristics that can enhance oil sorption capacity.[12] The water-

repelling nature of cellulose acetate—where its fibers demonstrated a high water contact angle of 154.3 degrees—further promotes selective oil uptake from oil-water mixtures, making CA-based electrospun mats a promising platform for sustainable oil remediation.[13,14]

The morphology and performance of electrospun fibers are strongly influenced by solution properties, including polymer solubility, viscosity, surface tension, electrical conductivity, and solvent volatility. Consequently, the selection of an appropriate solvent system plays a critical role in fiber formation and the resulting functional properties of electrospun mats.[15,16] Acetone and acetic acid are among the most widely investigated binary solvent systems for electrospinning CA because they effectively dissolve the polymer while providing complementary modes of evaporation during fiber formation.[15,17,18] Acetone's high volatility promotes rapid solvent evaporation and fiber solidification, whereas acetic acid evaporates more slowly, improving solution stability and spinnability. Previous studies have demonstrated that varying the acetone-to-acetic acid ratio significantly influences fiber diameter, bead formation, and overall fiber morphology, highlighting solvent composition as a critical parameter governing the structure of electrospun CA mats.[15,16,17,18]

In addition to solvent selection, polymer blending has been widely employed to tailor the morphology and physical properties of electrospun nanofibers.[19] PVP is frequently incorporated into electrospinning solutions because it enhances solution viscosity and polymer chain entanglement, facilitating stable jet formation while reducing bead defects and improving fiber uniformity.[20] These morphological improvements may increase the accessible surface area and porosity of electrospun mats, characteristics that are desirable for sorption-based applications. However, PVP is an inherently hydrophilic polymer, and its incorporation into CA may alter the wettability of the resulting fibers, potentially reducing their preferential affinity for hydrophobic oils.[20] Therefore, evaluating PVP incorporation presents an opportunity to investigate the tradeoff between enhanced fiber morphology and changes in oil sorption behavior.

Although previous studies have established that solvent composition strongly influences the morphology of electrospun CA,[15,17,18] comparatively fewer investigations have examined how these processing parameters affect oil sorption performance, particularly in conjunction with polymer blending strategies such as PVP incorporation. Developing a clearer understanding of the relationship between electrospinning solution composition, fiber morphology, and oil absorption is essential for optimizing CA-based sorbents for environmental remediation applications.

Therefore, this study investigates the influence of electrospinning solution composition on the oil sorption performance of CA-based mats for oil-water remediation. Specifically, electrospun mats fabricated from pure CA and CA/PVP solutions were evaluated to determine the effects of acetone/acetic acid solvent composition and polymer blending on oil absorption capacity. By correlating processing parameters with oil sorption performance, this work aims to provide insights into the design of sustainable, cellulose-based electrospun sorbents for efficient oil-water separation.

METHODS AND PROCEDURES

Laboratory Materials

CA (Sigma Aldrich, USA) with the molecular mass of Mn~30,000 and PVP with the molecular mass of Mw~1,300,000 were used to prepare the electrospinning solution used in this experiment. The solvents used were acetic acid (Sigma Aldrich, ACS reagent grade) and acetone (Sigma Aldrich, ACS reagent grade).

Sample Preparation and Electrospinning of CA-Based Nanofibers

Four CA-based electrospinning solutions were prepared to evaluate the effects of PVP incorporation, CA concentration, solvent composition, and electrospinning method. The first solution contained CA and PVP at a 2:1 mass ratio in a binary acetic acid/acetone solvent system with a 3:2 volume ratio and a total polymer concentration of 17.6% (w/v). The second solution consisted of pure CA at a concentration of 10.0% (w/v) in an acetone/acetic acid solvent system with a 10:1 volume ratio. The third solution also consisted of pure CA in the same 10:1 acetone/acetic acid solvent system but at an increased concentration of 15.0% (w/v). The fourth solution consisted of pure CA at 10.0% (w/v) in a 7:3 acetone/acetic acid solvent system and was processed using a high-throughput electrospinning setup. All solutions were subjected to three 20-min ultrasonic agitation cycles prior to electrospinning.

The CA/PVP solution was electrospun through a 20-gauge needle at a flow rate of 1.6 mL/h, an applied voltage of 17 kV, and a working distance of 15 cm between the needle tip and grounded collector. The 10.0% CA solution prepared using the 10:1 acetone/acetic acid solvent system was electrospun through a 20-gauge needle at 1.8 mL/h, 17 kV, and a 7-cm working distance. The 15.0% CA solution was electrospun through a 20-gauge needle at 1.2 mL/h, 12 kV, and a 10-cm working distance. The fourth solution was processed using a high-throughput electrospinning setup at a flow rate of 11 mL/h and an applied voltage of 27 kV. All electrospun mats were collected on grounded aluminum foil.

Oil Sorption Experiment

The resulting electrospun mats were subsequently placed under different exposure conditions. Sample flakes were cut from the electrospun mats and measured for their initial mass before being added to the oil-containing vials. The vials used for the oil

sorption experiments contained 10 mL of distilled water with 100 µL 5W-30 motor oil. The exposure conditions included immediate removal from the oil and 10-minute exposure periods. Each exposure condition underwent two trials. Additional samples were exposed to 10 mL of distilled water for 10 minutes to provide comparison for water uptake. Following exposure, samples were immediately weighed to determine their wet mass and subsequently allowed to dry for approximately 48 hours before final mass measurements were obtained. The gravimetric measurements were used to quantify changes in sample mass associated with oil and water exposure and subsequent drying. Results from the pure CA and CA/PVP formulations were compared across the different exposure conditions to evaluate differences in oil sorption behavior.

Contact Angle

The hydrophobicity of the electrospun cellulose acetate mats was evaluated by measuring the static water contact angle. A water droplet was placed on the surface of the electrospun mat, and the droplet profile was imaged using dark-field reflective microscopy. Images were acquired using a 5× optical magnification objective with a 35 mm sensor, corresponding to approximately 25× apparent magnification, with a field of view of approximately 4.8 × 6.0 mm. The resulting droplet profiles were analyzed to determine the water contact angle at the mat surface.

UV-Vis Spectroscopy

Optical analysis of the filtered emulsions was conducted using a UV-Vis spectrophotometer integrated with OceanView software. Standard oil-in-water emulsions were prepared using 5W-30 motor oil (density 0.85 g/mL). A master stock solution was serially diluted to construct a concentration calibration curve. Because dispersed oil droplets physically scatter light (turbidity) rather than absorbing at a single quantum peak, broad-spectrum absorbance was integrated and averaged across the 350 nm to 900 nm wavelength range via the OceanView interface. This methodology prevents detector saturation in the ultraviolet range while stabilizing readouts. Experimental filtrate samples (10 mL) were diluted with 10 mL of distilled water prior to measurement and prepared with ultrasonication agitation and vortex mixing for an hour each. The averaged absorbance values were evaluated against the linear calibration equation to calculate the final oil concentration, which was subsequently converted to absolute volume (μL) and mass (g) removed to determine the optical sorption capacity.

Characterization

The electrospun mats were characterized using scanning electron microscopy (SEM) to examine fiber morphology and quantify fiber diameter. SEM micrographs were analyzed using the GIFT (General Image Fiber Tool) ImageJ macro for automated fiber diameter quantification.[21,22] The images were processed using the GIFT workflow to identify individual fibers and determine their diameters, providing a quantitative characterization of the fiber size distribution.

RESULTS

Gravimetric Oil Sorption Capacity

The oil sorption performance of the electrospun cellulose acetate (CA) and cellulose acetate/polyvinylpyrrolidone (CA/PVP) mats was evaluated by gravimetric analysis following exposure to 5W-30 motor oil. Sorption capacity (S) was calculated using Equation 1:

$$S = \frac{m_{\text{dry, final}} - m_{\text{initial}}}{m_{\text{initial}}}$$

where m_{initial} is the dry mat mass prior to testing, and $m_{\text{dry, final}}$ is the mass remaining after immersion and subsequent air drying. Expressing performance as mass-based sorption capacity ($g \cdot g^{-1}$) accounts for the lightweight, highly porous nature of the nanofibrous networks. The comparative sorption capacities across all formulations are illustrated in Figure 1, with corresponding individual replicate data provided in Table 1.

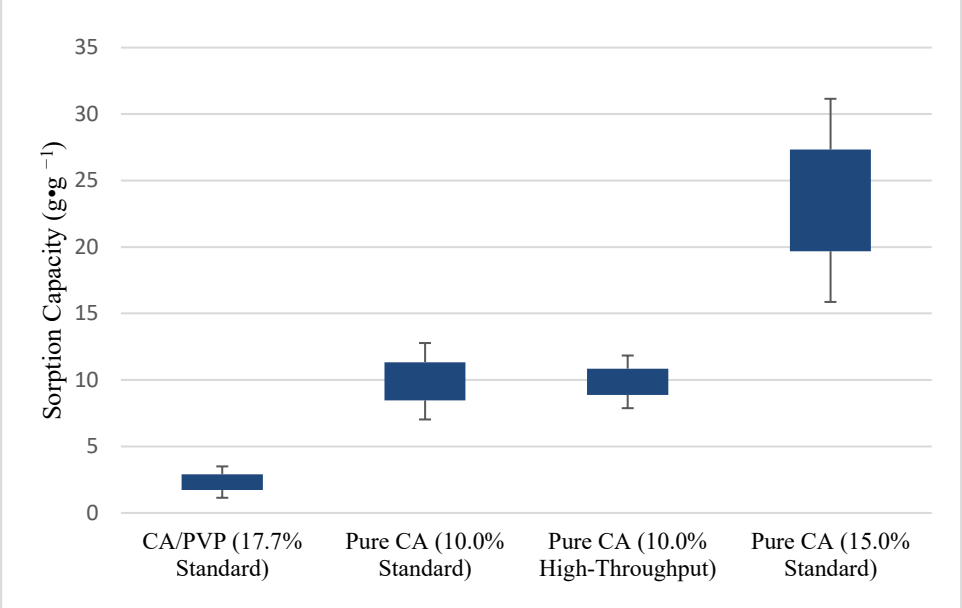


Figure 1. Oil Sorption Capacity of Electrospun CA and CA/PVP Mats

Formulation	Exposure Time	Initial Mass (g)	Final Dry Mass (g)	Oil Retained (g)	Sorption Capacity (g·g−1)
CA / PVP (17.7%)	Immediate	0.0170 ± 0.0008	0.0632 ± 0.0159	0.0462 ± 0.0168	2.75 ± 1.12
	10 min	0.0159 ± 0.0031	0.0478 ± 0.0285	0.0319 ± 0.0257	1.89 ± 1.25
Pure CA (10.0% Standard)	Immediate	0.0082 ± 0.0020	0.0784 ± 0.0047	0.0702 ± 0.0040	8.78 ± 1.79
	10 min	0.0084 ± 0.0006	0.1020 ± 0.0361	0.0936 ± 0.0357	11.02 ± 3.59
Pure CA (10.0% High-Throughput)	Immediate	0.0072 ± 0.0010	0.0695 ± 0.0018	0.0622 ± 0.0033	8.78 ± 1.85
	10 min	0.0068 ± 0.0003	0.0813±0.0134	0.0745 ± 0.0131	10.93 ± 1.48
Pure CA (15.0% Standard)	Immediate	0.0037 ± 0.0012	0.0846 ± 0.0099	0.0809 ± 0.0112	23.97 ± 10.95
	10 min	0.0042 ± 0.0006	0.0990 ± 0.0048	0.0949 ± 0.0041	23.05 ± 2.53

Table 1. Gravimetric Data of Electrospun CA and CA/PVP Mats

Influence of Polymer Composition and Concentration

Polymer formulation and solid concentration significantly influenced oil retention capacity ($p < 0.05$). Pure CA nanofibrous mats demonstrated markedly higher oil uptake compared to the CA/PVP blend mats. The addition of hydrophilic PVP in the CA/PVP formulation (17.67% w/v, 3:2 AA:acetone) yielded the lowest overall performance, achieving sorption capacities of $2.75 \pm 1.13\ g \cdot g^{-1}$ for immediate exposure and $1.88 \pm 1.25\ g \cdot g^{-1}$ following 10 minutes of immersion ($2.32 \pm 1.18\ g \cdot g^{-1}$ combined mean).

Eliminating PVP and increasing the relative acetone ratio in the standard pure CA formulation (10.03% w/v, 1:10 AA:acetone) substantially elevated oil uptake to $8.78 \pm 1.79\ g \cdot g^{-1}$ for immediate immersion and $11.02 \pm 3.59\ g \cdot g^{-1}$ after 10 minutes ($9.90 \pm 2.87\ g \cdot g^{-1}$ combined mean). To evaluate process scalability, a high-throughput 10.00% CA formulation was evaluated under identical conditions, exhibiting sorption capacities of $8.77 \pm 1.85\ g \cdot g^{-1}$ (immediate) and $10.93 \pm 1.48\ g \cdot g^{-1}$ (10 minutes), yielding a combined mean of $9.85 \pm 1.98\ g \cdot g^{-1}$. The close agreement between standard and high-throughput 10% CA runs indicates that high-throughput electrospinning preserves the porous micro-architecture and intrinsic oil holding capacity of the pure cellulose acetate matrix.

Increasing the precursor CA concentration to 15.00% w/v produced the maximum performance observed across all experimental conditions, reaching mean sorption capacities of $23.97 \pm 10.95\ g \cdot g^{-1}$ and $23.05 \pm 2.53\ g \cdot g^{-1}$ for immediate and 10-minute

exposures, respectively ($23.51 \pm 7.64\ g \cdot g^{-1}$ combined mean).

Water Retention and Immersion Kinetics

To isolate motor oil retention from residual aqueous fluid uptake, control samples were subjected to identical immersion and drying protocols using pure water. Across all formulations, dry masses following water exposure returned to near-baseline levels ($m_{dry,\ final} \approx m_{initial}$), confirming that ambient drying efficiently removed absorbed water and that residual dry mass gains were strictly attributable to retained non-volatile motor oil.

Furthermore, immersion time—comparing immediate contact with a 10-minute saturation period—did not produce a statistically significant change in total capacity for the high-performing 15.00% CA formulation ($23.97\ g \cdot g^{-1}$ vs. $23.05\ g \cdot g^{-1}$). This behavior indicates rapid uptake kinetics and near-instantaneous surface saturation upon initial contact with the oil phase.

UV-Vis Spectrophotometric Analysis and Method Comparison

Optical analysis confirmed a highly linear relationship ($R^2 = 0.9792$) between standard oil concentrations and averaged 350–900 nm absorbance.

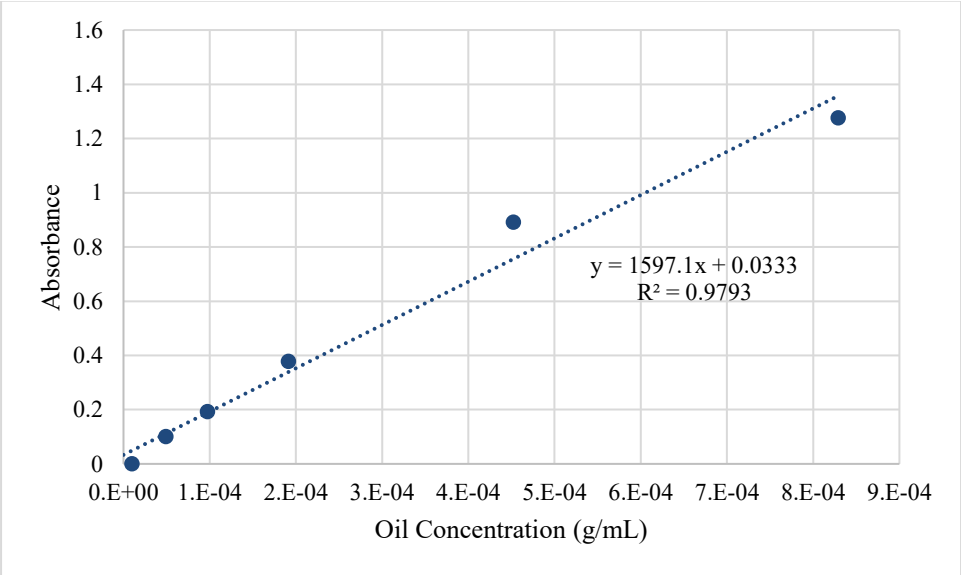


Figure 2: UV-Vis Calibration Curve. The x-axis denotes oil concentration (g/mL), and the y-axis denotes averaged broad-spectrum absorbance (350–900 nm)

Total oil removal capacities were quantified using both UV-Vis spectrophotometric analysis and direct gravimetric measurements (Table 2). Gravimetric volumes were calculated by converting the physical dry mass of oil retained by the membranes into microliters using the 0.85 g/mL density of the 5W-30 oil. The UV-Vis calculations provided a highly consistent measure of residual suspended oil, characterized by exceptionally tight standard deviations across the pure CA sorbent trials. While both methods demonstrated similar overarching trends—specifically that pure CA sorbents outperformed the CA/PVP composite—the gravimetric method exhibited significantly higher variance between sample batches. Notably, the gravimetric calculations for the Pure CA (15.0%) condition averaged 103.4 µL, exceeding the physical maximum of 100 µL of oil introduced to the system. This discrepancy strongly suggests that residual water retention or membrane swelling artificially inflated the final dry mass. This physical limitation validates the necessity and superior accuracy of the broad-spectrum UV-Vis optical method for quantifying emulsified oil and determining actual membrane sorption capacities (Table 3).

Formulation	UV-Vis Calculated Oil Removed (µL)	Gravimetric Oil Retained (µL)	Difference (µL)
CA / PVP (17.7%)	82.9 ± 6.4	45.9 ± 19.9	37
Pure CA (10.0% Standard)	98.9 ± 0.6	96.3 ± 25.5	2.6
Pure CA (10.0% High-Throughput)	97.3 ± 1.6	80.4 ± 10.9	16.9
Pure CA (15.0% Standard)	98.7 ± 0.6	103.4 ± 10.8	-4.7

Table 2: Comparison of Optical vs. Gravimetric Oil Removal Capacity

Formulation	Initial Mass (g)	UV-Vis Calculated Oil Mass (g)	UV-Vis Sorption Capacity (g/g)
CA / PVP (17.7%)	0.0165 ± 0.0020	0.0705 ± 0.0063	4.30 ± 0.34
Pure CA (10.0% Standard)	0.0083 ± 0.0012	0.0841 ± 0.0006	10.30 ± 1.56
Pure CA (10.0% High-Throughput)	0.0070 ± 0.0006	0.0827 ± 0.0016	11.88 ± 1.00
Pure CA (15.0% Standard)	0.0039 ± 0.0008	0.0839 ± 0.0006	22.38 ± 5.48

Table 3: Formation Sorption Capacity Based on UV-Vis Analysis

Contact Angle Measurements

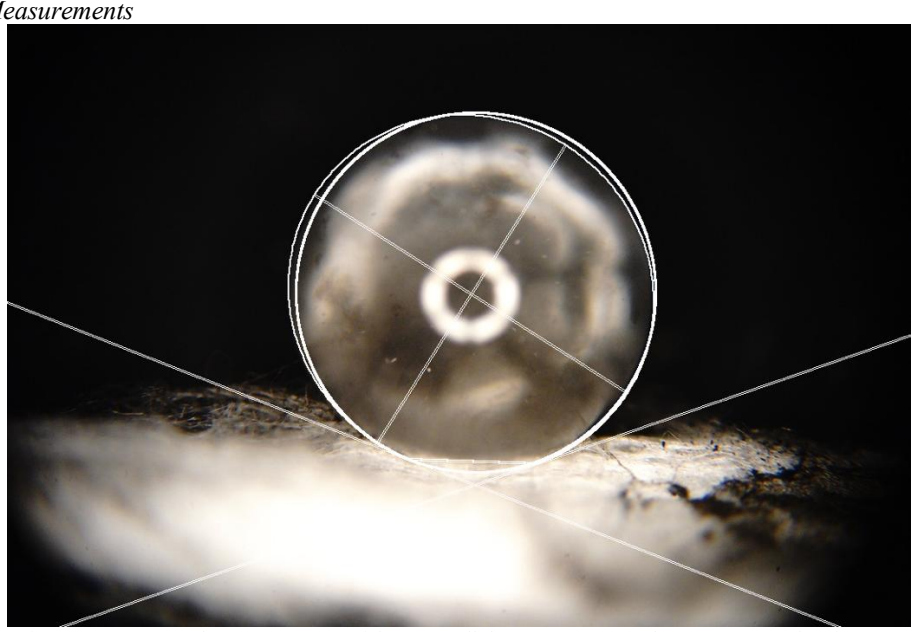


Figure 3: Static water contact angle measurements of the 15% cellulose acetate (CA) electrospun mat, showing contact angles of 160.2° and 159.6° on the left and right sides of the sample, respectively.

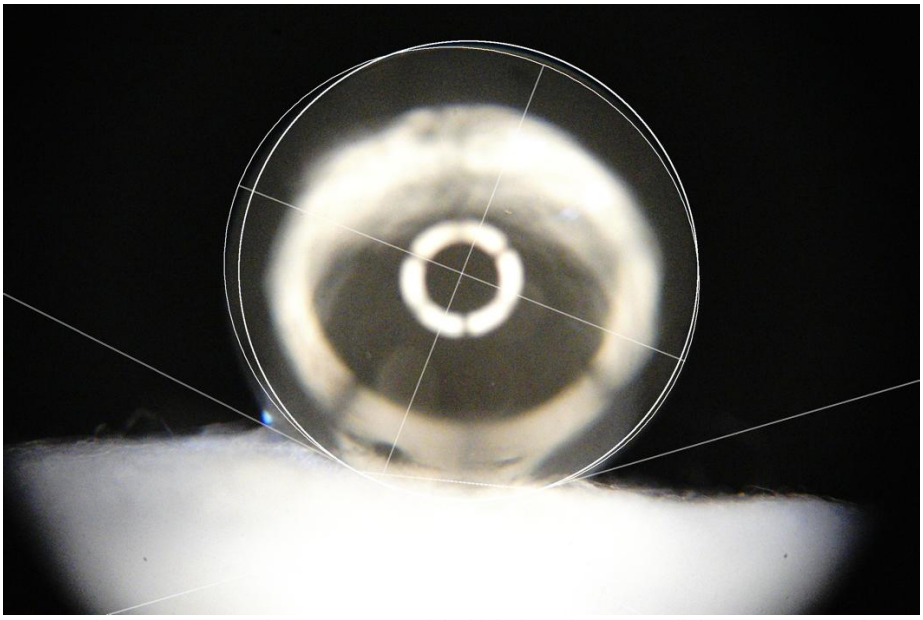


Figure 4. Static water contact angle measurements of the high-throughput 10% cellulose acetate (CA) electrospun mat, showing contact angles of 158.9° and 158.3° on the left and right sides of the sample, respectively

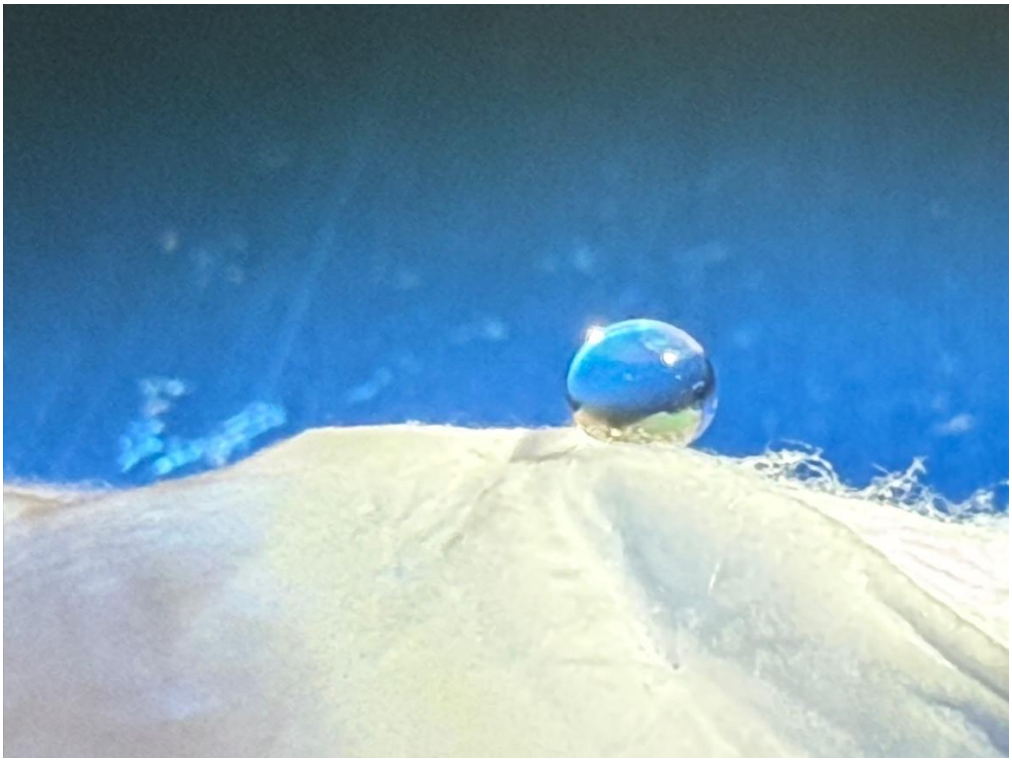


Figure 5: Representative side-view image of a water droplet on the electrospun 15% CA mat, illustrating the highly rounded droplet profile and limited spreading across the fiber surface

The wettability of the electrospun CA mats was evaluated using static water contact angle measurements. The 15% CA formulation exhibited contact angles of 160.2° and 159.6° on the left and right sides of the sample, respectively, corresponding to an average contact angle of 159.9° (Figure 3). The high-throughput 10% CA formulation exhibited contact angles of 158.9° and 158.3°, with an average contact angle of 158.6° (Figure 4). Both formulations exhibited contact angles substantially greater than 90°, indicating highly hydrophobic, superhydrophobic surfaces. The exceptionally high contact angles indicate minimal spreading of water droplets across the electrospun fiber surfaces and demonstrate the strong water-repellent character of the CA mats. A representative side-view image of a water droplet on the electrospun 15% CA mat further illustrates the minimal spreading and highly rounded droplet profile observed on the surface (Figure 5).

SEM Imaging

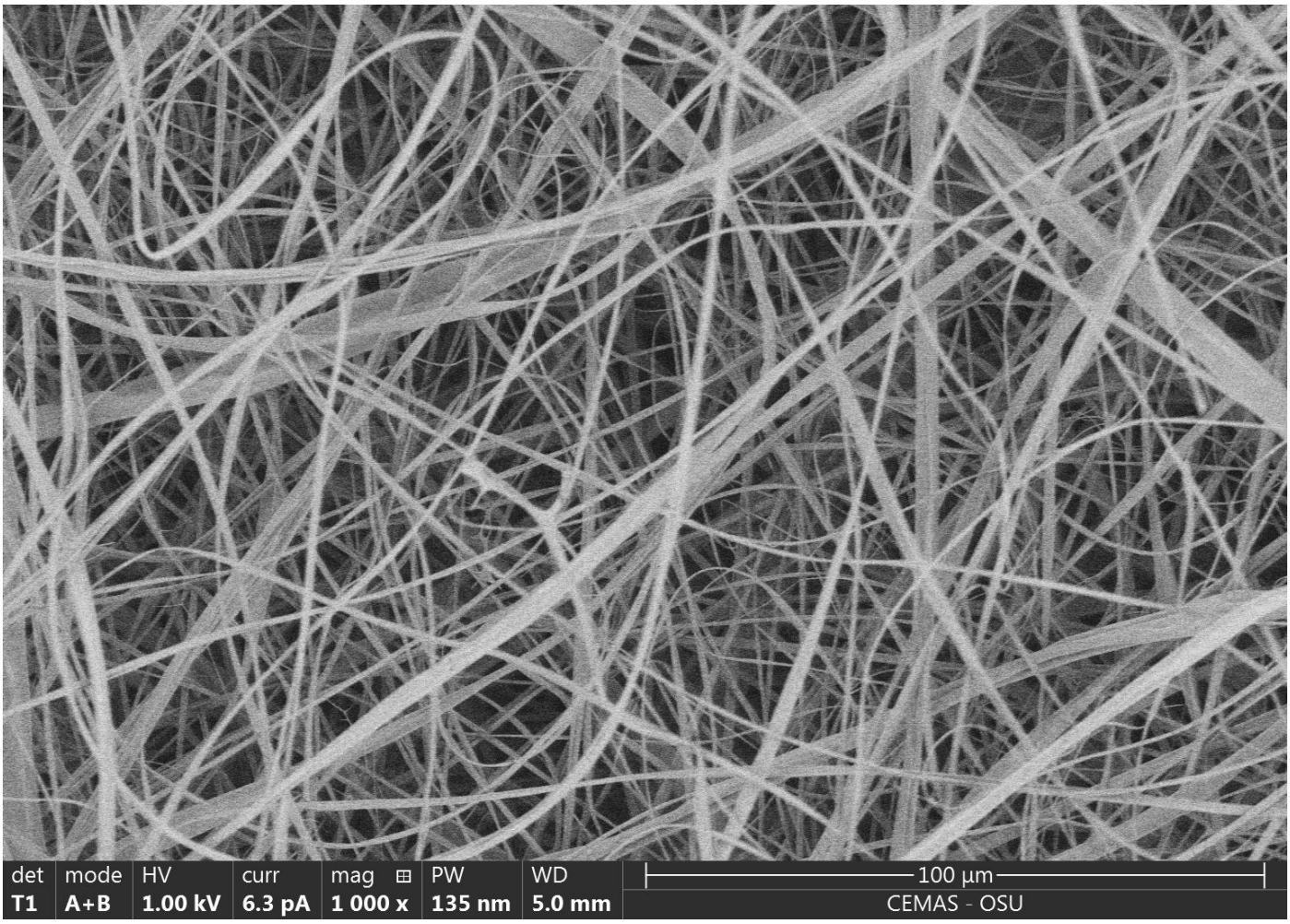


Figure 6: Scanning electron microscopy (SEM) image of electrospun CA fibers from the standard 15% CA formulation. The image shows a randomly oriented fibrous network with overlapping fibers and interstitial void spaces. SEM imaging was performed at 1000x magnification; the scale bar represents 100 µm

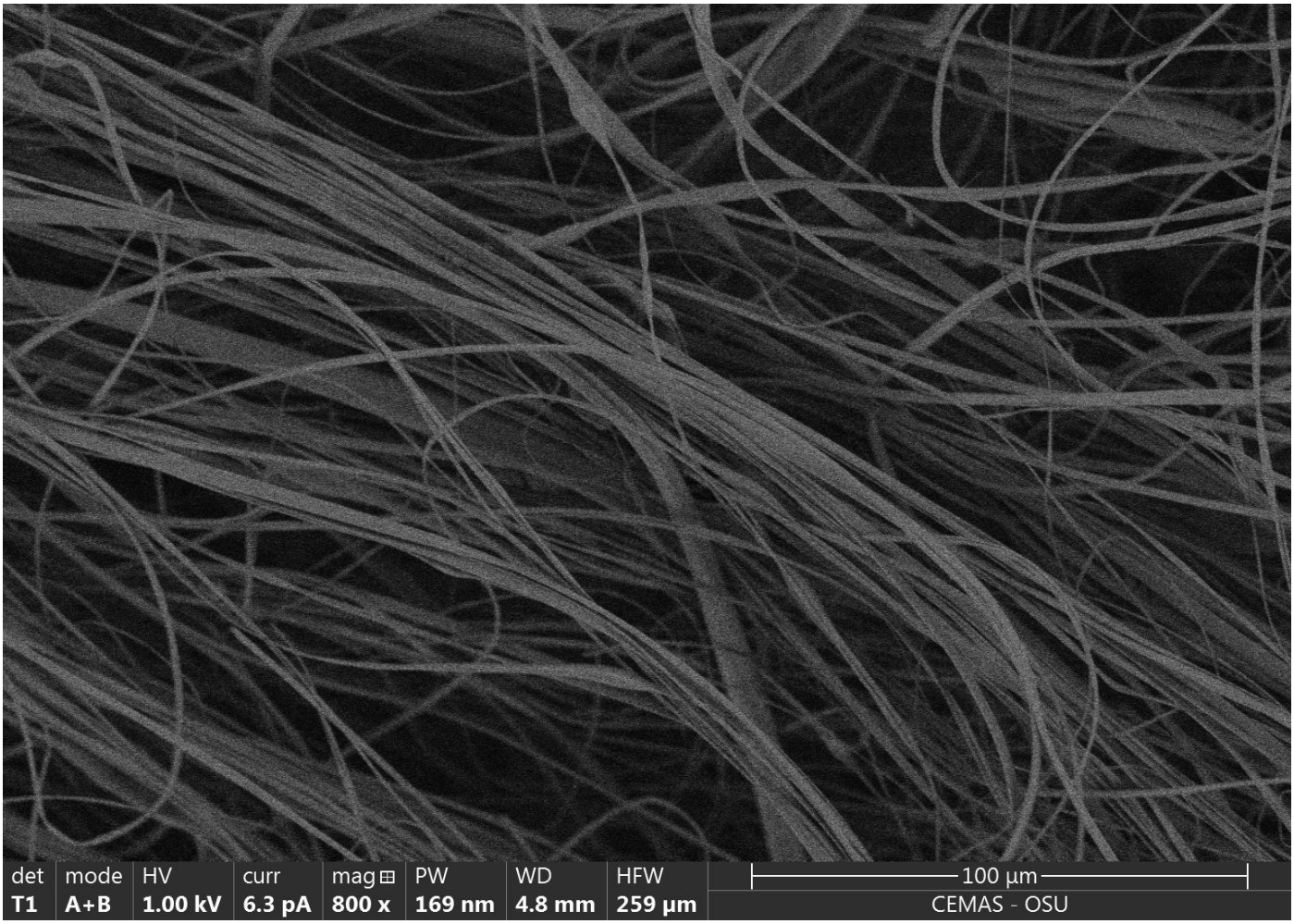


Figure 7: Scanning electron microscopy (SEM) image of electrospun CA fibers from the high-throughput 10% CA formulation. The image shows a randomly oriented fibrous network with overlapping fibers and interstitial void spaces. SEM imaging was performed at 800x magnification; the scale bar represents 100 µm

Fiber diameter measurements obtained through ImageJ analysis revealed differences in the mean fiber diameters of the electrospun CA mats prepared using the standard 15% and high-throughput 10% formulations. The standard 15% CA formulation exhibited a mean fiber diameter of 509 nm (SD = 222 nm; n = 463), whereas the high-throughput 10% CA formulation exhibited a larger mean diameter of 1154 nm (SD = 488 nm; n = 358). Thus, the high-throughput 10% CA fibers had an approximately 2.27-fold greater mean diameter than the standard 15% CA fibers. The standard 15% formulation exhibited a slightly higher coefficient of variation (43.6%) than the high-throughput 10% formulation (42.3%), indicating similar relative variability in measured fiber diameters. These results demonstrate differences in fiber-scale morphology between the two formulations, providing a quantitative basis for comparing their fibrous architectures in relation to wettability and oil–water separation performance.

DISCUSSION

Effect of Polymer Composition and Concentration on Oil Sorption

The gravimetric results demonstrate that both polymer composition and concentration influenced the oil-sorption performance of the electrospun mats. Pure CA exhibited substantially greater oil retention than the CA/PVP composite, while increasing the CA concentration from 10.0% to 15.0% produced the largest improvement in sorption capacity. The overall trend indicates that a predominantly CA-based matrix and increased CA concentration were favorable for oil retention under the conditions investigated.

The lower performance of the CA/PVP formulation can be attributed in part to differences in polymer chemistry. PVP is a highly hydrophilic polymer that is frequently incorporated into electrospinning formulations because its high molecular weight and chain-entanglement characteristics can influence solution viscosity and electrospinning stability.[20] As-cast CA is also hydrophilic. In contrast, electrospun CA provides a hydrophobic matrix that is more favorable for interaction with the nonpolar motor-oil phase. Incorporation of PVP therefore introduces a hydrophilic component that may alter the surface chemistry of the

fibers and reduce their relative affinity for oil. This difference in polymer chemistry provides a plausible explanation for the lower oil-retention capacity of the CA/PVP mats.

The effect of polymer concentration was particularly pronounced for the pure CA formulations. Increasing polymer concentration generally increases solution viscosity and chain entanglement, which can stabilize the electrospinning jet and produce a more continuous fibrous network.[12] The resulting changes in fiber dimensions, packing density, and inter-fiber void volume can substantially affect the amount of oil that can enter and remain within the mat.[16-20] The high sorption capacity of the 15.0% CA formulation therefore likely reflects a favorable combination of CA surface chemistry and electrospun network architecture. A sufficiently interconnected fibrous network can provide extensive contact with the oil phase while also physically trapping oil within the spaces between fibers. This interpretation is consistent with established descriptions of oil sorption by fibrous materials, in which oil retention can arise from surface adsorption, absorption, and physical trapping within porous structures.[23]

The difference between the CA/PVP and pure CA formulations should also be interpreted in the context of their solution compositions. The CA/PVP formulation contained 17.7% total polymer in a 3:2 acetic acid/acetone system, whereas the standard pure CA formulations used 10.0% or 15.0% CA in a 1:10 acetic acid/acetone system. Consequently, the lower CA/PVP performance reflects the combined effects of polymer composition, polymer concentration, and solvent environment rather than the effect of PVP alone. The comparison between the 10.0% and 15.0% pure CA formulations is therefore particularly informative because their nominal solvent composition was held constant, allowing the influence of CA concentration to be examined more directly.

Influence of Solvent Composition on Electrospinning and Sorption

The solvent system plays an important role in determining the properties of electrospun CA mats. Electrospinning is highly dependent on solution characteristics such as polymer solubility, viscosity, electrical conductivity, volatility, and solvent evaporation rate. These properties influence the stretching and solidification of the polymer jet and consequently determine the morphology and physical properties of the resulting fibers.[16-20]

Acetone and acetic acid are well-established components of solvent systems used for electrospinning cellulose derivatives.[17] Variations in their relative proportions can modify the behavior of the electrospinning jet and the morphology of the deposited fibers. Ho et al. demonstrated that changing between pure acetone and an acetic acid/acetone mixture produced measurable differences in the morphology and physical properties of electrospun polycaprolactone membranes.[24] Although their study examined PCL rather than CA, the results support the broader principle that the relative composition of a binary solvent system can significantly influence electrospinning behavior.

This effect is particularly relevant to the present study because the CA/PVP and pure CA formulations were produced under different solvent environments. Differences in solvent volatility and polymer–solvent interactions would be expected to alter jet stretching and solidification, thereby influencing the morphology of the resulting mats. The superior performance of the pure CA formulations may therefore reflect both their polymer chemistry and the solvent environment used during electrospinning.

The comparison between the 10.0% and 15.0% standard CA formulations is especially informative because both used the same nominal acetic acid/acetone ratio. The greater sorption observed at 15.0% CA therefore supports the interpretation that polymer concentration and the associated changes in fibrous architecture contributed substantially to the increase in oil retention.

Rapid Oil Uptake by Electrospun CA Networks

The similarity between immediate and 10-min sorption measurements for the 15.0% CA formulation indicates that substantial oil uptake occurred rapidly following contact with the oil phase. The absence of a statistically significant increase with extended exposure suggests that the dominant uptake processes occurred shortly after initial contact rather than requiring prolonged immersion. That is, oil absorption happens rapidly.

This rapid uptake is consistent with the physical characteristics of electrospun fibrous materials. The interconnected network provides a large surface area and numerous inter-fiber spaces that can rapidly interact with an oil phase. When the mat contacts oil, capillary forces and oil–fiber interactions can promote rapid spreading of the oil across the available fiber surfaces, while the porous structure provides locations for physical retention. Jiang et al. similarly described oil retention in nonwoven sorbents in terms of adsorption, absorption, and trapping mechanisms associated with the fibrous structure.[23]

Rapid uptake is particularly relevant to oil-spill sorbent applications because effective sorbents must capture oil shortly after deployment. The present results suggest that the electrospun CA network can achieve substantial oil retention without prolonged exposure, consistent with uptake dominated by readily accessible surface and pore interactions rather than slow penetration through the material.

Biomimetic Interpretation of Oil-Water Separation

The interaction between polymer chemistry and fibrous architecture observed in this study can be interpreted within the broader

framework of biomimetic surface design. Natural surfaces frequently achieve selective interactions with liquids by integrating chemical composition with multiscale structure, roughness, and porosity. Bhushan describes this relationship through biologically inspired wetting phenomena such as the Lotus Effect and Salvinia Effect, in which hierarchical architectures modify how liquids interact with a material interface.[25] These principles are particularly relevant to electrospun materials because electrospinning transforms a polymer solution into a three-dimensional network of interconnected fibers. The resulting material combines extensive surface area with nanoscale and microscale roughness and interconnected void spaces, creating an interface where polymer, liquid, and air interact simultaneously.

The Salvinia effect provides a particularly relevant biological model for understanding how such architecture can influence liquid behavior. *Salvinia molesta* maintains an air layer when submerged through specialized egg-beater-shaped trichomes whose geometry promotes air retention at the leaf surface.[25,26] The trichomes consist of multiple hairs that extend from the leaf and converge toward their tips, producing a three-dimensional architecture that supports a persistent air–water interface. Kim et al. demonstrated the structural importance of this geometry using *Salvinia*-inspired surfaces with flexible upper pillars designed to cluster at their tips. These pillars possessed a base diameter of 40 μm and narrowed to approximately 17 μm at the tips, allowing neighboring structures to converge into an egg-beater architecture.[26] This organization illustrates how the dimensions and spatial arrangement of fine structural elements can determine the ability of a surface to maintain air at the liquid interface.

A related architectural principle emerges naturally from electrospinning. The CA mats contain a dense network of overlapping fibers that intersect to create interconnected void spaces and localized surface irregularities. ImageJ analysis revealed a mean fiber diameter of 509 ± 222 nm for the standard 15% CA formulation, compared with 1,154 ± 488 nm for the high-throughput 10% formulation. Despite this difference in fiber dimensions, both formulations exhibited exceptionally high water contact angles, averaging 159.9° and 158.6°, respectively. This relationship suggests that the water-repellent behavior of the mats is not restricted to a single fiber diameter but may emerge from the combined effects of CA surface chemistry, fiber-scale roughness, and the collective organization of the fibrous network. In this respect, electrospinning provides a means of generating the structured interface needed to explore the liquid-management principles exemplified by *Salvinia.*

The importance of these air-filled regions can be understood through the Cassie–Baxter wetting framework described by Bhushan.[25] On a sufficiently rough or porous hydrophobic surface, a liquid may contact only a fraction of the underlying solid while air occupies the remaining interface. This heterogeneous interface reduces the effective area directly wetted by water and can enhance water repellency.[25] The electrospun CA architecture is well suited to this type of interface because its interconnected fibers continuously generate boundaries between solid and void throughout the mat. Consequently, the hydrophobicity of CA can be expressed across a substantially more complex interface than would be present on a continuous polymer film. The combination of CA surface chemistry with electrospun roughness and porosity may therefore promote water resistance while preserving extensive polymer surface available for oil interaction.

This architecture is particularly advantageous for oil sorption because the same fibrous network that modifies water wetting also provides a large internal surface area and accessible pathways for oil. Oil can penetrate the interconnected spaces and interact with the extensive CA fiber surface, while the hydrophobic fiber surfaces and air-filled regions can impede complete water penetration. The resulting interface creates distinct conditions for the two liquids: oil can access the porous interior and occupy the available inter-fiber volume, whereas water encounters hydrophobic polymer surfaces and air-filled gaps that can resist displacement. Thus, the electrospun architecture provides both the interfacial area required for oil uptake and the structural environment that can favor selective interaction with oil over water.

Taken together, these findings suggest that the biomimetic relevance of electrospun CA lies not in reproducing the exact geometry of Salvinia trichomes, but in translating their underlying design principles into a fibrous material. Whereas Salvinia trichomes stabilize an air–water interface, the electrospun CA mats combine high apparent water repellency with oil-sorption capacity, as demonstrated by the high contact angles of both formulations and the strong sorption performance of the standard 15% CA mat. This biomimetic perspective connects the observed oil-retention behavior to two complementary aspects of material design: CA supplies the surface chemistry governing liquid affinity, while electrospinning constructs the hierarchical physical architecture through which those properties operate. Although the precise wetting mechanism remains to be established, the findings support the potential of translating biological design principles into functional materials without requiring exact structural replication.

The significance of electrospun CA lies in its potential to integrate multiple functions within a single material and fabrication process. Rather than relying on separately engineered surface structures or additional functional coatings, electrospinning produces a fibrous CA network whose surface chemistry and architecture may jointly support water repellency, oil affinity, and oil uptake. The observed performance therefore highlights CA as a promising platform for biomimetic oil–water separation, in which a single polymer and a one-step process may reproduce complementary functions associated with the Salvinia effect. This integration offers a potential route toward simpler fabrication of multifunctional sorbents.

High-Throughput Electrospinning

The close agreement between the standard and high-throughput 10.0% CA formulations indicates that increased electrospinning throughput did not substantially compromise the oil-retention behavior of the CA mats under the conditions examined. High-throughput electrospinning is important because the relatively low production rate of conventional single-needle electrospinning can limit the practical scalability of nanofibrous materials. Technologies designed to increase electrospinning throughput provide a pathway for producing larger quantities of fibrous material while retaining the advantages associated with electrospun architectures.[30,31] Gilmore and Gouma have also demonstrated a scalable, self-contained electrospinning platform designed to increase production capacity.[32]

This result provides preliminary support for the scalability of electrospun CA as an oil-sorbent platform. Maintaining comparable sorption performance at increased production throughput is particularly relevant to environmental applications, where practical deployment requires production of sufficient quantities of sorbent material.

Comparison of Gravimetric and UV-Vis Measurements

The gravimetric and UV–Vis measurements provide complementary perspectives on oil removal by the electrospun mats. Both approaches demonstrated the same general formulation trend, with pure CA exhibiting greater oil-removal performance than the CA/PVP composite. However, the methods quantify different aspects of the oil–water system and therefore should not be interpreted as directly equivalent measurements.

Gravimetric analysis measures the increase in dry mat mass following exposure to the oil–water mixture. Under the experimental conditions, the water-control samples generally returned close to their original dry masses following drying, indicating that persistent water contributed relatively little to the final mass. The mass increase of the oil-exposed samples therefore provides a useful operational measure of material retained by the mat.

The gravimetric data also demonstrate why weight-based sorption capacity is particularly sensitive for electrospun materials. The initial masses of the samples were only a few milligrams, so relatively small differences in final mass produced large differences when expressed in g/g. This effect was most apparent for the 15.0% CA samples, which exhibited both the highest capacity and the greatest variability for immediate exposure.

The UV–Vis analysis provided a second means of evaluating oil removal from the aqueous system. The calibration curve exhibited a strong linear relationship between oil concentration and averaged absorbance across the measured wavelength range, with an R^2 value of 0.9792. The UV–Vis-derived values were also relatively consistent across the pure CA formulations, with calculated oil-removal volumes close to the approximately 100 μL of oil introduced into each system.

The difference between the methods is primarily one of measurement basis. Gravimetry evaluates material retained by the mat after drying, whereas UV–Vis evaluates the oil remaining in the aqueous phase through the established calibration relationship. The two measurements therefore provide complementary information: gravimetry characterizes oil retained by the sorbent, while UV–Vis provides an independent assessment of oil remaining in the surrounding aqueous phase.

Comparison with Conventional Polypropylene Sorbents

The oil-sorption performance of the CA mats can be contextualized by comparison with conventional polypropylene (PP) sorbents. Previous studies have reported an oil-sorption capacity of 8.96 g/g for nonwoven PP sorbents.[23] Under the conditions of the present study, the standard 10.0% CA formulation produced a comparable capacity, while the 15.0% CA formulation substantially exceeded the reported PP value. These results demonstrate that electrospun cellulose acetate can achieve oil-sorption capacities within or above the range reported for conventional PP nonwoven sorbents.

The performance of the CA mats is likely associated with the combination of cellulose acetate chemistry and the high-surface-area, interconnected architecture generated through electrospinning. The fibrous network provides extensive oil–fiber contact and interconnected spaces capable of retaining oil within the mat. Thus, the present results demonstrate the potential of a cellulose-derived electrospun material to provide substantial oil-sorption capacity while offering an alternative polymer basis to conventional PP sorbents.

The environmental significance of this comparison is also relevant to sorbent material selection. PP is a persistent synthetic polymer, whereas CA is derived from cellulose and has demonstrated substantial biodegradation under aqueous environmental conditions. Serbruyns et al. evaluated cellulose diacetate using standardized biodegradation tests in freshwater, seawater, and seawater/sediment environments and reported greater than 90% relative biodegradation in freshwater after 100 days and in seawater after 142 days, with greater than 70% degradation at a seawater/sediment interface after 360 days.[33] These findings indicate that cellulose acetate can undergo substantial biological degradation across several aquatic environments, providing an environmental distinction from persistent synthetic polymers such as PP. Accordingly, electrospun CA combines substantial oil-retention capacity with a cellulose-derived material that has demonstrated biodegradation under relevant environmental conditions.

CONCLUSIONS

Taken together, the results demonstrate that electrospun CA mats can achieve substantial oil-retention capacity, with performance strongly influenced by polymer concentration and composition. Pure CA consistently outperformed the CA/PVP composite, while increasing the CA concentration from 10.0% to 15.0% produced the greatest improvement in oil retention. The comparable performance of standard and high-throughput 10.0% CA formulations further indicates that increased electrospinning throughput can be achieved without substantially compromising sorption performance.

The 15.0% CA formulation reached an average oil-retention capacity of approximately 23.5 g/g, exceeding the 8.96 g/g polypropylene benchmark.[21] Together with the renewable cellulose-derived basis of CA, these results support further investigation of electrospun CA as a high-capacity oil-sorbent material and provide a foundation for future studies of its reusability, degradation, and broader environmental performance.

REFERENCES

1. A. K. Sahoo et al., "Network-based investigation of petroleum hydrocarbons-induced ecotoxicological effects and their risk assessment," *Environment International*, vol. 194, p. 109163, Dec. 2024. doi: 10.1016/j.envint.2024.109163.

2. M. F. Fingas, *Handbook of Oil Spill Science and Technology*. Hoboken, NJ, USA: Wiley, 2015. doi: 10.1002/9781118989982.

3. National Oceanic and Atmospheric Administration, *Shoreline Assessment Manual*, 4th ed. Seattle, WA, USA: Emergency Response Division, Office of Response and Restoration, U.S. Department of Commerce, 2013.

4. M. F. Fingas, *Oil Spill Science and Technology*, 2nd ed. Cambridge, MA, USA: Gulf Professional Publishing, 2017.

5. G. C. Pratt *et al.*, "Modeled Air Pollution from *In Situ* Burning and Flaring of Oil and Gas Released Following the *Deepwater Horizon* Disaster," *Annals of Work Exposures and Health*, vol. 66, no. Suppl. 1, pp. i172–i187, Sep. 2020. doi: 10.1093/annweh/wxaa084

6. National Academies of Sciences, Engineering, and Medicine, *The Use of Dispersants in Marine Oil Spill Response*. Washington, DC, USA: National Academies Press, 2020. doi: 10.17226/25161.

7. F. L. Motta, S. R. Stoyanov, and J. B. P. Soares, "Application of Solidifiers for Oil Spill Containment: A Review," *Chemosphere*, vol. 194, pp. 837–846, Mar. 2018, doi: 10.1016/j.chemosphere.2017.11.103.

8. Z. Asif, Z. Chen, C. An, and J. Dong, "Environmental Impacts and Challenges Associated with Oil Spills on Shorelines," *Journal of Marine Science and Engineering*, vol. 10, no. 6, p. 762, May 2022, doi: 10.3390/jmse10060762.

9. G. Crini and E. Lichtfouse, *Green Adsorbents for Pollutant Removal: Innovative Materials*. Cham, Switzerland: Springer, 2018. doi: 10.1007/978-3-319-92111-2.

10. J. Mao, W. Deng, M. Zhao, and J. Li, "Recent Advances in Waste-Derived Sorbents for Oil Sorption and Oil–Water Separation: Progress and Future Prospects," *Separation and Purification Technology*, vol. 402, p. 138659, Sep. 2026, doi: 10.1016/j.seppur.2026.138659.

11. J. Saleem, Z. K. B. Moghal, R. A. Shakoor, and G. McKay, "Sustainable Solution for Plastic Pollution: Upcycling Waste Polypropylene Masks for Effective Oil-Spill Management," *International Journal of Molecular Sciences*, vol. 24, no. 15, Art. no. 12368, Aug. 2023, doi: 10.3390/ijms241512368.

12. S. S. Vhatkar, A. Kumari, P. Kumar, G. Sahoo, and R. Oraon, "Electrospun Nanofibers for Energy and Environment Protection," in *Electrospun Nanofibers: Fabrication, Functionalisation and Applications*, S. K. Tiwari, K. Sharma, V. Sharma, and V. Kumar, Eds. Cham, Switzerland: Springer International Publishing, 2021, pp. 23–52.

13. F. Mikaeili and P. I. Gouma, "Super Water-Repellent Cellulose Acetate Mats," *Scientific Reports*, vol. 8, Art. no. 12472, Aug. 2018, doi: 10.1038/s41598-018-30693-2.

14. O. Suwantong and P. Supaphol, "Applications of Cellulose Acetate Nanofiber Mats," in *Handbook of Polymer Nanocomposites: Processing, Performance and Application, Volume C: Polymer Nanocomposites of Cellulose Nanoparticles*, J. K. Pandey, H. Takagi, A. N. Nakagaito, and H.-J. Kim, Eds. Berlin: Springer Berlin Heidelberg, 2016, pp. 355–365.

15. S. Majumder, M. A. Matin, A. Sharif, and M. T. Arafat, "Understanding Solubility, Spinnability and Electrospinning Behaviour of Cellulose Acetate Using Different Solvent Systems," *Bulletin of Materials Science*, vol. 42, no. 4, Art. no. 163, May 2019, doi: 10.1007/s12034-019-1857-6.

16. P. Sánchez-Cid, J. F. Rubio-Valle, M. Jiménez-Rosado, V. Pérez-Puyana, and A. Romero, "Effect of Solution Properties in the Development of Cellulose Derivative Nanostructures Processed via Electrospinning," *Polymers*, vol. 14, no. 4, Art. no. 665, Feb. 2022, doi: 10.3390/polym14040665.

17. W. Alkaron, A. Almansoori, K. Balázsi, and C. Balázsi, "Preparation and Morphology Study of Electrospun Cellulose Acetate Fibers Using Various Solvent Systems and Concentrations," *Periodica Polytechnica Chemical Engineering*, vol. 69, no. 3, pp. 427–438, Sep. 2025, doi: 10.3311/ppch.41199.

18. M. Maher Mehanna, "Electrospun Fibrous Mat of Cellulose Acetate: Influence of Solvent System (Acetic Acid/Acetone) on Fiber Morphology," *International Journal of Pharmaceutical Investigation*, vol. 10, no. 1, pp. 82–85, Mar. 2020, doi: 10.5530/ijpi.2020.1.15.

19. J. K. Lee *et al*., "Polymer-Based Composites by Electrospinning: Preparation & Functionalization with Nanocarbons," *Progress in Polymer Science*, vol. 86, pp. 40–84, Nov. 2018, doi: 10.1016/j.progpolymsci.2018.07.002.

20. M. Kurakula and G. S. N. Koteswara Rao, "Moving Polyvinyl Pyrrolidone Electrospun Nanofibers and Bioprinted Scaffolds Toward Multidisciplinary Biomedical Applications," *European Polymer Journal*, vol. 136, Art. no. 109919, Aug. 2020, doi: 10.1016/j.eurpolymj.2020.109919.
21. A. Götz, V. Senz, W. Schmidt, J. Huling, N. Grabow, and S. Illner, "General Image Fiber Tool: A Concept for Automated Evaluation of Fiber Diameters in SEM Images," *Measurement*, vol. 177, Art. no. 109265, 2021, doi: 10.1016/j.measurement.2021.109265.
22. J. Huling, A. Götz, N. Grabow, and S. Illner, "GIFT: An ImageJ Macro for Automated Fiber Diameter Quantification," *PLOS ONE*, vol. 17, no. 10, Art. no. e0275528, 2022, doi: 10.1371/journal.pone.0275528.
23. P. Jiang, L. Lou, and S. Ramkumar, "Comparison of Oil Sorption Capacity of Nonwoven Sorbents," *AATCC Journal of Research*, vol. 10, no. 2, pp. 101–109, Mar.–Apr. 2023, doi: 10.1177/24723444221132053.
24. M. H. Ho, T. B. T. Do, N. N. T. Dang, A. N.-M. Le, H. T.-K. Ta, T. V. Vo, and H. T. Nguyen, "Effects of an Acetic Acid and Acetone Mixture on the Characteristics and Scaffold-Cell Interaction of Electrospun Polycaprolactone Membranes," *Applied Sciences*, vol. 9, no. 20, Art. no. 4350, Oct. 2019, doi: 10.3390/app9204350.
25. B. Bhushan, *Biomimetics: Bioinspired Hierarchical-Structured Surfaces for Green Science and Technology*, 3rd ed. Cham: Springer, 2018. doi: 10.1007/978-3-319-71676-3.
26. M. Kim, S. Yoo, H. E. Jeong, and M. K. Kwak, "Fabrication of *Salvinia*-inspired surfaces for hydrodynamic drag reduction by capillary-force-induced clustering," *Nature Communications*, vol. 13, Art. no. 5181, 2022, doi: 10.1038/s41467-022-32919-4.
27. W. Barthlott *et al*., "Adsorption and Superficial Transport of Oil on Biological and Bionic Superhydrophobic Surfaces: A Novel Technique for Oil–Water Separation," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 377, no. 2150, Art. no. 20180219, 2019, doi: 10.1098/rsta.2018.0219.
28. D.-H. Kim, R. Mauchauffé, J. Kim, and S. Y. Moon, "Simultaneous, Efficient and Continuous Oil–Water Separation via Antagonistically Functionalized Membranes Prepared by Atmospheric-Pressure Cold Plasma," *Scientific Reports*, vol. 11, Art. no. 3169, 2021, doi: 10.1038/s41598-021-82761-9.
29. C. Han, "Super-Hydrophobic High-Throughput Electrospun Cellulose Acetate (CA) Nanofibrous Mats as Oil Selective Sorbents," M.S. thesis, Dept. Mater. Sci. Eng., Stony Brook Univ., Stony Brook, NY, USA, 2015.
30. T. Gilmore and P. I. Gouma, "Electrospinning for Biomaterials Applications," *ACERS Bulletin*, vol. 103, no. 9, pp. 26–32, 2024.
31. F. Mikaeili, O. Abe, and P. I. Gouma, "High Throughput Electrospinning Technologies and Applications," in *ASM Handbook, Volume 23A: Additive Manufacturing in Biomedical Applications*. Materials Park, OH, USA: ASM International, 2022.
32. T. Gilmore and P. I. Gouma, "Scalable Electrospinning Using a Desktop, High Throughput, Self-Contained System," *Scientific Reports*, vol. 14, Art. no. 25844, 2024, doi: 10.1038/s41598-024-77061-7.
33. L. Serbruyns, D. Van de Perre, and D. Hölter, "Biodegradability of Cellulose Diacetate in Aqueous Environments," *Journal of Polymers and the Environment*, vol. 32, pp. 1326–1341, 2024, doi: 10.1007/s10924-023-03038-y.

DATA AVAILABILITY STATEMENT

The raw data generated and analyzed during this study are provided in the manuscript.

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AUTHOR INFORMATION

Authors and Affiliations
The Ohio State University, Department of Materials Science and Engineering, Columbus, Ohio, USA

Koen Kwak, Antonia Akoto-Yeboah, Blaine Lee, & Pelagia-Iren (Perena) Gouma

Northwestern University, Evanston, Illinois, USA

Koen Kwak

Author Contributions
The experiments were designed and performed by K.K. under the supervision of P.G. SEM characterization was performed by A.A., while UV-Vis and contact angle measurements were performed by B.L. Data analysis was conducted by K.K., A.A., and B.L. The manuscript was written by K.K. and edited by A.A.

Corresponding Authors

Correspondence should be addressed to Koen Kwak (koenjkwak@outlook.com), Antonia Akoto-Yeboah (akoto-yeboah.1@osu.edu), Blaine Lee (lee.9856@osu.edu), & Pelagia-Iren (Perena) Gouma (gouma.2@osu.edu).

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