PROCESS ENGINEERING FOR EFFICIENT TEXTILE-TO-TEXTILE RECYCLING

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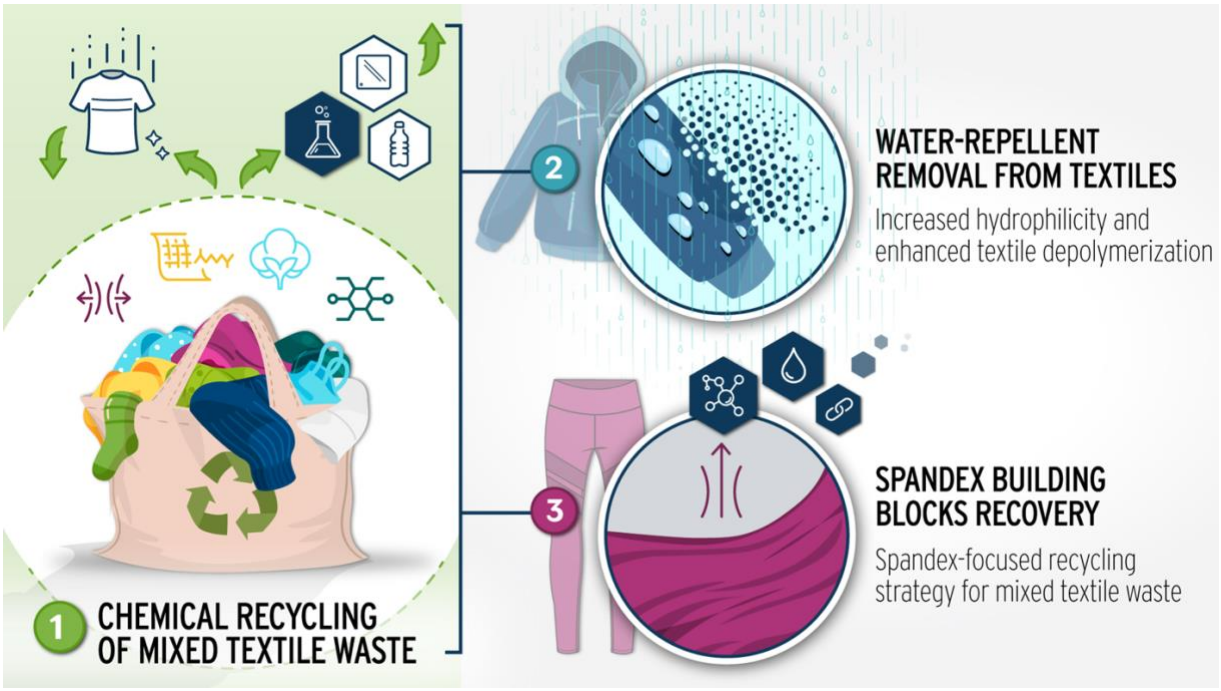
Thursday, December 4th, 2026 @ 2:00 PM EST

CCM 106 | https://udel.zoom.us/j/97908484856 | (Password: textile)



Textile waste has become a global environmental challenge, with more than 132 million tons of textiles discarded annually and less than 1% recycled back into new fibers. Modern garments are increasingly composed of polyester, cotton, nylon, and spandex blends, often finished with durable coatings such as per- and polyfluoroalkyl substances (PFAS). These heterogeneous, chemically complex structures resist both mechanical and chemical recycling, leading to widespread landfilling, incineration, and material value loss. Achieving a circular textile economy requires new process-engineering solutions capable of overcoming the intertwined challenges of fiber blending, surface finishes, and spandex compatibility.

This dissertation advances process-engineering strategies for efficient textile-to-textile recycling by addressing three major barriers: the heterogeneity of mixed-fiber textiles, the presence of persistent fluorinated finishes, and the lack of circular pathways for elastomeric spandex. To overcome these challenges, this work integrates microwave-assisted heating, plasma surface modification, and solvent-driven depolymerization to recover high-value intermediates from complex post-consumer textiles.

First, we address the challenge of recycling mixed-fiber textiles, where polyester, cotton, nylon, and spandex are tightly interlaced and often coated with dyes and chemical finishes. Individual and mixed-component experiments revealed slight interactions among fibers, enabling complete depolymerization of polyester to bis(2-hydroxyethyl) terephthalate (BHET) and spandex to monomers such as 4,4′-methylenedianiline (MDA) within 15 minutes under microwave-assisted heating using a ZnO catalyst, while cotton and nylon remained largely intact. The recovered components can be integrated directly into the textile manufacturing value chain for textile-to-textile recycling or used in other applications, outlining a pathway toward high global textile circularity.

Next, we introduce non-thermal atmospheric plasma (NTAP) as a surface-selective method to remove polymeric PFAS coatings from UV- and water-resistant textiles. Plasma treatment enabled rapid, uniform removal of surface fluorine, far outperforming Soxhlet and microwave extraction. Plasma-treated textiles exhibited increased hydrophilicity, improving solvent uptake and subsequent microwave-assisted depolymerization. These results were validated across real-world fabrics, underscoring practical relevance for both recycling and pollution mitigation.

Finally, we focus on closing the loop for spandex, whose elasticity makes it a major barrier to textile circularity. This work demonstrates an approach to recover spandex's key building blocks by achieving complete depolymerization of spandex in butanol into dibutyl(methylenebis(4,1-phenylene)) dicarbamate (DBC) and polyol within 10 minutes under microwave-assisted heating over dibutyltin dilaurate (DBTDL) catalyst. Under optimized

conditions, polyester depolymerizes completely while cotton and nylon remain mostly intact. Reactive distillation for DBC thermolysis shows promise for 4,4′-methylenediphenyl diisocyanate (MDI) recovery, unlocking full circularity potential of clothing waste heavy in spandex.

In summary, this dissertation establishes an integrated process-engineering framework for the chemical recycling of complex post-consumer textiles.