Automation of Mini-Tube Production of Electrospun Nanofibers

Design, Development, and Use of Tube-O-Matic

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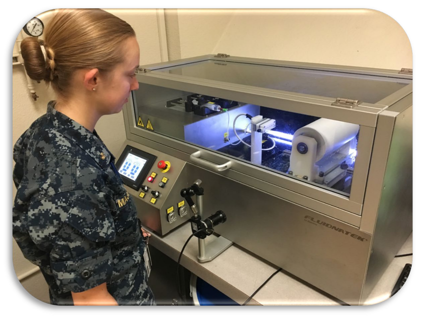
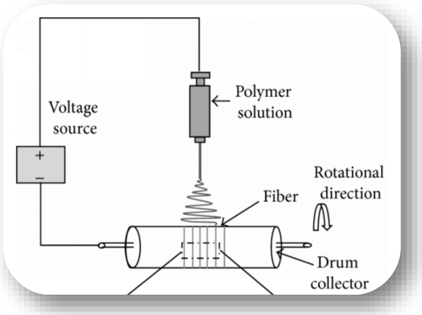
Background

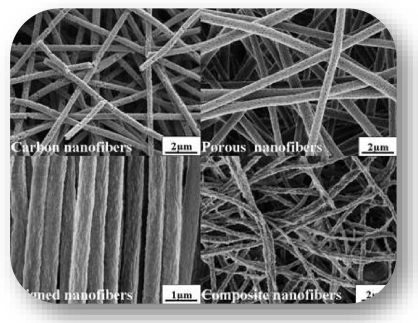
What are nanofibers? - Nanofibers are polymer-based fibers with a diameter equal to or less than 100 nm. These fibers come in the form of bundles or mats of threads with thicknesses on the order of millimeters. Nanofibers can contain a variety of precursors, or additives, which provide unique properties beyond those of the bulk polymer material.



Electrospinning Equipment



Electrospinning Process



Nanofiber Examples

How are nanofibers made? - Nanofibers are often created via electrospinning, a process that involves drawing out fibers of polymer solution using a difference in voltage potential. Single fibers are emitted from a syringe spinneret and deposited on a mylar sheet wrapped around a rotating collector drum of opposite charge. The mylar sheet and mesh are then cut and removed from the drum.

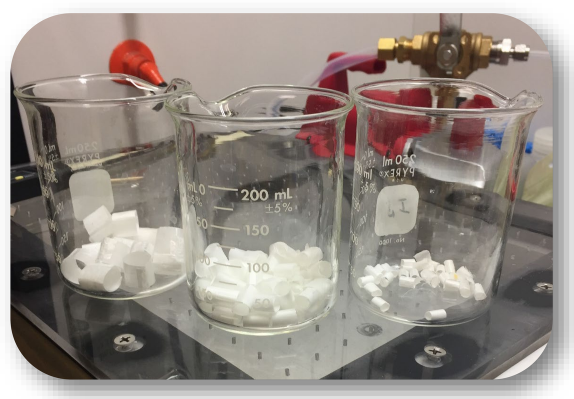
What are nanofibers used for? - Nanofiber applications include tissue engineering, drug delivery, cancer diagnosis, and optical sensors. LLNL has found that using nanofiber tubes as filter media reduces the pressure drop across the filter. Improving filtration technology will work to increase fire safety in Department of Energy (DOE) nuclear facilities.

Production time for creating small nanofiber tubes out of electrospun mesh is limiting LLNL's ability to further research filter performance. The current process is performed by hand and takes upwards of eight hours to produce tubes from a single nanofiber mat, about the size of a piece of paper.

Conclusion

The Tube-O-Matic is now located at B691's electrospinning facility and will soon be fully operational, supporting research at LLNL.

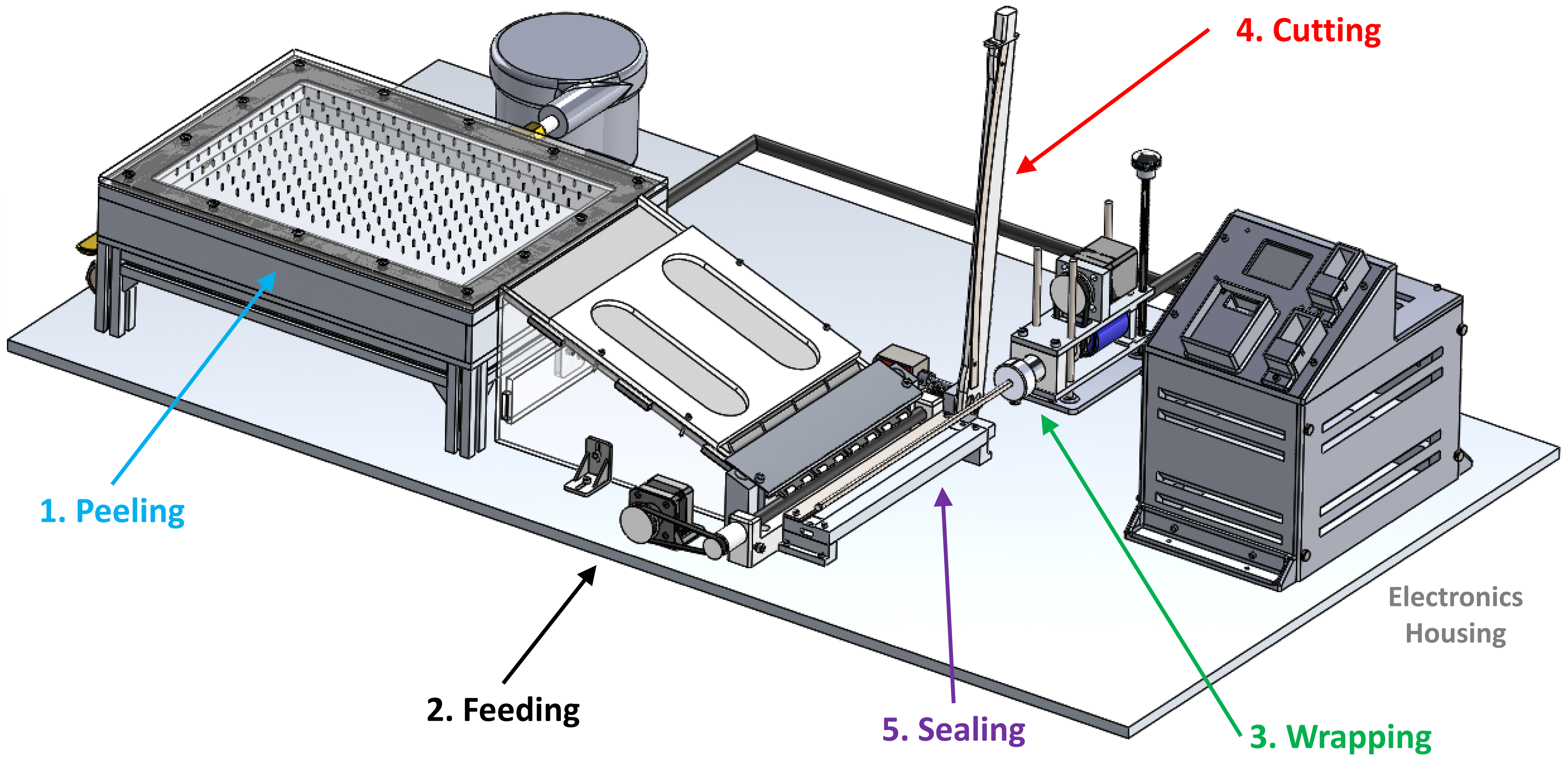
The senior design project at Cal Poly was largely a success. The completed prototype creates free-standing nanofiber tubes faster than the current process employed by LLNL. 56 tubes were produced from one nanofiber mesh in 41 minutes, beating our goal by 19 minutes. Additionally, we succeeded in building a machine that allows variable tube dimensions. T.O.M. is able to manufacture tubes of diameters 4 - 12 mm in increments of 2 mm. We were unable to meet our heat-sealed seam requirement of less than 2 mm and our goal of less than 5/100 throwaway tubes. Future testing and process refinement will optimize heat-sealer functionality and mitigate failure rate.



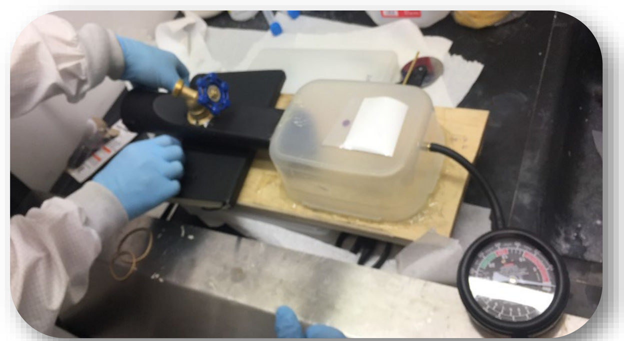
Tubes Produced Using T.O.M.

This project provided us with invaluable experience developing a system that integrates multiple assemblies. It stretched our creative muscles, tested our problem-solving skills, and resulted in a unique device that will help LLNL expedite their nanofiber tube production process to further support advanced filter research.

Final Design



Prototyping Stages



Vacuum Table Prototype

Vacuum Mandrel

Nanofiber Mesh

Stage 1

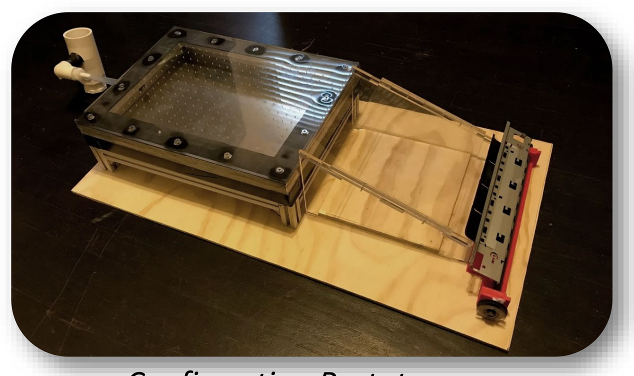
The original prototype was an early-concept test rig for the vacuum table and mandrel. It was assembled using recycled Tupperware and a shop vac.

Stage 2

The next iteration tested the inclined ramp and rollers concept. We disassembled and used HP Deskjet printer parts to mimic a passive roller design.

Acrylic Ramp Prototype

Passive Roller Design



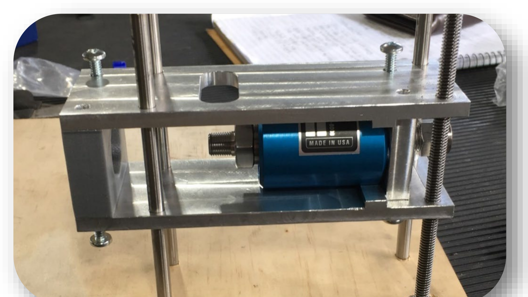
Confirmation Prototype

Stage 3

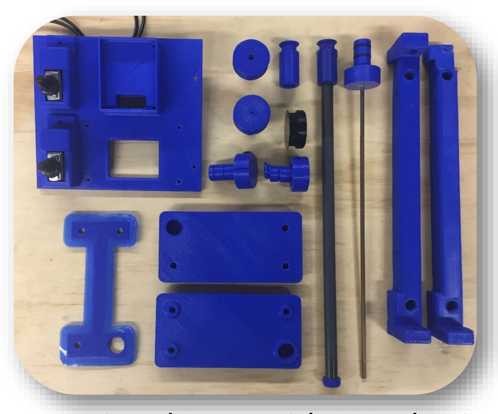
The team's finished confirmation prototype included the vacuum table, ramp, and roller assemblies. The vacuum table still operated using a shop vac and was held together with duct tape.

Manufacturing

Precision Milling for Mandrel Holes



Tight Tolerances Between Parts



3D Printed Parts with PLA Plastic

7 Modified off-the-shelf components

49 Off-the-shelf components used as-is

61 Parts custom manufactured by the team

117 Total unique parts used in T.O.M. device

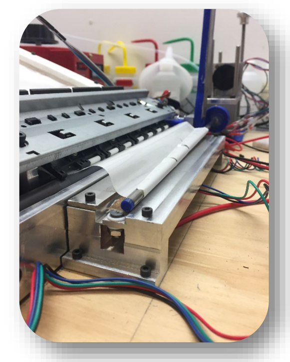
Problem Statement

Our objective was to develop a semi-automated process for manufacturing freestanding nanofiber tubes to reduce production time and improve control over final tube dimensions. We broke this process into five key functions:

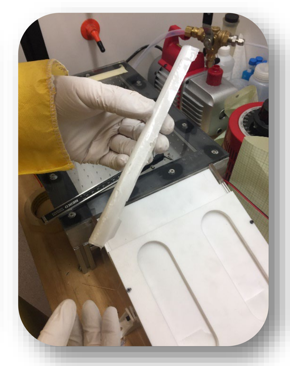
1. **Peeling** - The operator places the mesh face down on the vacuum table and manually peels the backing layer.
2. **Feeding** - The operator places the mesh in the ramp, which constrains and aligns the mesh. At the bottom of the ramp, a driven printer roller feeds the mesh through the device.
3. **Wrapping** - The rotating vacuum mandrel sucks the mesh sheet and rolls it into a tube of one or more layers. Interchangeable mandrels roll a range of tube diameters.
4. **Cutting** - A shear blade between the rollers and the mandrel cuts the mesh sheet lengthwise to decide tube thickness via number of wraps.
5. **Sealing** - The operator lowers the wrapped tube onto the heat-sealing element for several seconds to seal the tube.

Finally, the operator removes the tubes and cuts them into smaller pieces based on the desired tube length.

Testing Results



Wrapping on 4mm Mandrel



Full Length 6mm Diameter Tube

Completed Tubes From Testing

Left Beaker: 4mm tubes
Center Beaker: Fifty-six 6mm tubes were produced from one sheet during testing.
Right Beaker: 12 mm tubes

Left: During testing, the mesh was successfully wrapped around a 4mm mandrel. Next, the mesh was cut to length using the shear blade.

Center: A 6mm tube after removal from the mandrel. The Teflon mandrel surface allowed for easy removal of the tube after heat sealing. This was an improvement from previous prototypes in which mesh was directly rolled onto the stainless steel mandrel.

Tabulated Testing Results

Test Description	Target	Actual	Error	Status
Tube Production Rate Test	1 hour	41 min	-	PASS
Dimension Test: Tube inner diameter	2-12 mm in increments of 1mm	X + 0.82 mm	14%	PASS
Dimension Test: Width of heat-sealed seam	< 2mm	2.58 mm	29%	FAIL
Tube Failure Rate	< 5 throwaway tubes out of 100	20%	15%	FAIL
Cylindricity Test	Tube can roll down a 30-45° incline	100%	-	PASS

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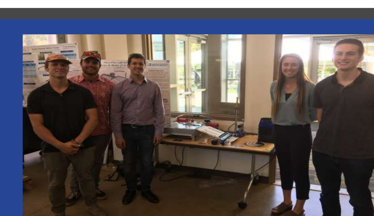

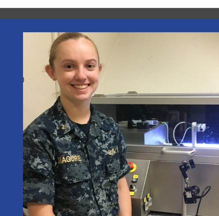

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