FMRI RET 2014-Effect of Viscosity on Fiber Formation and Functionality

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Abstract

Electrospinning involves placing a polymer solution into a syringe to which an electric field is then applied, which overcomes the surface tension of the polymer solution. A polymer jet is then ejected from the syringe needle tip, undergoes plastic stretching, and is deposited onto the collector as extremely thin fibers that range in diameter from nanometers to a few microns [1]. Changing the concentration or molecular weight of the polymer changes the viscosity, which can change the diameter of the fiber and the number of beads that form on the fiber. While there are many other parameters that affect electrospinning, our focus is on researching how viscosity affects fiber formation and functionality.

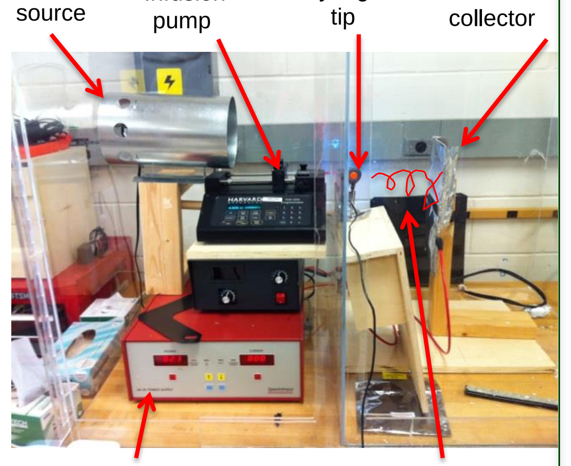


Figure 1. Electrospinning equipment

Background

The viscosity of a fluid is a measure of its resistance to flow [2]. Shear refers to the force required to move a layer of fluid in relation to another layer. The greater the friction, the greater the force required to move the liquid.

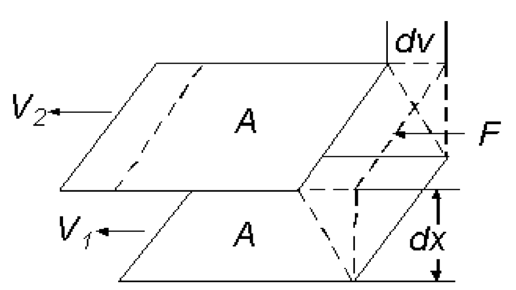


Figure 2. Viscosity.

$$\text{Viscosity} = \eta = \frac{F'}{S} = \frac{\text{shear stress}}{\text{shear rate}}$$

Two equal areas of parallel planes of fluid are moving in the same direction at different velocities, V_1 and V_2, and are separated by a distance *dx*. The shear rate, or velocity gradient, is calculated as dv/dx. F' symbolizes the shear stress, which is the force per unit area that is required to produce the shearing action (F/A). If a material requires a shear stress of one dyne per square centimeter to produce a sheer rate of one reciprocal second, then it has a viscosity of one poise (P)[3].

In a rotational viscometer, a spindle is used as a measurement tool through a calibrated torsion spring. The spindle is immersed in the test fluid. The spring will deflect as the fluid drags against the spindle.

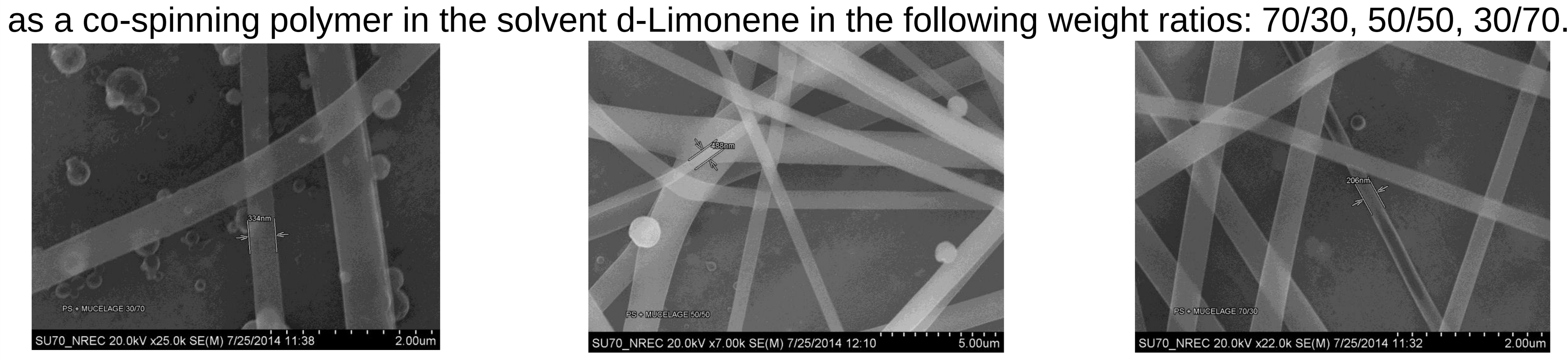
Figure 3. Fungilab Rotational Viscometer

Objectives

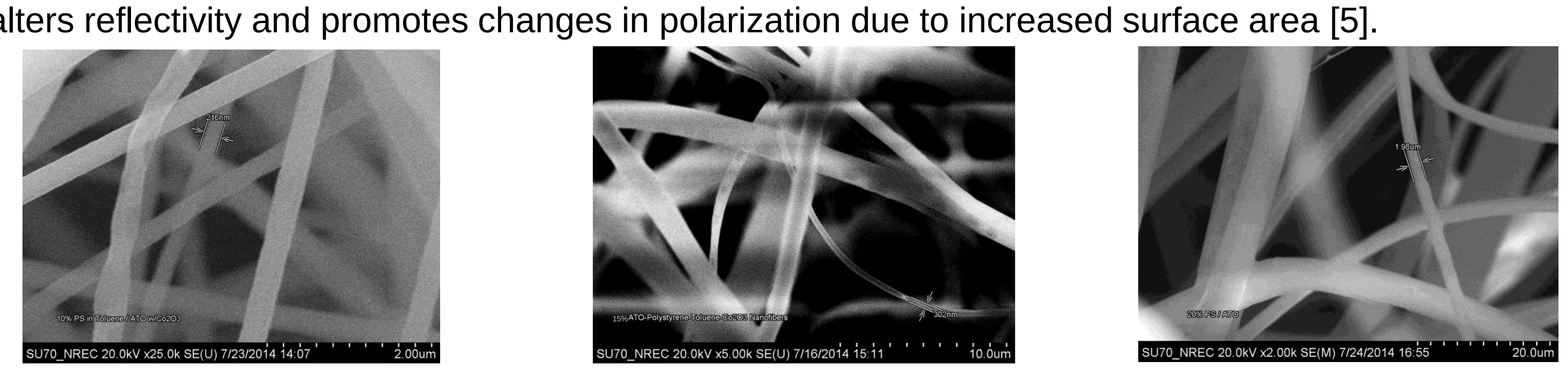
The objective of this research is to determine how viscosity affects fiber formation and functionality. The parameters for the polymer solutions that will create optimum fibers for water filtration, piezoelectric applications, thermal reflective military applications and self-healing capability for military applications can then be determined.

Applications

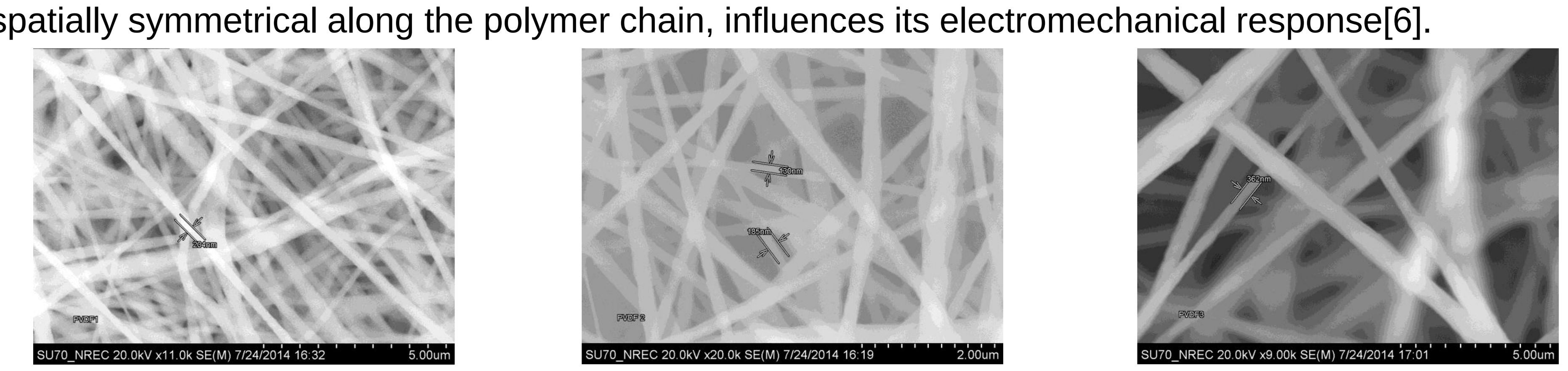
Water Filtration – Cactus mucilage, a neutral, complex carbohydrate from the prickly pear plant,*Opuntia ficus-indica,* has – OH (hydroxyl) and –CO groups (carbonyl and carboxyl) functional groups that react with arsenate for adsorption[4]. To electrospin cactus mucilage, we used polystyrene as a co-spinning polymer in the solvent d-Limonene in the following weight ratios: 70/30, 50/50, 30/70.



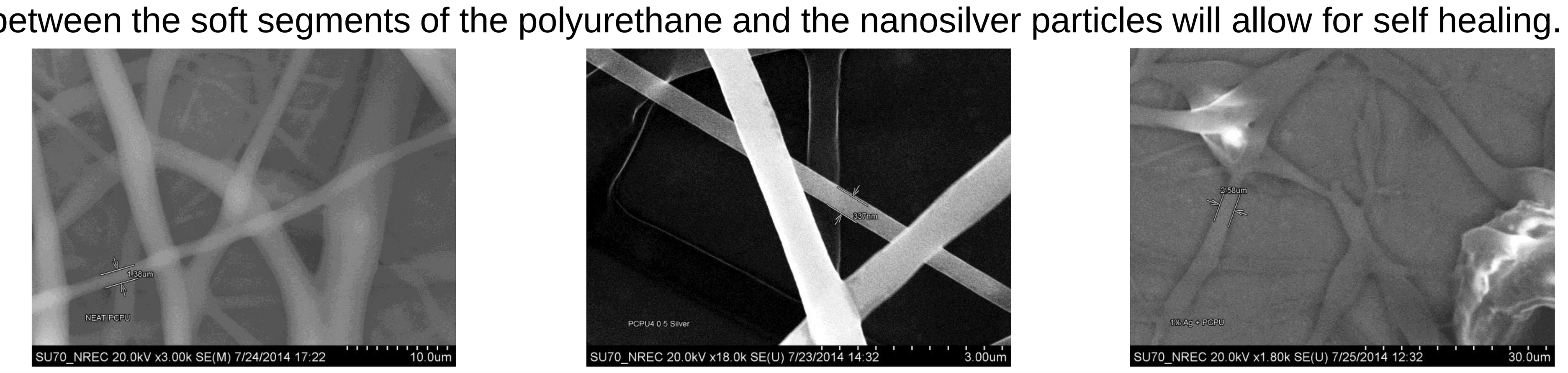
Thermal Reflective Military Applications Cobalt doped antimony tin oxide (ATO) nanofibers are being researched for use in thermal reflective military applications as protection against infrared laser degradation for fiber composites. Cobalt oxide (CoO) is a metal oxide sol-gel solution with high conductivity and thermal infrared reflective properties. With high heat treatment temperatures, and because of the similar ionic radii (Sn = 0.071 nm and Co = 0.071 nm), Co^{3+} from Cobalt oxide can merge into the crystal lattice structure of ATO and replace Sn^{3+} dislocations and defects. We hypothesize this alters reflectivity and promotes changes in polarization due to increased surface area [5].



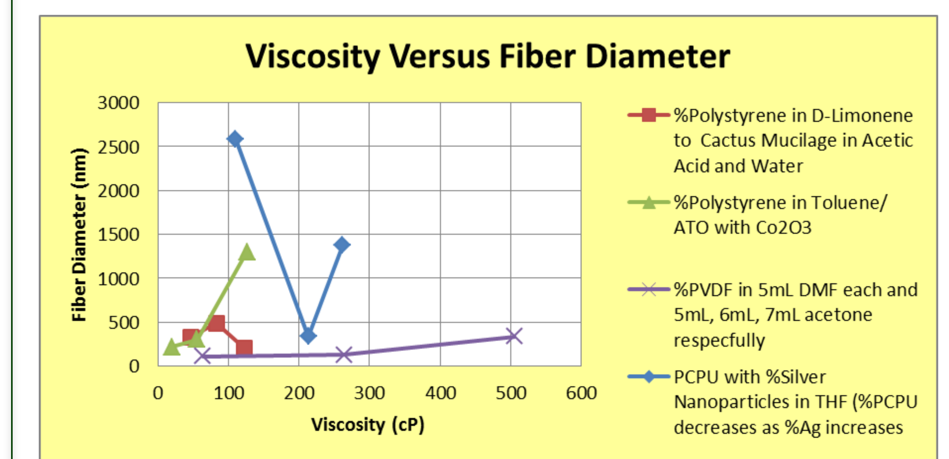
Energy Generation – Polyvinylidene difluoride (PVDF) is a piezoelectric polymer that is being researched for energy generation application for possible use in robotics, computers, medical devices and various transducers. Its polarity, which is due to the hydrogen and fluorine atoms that are spatially symmetrical along the polymer chain, influences its electromechanical response[6].



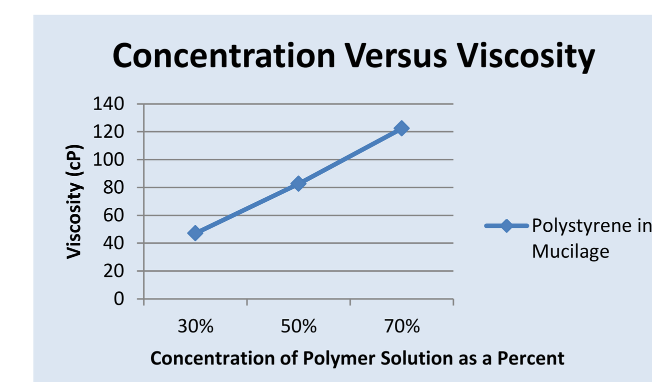
Self-Healing Military Applications– Polycarbonate Polyurethane (PCPU) fibers with nanosilver particles are being researched for military applications due to PCPU's self-healing capability. When the surface of PCPU is disrupted, the hydrogen bonding between the polyol based soft segments and urethane based hard segments of polyurethane are now accessible[7]. Hydrogen bonding that occurs between the soft segments of the polyurethane and the nanosilver particles will allow for self healing.

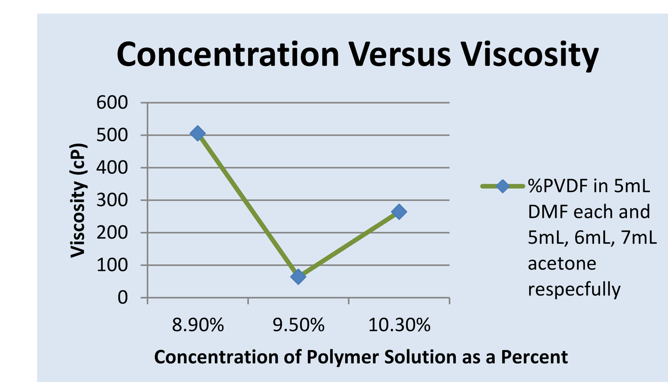


Conclusions

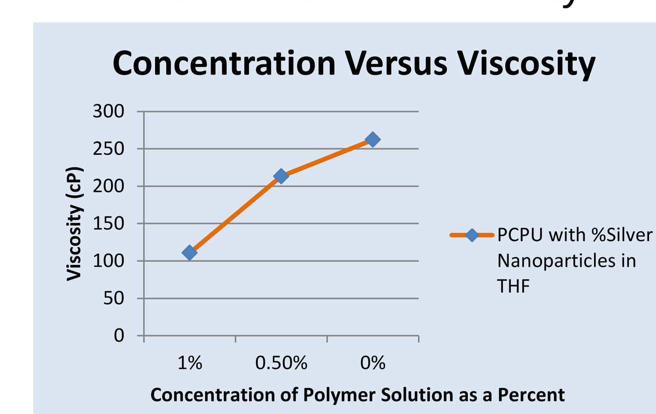


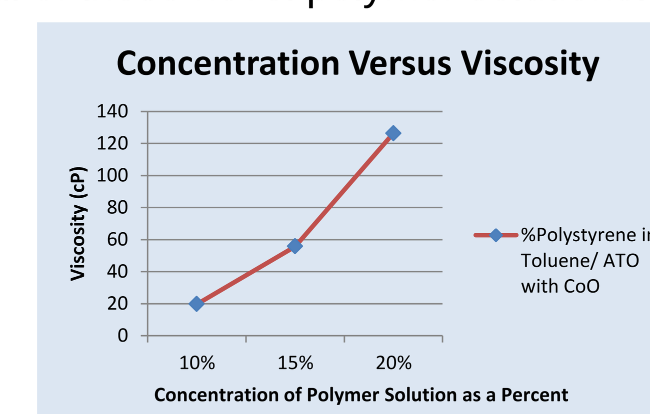
With these novel polymer solutions, there is no tracking for viscosity. Time permitting, further investigations can be done by taking an average diameter of 100 or more fibers for each polymer sample.





Concentration tracks viscosity for all of these novel polymer solutions.





Concentration does affect functionality of the fibers. When filtering a 50 ppb arsenic in water solution, the 50:50 polymer solution of polystyrene:mucilage removed an average of 18.94% of the arsenic out of the water, compared to the 70:30 solution, which removed 9.72%. Further investigations can test how concentration affects the functionality of the other types of polymer solutions.

Referenced Resources

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For more information about the program visit: http://fmri-ret.eng.usf.edu/. The Research Experience for Teachers (RET) at the Functional Materials Research Institute at USF is funded by the National Science Foundation under award number 1301054.