Processing biopolymers into 3D nanofiber sponges

Prof. Dr. Christian Adlhart
Head of Center for Functional Materials and Nanotechnology, Institute of Chemistry and Biotechnology, adas@zhaw.ch

Nanofibers are 100 to 1,000 times thinner than human hair. They are characterized by a large specific surface area and are used wherever interactions with surfaces are critical. Filters, membranes in protective clothing, coatings of implants or chemical sensors may contain nanofibers. At ZHAW, we have been working for several years on a process to produce ultralight sponges from nanofibers. In this process, the fibers are cut and dispersed. The dispersions are freeze-dried and a highly porous fiber skeleton remains. This is suitable, for example, as a high-performance filter [1] or thermal insulator [2].

Using materials from side streams

In the BIOMAT project, we wanted to replace synthetic polymers such as nylon or the starch-based biopolymer pullulan, with renewable materials from side streams that do not compete with food production. The polysaccharide chitin can be obtained from the cell walls of fungi remains or the exoskeleton of crustaceans. The corn protein zein is a by-product of bioethanol production.

Property	Nylon	Chitosan
Fiber diameter / nm	175	309
Specific surface area / $m^2\ g^{-1}$	13	8.4
Bulk density / mg cm^{-3}	16.6	5.8
Porosity / %	98.5	99.6
Effective modulus / kPa	5.3	43

Table 1: Properties of nylon and chitosan nanofiber sponges.

Biopolymers differ from synthetic polymers in that they contain many functional groups, such as OH or NH_2. This often makes them more difficult to process, but offers the possibility of selectively functionalizing the fibers through chemical reactions. In the processing of biopolymers, we want to develop strategies to avoid the use of organic solvents according to the principles of green chemistry, e.g. through the use of aqueous processes. We have succeeded in this with chitosan nanofibers, Figure a, and their conversion into ultralight and highly porous nanofiber sponges [3]. The comparison with a nylon nanofiber sponge [4], Figure b, shows the potential of this by-product from the food industry (Table 1). Although the chitosan nanofibers were slightly thicker and their specific surface area correspondingly lower, the chitosan material was 3 times lighter and consisted almost entirely of air (99.6 % porosity). The 8-fold stiffness with a modulus of 43 kPa was impressive.

In practice, we used the material as a filter for microplastics. In model tests > 99.4 % of all particles were removed. Since the sponge was flexible, liquids could be pumped through the filter by mechanical movements like an oyster [3]. We are currently working on zein-based nanofiber sponges. Characterized by a hydrophobic surface, they are suitable for separating water-in-oil emulsions, Figure c, or removing oil spills, Figure d, similar to our silane-modified pullulan sponges [5]. This is because these materials can absorb more than 100 times their own weight in oil. Although we assume that the bio-based nanofiber sponges are biodegradable, thus closing the material cycle, we have yet to confirm this in the context of BIOMAT. ■

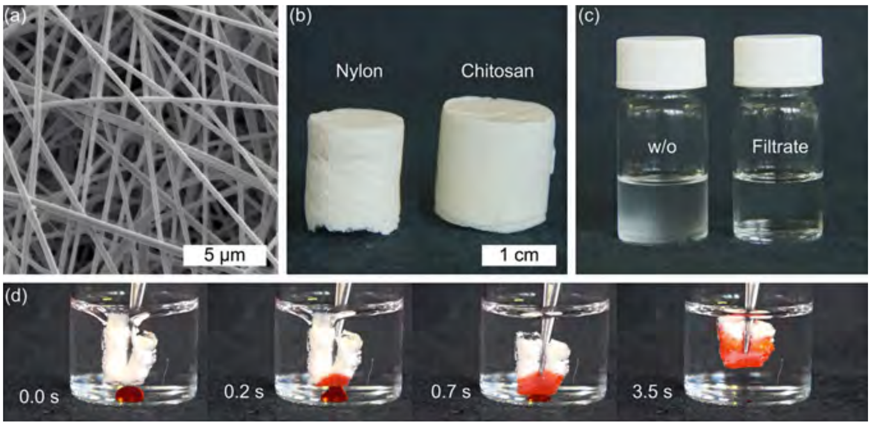

Fig.: (a) Scanning electron microscope (SEM) image of chitosan nanofibers; (b) crude oil based nylon and biomaterial based chitosan nanofiber sponge; (c) water-in-oil emulsion and filtrate after passage through chitosan nanofiber sponge; (d) rapid uptake of sudan red dyed chloroform from water.

[1] Deuber, F.; Mousavi, S.; Federer, L.; Hofer, M.; Adlhart, C. *ACS Appl. Mater. Interfaces* 2018, *10* (10), 9069, 10.1021/acsami.8b00455. **[2]** Zhao, S.; Emery, O.; Wohlhauser, A.; Koebel, M. M.; Adlhart, C.; Malfait, W. J. *Mater. Des.* 2018, *160,* 294, 10.1016/j.matdes.2018.09.010. **[3]** Risch, P.; Adlhart, C. *ACS Appl. Polym. Mater.* 2021, *3* (9), 4685, 10.1021/acsapm.1c00799. **[4]** Mousavi, S.; Filipová, L.; Ebert, J.; Heiligtag, F. J.; Daumke, R.; Loser, W.; Ledergerber, B.; Frank, B.; Adlhart, C. *Sep. Purif. Technol.* 2022, *284,* 120273, 10.1016/j.seppur.2021.120273. **[5]** Deuber, F.; Mousavi, S.; Federer, L.; Adlhart, C. *Adv. Mater. Interfaces* 2017, *4* (12), 1700065, 10.1002/admi.201700065.