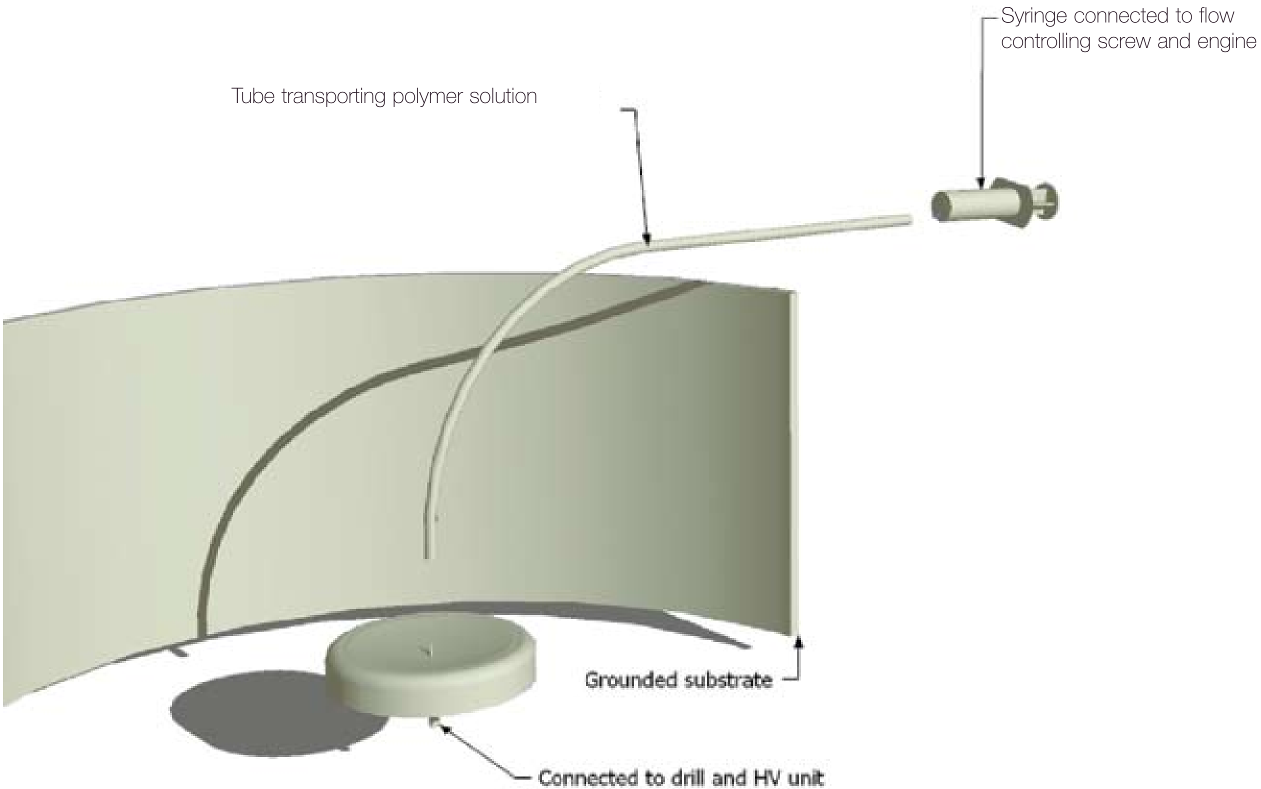


Figure 1. Principle sketch of the large-scale electrospinning device developed at IFP RESEARCH AB [2].

Nanofibers in technical textiles

Anna Nelvig, Jonas Engström, Bengt Hagström, Pernilla Walkenström, IFP Research AB

Electrospinning of nanofibers at IFP Research AB

Electrospinning is a straightforward method of producing polymeric fibers with diameters in the range of a few hundred nanometers. The surface to weight ratio as well as the porosity of a nanofibrous web is large compared to other non-woven materials, and can be utilized for technical surplus in a range of applications such as technical textiles.[1]

At IFP Research AB, we are presently focusing on the use of nanofibers in technical textiles. As a consequence we need to be able to produce large amounts of nanofibers for testing and prototype manufacturing. Until a few years ago we focused on small-scale electrospinning, however we have now developed an up-scaled principle of electrospinning nanofibers.[2] The principle is based on centrifugal forces working on a polymer solution simultaneously with electrostatic forces and can be seen in Figure 1. A pump applies the polymer solution on a rotating disc that hurls the solution into the applied electric field.

The polymer solution is applied on to a rotating disc through a tube. High voltage is applied to the polymer solution and a grounded metallic cage surrounds the device. Centrifugal and electrostatic forces initiates fiber formation, the fibers are collected on the walls of the grounded cage.

The authors have worked within the field of electrospinning of nanofibers for several years, at IFP Research AB. Their various background creates a multidisciplinary team representing competences within polymer chemistry, chemical engineering and mechanical engineering. Within technical textiles, the targeted applications have mainly been filters and sound absorption materials.

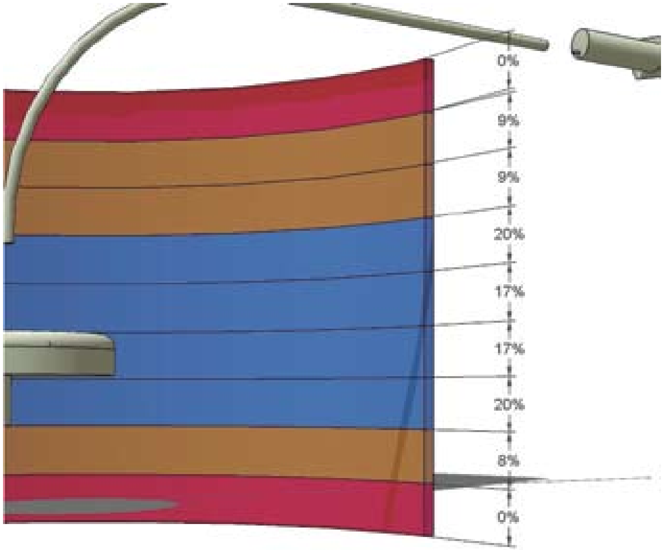


Figure 2. The spread of nanofibers spun in the large-scale electrospinning device developed at IFP Research AB

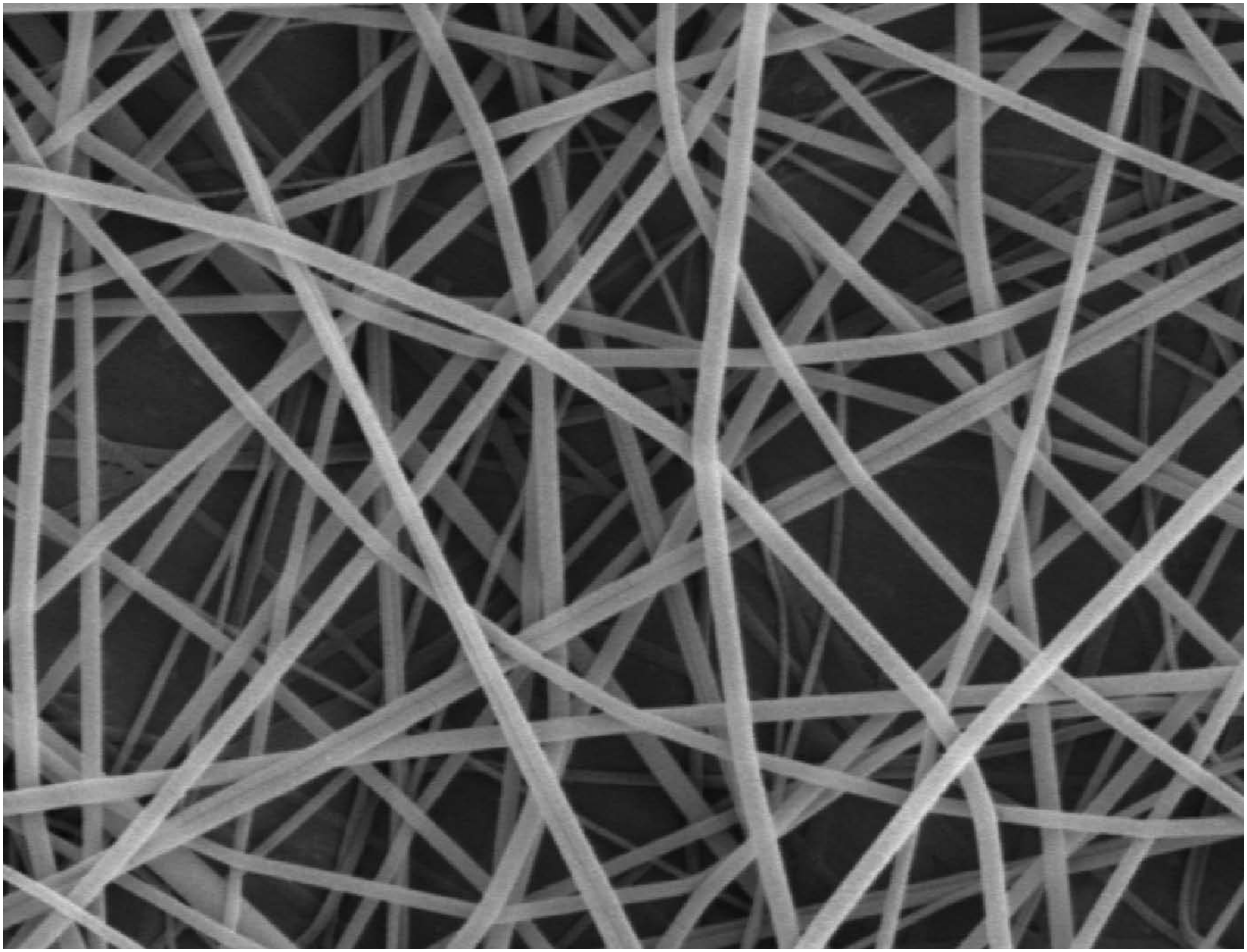
During a recent diploma work (Karl Ivanovic) at IFP Research AB the parameters of the new device were investigated. Figure 2 shows the percentage spread of the nanofibers on the grounded collector. One problem is obviously to obtain an evenly distributed web of nanofibers over a large area. By creating a cage that passes the rotating disc several times the layer is to be more even.

Environmentally friendly approaches

When it comes to large-scale production of nanofibers in the production line of technical textiles, environmental aspects must be taken into consideration. We are therefore working mainly with water-based systems, which is also economically and technically preferable over organic solvents. Examples of water–soluble polymers are cellulose acetate (CA), polyvinylalcohol (PVA) and polyvinylpyrrolidone (PVP). The latter are shown in Figure 3.

However, nanofibers spun from water-based systems dissolve in contact with water, and even humid air. The use of nanofibers for applications in technical textiles, e.g. in air filters demands for waterproof materials. We have tried a few different possibilities to obtain water resistant fibers from water-based systems:

Figure 3. SEM picture of electrospun nanofibers of PVP with diameters between 200-400 nm.



By cross-linking the polymer chains within the fibers dissolution of the web could be prevented. However, although the cross-linked PVA-web withstands water, swelling temporarily turns the fibers into a film. By soaking the film in organic solvents the fiber structure can be restored. This procedure is shown in Figure 4 a, b and c. Work is in progress to increase the degree of cross-linking in order to prevent film formation.

Another possibility is to treat the water-soluble fibers with hydrophobic plasma it is possible to create a water resistant membrane on their surface. A group of students (from the course *Surface Technology* given by the Department of Polymer Technology, Chalmers University of Technology) performed experiments with plasma treatment on PVA nanofibers in a project work at IFP Research AB. Their work showed that trifluoromethane was the most efficient gas for plasma treatment of PVA. The hydrophobic layer from the plasma treatment stays active for at least a couple of weeks. The results may be improved by using another kind of plasma equipment or by storing the samples in a different way. Nonetheless, using this method for fibers in a filter means short filter life length.

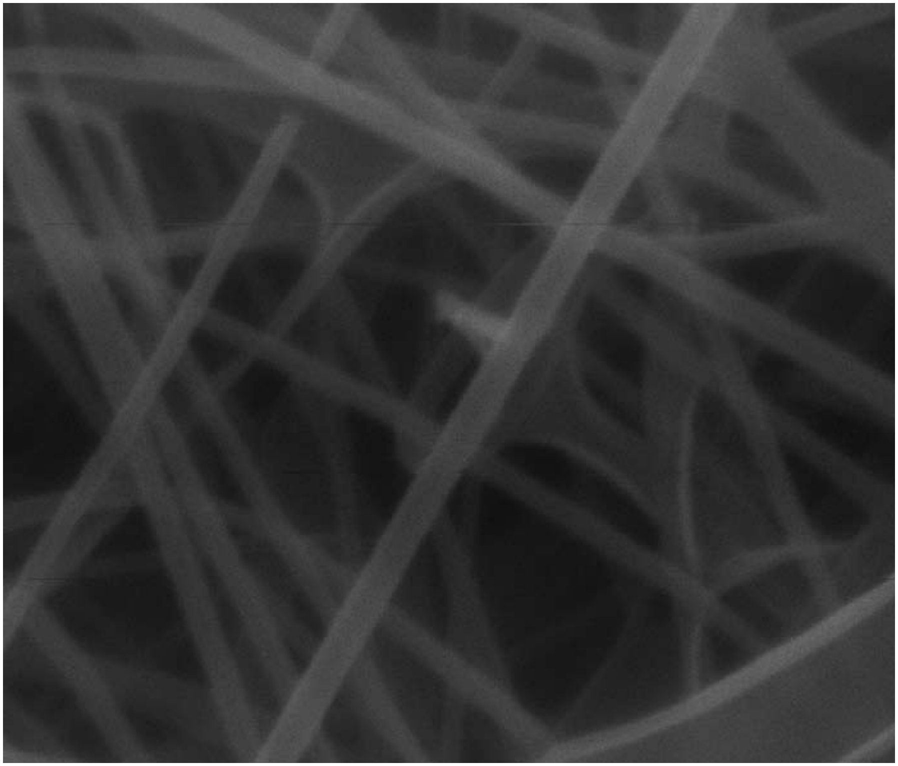


Figure 4 a. SEM picture of PVA nanofibers electrospun with a cross-linking agent. The fiber diameters are between 200-400 nm.

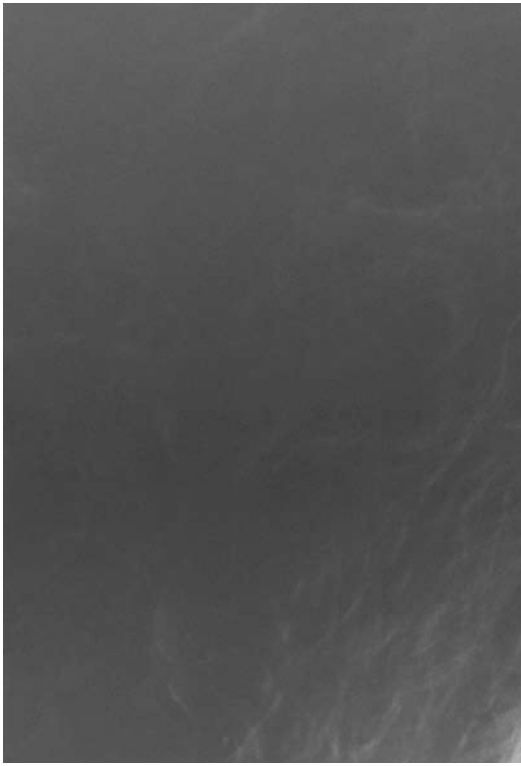
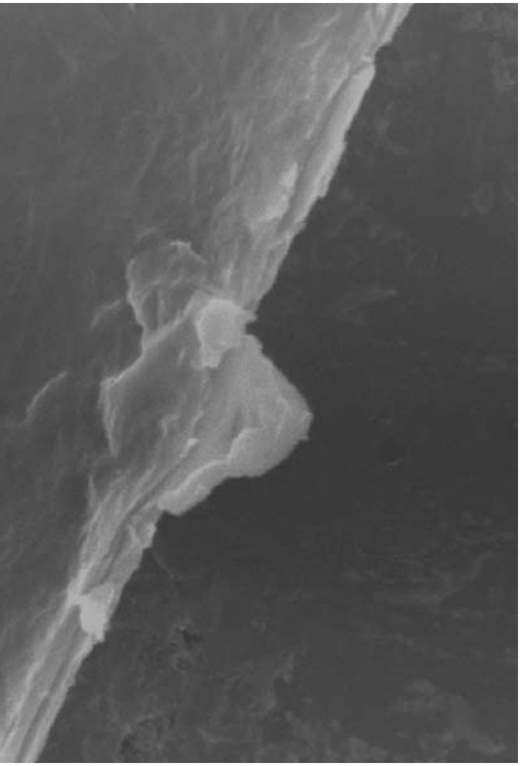


Figure 4 b. The cross-linked PVA nanofibers forms a film the moment they are soaked in water. The length of the figure represents about 150 µm.



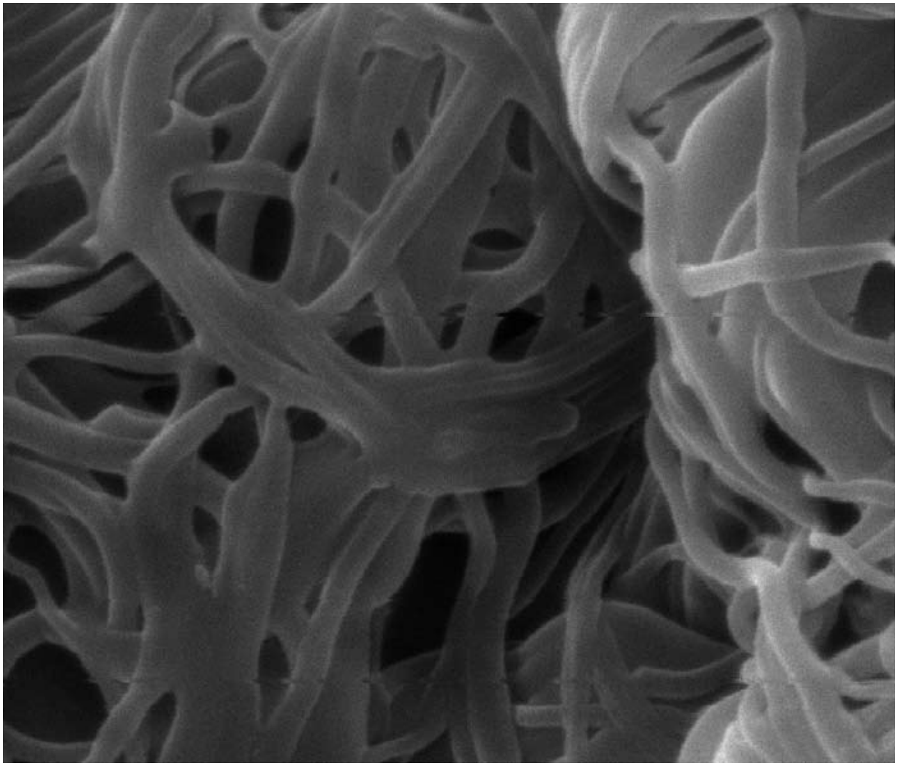


Figure 4 c. Treating the film of cross-linked PVA nanofibers with organic solvents partially restores the fiber structure. The length of the figure represents about 60 μm.

Technical Textiles
IFP focuses on implementing nanofibers in filter- and sound absorbing applications, there providing technical surplus value like increased filter efficiency and sound absorbing properties.

Air filtration
There are several different classes of filters depending on area of use; some different samples are shown in Figure 5. Roughly speaking there are coarse filtering and fine filtering. Coarse filtering is used in ventilation systems in offices, public buildings, schools, etc. Fine filtering is used in more sensitive environments such as hospitals or laboratories where viruses and bacteria are handled. Fine filtering is also used where small, harmful particles exist in large amounts, for example in the operator's cabin in mining vehicles, in industrial vacuum cleaners, and in high performance breathing masks used for asbestos handling or similar.

Using nanofibrous webs instead of the common dense HEPA media (High Efficiency Particulate Air-filter) allows the production of filters with very high particle retention while the pressure drop over the filter remains low. This is a consequence of increased surface energy and porosity within the structure when using nanofibers.

Figure 5. In the foreground; HEPA filters for vacuum cleaners from Dinair Filter AB.
In the background; different classes of coarse filters from Dinair Filter AB and CE Produkter AB.

Initial experiments with nanofibers spun on a coarse substrate, see Figure 6, shows that the pressure drop over a thin web of nanofibers is small. A lower pressure drop means a lower cost for the user by the means of air pumping systems. The same experiments also indicate that the nanofibers have the ability to trap a large amount of very small particles. This is due to the higher surface energy provided by the nanofibrous structure, which increases the degree of the filtering mechanisms controlled by diffusion, interception and impaction. The decrease in pressure drop is a consequence of the high porosity.

Sound absorption

Noise, or unwanted sound, is a growing environmental problem in today's society. Long exposure to noise can lead to work related stress, impaired hearing, and sleeping disorder. Thus, noise can be considered a threat to public health. In a survey from 2001, 9 % of the responders said they were disturbed by noise from traffic, and 9 % that they were disturbed by noisy neighbours.[3] As many as 22 % of the responders claimed to be disturbed by noise of some form. Increasingly higher demands are therefore set on noise reduction in new products, e.g. low noise levels from the road are becoming a very important sales argument for new cars.

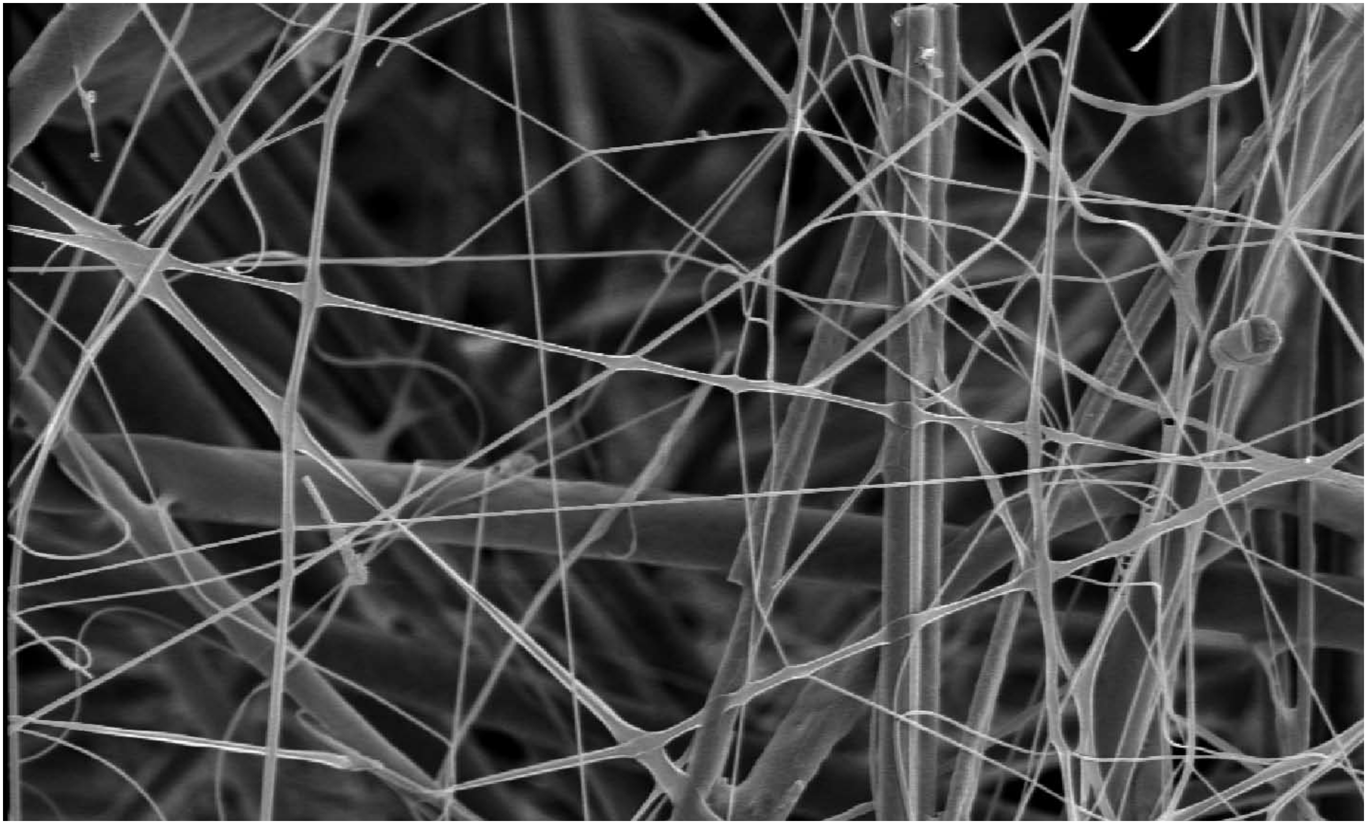


Figure 6. PVA electrospun on a non-woven substrate of celloluse. The fibers of the substrate have diameters in the range of 2-10 µm, while the PVA fibers have diameters in the range of 200-700 nm.

Research has shown that nanofibers, i.e. fibres with diameters in the range from a few nanometres up to several micrometers, have very attractive properties for sound absorption. For some frequencies, absorbents based on nanofibers can have much higher absorption factors compared to traditional absorbents. Today, the Czech company Elmarco has two patents for a product called NanoSpider Acoustic Web, which is a compound material consisting of several layers of carded webs and layers of nanofibers in between.[4-6] Elmarco suggests several applications for this product, but in order to be efficient as a sound absorbent it has to be approximately 40 mm thick.

In October 2007, IFP Research AB in cooperation with a number of Swedish SME:s will start a project where nanofibers for sound absorption will be studied. The general idea is to manufacture nanofiber based materials with a controlled porosity in order to achieve better sound absorption properties. In this technique a sound wave hitting the surface of the absorbent will experience a progressively denser material as it penetrates the material. In this way most of the sound will be absorbed within the material instead of reflected at the surface. The expectation is that this type of materials can be made thinner and lighter than today's sound absorbents.

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