Herbert Sixta
Professor of Biorefineries
Department of Forest Products Technology
School of Chemical Technology

IONCELL-F, a novel Man-made Cellulosic Fiber

The first artificial fibers were introduced by the French scientists Hilaire de Chardonnet at the World Exhibition in Paris in 1889. The material, consisting of nitrocellulose, was extremely flammable and thus could not reach any importance in the textile industry. Only a few years later in 1892 the first viscose patent on the viscose process was granted to the British scientists, Charles Frederick Cross, Edward John Bevan and Clayton Beadle. The first commercial viscose plant was built by the British company Courtaulds Fibers in 1905 before the first industrial plants came on stream in Central Europe and USA. Although the use of toxic carbon disulfide posed a significant health and safety risk, the viscose technology succeeded against other fiber production technologies mainly because of the unique fiber quality and the broad variety of different fiber types ranging from standard fibers to cotton-like Modal and Polynosic fibers and very strong technical fibers such as tyre cord. In the beginning of the 20th century, the viscose fiber production grew very slowly. Only 3.000 t of fibers have been produced in the year 1930. The viscose boom, however, started in the 1930s with many new installations, triggered by the continuously improved technology and the starting preparations for war in Germany to become independent on cotton imports. The global viscose production reached almost 600.000 t in 1940 during World War II. Parallel to the upturn of viscose fibers, Nylon, the first synthetic fiber, was invented by Wallace Carothers from DuPont. Its production started in 1935. The thermoplastic polymer was first used as a material for women's stocking, parachutes, ropes and the like before it entered the textile market. Although the viscose fiber market kept on growing until the late 1970s, the amount of synthetic fibers, complemented by polyester, polypropylene and acrylic fibers, developed significantly faster. The global production of synthetic fibers equaled the viscose fiber production already in the late 1960s. The synthetic fiber production continued to grow by 5-10% on average per year, while the viscose fibers peaked end of the 1970s before it lost more than 40% of its production in the beginning of 2000. The consumption of natural fibers, consisting of cotton (78-83%), wool (4%), flax, hemp, jute and ramie (altogether 13%) and others (silk, abaca, algave, coir, kapok, sisal and silk, altogether 5%), increased by about 65% since 1965. The natural fibers consumption, however, stagnates since 2004 at 31 Mio±1.5 t/a. As shown in Figure 1, the global consumption of synthetic fibers exceeded that of natural fibers already sixteen years ago in 1998. Today, the annual synthetic fiber consumption exceeds that of natural fibers by about 20 Mio t.

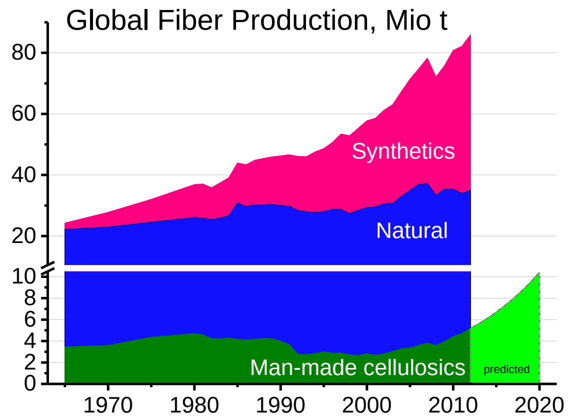

Figure 1: Global production of man-made cellulosics (viscose, Lyocell, Acetate filaments and staple fibers), natural fibers (cotton, wool, flax, hemp, jute, ramie, abaca, agave, coir, kapok, sisal and silk) and synthetic fibers (both filaments and staple fibers of polyamide, polyester, polypropylene and polyacrylnitrile). Source: The Fiber Year 2013 - World Survey on Textiles & Nonwovens.

The increasing prosperity of the growing population increases the demand of cellulosic textile fibers, which can no longer be satisfied by the global growth of cotton and the existing cellulose man-made cellulosic fiber (MMCF) capacities. As of 2001, the increasing demand for MMCF was covered by additional installation of viscose fiber production units mainly in China. Globally, the total man-made cellulosic fiber production (staple + filament) increased from 2.7 to 5.2 Mio t/ in 2012 which corresponds to an average annual growth rate of 5.6%. However, with increasing environmental awareness also in the Asian countries, new abatement technologies have to be installed, which in turn impairs the economic feasibility against the new NMMO-based Lyocell fiber technology. In addition, NMMO-based Lyocell fibers, e.g. Tencel®, reveal a better wearing comfort than viscose fibers owing to their superior moisture absorption/desorption behavior and the much better dimension stability under wet conditions. Currently, the NMMO-based Lyocell technology is completely covered by Lenzing AG and the company's policy prevents that this technology can be licensed by other companies. Despite the high patent coverage in the field of the NMMO-based Lyocell technology by the Lenzing AG, alternative technologies have been developed over the years, making it possible that the first NMMO-based Lyocell installations will incur in Asia in the foreseeable future. However, NMMO, as a cellulose solvent, has some intrinsic shortcomings such as its chemical and thermal instability which affords the addition of stabilizers, but are no guarantees of avoiding dangerous runaway reactions. The extension of the Lyocell spinning technology to direct cellulose solvents of high thermal and chemical stability is very attractive from a safety, environmental and economic point of view.

With the rediscovery of ionic liquids (ILs) as powerful cellulose solvents in 2002 by Rogers and his co-workers new research efforts were initiated to design task specific ILs aiming at the substitution of NMMO as the only commercial direct cellulose solvent. The ionic liquids, which proved to be effective cellulose solvents and thus have been used for the preparation of spinning dopes, were all imidazolium-based. It was shown that, compared with the NMMO process, the direct dissolution of cellulose is more easily controlled, the process is inherently safer, and fibers with properties equal to those produced from NMMO solution were obtained. However, the imidazolium-based ionic liquids have shown to be not inert towards cellulose. Depending on the substituents on the imidazolium ring and the chemical nature of the anion, cellulose underwent severe degradation, especially at higher temperatures (>90°C) which again afforded the addition of stabilizers.

Quite recently, researchers at Helsinki University and Aalto University were successful in developing a novel cellulose spinning solvent consisting of a superbase / acid ion pair, which revealed excellent spin stability resulting in outstanding fiber properties. The optimum rheological properties of the cellulose dope for spinning are attained even at moderate temperatures at which uncontrolled cellulose degradation can be avoided. The mechanical properties of the resulting fibers are outstanding and reach the highest level known for commercial regenerated cellulose fibers (tensile strength 700 – 870 MPa, elastic modulus 25 – 35 GPa). Figure 2 underlines the superior mechanical properties of the novel IONCELL fiber.

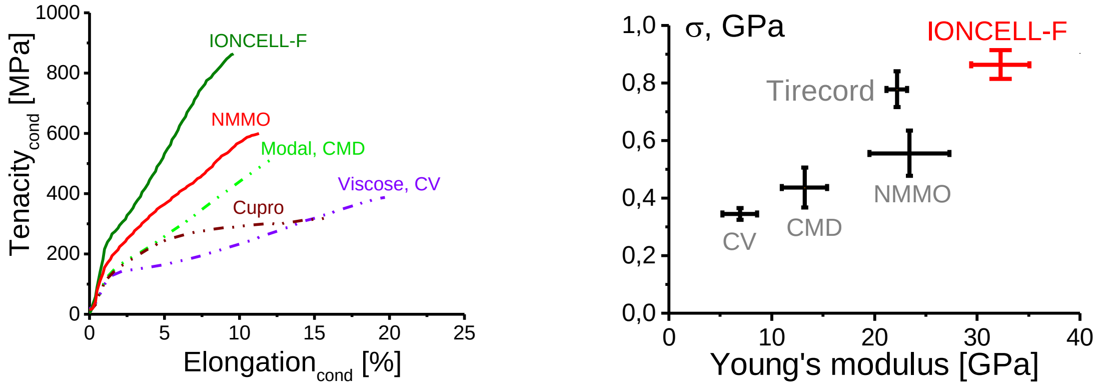

Figure 2, Left: Stress-strain curve of the Ioncell-fiber and of commercial regenerated cellulose fibers. Right: tensile strength vs. Young's modulus of Ioncell fiber in comparison to commercial regenerated cellulose fibers.

After the breakthrough of the new Ioncell-fiber development in early spring 2013, our team continued optimizing the process for several months to allow stable and secure spinning conditions before we agreed to produce the necessary amount of staple fibers for the manufacture of a knitted scarf which was presented on the occasion of the annual Finnish Bioeconomy Cluster (FIBIC) seminar.

In one of the autumn meetings of FIBIC a representative of the famous Finnish textile and Fashion Company Marimekko® showed interest in our Ioncell-fiber. After a short meeting, we agreed on a collaboration with Marimekko® and Helsinki University to prepare the fiber material for the manufacture of a dress which should then be presented on the occasion of Marmekko®'s autum/winter fashion show in Helsinki Central Railway Station's ticket hall on March 13, 2014.

We were very excited about this opportunity and our PhD students Anne Michud, Shirin Asaadi and Yibo Ma produced the necessary amount of staple fibers from a Finnish birch pulp under the guidance of Dr. Michael Hummel. The whole project was coordinated by Marjaana Tanttu, a master's student of the Department of Textile Design, School of Arts Design and Architecture at Aalto University. With joint forces almost 1 kg of staple fibres were produced. To obtain a small natural crimp, the fibers were washed offline with hot water and air dried without tension. The continuous filaments were cut into staple fibers of 37 mm length, opened and conditioned at controlled conditions for three days. The yarn was then spun at the Swedish School of Textiles (University of Borås, Sweden) using a mini spinning line comprising of a Laboratory carding machine, a Stiro-Roving-Lab, and a Ring-Lab Fibers. All fibers were carded twice. After the first carding, the sliver was cut, folded, and then fed back to the card in perpendicular orientation compared to the first round. Subsequently, the sliver was fed in tube shape to a drafting machine. The sliver was first drafted once, then doubled and drafted again. Finally two of the double-drafted slivers were combined and drafted together to form a roving which was fed to a spinning unit. A 35 mg ring was used to produce the yarn. Parts of the yarn were dyed in order to provide the material to produce the desired pattern in the dress. The yarn was then knitted with a Stoll flatbed knitting machine. The dress shown in

Figure 3 was designed by Tuula Pöyhönen from Marimekko® and presented on the occasion of the fashion show in Helsinki Central Railway Station's ticket hall on March 13, 2014.

Figure 3: The dress Allu, designed by Tuula Pöyhönen, is knitted out of the Ioncell fibre which is produced from birch Kraft pulp from a Finnish pulp mill (Courtesy to Marimekko®). Fashion show in Helsinki Central Railway Station's ticket hall on March 13, 2014.