CHEMICAL RECYCLING OF TEXTILE WASTE

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Abstract: *Chemically recycled textile waste can be used to manufacture new textile products. It can ensure up cycling process. Two groups of chemical recycling are: recycling at the polymer level and recycling at the monomer level. The basic steps of chemical recycling process are: preparation, cleaning and recycling of the waste. Chemical recycling technologies have been developed for the processing of cotton, polyester and poly-cotton. Currently, the most part of chemical recycling companies operate at their research centers and first pilot factories, and still improve their recycling methods. Chemical recycling technologies will be commercially effective in the next 5-10 years. Innovative textile waste recycling companies in Europe are: Renewcell/Circulose, Infinite Fiber Company, SaXcell, Södra, Worn Again Technologies, Carbios (France), Erema.*

Keywords: textile waste, chemical recycling, up cycling, cotton, polyester, poli-cotton.

HEMIJSKA RECIKLAŽA TEKSTILNOG OTPADA

Apstrakt: *Hemijskom reciklažom i korištenjem" vlakno-od-vlakna" tehnologije, od tekstilnog odpada mogu da se proizvedu nova vlakna. Hemijska reciklaža obezbeđuje reciklažu na gore. dve grupe hemijske reciklaže su: reciklaža na polimernom i reciklaža na monomernom nivou. Osnovne etape rada u procesu hemijske reciklaže su: priprema, čišćenje i reciklaža otpada. Tehnologije hemijske reciklaže su razvijene za preradu pamuka, poliestera i poli-pamuka. Trenutno većina kompanija koje koriste metode hemijske reciklaže rade na poboljšavanju svoje tehnologije u laboratorijama i pilot fabrikama malih kapaciteta. Tehnologije hemijske reciklaže su još uvek u procesu istraživanja i razvoja, i komercijalno će biti efikasne tek u narednih 5 do 10 godina. Kompanije koje primenjuju hemijsku reciklažu tekstilnog otpada u Evropi su: Renewcell/ Circulose, Infinite Fiber Company, SaXcell, Södra, Worn Again Technologies, Carbios (France), Erema.*

Ključne reći: tekstilni otpad, hemijska reciklaža, reciklaža na gore, pamuk, poliester, poli-pamuk.

1. INTRODUCTION

The global increase in consumption and production of textile products has resulted in significant accumulation of textile waste in many countries of the world. The collection of textile waste, its sorting and recycling makes great challenges for society [1,2,3,4]. However, almost 100% of the textile waste created in the process of production and consumption of clothing can be recycled. In an ideal scenario, more than 60% of garments could be reused, 35% could be recycled and turned into other products, and only 5% should end up in landfills. But currently, most textile products end up in landfills at the end of their life cycle [5].

Up to now, mechanical recycling has the most developed technologies and application. However, it can ensure only *down cycling* of textile products, as recycled fibers have lower quality than virgin fibers. The mechanically recycled fibers can be used to manufacture non-wovens and composite materials for furniture, auto, and other industries [6]. Only less than 1% of collected textile waste is chemically recycled to make new textile products using fiber-to-fiber (F2F) recycling technology [1,2].

2. CHARACTERISTICS OF CURRENTLY DEVELOPED CHEMICAL RECYCLING TECHNOLOGIES

Chemical recycling involves the use of chemical processes or materials to break down textile waste into its raw materials. There are various technologies that belong to this type of recycling, but they can generally be categorized into two groups: chemical recycling at the polymer level and chemical recycling at the monomer level [1,2].

1. recycling at the polymer level:

- *pulping process* - cellulose-based textile waste (cotton, flax, hemp, bamboo and MMCF) is recycled to obtain a pulp similar to wood pulp. Such cellulose pulp can be used to create new MMCFs.
- *dissolution and hydrothermal processes* - used for recycling polyester and poly-cotton textile waste to melt polyester. The obtained polyester can be used for production of new fibers.

2. recycling at the monomer level:

- *methanolysis, glycolysis, hydrolysis and enzymatic decomposition* - used for recycling polyester and polyamide textile waste.

The specifics of the chemical recycling process vary depending on the technology used, but the basic work phases are following:

- *preparation of the waste* - waste is sorted on the bases of its origin, contaminants like zippers and buttons, leather labels are separated and the waste is mechanically shredded in small pieces,
- *cleaning of the waste* - dyes, softeners, and other additives that are used producing textiles are removed using different chemical processes.
- *recycling of the waste* - the waste is regenerated to turn it into fibers for textile manufacturing.

The regenerated fibers can be used to produce a variety of textile products of the same or even higher quality. All chemical recycling processes are well controlled and closed processes. The amount of waste generated during chemical recycling is very small. Currently, chemical recycling technologies have been developed for the processing cotton, polyester and poly-cotton [7].

Cotton recycling methods tolerate 10 to 15% of other fibers in the treated textile waste. Fibers of other origins are separated as waste, or burned and used as energy to support recycling process. Cellulose pulping process is the most commonly used method to recycle cotton waste. Different cotton recycling technologies are developed in Scandinavian countries. They are based on long time accumulated knowledge and experience of wood pulp and paper production in this part of Europe.

Although textile materials made from recycled polyester have been already long time used in the fashion industry, the polyester fibers in these materials are obtained from recycled plastic bottles, not from textile waste. The process of separating textile dyes and additives used in the fabric manufacturing process is critical recycling polyester textiles. Their presence in the treated waste seriously reduces the quality of the recycled products. Currently, several new technologies are being developed that manage to purify polyester from undesirable contaminants and with it, to produce recycled polyester that is suitable again for the production of textile fibers.

The first methods of poly-cotton recycling could not preserve both components of the material. Unsuitable for making new fibers became either polyester or cotton. In recent years, advanced recycling technologies have been developed that gently separate polyester from cotton and thus preserve both raw materials. Recycled polyester and regenerated cellulose fibers can be used to make new textiles.

However, so far methods have not been developed for the recycling viscose and lyocell, which are already regenerated cellulose fibers.

Currently, chemical recycling of textile waste has serious economic challenges. The production of recycled fibers is more expensive than the production of new virgin fibers. For example, the production of cellulose fibers from textile waste is twice as expensive as the production of traditional cellulose fibers from wood pulp. Currently, very little textile waste is recycled in industrial conditions and in larger capacities. Recycling companies are still testing and improving their technologies to enable large-scale waste recycling. Also, large quantities of correctly sorted and prepared textile waste are needed for industrial recycling [8]. For example, the company Sodra (Sweden) is looking for suppliers of cotton and poly-cotton waste in a minimum quantity of 25 tons in one delivery. Manual sorting of waste cannot provide the necessary quantities of waste, but automated sorting systems are expensive, and they are also still in the development phase.

Companies that develop advanced chemical recycling technologies are mostly supported and promoted by their shareholders and famous fashion brands that believe in the successful future of sustainable materials. Unique clothing styles, small series or collections of garments are created from textile materials made from recycled fibers to inform the public about innovations in recycling technologies and attract the attention of new potential investors and possible business partners. Chemical recycling technologies are still in the research and development phase, they will probably not be commercially effective until the next 5-10 years [8].

3. EUROPEAN TEXTILE WASTE CHEMICAL RECYCLING COMPANIES

The chemical recycling technologies for textile waste are being developed in different countries of the world, such as USA, Canada, Australia, China also in Europe. Many of them are already in the process of constructing pilot and commercial plants. Innovative textile waste recycling companies in Europe are: *Renewcell/Circulose* (Sweden), *Infinite Fiber Company* (Finland), *SaXcell* (Netherlands), *Södra* (Sweden), *Worn Again Technologies* (Switzerland), *Carbios* (France), *Erema* (Austria).

3.1. Cotton chemical recycling companies

3.1.1. Renewcell (Sweden)

Textile recycling company *Renevcell* from Sweden was founded in 2012. It uses a pulping process to create regenerated cellulose pulp patented under the name Circulose®. In 2021, *Renevcell* completed its first pilot factory. In 2022, the company launched the industrial production of Circulose® in cooperation with viscose fiber manufacturers Birla Cellulose (India), Easrman (USA), Lensing (Austria) and Tangshan Saniou (China) [9]. Renewcell uses post-industrial and post-consumer waste of at least 95% cotton as raw material for Circulose® pulp. The ready Circulose® pulp comes in the form of dehydrated sheets [11]. Dissolving the pulp it can be used to make viscose, modal or lyocell fibers. In textile materials, Circulose® is mixed with other fibers such as cotton [11,12].

Despite of successful and steady development, in February 2023, Renewcell filed for bankruptcy. The main reasons of business failure are mentioned: the form of ready Circulose® (dehydrated sheets), requirements for specific textile waste (at least 95% cotton) and the high price of Circulose® (twice as expensive as wood pulp) [10,13]. In June 2024, the remaining assets of the bankruptcy were purchased by the Swedish private company *Altor* and the company *Renewcell* was renamed to *Circulose*. The new owner of Renewcell is ready to develop an effective business strategy to protect and improve the production of cellulose pulp Circulose® [14].

3.1.2. Infinite Fiber Company (Finland)

Infinited Fiber Company (IFC) was founded in 2016. From 2018, *Infinited Fiber* has been operating in their pilot factory in Espoo, Finland [15]. The company *Infinite Fiber* has developed a technology for recycling cotton textile waste. After the textile waste cleaning process, the remaining cellulose is decomposed with urea to create cellulose carbonate powder. The powder is dissolved into liquid cellulose with a syrup consistency ready to be wet spun into filament fibers [16]. The manufactured cellulose carbonate fibers are patented and named Infinna™. Infinna™ is promoted as a replacement for cotton as the properties and strength of the fibers are similar to cotton fibers [17]. Cellulose carbonate fibers can be produced from cotton or other origin textile waste with 88% cellulose content. Currently, the company is building its first commercial plant in northern Finland. Industrial production of Infinna™ fibers is expected to start in 2026 [15].

3.1.3. SaXcell (Netherlands)

SaXcell was established in the Netherlands in 2015 [18,19]. The company has developed a technology for recycling textile waste containing at least 90% cotton. Regenerated cellulose is obtained for the production of viscose or lyocell fibers. The end product of the company is cellulose fiber SaXcell. Currently, the company promotes SaXcell L30 fiber, which consists of 30% recycled cellulose and 70% wood pulp [19,20]. In 2020, *SaXcell* built its first pilot plant in Goor (Netherlands) and started to produce cellulosic pulp. Currently, the company is developing a small production plant in Enschede (Netherlands) [18,21].

3.2. Poly-cotton chemical recycling companies

3.2.1. Södra (Sweden)

The company *Södra* was founded in 1938 as an association of forest owners and an international grouping of the forestry industry. The main business areas of the company are: wood processing, production of paper pulp and biofuel, as well as production of cellulose pulp for the world's largest viscose producers [22].

In 2019, *Södra* announced its own textile waste recycling technology and the first product OnceMore® - wood pulp with 3% cellulose from recycled textiles [23]. Today, OnceMore® pulp already contains 20% cellulose from recycled textiles [24].

Södra recycles poly-cotton textile waste with a minimum of 70% cotton and 30% polyester, in white or off-white colour. Textile waste generated in hospitals and hotels (worn out bed linen, towels, tablecloths, bathrobes) are mostly used [22]. OnceMore® pulp is obtained in the process of dissolving polyester in textile waste and making cellulose pulp from cotton. Polyester is burned and used as energy for recycling process [24]. The separated cellulose pulp can be used to produce viscose, modal and lyocell [24]. Currently, OnceMore® pulp contains 20% recycled pulp and 80% wood pulp and is produced in a factory in the town of Morrum in the southern part of Sweden. Production capacity 6000 tons per year. In the near future, *Södra* plans to produce OnceMore® pulp from 50% recycled textile material and 50% wood material [24,25].

3.2.2. Worn Again Technologies (Switzerland)

Company *Worn Again Technologies* was established in 2012. The company has developed a technology for recycling poly-cotton textile waste [26]. A dissolution method is used to separate textile dyes, additives, and polyester from cellulose. Textile waste used in recycling process: 100% polyester, 100% cotton, poly-cotton, 10% tolerance to other fibers (nylon, wool, elastan) [27,28]. Till 2022, the company was developing its technology in laboratory conditions. In 2022, the company built the first pilot plant in Winterthur to recycle textile waste up to 1,000 tons per year. In 2025, the company plans to launch the production of PET and MMCF fibers in industrial capacities of up to 50,000 tons per year [26].

3.3. Companies for chemical recycling of polyester

3.3.1. Carbios (France)

Carbios is a biotech company that develops methods for biological recycling of plastics and textiles [29]. *Carbios'* technology uses enzymes to break down polyester fibers from textile waste into their basic components. These components are then used to produce new, recycled PET materials, such as fibers for the textile industry [30].

In 2021, the company started the production process in the first biorecycling pilot plant [29]. Currently, the first factory for larger capacities is being built. It will be completed in the second part of 2025. An automated textile waste sorting company *Nouvelles Fibers Tekstiles* (France) will prepare textile waste of polyester origin in the volume of 5,000 tons per year to support manufacturing process at the new factory [30].

3.3.2. Erema (Austria)

The company *Erema* (Engineering Recycling Maschinen und Anlagen Ges.m.b.H), founded in 1983, produces systems and technologies for recycling various types of plastics. Their textile recycling technology enables the repelletization of polyester textile waste [31]. The equipment developed by *Erema* integrates a shredder for textile waste, technology for cleaning and melting polyester fibers, as well as an extruder for creating recycled plastic pellets. Polyester granules from recycled textiles are mixed with granules from recycled plastic bottles to produce new polyester fibers for textile production. The company recycles various textile waste of polyester origin, such as work clothes, school uniforms, textiles used in hospitals and hotels (bed linen, tablecloths), advertising banners [31,32].

In 2024, *Erema* opened its first polyester textile waste recycling plant in Kettering (Great Britain) to recycle 2,500 to 5,000 tons of polyester per year. The factory is built in the processing center of the *Salvation Army Trading Company* (SATCoL) - the largest collector of textile waste in Great Britain [33]. *Erema* also plans to start cooperation with the company *Erdotek* - a collector and sorter of textile waste in the Netherlands [31].

4. CONCLUSIONS

The chemical recycling technologies are very much promising as they are ready to help the textile industry to reduce its ever-growing environmental footprint. Large number of new textile waste recycling companies are established in Europe, USA, Canada, Australia, China. The most part of them operate at their research centers and first pilot factories and still improve their recycling methods. They are looking for financial and promotional support to start commercial scale production of their end products. To safeguard their further manufacturing processes the companies already now are looking for cooperation with textile fiber manufacturers and waste collectors. The world's largest fiber manufacturers Birla Cellulose (India), Easrman (USA), Lensing (Austria) and Tangshan Saniou (China), others are interest in sustainable fiber production. Textile waste collecting and sorting capacities are problematic. Although many countries have large amounts of accumulated textile waste, its collecting and sorting is not done or it is done in small volumes. Currently commercial scale production in Europe has developed only two Swedish companies *Renewcell/Circulose* and *Södra*.

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