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Manufacturing and Usage of Lyocell Fabric

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In Loving Memory of Late Professor Doctor ""Mohamed Refaat Hussein Mahran""

Abstract
Lyocell fabric, also known as Tencel, is a type of cellulose-based fabric made from wood pulp. It is highly praised for its desirable physical and chemical properties. Firstly, it has excellent moisture absorption and release capabilities, making it a popular choice for activewear and underwear. Its high breathability allows for enhanced comfort and prevents the growth of bacteria. Secondly, lyocell fabric has great strength and durability, making it resistant tso tears and wrinkles. It is also known for its softness, smoothness, and hypoallergenic properties, making it suitable for individuals with sensitive skin. Moreover, this fabric is easily dyed, resulting in vibrant and long-lasting colors. Its chemical composition also makes it biodegradable and environmentally friendly. Overall, lyocell fabric has a wide range of applications, including apparel, home textiles, and even medical textiles due to its moisture management properties. It is also commonly blended with other fibers such as cotton and polyester to enhance its properties.
Keywords: Lyocell fabric , Tencel, hypoallergenic .

1. Introduction

The lyocell process, which has gained popularity over the traditional viscose process, has evolved as a modern method for producing regenerated cellulose. This is due to the fact that the Lyocell approach uses direct cellulose dissolution in N-methyl-morpholine-N-oxide (NMMO), has a shorter dope preparation time, and is eco-friendly process[1, 2]. Furthermore, it possesses a number of distinguishing qualities, including high strength, a round cross section, and a compact structure[3]. Lyocell is the first of a new generation of cellulosic fibres produced through a solvent spinning technique. The desire for an eco-friendly technique that uses renewable resources as raw materials was the main factor in its establishment[4-8].

To prepare the spinning solution for the rayon process, hazardous chemicals are used. As a result, several attempts were undertaken to develop novel solvents capable of directly dissolving cellulose. Among these, N-methylmorpholine-N-oxide (NMMO) proved to be the best solvent, resulting in Courtaulds' commercial success with cellulose fibres under its trademark Tencel in 1994[9].

This cellulosic fibre is derived from wood pulp produced from sustainable sources. The wood pulp is dissolved in a solution of an 'amine oxide' (usually N-methylmorpholine-N-oxide). The solution is spun into fibres and the solvent extracted while the fibres are washed. More than 99.5% of the solvent is recovered throughout the manufacturing process[10]. The solvent itself is non-toxic, and all the wastewater produced is safe. Lyocell fibres provide a wide variety of characteristics that are ideal for garments and home textiles. Lyocell may be used to create a variety of desirable textile materials that are both pleasant to wear and have high physical performance. Lyocell is useful for nonwoven textiles and papers due to its performance and absorbency. Lyocell has all of the advantages of a cellulosic fibre in that it is completely biodegradable and absorbent. It has excellent strength in both wet and dry conditions[9]. It blends well with fibres such as cotton, linen and wool. In this review, the manufacture, characteristics, and applications of lyocell fibres are discussed in detail.

2. The lyocell manufacture processes:

2.1. Preparation of the Raw Material:

N-Methylmorpholone N-Oxide: The abbreviation for N-methylmorpholine N-oxide is

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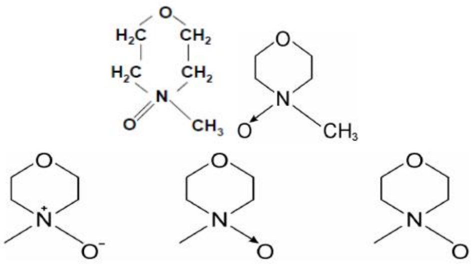
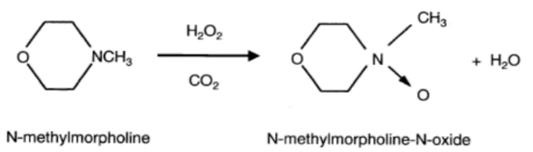
NMMO. NMMO's chemical formula: three different N-methylmorpholine-N-oxide formulas are shown in (scheme 1) [11].



Scheme (1): Different possible chemical form of NMMO

Preparation N-methylmorpholine N-oxide: The ternary amine N-methylmorpholine is oxidised with hydrogen peroxide to generate NMMO, as illustrated in(scheme 2) [12].



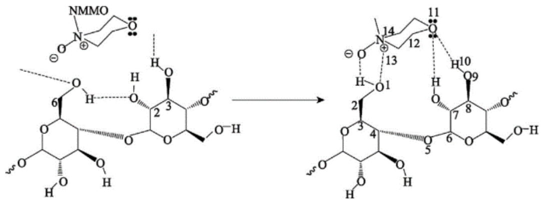
Scheme (2): Preparation reaction of NMMO

2.2. Solvation and Dissolution

The mechanism of cellulose direct dissolution in NMMO consists of two stages: swelling and gradual dissolution. Due to the strong polarity of the N-O bond, NMMO exhibits superb dissolving ability on cellulose, making it an effective hydrogen bond acceptor solvent. The N-O bond, which has a higher basicity than the hydroxyl group, will interact with the hydrogen atom on the hydroxyl group of cellulose throughout the dissolution process, forming new hydrogen bonds between NMMO and cellulose in both crystalline and amorphous areas[13, 14]. Ultimately, a new and re-structural hydrogen bond network is formed, resulting in cellulose dissolution. The mechanism of cellulose dissolution in the NMMO is represented in (scheme 3).

The number of bonded NMMO for each glucose unit plays an important role in cellulose dissolution, and it was found that at cellulose concentrations ranging from 7.5 to 10.5%, there were nine NMMO molecules for each glucose unit on average[3]. A thermodynamic simulation research on the crystalline and dissociated phases indicated that the nonpolar (hydrophobic) effect of NMMO, in addition to the well-known polar (hydrogen bonding) effect, plays a crucial role [15].

Due to radical reactions, a portion of NMMO will be thermally degraded to different compounds during the cellulose dissolving process and the recycling of NMMO (by distillation of NMMO/water solution at high temperatures)[16]. N-methyl morpholine, morpholine, and formaldehyde were the main products of degradation. The radical reaction of NMMO rises significantly when transition metal ions are abundant in dissolving pulp. Some stabilizers, such as a combination of alkaline and antioxidants (NaOH, isopropyl gallate), can be used to reduce NMMO degradation [17]. Both swelling and dissolving occur throughout the cellulose pulp dissolution process [18].

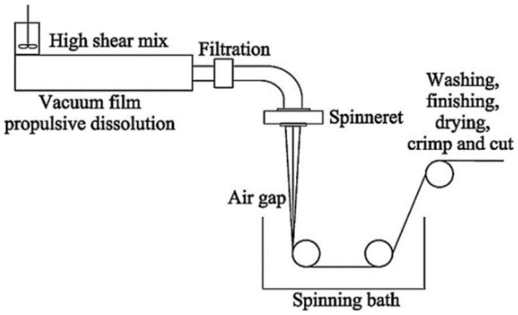


Scheme (3): Mechanism of dissolving cellulose in N-methyl morpholine-N-oxide (NMMO)/H2O dissolution system[19].

Its first phase is to rewet cellulose fibers in a dilute NMMO aqueous solution under the typical conditions of: 50 to 60% NMMO, 20 to 30% water, and 10 to 15% pulp [16], Which will allow for considerable cellulose swelling. Following that, an excess of water is eliminated bydistillation,resulting in the required cellulose/NMMO/water ratio[20]. Compositions typically consist of 67% NMMO, 20% water, and 13% cellulose. Under the circumstances described above, cellulose is dissolved in NMMO at 120°C (a safe temperature for NMMO), generating a highly viscous solution (a brown, transparent cellulose solution)[21]. Ternary solutions usually take place at temperatures ranging from 90 to 120ºC. More water should be withdrawn to achieve the optimum cellulose/ NMMO/water ratio for dissolving cellulose to generate cellulose dope. A high temperature (greater than 120ºC) will result in undesirable NMMO loss due to degradation[17].

2.3. Spinning

Lyocell fibers are produced in an “organic solvent dry jet wet spinning” approach, as shown in (scheme 4) [22]. The dopes in the NMMO/water system are first extruded from the spinning nozzle into an air gap, and then the formed filament is immediately inserted into a coagulation bath to continue its formation[20]. The spinning process's ability in the dry jet-wet spinning process is highly reliant on parameters, especially dope viscosity, air gap, spinning temperature, and spinning speed. The lyocell dope has a higher viscosity, which is responsible for the lyocell fiber's enhanced strength features. Furthermore, the high viscosity of the lyocell spinning solution allows for exceptionally stable spinning of fibres through the air gap[23]. The following are typical spinning phase parameters: The spinning speed is 24–40 m/min, the spinning dope temperature is 80–120 °C, the air gap length is 10–50 mm, the coagulation temperature is 15–25 °C, the coagulation concentration is 10%–25% (NMMO), and the draw ratio is 2–6 times[24].



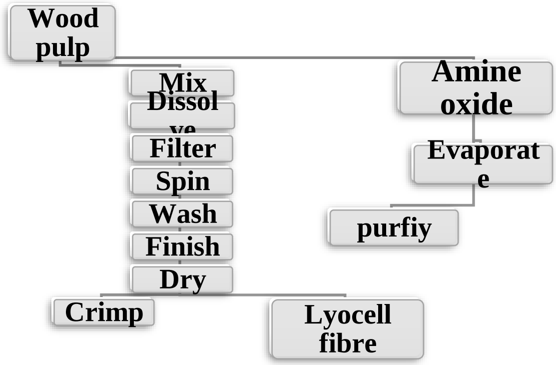
Scheme (4): Dry jet wet spinning in lyocell process.

In the end, we can summarize the lyocell manufacturing process into few steps, which exhibited the process in a diagram as shown in (scheme 5)[25-27]:

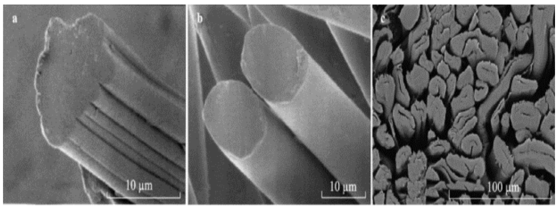
- Dissolution: This phase includes dissolving the pulp fibres and mixing them with the solvent by applying intense shear pressures and simultaneously evaporating water. Cellulose is dissolved in an aqueous environment containing NMMO to produce a high viscous dope.
- Filtration: The formed dope is filtered to eliminate coarse components.
- Spinning regeneration: The dope is extruded into an air gap through a gap in the spinneret and then regenerated in a coagulation bath.
- Washing: The resultant lyocell fibres are washed, and the residual NMMO is recycled. Since more than 99% of the solvent is recovered and recycled, the fibre production process is eco-friendly.
- Finishing: This phase involves post-treatment of the fibers, including bleaching, finishing, and drying.

2.4. Structure of lyocell fiber

The cross-section of lyocell fibre is almost circular. Its longitudinal surface is particularly smooth and cylindrical, which could be caused by the unique dry jet-wet spinning production technique, in which the cellulose fibres undergo quick and high solvent penetration, resulting in consistent coagulation [28]. Tencel's unique spinning procedure from standard viscose fibre results in the formation of very long exclusive crystalline arrangements of its cellulose units that are particularly highly oriented in the fiber's longitudinal axis [29]. Lyocell fibre is structurally distinct from viscose fibre and native cotton fibre, and this distinction allows lyocell rayon fabrics to exhibit a better fabric feel and drape. The cross-sections of viscose, lyocell, and cotton are lace-shaped, generally round, and flat, as illustrated in the (scheme 6).The lyocell fiber is easy to form a skin-core structure [24]. The fibrils appear to be linked together by a thin skin. The skin is very thin and exhibits a low degree of crystallinity (3% in area). As indicated in the (scheme 7), the core is mostly made of multiple fibrils aligned along the fibre axis with high orientation, regular structure, low contact area, and lateral cohesion between fibril bundles.

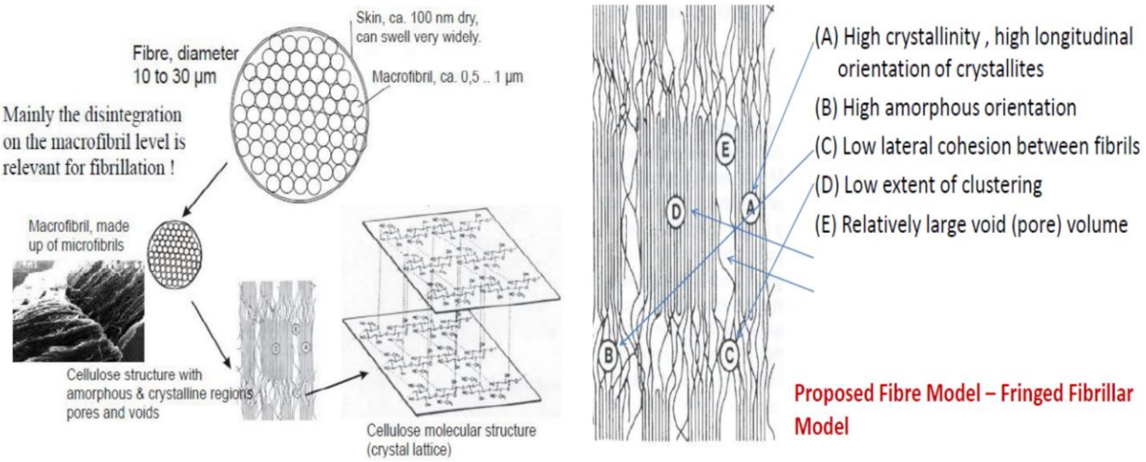


Scheme (5): Manufacture process for the lyocell fibers



Scheme (6): Cross sections of viscose, lyocell and cotton fibers: (a) viscose fiber; (b) lyocell fiber; (c) cotton fiber

Lyocell fibres have a crystallinity index (CrI) of (0.44). In compared to viscose fibres, lyocell fibres exhibit stronger mechanical properties, higher dry and wet tenacity, and higher wet modulus. Fibres are oriented and crystallised during the air gap and coagulation phases of the lyocell spinning process, resulting in the distinctive fibre structure with high crystallinity, well-aligned amorphous areas, low surface roughness, and longitudinal structure. On the regenerated fibre surface, unexpected fibrillation might occur during the same procedure [30]. As a result, various steps must be taken to control the fibrillation.



Scheme (7): Fiber model for lyocell fiber[31]

For example, lyocell fibre can be treated with various types of alkali, dyed with polyfunctional reactive dyes, and treated with cross-linking agents and enzymatic treatments [13].

Although fibrillation has been considered a drawback in some applications, the filaments provide a pleasant touch, known as "peach skin." [13].

3. Mechanical and physical properties of lyocell fabric

Lyocell has a stronger mechanical strength than viscose and cotton. These can be due to structural differences [32]:

- Almost no degradation of cellulose in the spinning of the lyocell type. The cellulose chain is long and the intermolecular hydrogen bonds are strong.
- high crystallinity and a tightly contact of cellulose molecule.
- The highly organised cellulose chain organisation, as well as the strong covalent bonds, all contribute to lyocell's high orientation in both crystalline and amorphous areas.

In numerous aspects, lyocell fibre is comparable to viscose rayon fibre, but it has superior qualities in terms of softness, drapability, dimensional stability, dye absorption, and colorfastness. The moisture regain of lyocell fibre is around 11%, which is a bit lower than that of viscose rayon [28]. This is mostly due to the higher cellulose crystallinity produced by the lyocell spinning process.

Lyocell fibres absorb moisture and have a high modulus, resulting in minimal shrinkage in water. Lyocell fibre, like other cellulose fibres, absorbs water properly and provides hygienic features to textile products. When washed, Tencel textiles and clothes exhibit higher stability [33].

Lyocell has been described as a “green and eco-friendly fiber” [34]. Tencel textiles are further distinguished by their silky handling, distinctive drape, and fluidity. Tencel is an excellent cotton substitute that has a significant presence in the textile industry for fashion wear, bed linen, towels, and so on. Tencel can be used successfully in the manufacture of pants and garments. They are also applicable to technical fabrics, nonwovens, and foils. Tencel fibres provide significant benefits in terms of adaptability to end-product needs, both when spun alone and in various blends, especially with cotton. Tencel additives to cotton improve yarn mechanical characteristics, including tenacity and elongation, as well as spinning stability[29].

As a cellulose fiber it possesses good comfort properties, like cotton, high strength due to orientation and crystallinity, like polyester fiber, and soft feel, similar to silk [2]. Due to its biodegradability, low toxicity, comfort, and other strong physical characteristics, lyocell fibre is an excellent substrate for antibacterial garments [35].

Lyocell fibre provides several advantages over natural and manmade fibres. Since over 99% of the organic solvent used in the production of lyocell fibre can be recycled and water is the only substance used in the coagulation bath without the need for any acid or alkali, lyocell fibre can be considered toxicologically and dermatologically harmless [36]. Since the molecular orientation in the direction of the fibre axis is relatively high during the manufacturing process, the crystallization degree is above 90%; hence, the tenacity value of lyocell is quite high when compared to that of other regenerated cellulose fibres [37]. The crystallization degree of lyocell fibre is 16% greater than that of modal fibre and 43% higher than that of viscose fibre. Furthermore, the dry tenacity value of lyocell fibre is substantially greater than that of other cellulosic fibres, and it is comparable to that of polyester fibre. [37]. As a result, lyocell can be regarded one of fibres which can be used blended with other fibres in order to manufacture strong yarns and fabrics [37]

Thermal characteristics of Lyocell fibre is slightly better than viscose fibre. Viscose fibre loses its strength above 150ºC. However, Lyocell fibre loses its strength above 170ºC. Viscose fibre begins to decompose at 300º C while Lyocell fibre decomposes at 400ºC[38].

Lyocell is a cellulosic fibre and can therefore be dyed with the same dyestuff types as other cellulosic fibres, such as reactive dyes [5]. However, its fundamental dyeing features provide a distinct profile, requiring the use of lyocell-specific dye application procedures [39].

Lyocell has an extraordinary dye fabrication, as evaluated by colour value. In general, the dye yield produced on lyocell is closer to that of mercerized cotton than that of other man-made cellulosics. However, due to the large dye fabrication, actions must be taken to enhance migrating and levelling qualities. In exhaust dyeing, this requires using high-temperature migration application techniques with delayed alkali addition to guarantee level dyes. Approaches that reduce the fixing rate are beneficial in cold pad batch reactive dye application because they give the dyes more time to penetrate the fibre completely[39].

4. Applications of lyocell fabric

4.1. In the medical field

Tencel textiles are widely used in medical fields due to their bacterial resistance. They are used to make gauzes, bandages, gloves, wipes, medical swabs, filters, biocomposites, medical dressings, head coverings, and battery separators, which are used in the operations shown in (scheme 8) [9]. Patients with severe allergies, skin infections, or psoriasis should wear them instead.

4.2. In non-woven textiles

Tencel fibres are additionally used in a variety of textiles. Non-woven because of its strength, durability, absorbency, and biodegradability. Tencel fibres have been more popular in nonwoven fabrics across the world lately. Tencel fibres are now being developed in order to improve processing performance appropriate to the fibres' qualities. Because of its limited bacterial growth, tencel is used in the production of socks. It is also frequently used in outdoor and indoor women's apparel, home furnishings, sports clothes, and protective gear such as "flame-retardant clothing" and protective clothing[40].

4.3. In the technical applications

Furthermore, because of its high modulus and shape stability, Lyocell is used in technical applications like conveyor belts. Lyocell fibres may be used to make specialty paper with high strength, opacity, and low air resistance [1].

Scheme (8): Various applications of lyocell fibers

4.4. In the home textiles and apparels

Lyocell fibres are widely used in a variety of applications, including textiles and various consumer and industrial products, due to their inherent qualities. Lyocell fibres feature excellent strength, smooth and silky handling, lustre and bulk, biodegradability, high absorbency, and simplicity in processing. [20], It might then be used in nonwovens. Lyocell fibres are excellent raw materials for home textile products such as mattresses, mattress pads, bed coverings, and linens, as well as clothing such as denim, chino, pants, casual wear, and towels. Furthermore, as illustrated in (scheme 9), filament lyocell fibres are ideal for both men's and women's clothes. [9]. Lyocell can be blended with a variety of other fibres such as silk, cotton, rayon, polyester, linen, nylon, and wool [41].

Scheme (9): applications of lyocell in the home textiles and apparels

5. Fund

The authors have no fund

6. Conflict of interest

The authors have no conflict of interest

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