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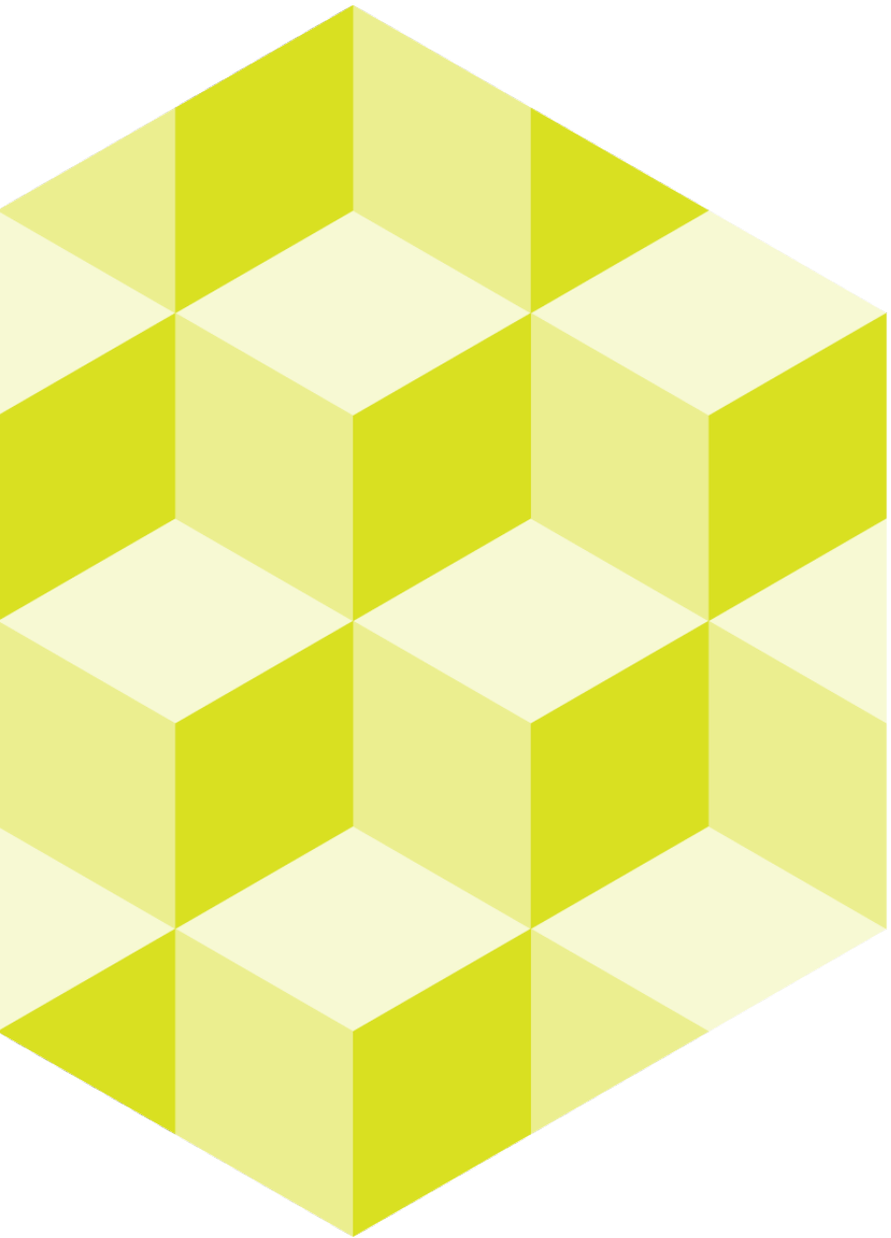
Diana Tuulik

1.3 Introduction to production and processes of man-made fibres

SusTexEdu

Funded by the Erasmus+ Programme of the European Union



SusTexEdu

SusTexEdu | Erasmus+

This learning material was developed in the Erasmus+ funded project Education Partnership of Textile and Clothing Sector Materials & Sustainability (SusTexEdu)

The goal of the project is to research and develop education in the textile and clothing sector related to textile materials, sustainability and circular economy.

The learning material has been prepared for piloting, and students will be asked for voluntary feedback after the course for the further development of the material.

Project coordinator: Metropolia UAS

Partners: Hogent (BE), Mome (HU), Omnia (FI), TTHK (EE), TTK UAS (EE), University of Borås (SE)

Funding: Erasmus+

Project period: 2022-2024

About this learning unit

CONTENT DESCRIPTION

- Basic knowledge about manmade fibre production and environmental aspects

LEARNING OUTCOMES

Student will be able to:

- Understand the productions methods of the manmade fibres and their effect to the environment

STUDENT WORKLOAD

1 ECTS, which is equal to 25-30 hours of work:
for example

- Lectures 12-16 h
- Group activities 4 h
- Independent study 9-14 h
- Learning diary 2 h

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Content

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Timeline of regenerated fibre production

1839 - separation of pure cellulose from wood

1846 - nitrocellulose

1891 - viscose manufacturing process

1897 - copper ammonia fibers (cupro)

1918 - cellulose acetate

1954 - triacetate

1955 - HWM-rayon (high wet modulus)

1987 - lyocell

Timeline of synthetic fibre production

1936 – polyamide production *(nylon – USA)*

1946 – polyester production

1950 – polyacrylic *(The DuPont Corporation)*

1954 – polytetrafluoroethylene *PTFE*

1957 – polypropylene

1959 – elastane *(lycra – DuPont)*

1965 - *KEVLAR®*

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Manufacturing of man-made fibres

The production process of man-made fibres consists

- collecting raw materials containing molecules suitable for the manufacture of fibres,
- separating the molecules and
- forming a fibre from the molecules.

Obtaining and pre-processing of the polymer (raw material) is usually carried out: in cellulose-cotton cleaning companies and pulp mills, synthetic polymers - in chemical plants. The polymeric substance used in the manufacture of synthetic fibres is synthesized.

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… manufacturing of man-made fibres

Usually, the raw material (polymer) is in the form of granules.

- Bringing the polymer to a viscous flow state is necessary to form fibres in the spinning machine.
- Dissolving the polymer can be done using different solvents depending on the fibre production method.

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… manufacturing processes of man-made fibres

3 different spinning methods

- **Wet spinning** – viscose, modal, lyocell, cupro, acrylic, modacrylic, PVC, PTFE, elastomeric, PVA
- **Dry spinning** - acetate, triacetate, acrylic, modacrylic, *Spandex* (major method), aramid
- **Melt spinning** – polyester, polyamide, polypropene, polyethylene

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Common principles of spinning methods

- A spinning pump delivers the liquid to the spinning nozzle or spinneret.
- The solution is pressed through the nozzle opening and tapered on its exit by the spinneret drawing-off.
- Spinning mass obtain its fibre shape by means of chemical reactions, coagulation, or solidification.

Differences between spinning methods

- … is in how the raw material (pellets or powder) is liquefied
- … in terms of how the filaments pressed through the nozzles solidify

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Wet spinning

1. Raw material is dissolved by chemicals
2. Fibre is spun into chemical bath
3. Fibre solidifies when coagulated by bath
    - oldest process
    - most complex
    - weak fibres until dry
    - washing, bleaching, etc., required before use
    - solvent may be recovered and reused

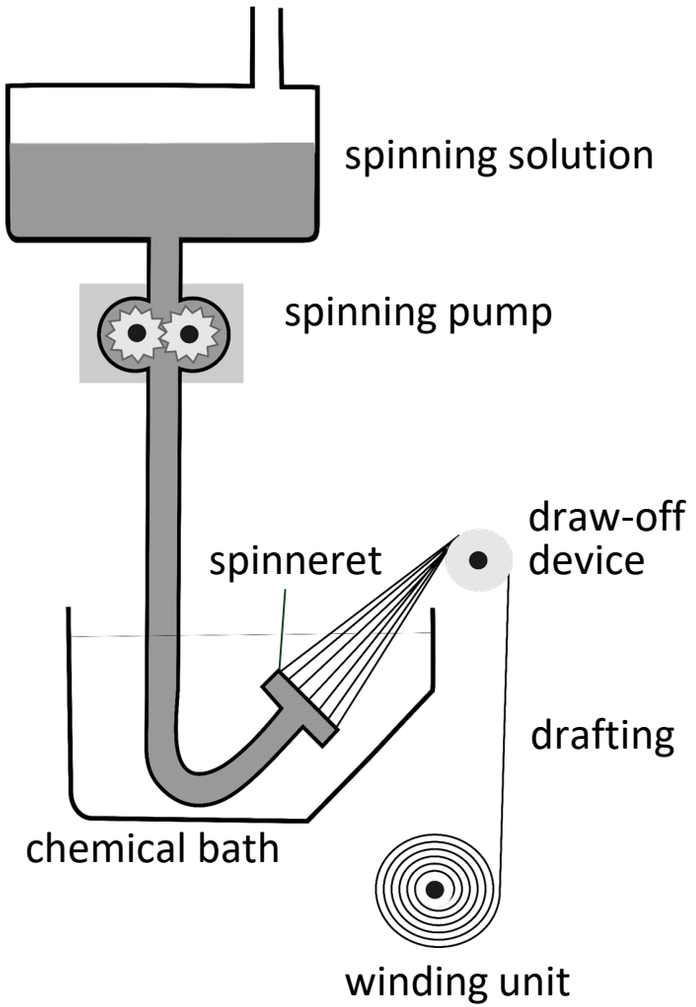

Image by SusTexEdu

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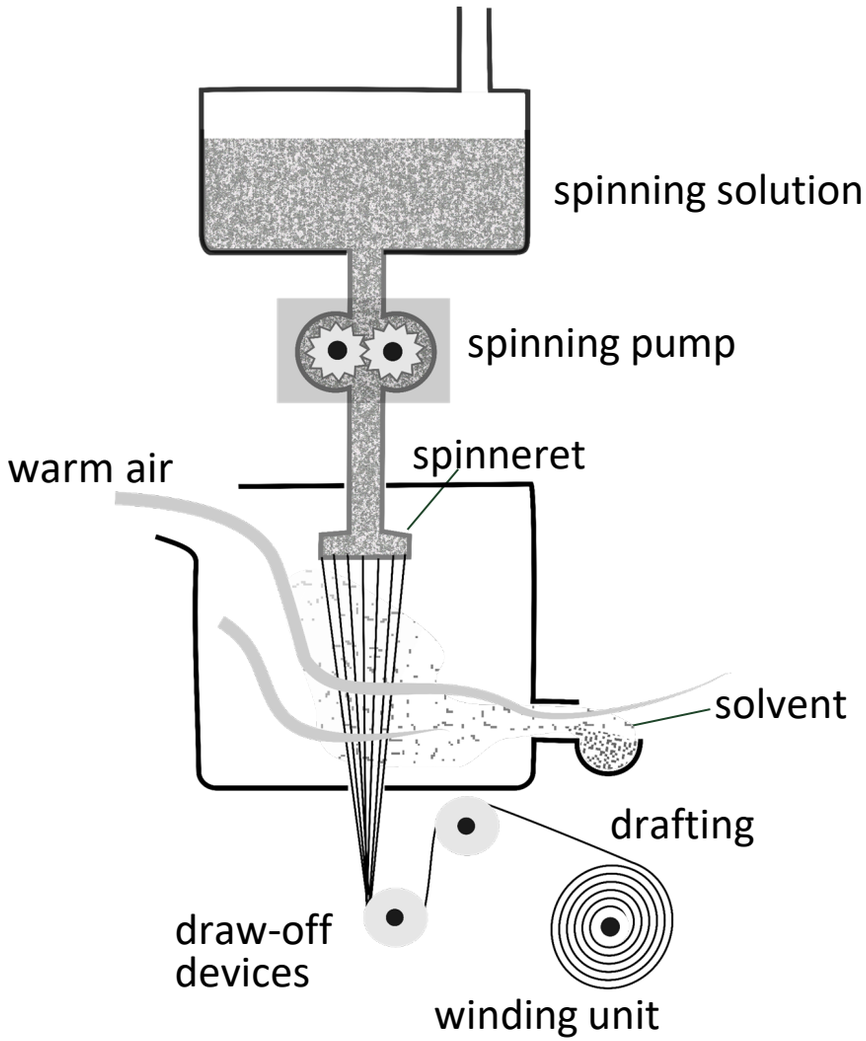
Dry spinning

1. Resin solids are dissolved by solvent
2. Fiber is spun into warm air
3. Fiber solidifies by evaporation of the solvent

- direct process
- solvent required
- solvent recovery required
- no washing, etc., required



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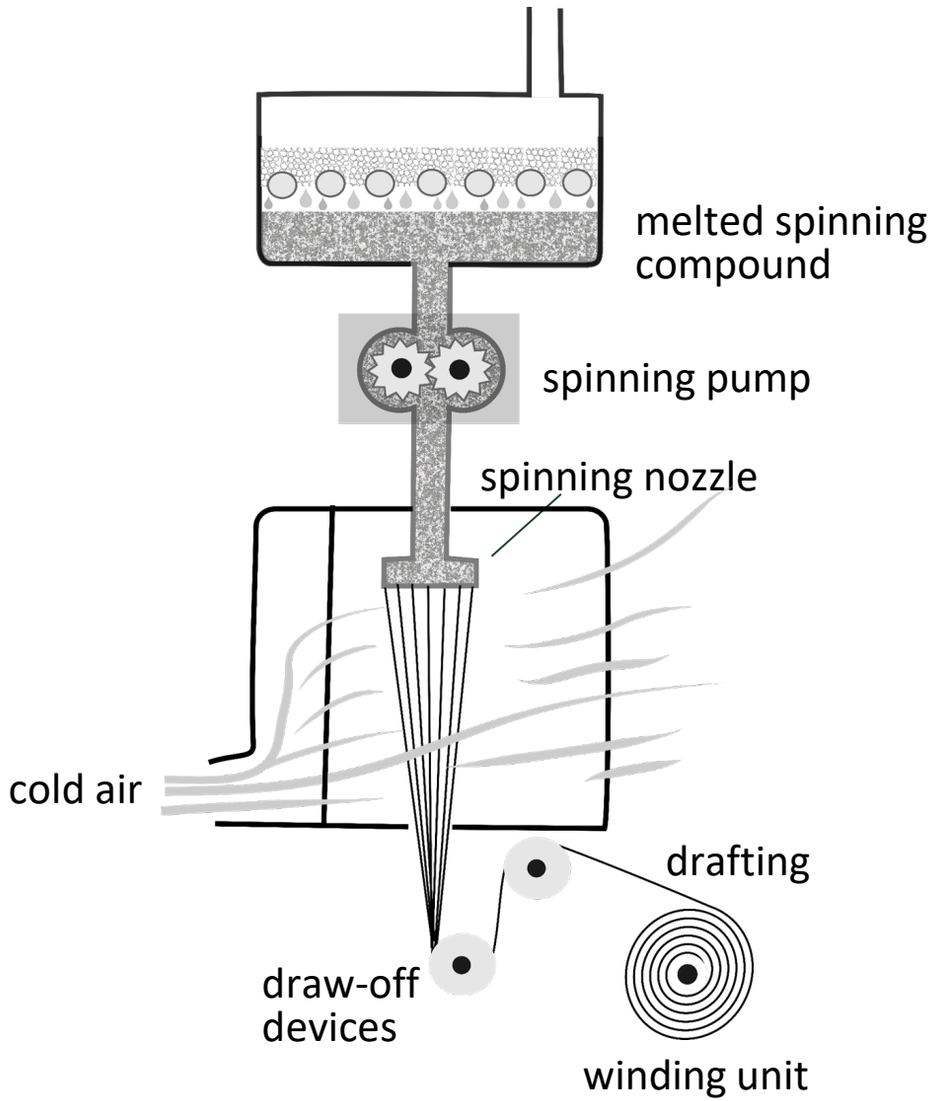
Melt spinning

1. Resin solids are melted in autoclave.
2. Fiber is spun into the air.
3. Fiber solidifies on cooling.

- least expensive
- direct process
- high spinning speeds
- no solvent, washing, etc., required
- fibers shaped like spinneret hole



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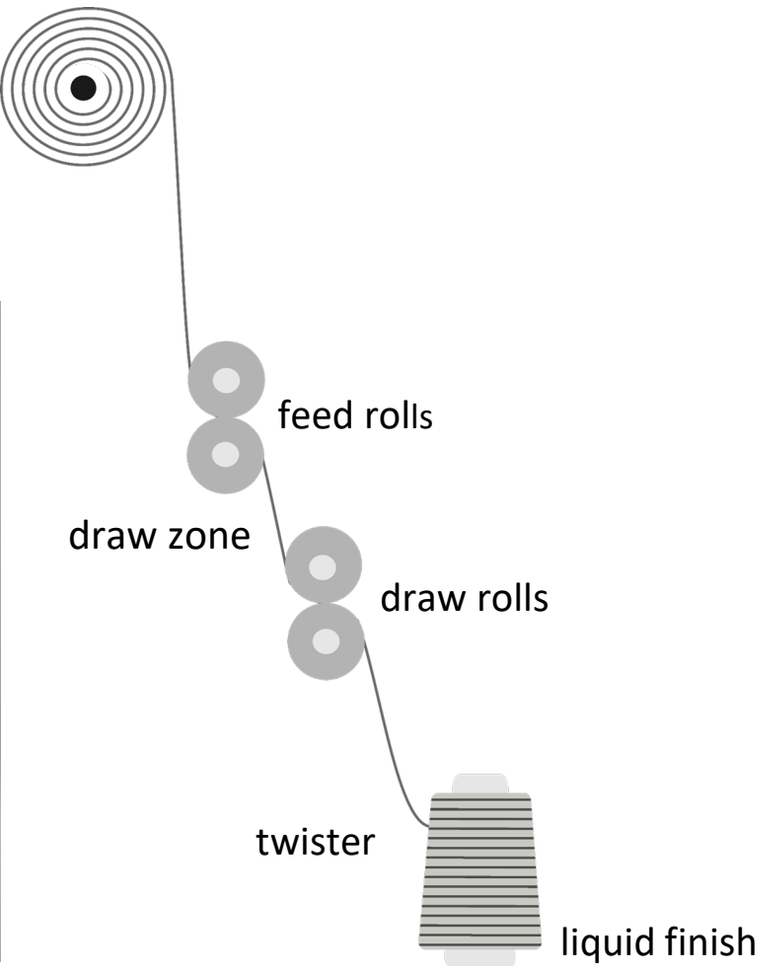
Melt spinning continuous filament

- Filament fibres can be drawn four to five times their original length to orient the molecular chains and develop the fibre´s mechanical properties and hand.
- The fibres are heat-set and wound on cones or spools.



Viscose filament above, photo by SusTexEdu
Drawing continuous filament, image by SusTexEdu

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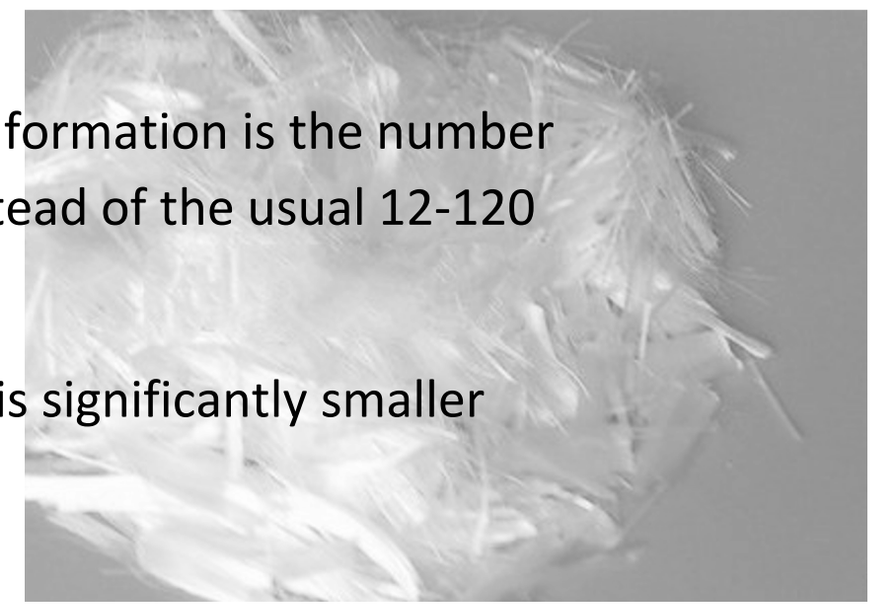
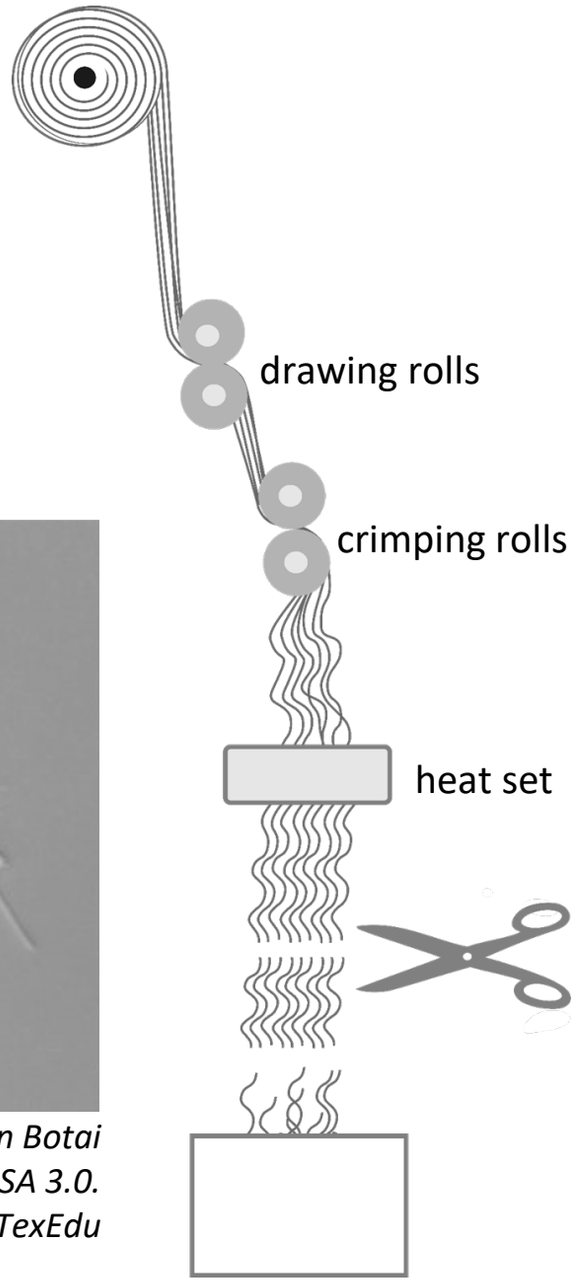
Melt spinning staple fibres

- Staple fibres emerge as undrawn tow.
- It is drawn, crimped and heat-set, cut to the desired length, and baled.
- The peculiarity of staple fibre formation is the number of nozzle openings, which instead of the usual 12-120 reaches 15 000 and more.
- The diameter of staple fibres is significantly smaller than that of complex threads.



Staple fibres above, photo by Henan Botai Chemical Building Materials on Wikipedia CC BY-SA 3.0. Drawing staple fibres on right, image by SusTexEdu



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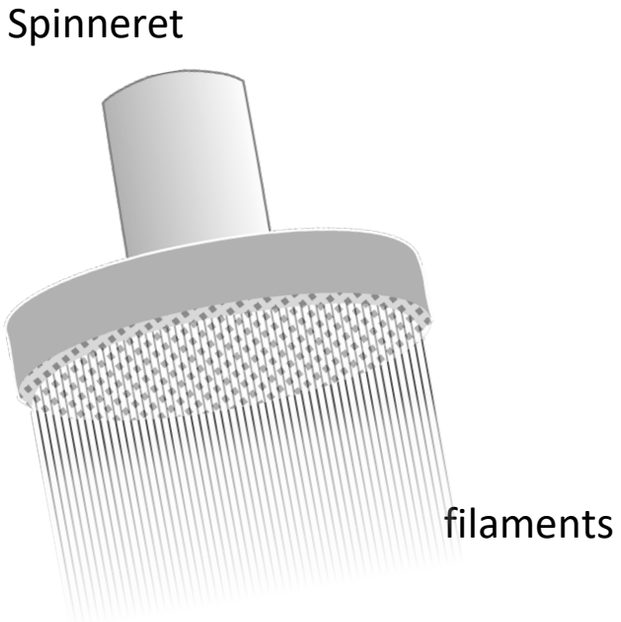
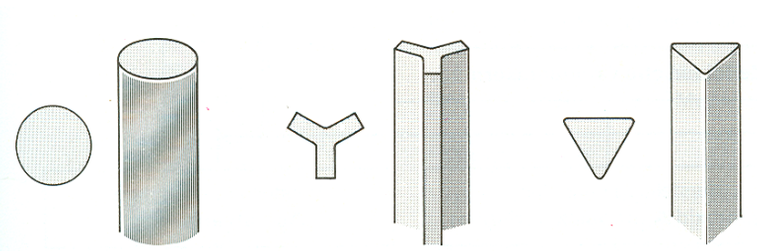
Spinneret

- Spinnerets are made of various materials (precious metal alloys of gold, platinum, iridium etc.) depending on the spinning solutions.
- The shape and size of the boreholes differ, e.g. for the production of viscose fibres, spinnerets have 30 000 to 90 000 capillaries.
- The diameter of the hole is about from 0,05 to 0,5 mm.
- The spinnerets´ holes can have beside circular form also various other shapes.



Spinneret showing extrusion of filament fibres, image by SusTexEdu



Different shapes of fibres

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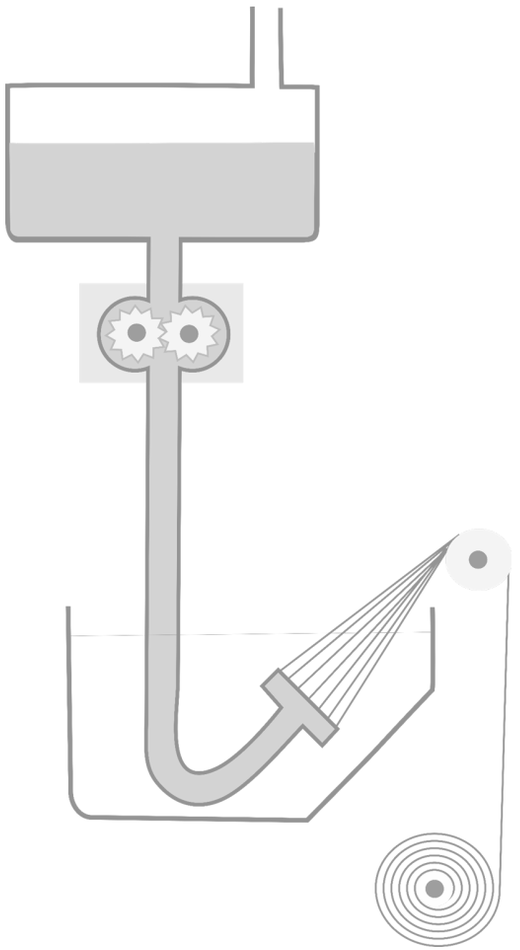
Production processes of regenerated cellulose fibres

Regenerated cellulose fibres are produced according to the viscose spinning method, which is the most common process among the wet-spinning methods.

- raw material - natural (wood pulp, cotton pulp)
- the cellulose is made chemically soluble
- the solution is converted back into pulp using a wet spinning process
- the molecule must be converted into fibre form - fibre spinning



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WOOD CELLULOSE FIBRES

Photos: 1 by Aapo Haapanen on Wikipedia (CC BY-SA 2.0), 2 , 3 and 4 by SusTexEdu

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Viscose (VI, CV)

- The raw material used for viscose is wood pulp (birch and spruce), which is obtained as almost pure cellulose. The wood pulp content must be at least 90%.
- Both filament and staple fibres are produced.
- Production of viscose began in the early 1900s.

Beech tree is also used as cellulose raw material. Photo by Jean-Pol Grandmont on Wikipedia, GFDL

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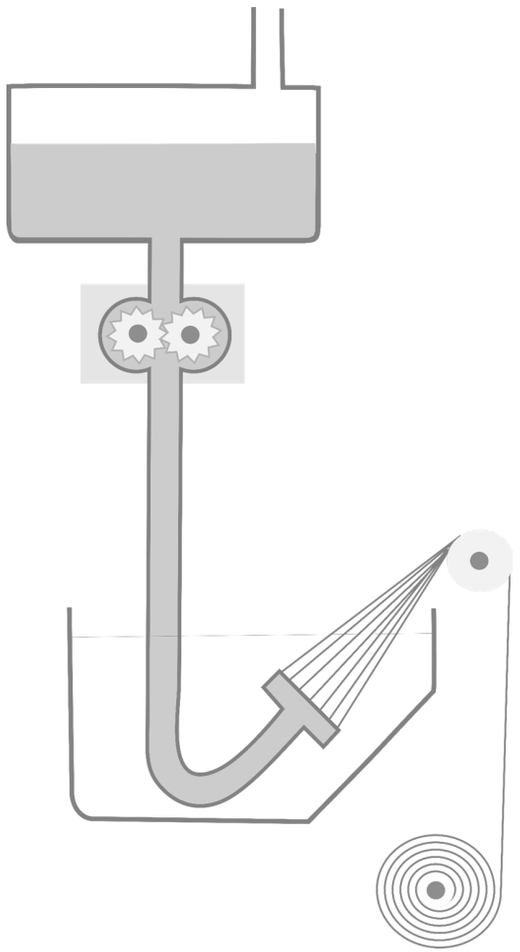
… viscose modifications

The viscose spinning method is flexible in terms of chemical and physical process parameters, which allows manipulation of the properties of the final fibres to a great extent.

- Solution-dyed
- Modified cross section
- Intermediate- or high-tenacity
- Optically brightened (*OBAs*)
- High absorbency
- Hollow fibres
- Microfibres
- Flame-retardant
- *Visil Rayon* – siliconized etc.



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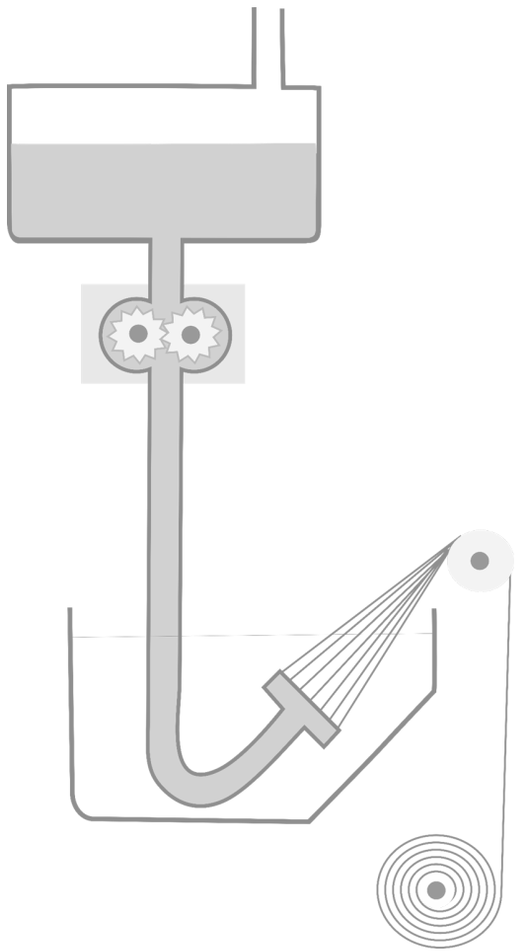
Modal (MD, CMD)

- The production process is the same as viscose, only:
  - to strengthen the fibres, the fibre molecules are made as unidirectional as possible,
  - the preliminary preparation stage is short (so that the cellulose molecules remain as long as possible),
  - the post-production stage is omitted or short-lived.
- Production of modal started 1955 *(HWM-rayon)*



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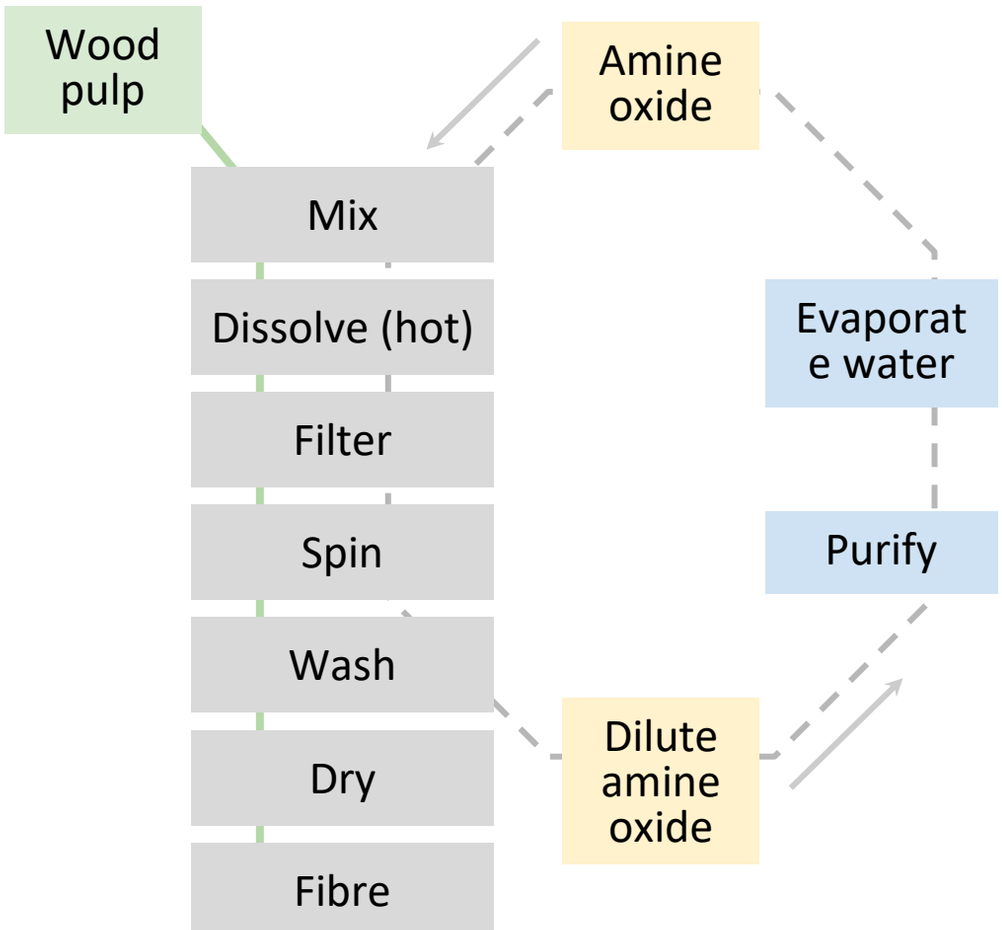
… modal fibre

- The cross-section of modal fibre is round.
- The fibre surface is smooth.
- The fibre has a dull sheen and can be produced in a matte finish like viscose.
- Also hollow, crimp and microfibre can be produced.

Lyocell (LY)

- Lyocell was created by making the production process of hydrated cellulose fibres more environmentally friendly. The raw material of lyocell is usually wood pulp.
- 1978 - A procedure was developed to dissolve cellulose without a prior chemical process
- 1990 - lyocell pilot - production begins
- 1992 - fiber name – lyocell
- Trade names: *Lyocell by Lenzing, NewCell (filament fibers), Tencel.*



Wet spinning process for lyocell
Source: Courtesy of Lenzing Fibers

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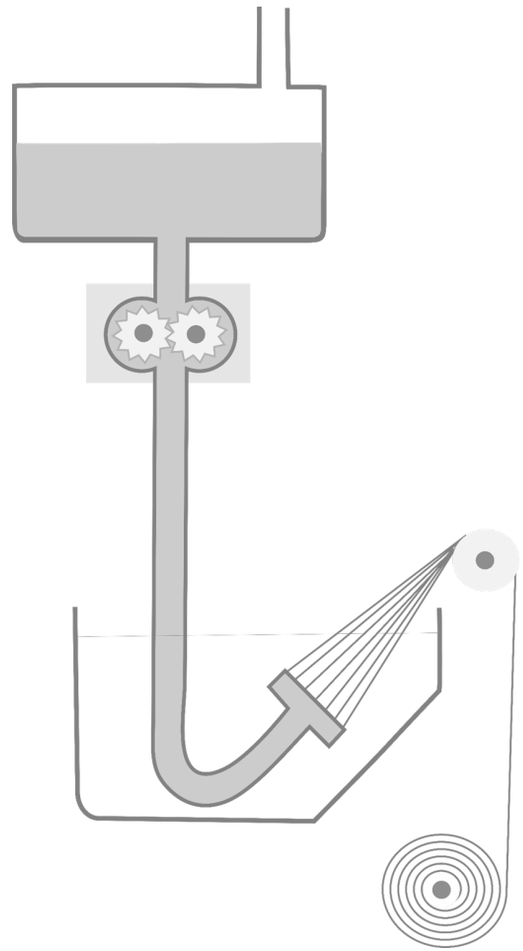
… lyocell fibre

- The cross-section of lyocell fibre is round.
- Mainly cotton type staple fibre (length approx. 40 mm) is produced.
- In terms of molecular length, lyocell is comparable to modal.
- Lyocell fibre can also be produced as crimp and microfibre.



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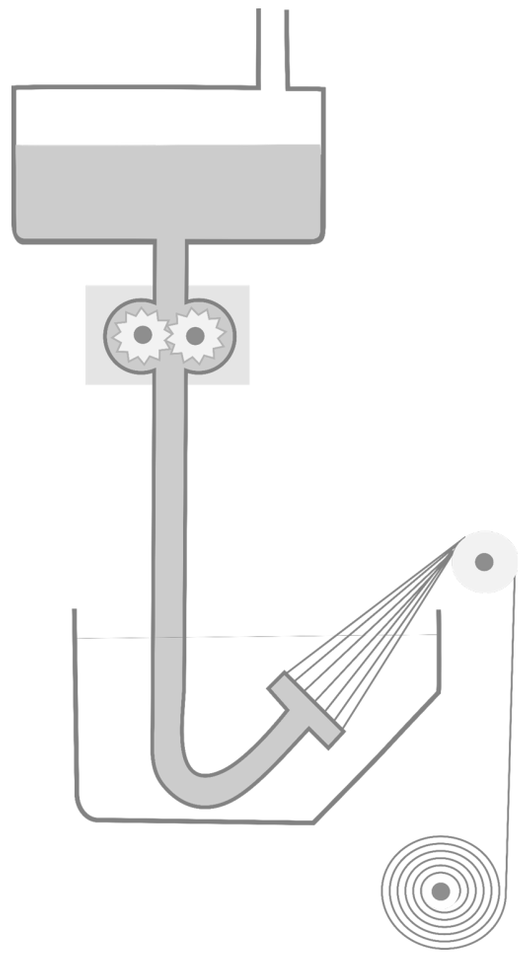
Cupro (CU, CUP)

- Cupro is a cellulose fibre obtained by the copper ammonia process.
- It was invented in 1897 - copper silk
- Production started in 1919 *(Bemberg®)*
- 1953 - continuous cupro spinning process was developed



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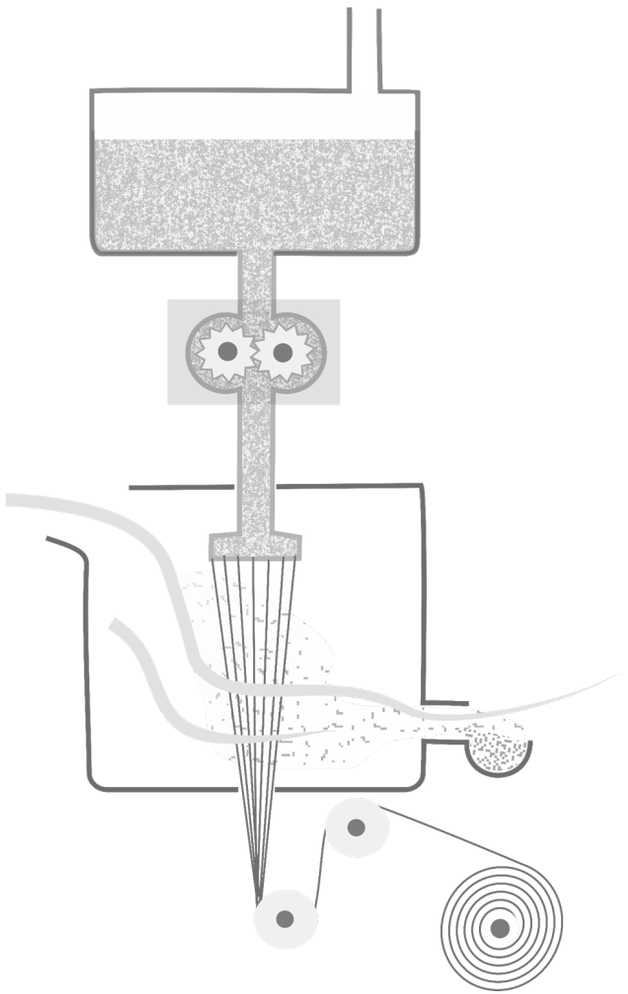
… cupro fibre

- The fibres are finer, softer and less shiny than viscose.
- The cross-section of cupro is almost round, which gives the fibre a characteristic silky sheen.
- The fibres are white or slightly bluish in color.
- It is mainly produced as filament fibre, both glossy and matte.
- Staple fibres are mainly are produced in wool and mohair types.
- Cupro is also produced as hollow fibre.

Acetate (AC)

- Acetate is a cellulose acetate fibre of which at least 74% but less than 92% of the hydroxyl groups are acetylated.
- Acetate is produced from wood pulp or cotton waste.
- Acetate fibre is obtained by dry spinning process.
- Production of acetate started in 1924.



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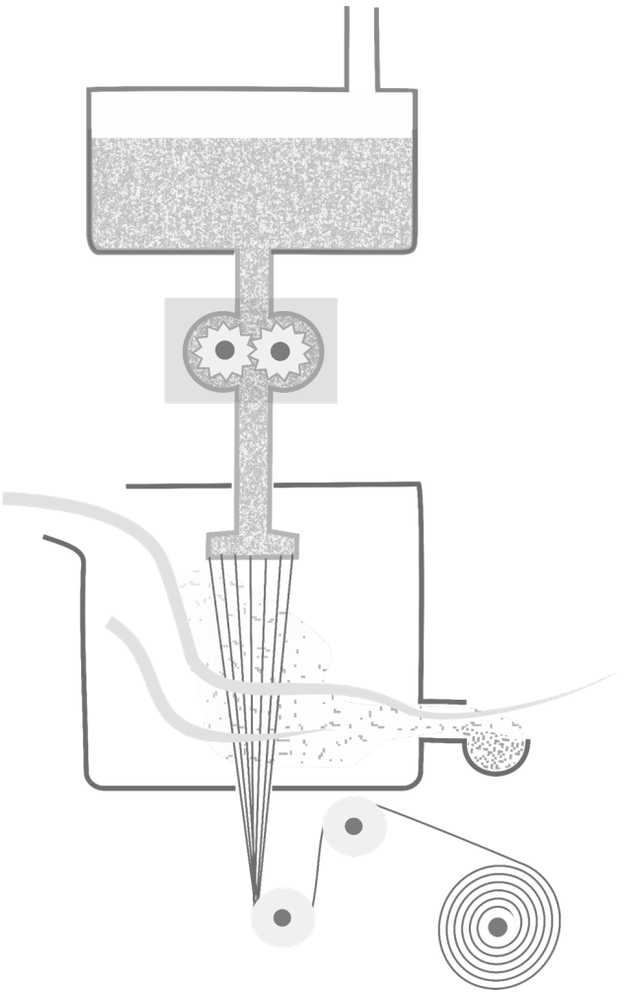
… acetate fibre

- It is possible to spin very fine acetate fibres that feel soft and have a silky matte sheen (reminiscent of natural silk).
- Acetate is lighter than viscose, it belongs to the category of medium weight fibres.
- The fibres have a grooved surface (deeper than viscose). The cross-section of the fibre has a shape of an irregular star.

Triacetate (TA, CTA)

- Triacetate is produced from triacetyl cellulose.
- The production process is similar to the acetate production process where all 3 hydroxyl groups of the cellulose are replaced by acetylene groups during acetylation.
- Triacetate is produced mainly by dry spinning process and the precipitation solution is mainly water.
- The raw material of the fibre must be very pure cellulose.
- Production of triacetate started 1954 in USA - camera film roll.



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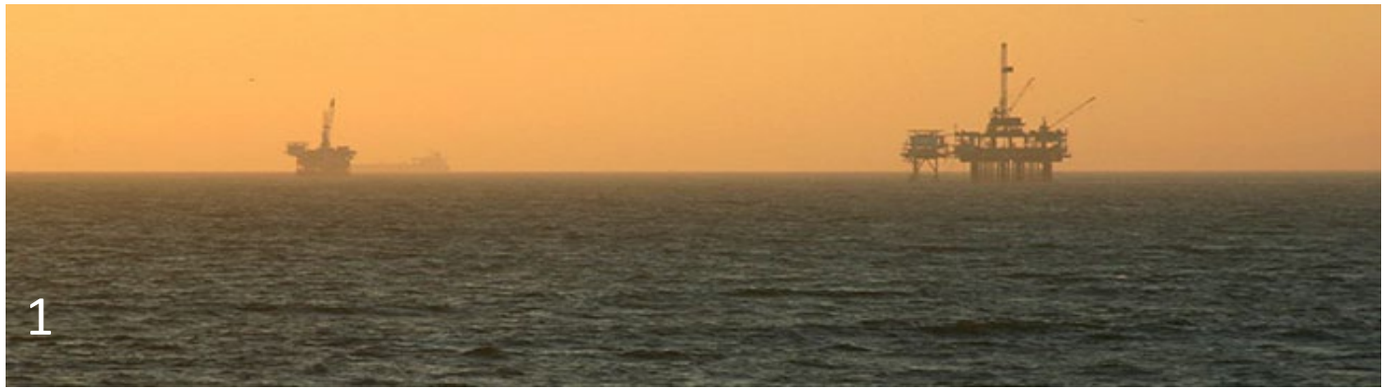

SYNTHETIC FIBRES

Photos: 1 by Aaron Logan CC BY 2.0, 2 by Daniel Schwen (CC BY-SA 2.5),
3 by Henan Botai Chemical Building Materials (CC BY-SA 3.0) and 4 (pes fibre) by SusTexEdu

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Production processes of synthetic fibres

The main raw materials are petroleum, natural gas and coal.

- The chain molecules of chemical fibres from synthetic polymers are produced artificially by synthesis of monomers.
- The production of fibres of synthetic polymer (spinning) is similar to natural polymers.

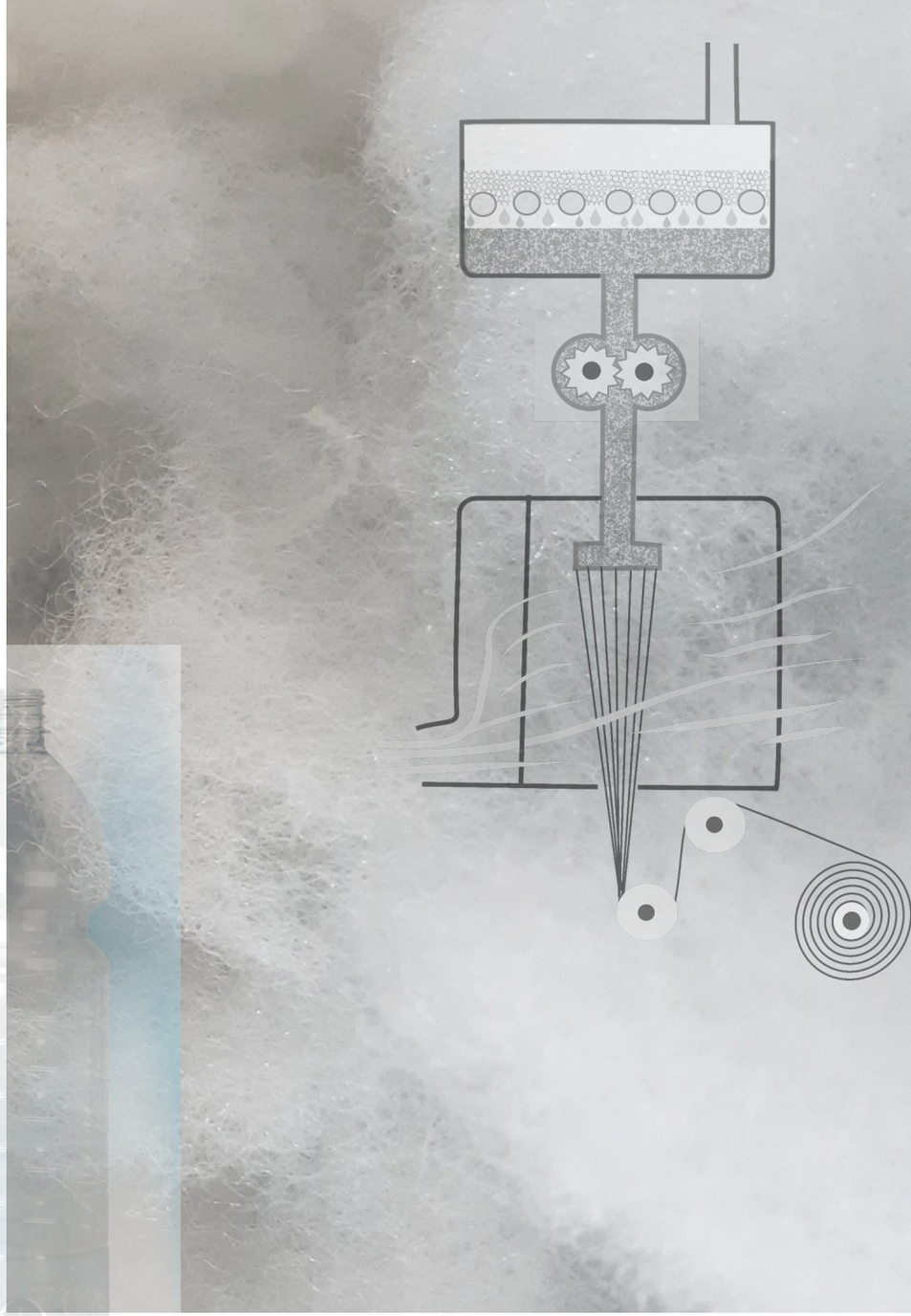
… production processes of synthetic fibres

3 different reaction mechanisms for production of polymers

- **Polymerization** (PVA, PVC, PAN, PTFE, PE, PP) – identical monomers are connected by covalent bonds between the single monomers. Double bonds within the monomers must first be broken.
- **Polycondensation** (PES, PA, AR) – different or identical molecules bind together while byproducts split off (eg. water, short-chain alcohols). This reaction requires that each monomer has at least two reactive groups.
- **Polyaddition** (EL) –hydrogen atoms are exchanged between the different monomers, which have at least two reactive groups each.

Polyester (Pes)

- Polyester is a fibre in which the fibre-forming substance is any long-chain synthetic polymer composed of at least 85 % by weight of an ester of a substituted aromatic carboxylic acid.
- Fibre has rod like shape with a smooth surface.
- Commercial production of polyester started 1951 in USA.



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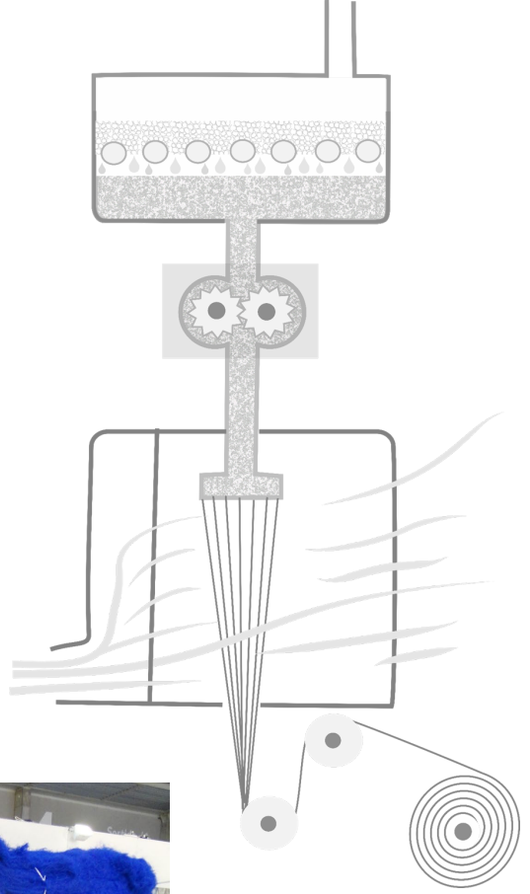
Polyamide (Pa)



- Polyamides are polymers (fibres) that contain an amide group.
- Polyamide is a fibre in which a fibre-forming substance is a long-chain synthetic polymer in which fewer than 85% of the amide linkages are attached directly to two aromatic rings.
- Two major types:
  - Polyamide 6.6
  - Polyamide 6
- Fibre has a rod like shape with a smooth surface.
- Polyamide was first time produced 1939 in USA.

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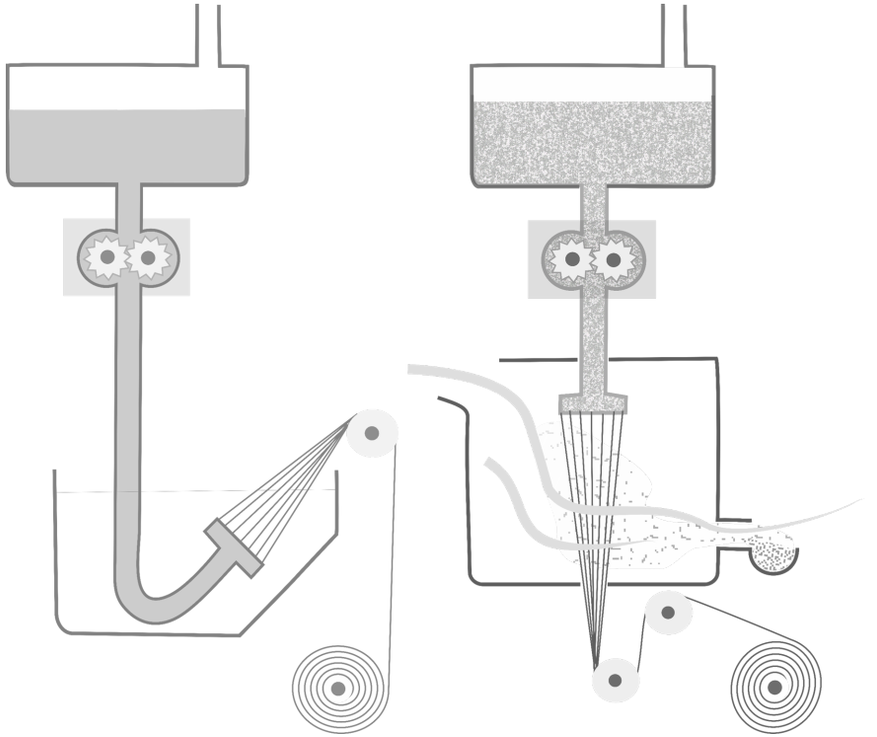
Acrylic, polyacrylic (AC)



- Acrylic is a fibre in which a fibre-forming substance is a long-chain synthetic polymer composed of at least 85% by weight of acrylonitrile units.
- Fibre has a rod like shape with a smooth surface.
- Acrylic was first time produced 1950 in USA.

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Modacrylic (MAC)

- Modacrylic is a fibre in which a fibre-forming substance is a long-chain synthetic polymer composed of fewer than 85% but at least 35% by weight of acrylonitrile units.
- Fibre has a circular shape with a smooth surface.
- Modacrylic was first time produced 1949 in USA.

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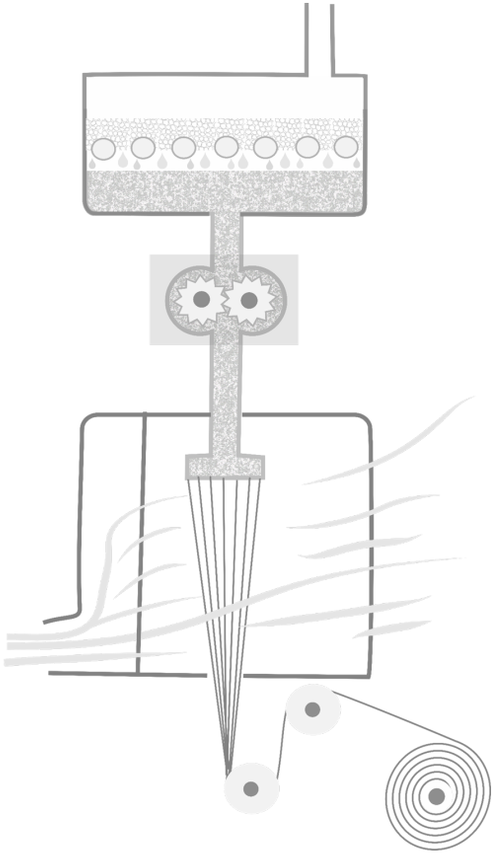
Olefin / Polypropylene (PP)

- Olefin is a fibre in which a fibre-forming substance is a long-chain synthetic polymer composed of at least 85% by weight of ethylene, propylene, or other olefin units except amorphous (non-crystalline) polyolefins that qualify as a rubber fibre.
- Olefin fibre has a rod like shape with a smooth surface.
- Olefin was first time produced 1961 in USA.



PP staple fibres, photo by Henan Botai Chemical Building Materials Co., Ltd on Wikipedia CC BY-SA 3.0

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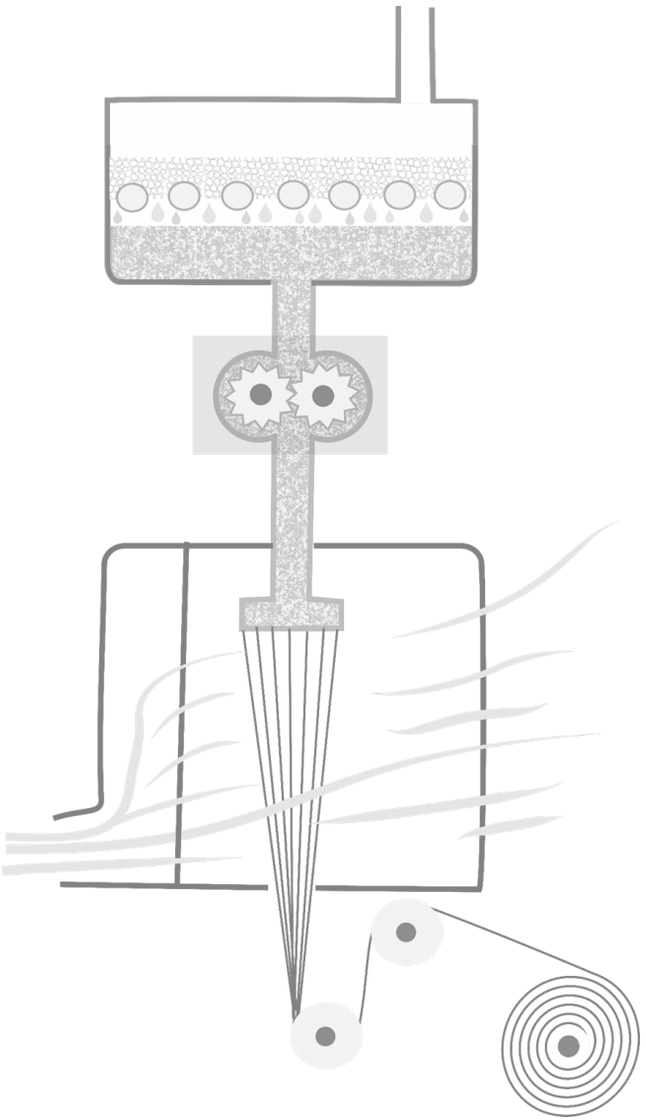
Elastane (EL/EA)

- Elastane is an elastomeric fibre.
- Elastane is a fibre in which a fibre-forming substance is a long-chain synthetic polymer composed of at least 85% segmented polyurethane.
- Fibre is extruded as a monofilament or in many very fine filaments that immediately fuse together to form a monofilament.
- Elastane (Spandex) was first time produced 1959 in USA.



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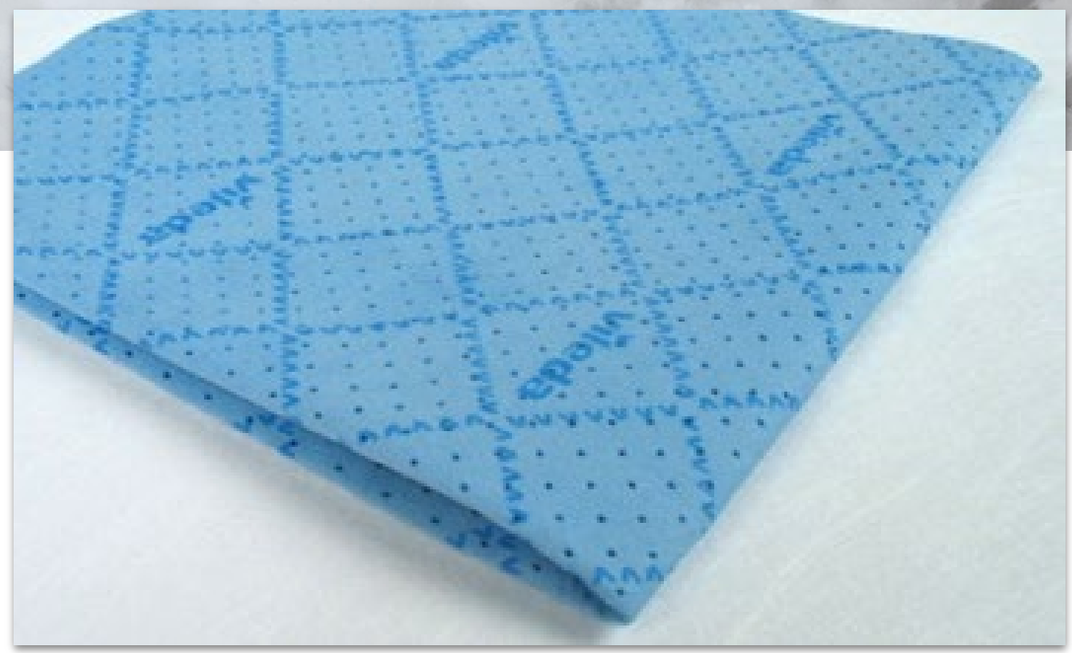
Microfibres

- Microfibres are manufactured fibres that are much finer than normal fibres.
- Microfibres can be: acrylic, polyamide, polyester, lyocell, viscose



Microfibre cloth suitable for cleaning sensitive surfaces, photo by Polyesterchen *on Wikipedia, Public domain*

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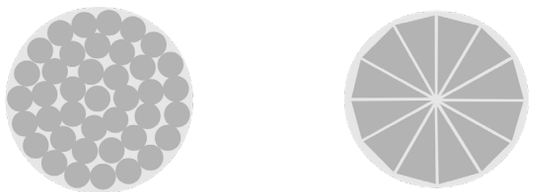
… manufacturing process of microfibres

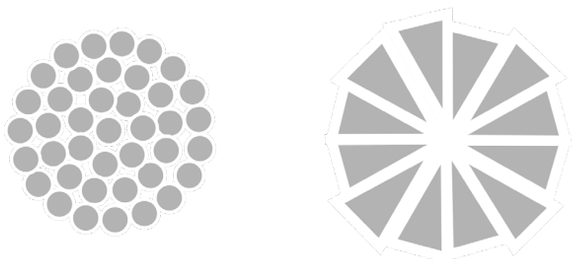
Two major processes of manufacturing microfibres

1. Extruding very fine filaments from the spinnerette and then further reduce the fibre size by drawing the yarn
2. Producing filament fibres of two different polymers. After the fabric is produced, the fibres are made to split apart into much finer filaments through a finishing process.

Fibres as extruded



Fibres as split or separated



Typical methods of splitting or separating microfibres, image by SusTexEdu

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Environmental and safety issues of microfibres

- Microfibre textiles tend to be flammable if manufactured from hydrocarbons (polyester) or carbohydrates (cellulose) and emit toxic gases when burning, more so if aromatic (PET, PS, ABS) or treated with halogenated flame retardants and azo dyes. Their polyester and nylon stock are made from petrochemicals, which are not a renewable resource and are not biodegradable.
- For most cleaning applications microfibres are designed for repeated use rather than being discarded after use.
- Microfibre products also enter the oceanic water supply and food chain similar to other microplastics.

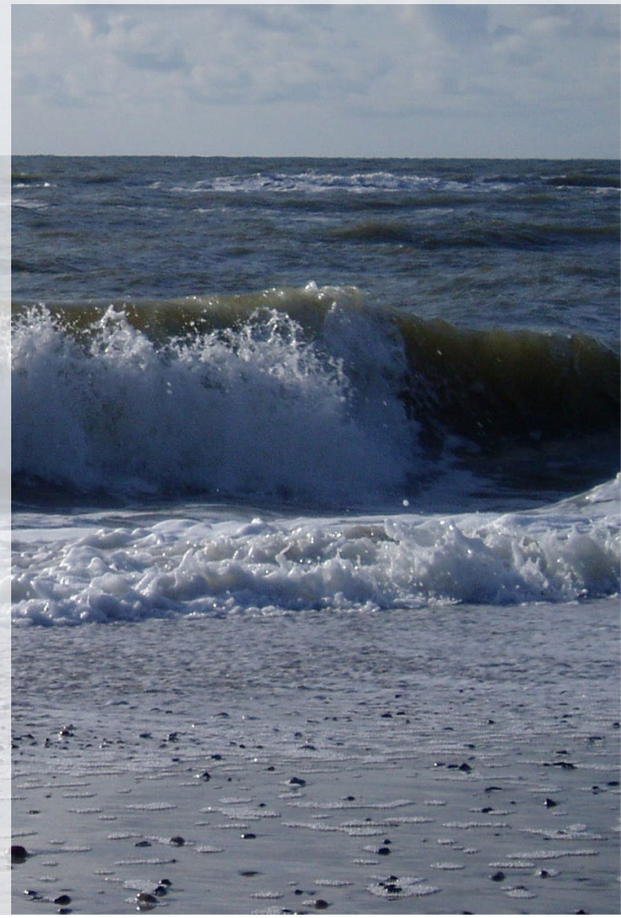

Photo by Muns on Wikipedia (CC BY-SA 2.0)

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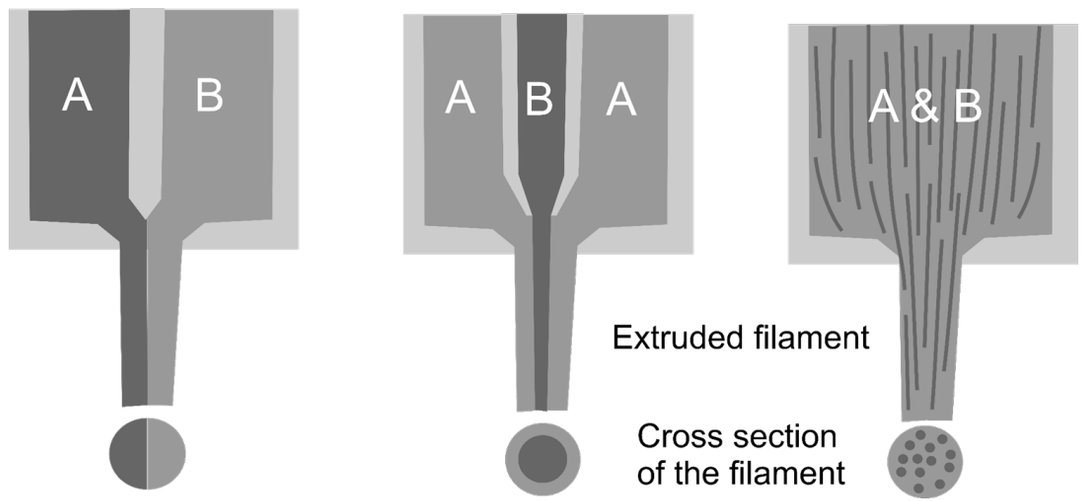
Bicomponent fibres

Bicomponent or multicomponent fibres are manufactured fibres that are a combination or mixture of two or more chemically and/or physically different components combined at or prior to the time of extrusion.



The principles of bicomponent spinning. Image by SusTexEdu
Source: Bicomponent Fibers by M.I.Kiron 2021 on Textile Learner

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Production of chemical inorganic fibres - Glass

- The fibre-forming substance is glass.
- The fibre has a round, rod like shape with a very smooth surface.
- As a result of high stretching, fused glass threads lose their fragility and acquire the characteristic properties of textile fibres.
- Glass balls (18-20 mm) are made, melted in furnaces at 1400 C
  → streams of molten glass pour through fine openings at the bottom of the furnace
  → are grabbed and stretched by a rapidly rotating drum
  → fine, smooth threads (1-20 µm) are obtained.
- Commercial production of glass fibre started 1936 in USA.

Glass fibre, photo above by NoiseD on Wikipedia, GDFL

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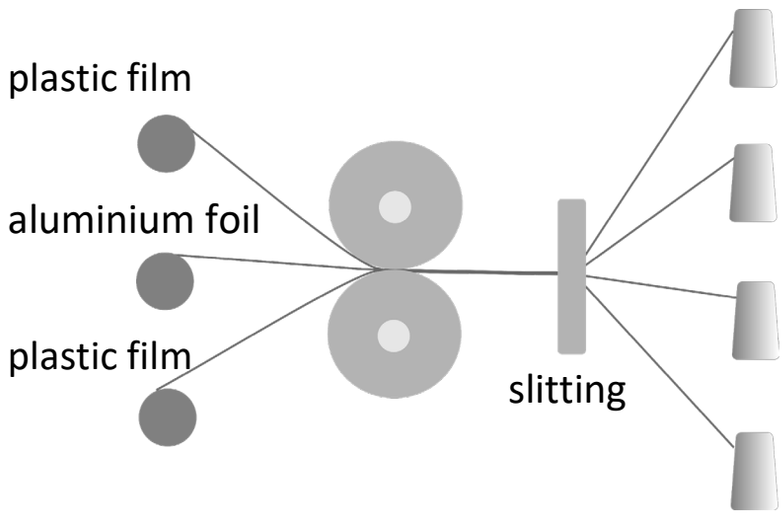
Metallic (ME)

- The earliest metallic fibres were stripes of real gold and silver. Later steel, copper and aluminum were used. Metallic fibres were first time commercial produced 1946 in USA.
- Metallic fibres are made by laminating, using a roll of aluminum foil and two rolls of transparent plastic film that are joined together with the aluminum foil sandwiched between the two sheets of plastic.

Metallic yarn, photo by rexess on Wikipedia, CC BY-SA 4.0



Laminating layers to produce a metal yarn. Image by SusTexEdu

SusTexEdu

Sustainability criteria

All aspects of the product should be examined when evaluating its green characteristics:

- production
- shipping
- use
- care
- disposal

Production	Non-production
Renewable material	Distribution-transportation
Resource conservation	Usage - cleaning
Energy savings	Disposal – recycling, reuse
Nonhazardous material usage	
Minimum waste	

Sustainability criteria
Source: Sarkar, Fabric Science 12th ed. 2023

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Learning materials

- Thompson, R. **„Manufacturing Processes for Textile and Fashion Design Professionals“** 2014
- Kadolph, S.J. „**Textiles**“ 2010
- Pizzuto, J.J. **„Fabric Science“** 2012
- Sarkar, A.K., Johnson, I., Cohen, A.C. **„J.J.Pizzuto's Fabric Science“** 2023 (p. 47-56)
- Sinclair, R. **„Textiles and Fashion. Materials, Design and Technology“** 2015
- Elsasser, V.H. **„Textiles. Concepts and Principles“** 2010
- Gries, T., Veit, D., Wulfhorst, B. **„Textile Technology“** 2015 (p.50-86)
- Collier, B.J. „**Understanding Textiles**“ 2009
- The Textile Institute **„Textile terms and Definitions“** 2002

Tips for learning more

VIDEOS of fibre production:

Wet Spinning Line for Producing Fibers from Cellulose, Gelatin, Collagen, Aramids, Acrylic, etc.

Melt spinning animation

Dry & Wet Spinning | Solution Spinning | Man made Fiber Production | Explained | TexConnect

The Viscose Fibre Line

Innovative by nature: How wood-based cellulosic fibers are made at Lenzing

The production of viscose fibres at Kelheim Fibres GmbH

Lenzing Modal Textile

TENCEL™ Lyocell: combining sustainability and comfort

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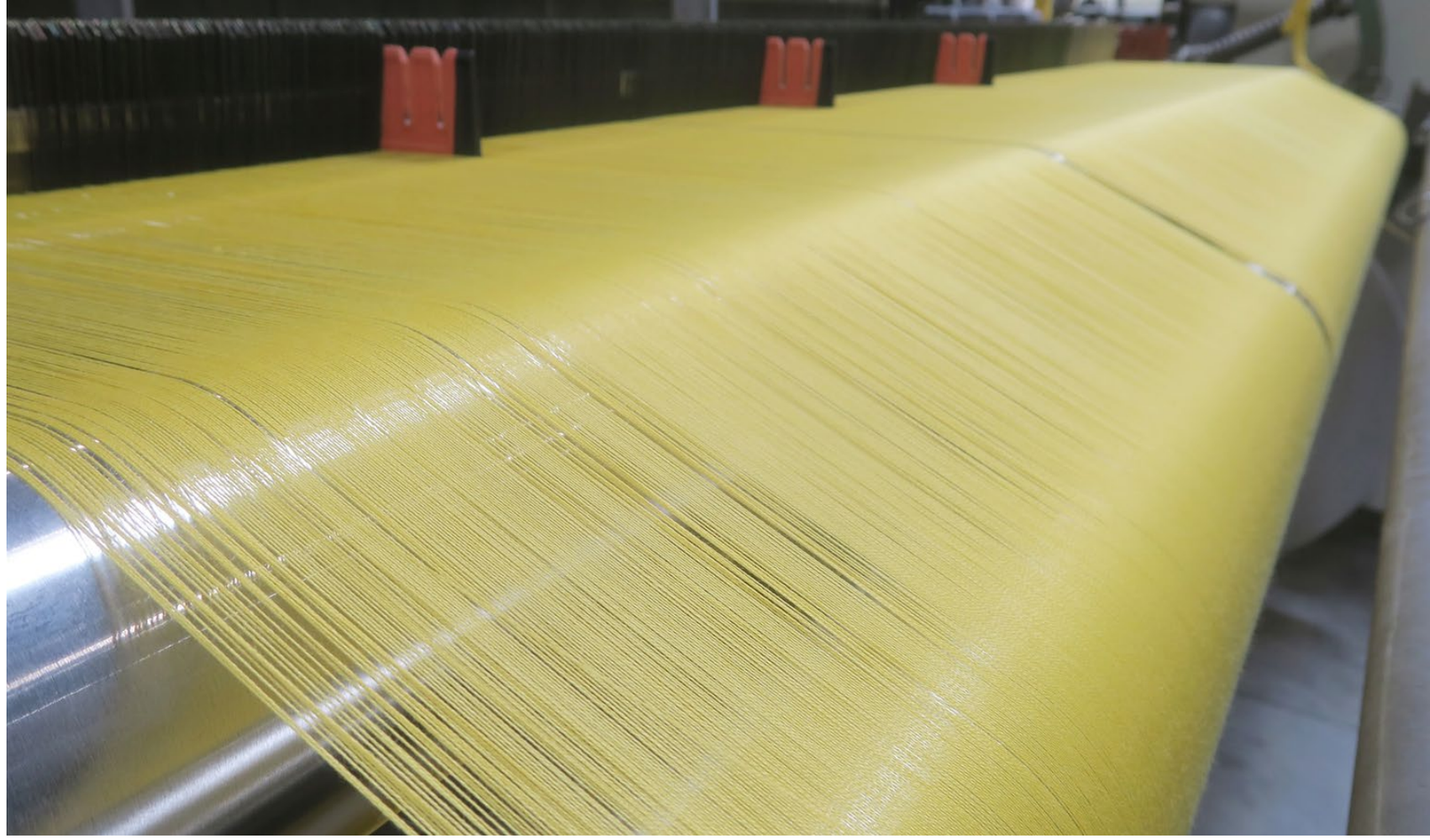
Visit the project website to see all the intellectual outputs of the project.



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