Chemistry of Natural Fibres

COTTON

- The word *cotton* is derived from the Arabic. Depending upon the arabian dialect , it is pronounced *kutan, qutn, qutun,* etc.
- Cotton is defined as white fibrous substance covering seeds harvested from Cotton Plant.
- It is classified as a natural, cellulose, seed, mono-cellular, staple fibre.
- The density of the fibre is 1.52 g/cm^3, which makes cotton a heavy fibre.

Fibre Morphology:

The macro-structure of cotton:

- Cotton fibre appears as a very fine, regular fibre.
- It ranges in length from about 10mm to 65 mm, depending upon the quality of the fibre.
- Cotton fibres are amongst the finest in common use.
- The fibre diameter ranges from about 11 µm to 22 µm.
- The fibre length to breadth ratio of cotton ranges from about 6000:1 for the longest and best types, to about 350:1 for the shortest and coarsest cotton types.
- The greater this ratio, the more readily can the cotton fibres be spun into yarn.
- Cotton fibres vary in colour from near white to light tan. The colour of cotton fibre depends on its type, environment, soil and climatic conditions under which it is grown. These factors influence the amounts of protein and minerals which will occur in the fibre and, thus, its colour.

The microscopic appearance of cotton:

- Under the microscope, the cotton fibre looks like a twisted ribbon and twisted tube. These twists or convolutions identify the cotton fibre under the microscope.
- The seed end of the fibre is quite irregular. The main part of the fibre, about ¾ to 15-16ths of its length, is quite regular, with a thick fibre wall, a canal along the centre of the fibre called lumen, and about 60 convolutions per cm.
- The fibre tip is less than ¼ of the fibre length and has no convolutions.
- The convolutions are formed after the cotton boll bursts open. When this happens, the limp, sap-filled cotton seed hairs begin to dry out, their cell walls collapse inward, decreasing the size of the lumen. When the cotton seed hairs cease shrinking, twisting and collapsing inward, they become the valuable convoluted cotton fibres.

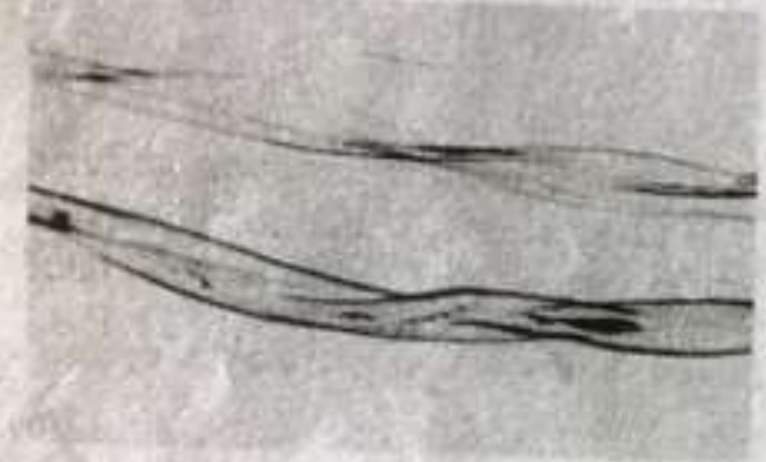

Figure 2.1a A longitudinal section of raw cotton, magnified 500 times. Note the convolutions or twist in the fibres.

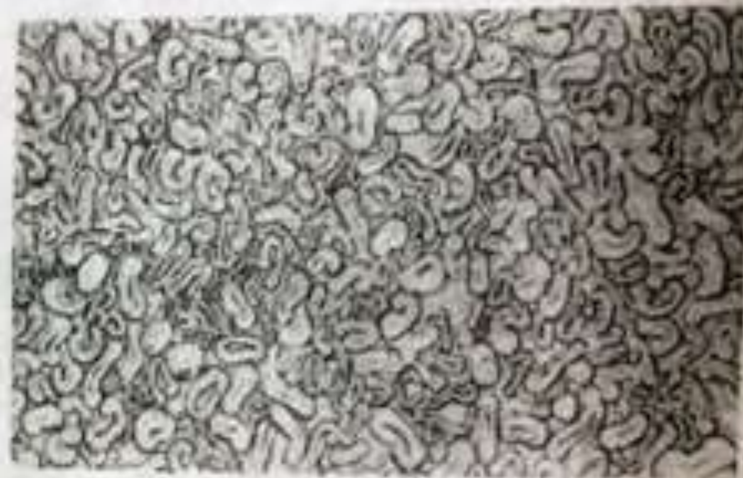

Figure 2.1b A cross-section of raw cotton magnified 500 times. Note the kidney shape of the cross-section of the fibres.

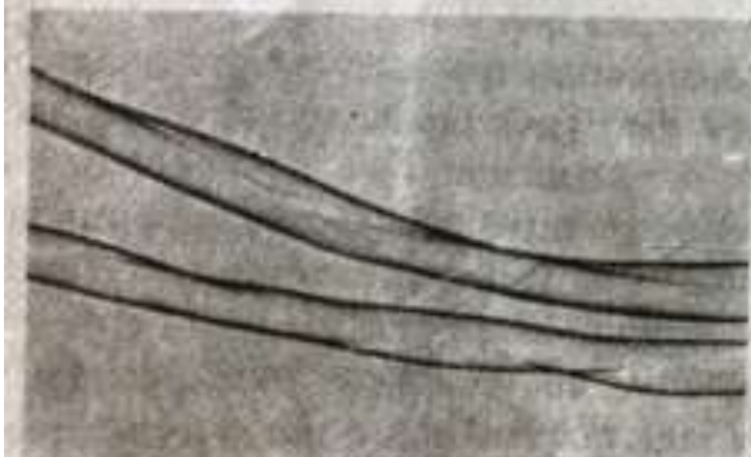

Figure 2.2a A longitudinal section of mercerised cotton, magnified 500 times. Note the much reduced prominence of the convolutions compared with raw cotton.

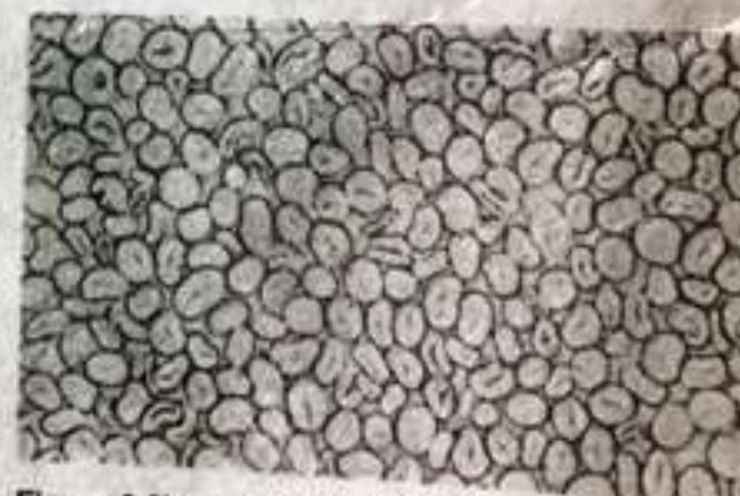

Figure 2.2b A cross-section of mercerised cotton, magnified 500 times. Note the oval to round shape of the cross-section of the fibres.

- The convolutions give cotton an uneven fibre surface, which increases inter-fibre friction and enables fine cotton yarns of adequate strength to be spun.
- The appearance of the cotton fibre's cross-section under the microscope is referred to as being kidney-shaped. This shape occurs from the inward collapse of the cotton fibre when it dries out, while still attached to its seed.
- The convolutions and kidney-shaped cross-section of the cotton fibre enable it to make only random contact with the skin. The countless minute air spaces which exist because of convolutions and kidney-shaped cross-section of cotton fibres increase the moisture absorbency of cotton textile materials thus making them more comfortable to wear.

The micro-structure of the cotton fibre:

- Cotton fibre is a single plant cell. Its cross-section is oval. However, like all plant cells, cotton has a distinct
- cuticle,
- well developed primary and secondary walls, and
- a lumen.

Cuticle:

- The cuticle is the ‘very outside’ or ‘skin’ of the cotton fibre.
- It is composed of a waxy layer (cotton wax) only a few molecules thick.
- The waxy nature of the cuticle enables it to adhere to the primary wall of the fibre.
- The inert nature of this cotton wax protects the rest of the fibre against chemical and other degrading agents.

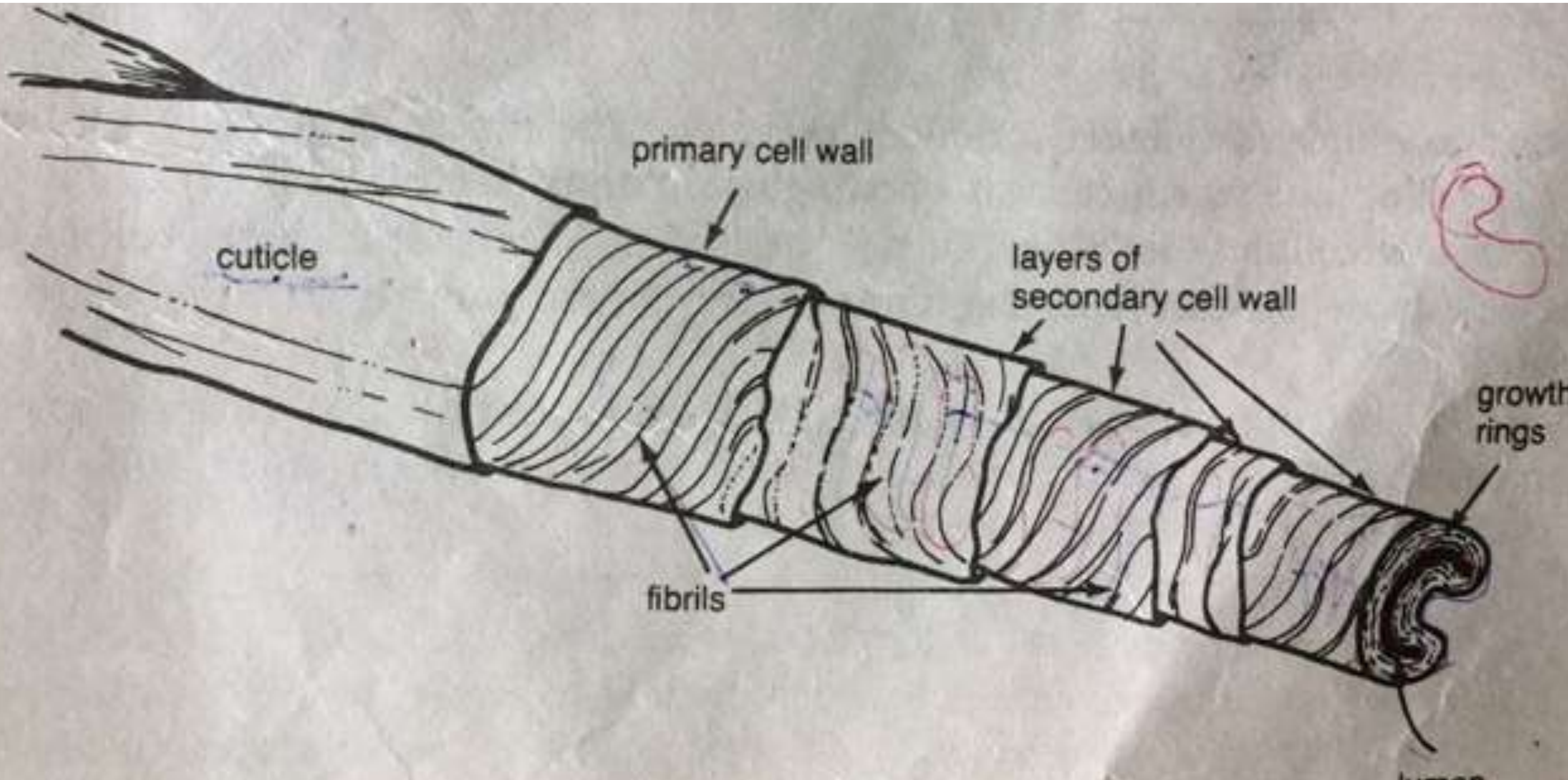

Figure 2.3 A morphological diagram of the cotton fibre.

- Kier boiling and bleaching during cotton finishing removes much of the cuticle or wax. This enables cotton to absorb moisture more quickly.
- Subsequent laundering will gradually remove most of the remaining cuticle.
- As the extent of the cuticle is decreased further, deterioration of the cotton textile material increases.

Primary cell wall:

- It is immediately under the cuticle, is about 200 nm thick.
- It is composed of very fine threads of cellulose, called fibrils.
- These fibrils are about 20 nm thick.
- The fibrils spiral at about 70^0 to the fibre axis.
- This spiralling imparts strength to the primary cell wall and hence, to the fibre.

Secondary cell wall:

- Beneath the primary cell wall lies the secondary cell wall, which forms the bulk of the fibre.
- Its fibrils are about 10 nm thick, but of undefined length.
- Near the primary cell wall, the fibrils of the secondary cell wall spiral at about 20^0 to 30^0 to the fibre axis. This spiral angle widens at about 20^0 to 45^0 for the fibrillar layers nearer the lumen.
- Much of the strength and stability of the cotton fibre and hence, of the yarns and fabrics may be attributed to these spiralling fibrils.
- Whenever the fibrils change the direction of their spirals, a weak area exists in the secondary wall structure. It is at these weak areas that the convolutions of the fibre also alter the direction of their twist.

Lumen:

- The hollow canal, running the length of the fiber, is called lumen.
- Its walls are the innermost, concentric layers of spirals of the secondary wall.
- The lumen was once the central vacuole of the growing cotton fiber.
- It was full of cell sap, which was composed of a dilute, aqueous solution of proteins, sugars, minerals and cell-waste products.
- When the sap evaporated, its constituents remained behind to contribute to the colour of the cotton fiber.
- Further, as the sap evaporated, the pressure inside the fiber became less than the atmospheric pressure on the outside. This caused the fiber to collapse inward resulting in the characteristics kidney-shaped cross-section of the cotton fiber.

The Polymer System: The cotton polymer

- The cotton polymer is a linear, cellulose polymer.
- The repeating unit in the cotton polymer is **cellobiose** which consists of two glucose units.
- It is not fully understood how cellulose is formed or polymerized by plants.
- The cotton polymer consists of about 5000 cellobiose units, i.e. its degree of polymerization is about 5000.
- It is a very long, linear polymer, about 5000 nm in length and about 0.8 nm thick.
- The most important chemical groupings on the cotton polymer are the hydroxyl groups or – OH groups.
- These are also present as methylol groups or $-CH_2\ OH$.
- Their polarity gives rise to hydrogen bonds between the OH-groups of adjacent cotton polymers.

- Van der Waals’ forces also occur but compared with the hydrogen bonds, the van der Waals’ forces are of little significance.

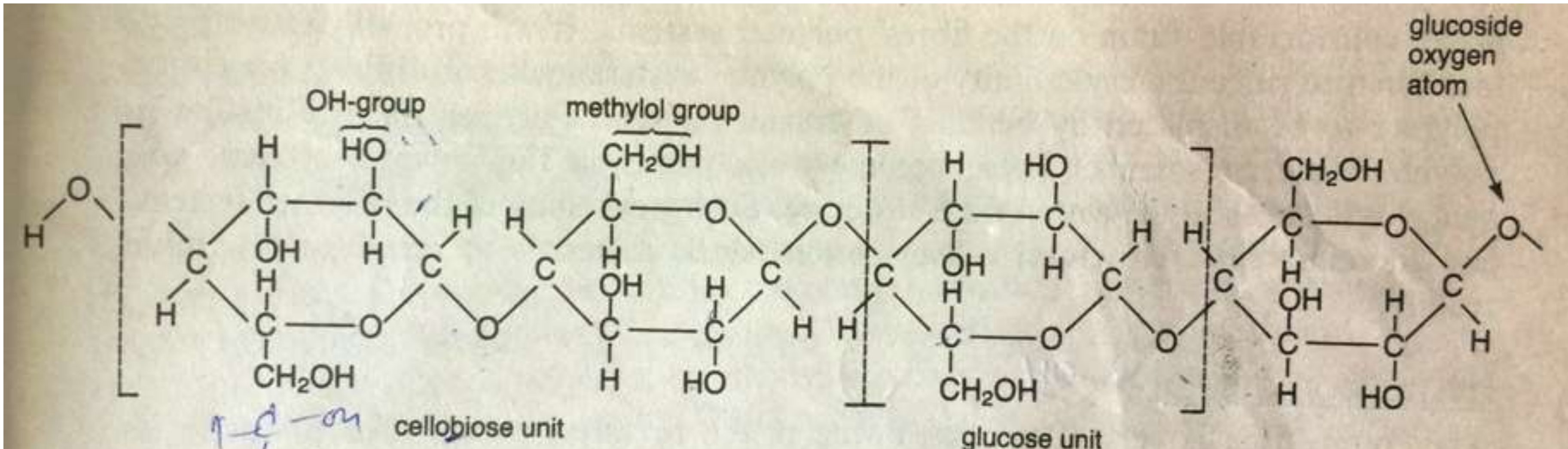

Figure 2.4 The chemical formula of the cellulose polymer. It is thought that the cotton cellulose polymer is composed of 5000 cellobiose units, while the flax cellulose polymer is thought to contain 18 000 cellobiose units.

The polymer system of cotton:

- Cotton is a crystalline fiber.
- Its polymer system is about 65 to 70% crystalline and about 35-30% amorphous.
- Cotton polymers are well oriented and probably no further apart than o.5 nm, in the crystalline regions.
- This is the maximum distance across which hydrogen bonds can form between polymers.
- Hydrogen bonds are the dominant and most important forces of attraction present in the polymer system of cotton. For this reason, van der Waals' forces which are also present have little relevance.

Physical properties:

1. Tenacity:

- The tenacity of cotton fiber is 3-5 g/denier (dry).
- The strength of cotton fibers is attributed to the good alignment of its long polymers (i.e.,about 70% crystalline), the countless, regular, hydrogen bond formations between adjacent polymers, and the spiralling fibrils in the primary and secondary cell walls.
- It is one of the few fibers which gains strength when wet.
- This occurs because of a temporary improvement in polymer alignment in the amorphous regions of the polymer system.
- The improved alignment when wet results in an increase in the number of H-bonds, with an approx 5% increase in fiber tenacity.

2. <u>Elastic-plastic nature:</u>

- The cotton fiber is relatively inelastic because of its crystalline polymer system, and for this reason cotton textiles wrinkle and crease readily.
- Bending or crushing of cotton textile materials places considerable strain on the fibers' polymer systems, cause polymer fracture which results in polymer disarrangements.
- These become weak points in the polymer system.
- Such weakening of the polymer system causes cotton textile materials to crease and wrinkle readily.

3. <u>Hygroscopic nature:</u>

- Very absorbent due to the countless polar –OH groups in its polymers; attract water molecules, which are also polar.
- These water molecules can only enter the polymer system in its amorphous regions.

- Due to this property cotton textile materials do not develop static electricity.
- The polarity of water molecules, attracted to the –OH groups on the polymers, dissipates any static charge which might develop.

4. Thermal properties:

- These fibres have the ability to conduct heat energy, minimising any destructive heat accumulation .
- Thus, they can withstand hot ironing temperatures.
- Excessive application of heat energy causes the cotton fibre to char and burn, without any prior melting. So, this indicates that cotton is not thermoplastic.

5. Composition: 94% cellulose, 1.3% protein, 1.2% ash, 0.6% wax, 0.3% sugar, traces of pigments and 2.6% others.

Chemical properties:

1. Effect of acids:

Weakened and destroyed by acids. Acidic conditions hydrolyse the cotton polymer at the glucoside oxygen atom.

2. Effect of alkalis:

- These fibres are resistant to alkalies and are unaffected by normal laundering.
- Mercerization (treating yarns or fabrics with NaOH) increases absorbency and improves the dye ability of cotton yarns and fabrics.
- **Mercerising without tension or slack mercerising**, causes the cotton fibres to swell; i.e., increase in thickness and contract in length.
- The swelling is due to alkali molecules, entering the amorphous regions of the fibres' polymer system which

force the cotton polymers further apart and results in greater inter-polymer spaces, permitting poorly aligned polymers to orient themselves as well as forming H-bonds.

- So, this explains the increase in fibre strength on mercerising.
- With **Mercerising under tension ,** which can be carried out only on cotton yarn or fabric, little swelling or fibre contraction occurs.
- The fibre emerges with increased strength and subdued lustre.
- Tensioning the cotton yarn or fabric in aqueous, alkaline liquor assists the fibre polymers to align themselves, leading to increase in H-bond formation.
- So, there is increase in tenacity and also fibre surface become smooth and more regular and reflect more light evenly which is responsible for the subdued lustre.

3. <u>Effect of bleaches:</u>

- The most common bleaches used on cotton textile materials are Sodium hypochlorite (NaOCl) and Sodium perborate ($NaBO_2 \cdot H_2O_2 \cdot 3H_2O$).
- Sodium hypochlorite is a yellowish liquid, smelling of chlorine. It bleaches cotton textile materials at prevailing room temperature.
- Sodium perborate is a white powder, contained in most commonly domestic laundry detergents. Bleaching with it is more effective when the laundry solution exceeds 50^{o} C in temperature.
- Both are oxidising bleaches and most frequently used on cotton textile materials and bleach more effectively in alkaline conditions.

4. Effect of sunlight : Prolonged exposure to sunlight weakens the cotton due to the heat energy of infrared rays which degrade the cotton polymers in the presence of atmospheric oxygen, moisture and air pollutants.

5. Effect of weather:

- Atmospheric moisture (humidity) contributes to the breakdown of the polymers on the surface of the cotton fibres through various hydrolytic reactions.
- The fibre discolouration, weakening of the fibre and break-down of the cotton textile material takes place.
- Air pollutants are acidic and rapidly accelerate fibre breakdown through acid hydrolysis to which cotton polymers are not resistant.
- This may cause fading of coloured cotton textiles due to the breakdown of the dye molecules in fibre polymer systems.

6. Effect of mildew: Cotton is readily attacked by moth and mildew. So it has to be saved from their attack by suitable methods.

7. Effect of Heat: Cotton fibre have the ability to conduct heat energy and can withstand hot ironing temperature. Cotton can be heated upto 150^{o} C without any damage. It scorches at $245\ ^{o}$ C and burns.

8. Affinity for dye stuff: It is a easy fibre to dye and print. It is having good affinity for direct, reactive, vat, sulphur and azoic dye stuffs , which is due to the polarity of its polymer and polymer system.