Chapter I
CHAPTER I

INTRODUCTION

Food, shelter and clothing are recognised as the primary needs of mankind. Clothing is worn for two main purposes: First, for protection or so to say to maintain body comfort, and secondly for adornment, to satisfy aesthetic senses. The use of polyester, polyamide and polyacrylonitrile in fabric manufacture is larger than the other man-made fibres. The statistical survey of the data of the production of these shows that the production of polyester is the highest in India as well as all over the world and during the past decade, the production of polyester has shown a spectacular rise\(^1\)\(^-\)\(^2\) (Figures 1.1 and 1.2). Also as per the Figure 1.3 of per capita consumption of textiles of the world\(^3\), the consumption of cotton was 71.4% of the total consumption in 1950 which is expected to reduce by 39.5% in 1985. Whereas in the case of synthetics the consumption was 0.0% in 1950 which is expected to reach up to 47.5% in 1985. This clearly indicates that the consumption trend for synthetics is prospering in comparison to the cotton which is reducing considerably. Reasons for such a rapid growth and consumption of polyester are its desirable qualities like high strength, attractive handle, dimensional stability, easy-care properties, suitability for blending with other fibres, etc. However, polyester has also certain undesirable qualities such as lack of hydrophilicity,
Fig. 1.1 : Production of Synthetic Textiles in India
Fig. 1.2: Production of Synthetic Textiles of the World
Fig. 1.3: Per Capita Consumption of Textiles of the World (Kg.)
generation of static electric charge, high soiling and poor soil-release property which make polyester uncomfortable for wearing purpose.

Before discussing the ways and means by which polyester can be made for comfortable, it would be worthwhile to discuss the synthesis, structure and properties of polyester.

**SYNTHESIS**

In chemical terms, the simplest route to get polyethylene terephthalate is the direct reaction of terephthalic acid with monoethylene glycol (EG), followed by poly-condensation of the "monomer", bis (beta-hydroxy ethyl terephthalate) or BHET.

**First Step**

\[
\text{HOOC-} \overset{\text{BHET}}{\longrightarrow} \text{-COOH + 2HOCH}_2\text{-CH}_2\text{OH} \rightarrow \text{HO-CH}_2\text{-CH}_2\text{OOC-} \overset{\text{BHET}}{\longrightarrow} \text{-COOH}_2\text{-CH}_2\text{OH + 2H}_2\text{O}
\]

But the difficulty of obtaining a sufficiently pure terephthalic acid was avoided in the earlier commercial production of PET by the use of dimethyl terephthalate (DMT) instead of terephthalic acid. DMT has a comparatively low melting point and is amenable to conventional methods of purification. The reaction of monoethylene glycol (EG) with DMT
is one of ester interchange (transesterification), resulting in the production of same bis(hydroxyethyl) terephthalate (BHET) and the release of methanol as explained by the following reaction:

First Step: Transesterification

\[
\begin{align*}
\text{CH}_3\text{OC}-\text{CH}_2\text{COOCH}_3 + 2\text{HOCH}_2\text{CH}_2\text{OH} & \xrightarrow{\text{Catalyst}} \text{EG} \\
\text{HOCH}_2\text{CH}_2\text{O}-\text{CH}_2\text{COOCH}_2\text{CH}_2\text{OH} + 2\text{CH}_3\text{OH} & \xrightarrow{\text{BHET}}
\end{align*}
\]

Second Step: Polycondensation

\[
\begin{align*}
\text{HOCH}_2\text{CH}_2\text{OC}-\text{CH}_2\text{COOCH}_2\text{CH}_2\text{OH} & \xrightarrow{\text{Catalyst}} \text{280-290°C, vacuum} \\
\text{HOCH}_2\text{CH}_2\text{[OC}-\text{CH}_2\text{COOCH}_2\text{CH}_2\text{]}_{\text{OH} + n\text{HOCH}_2\text{CH}_2\text{OH}} & \xrightarrow{\text{n = av. 80-110}}
\end{align*}
\]

The catalysts zinc, manganese, calcium and lead salts are used for transesterification and an antimony compound for the polycondensation.

**STRUCTURE AND PROPERTIES OF POLY(ETHYLENE TEREPTHALATE)**

Poly(ethylene terephthalate) (PET) is a linear polymer containing ester linkages which are repeated regularly.
Its formula is:

\[ \cdots \left( \text{O-CO-} \right) - \text{CO-CH}_2 - \text{CH}_2 - \cdots. \]

There are no active groups in this molecule, so that the only attractive forces between neighbouring chains are weak van der Waals' forces. However, the chains are straight and pack together very closely to form crystalline areas. The crystal structure of PET is shown in Figure 1.4. The unit cell of PET is triclinic and contains one repeating unit. The crystalline fold-period in fibre is generally 6-9 monomer units. About 60% of the material is crystalline.

**Fibre Structure**

The mechanical properties of polymers depend on their morphological characteristics. A number of different structural models have been suggested to represent different states of the fibre. Although, it appears that the melt spun and drawn PET fibres consist of at least three distinct phases: amorphous and crystalline domains of the microfibril and the inter-microfibrillar regions (intermediate phase or oriented amorphous phase). A model to represent such a structure has been proposed as shown in Figure 1.5. Lindner also suggested that there existed an intermediate state of order between amorphous and crystalline phases. Microfibrils consist of sequence of crystalline and amorphous regions arranged regularly as shown in the figure. The electron microscopic
Fig. 1.4: Crystal Structure of Polyester
SCHEMATIC STRUCTURE OF PET FIBERS
(Fiber Axis Vertical)

MICRO FIBRILS

CRYSTALLITES

EXTENDED "AMORPHOUS" MOLECULES

DISORDERED DOMAINS "A"

Fig. 1.5: Structural Model of PET Fibres
examination of PET fibre by Prevorsek indicates a fibrillar structure with each fibril appearing as a series of nearly equally spaced nodules and from dimensional consideration it can be inferred that these nodules represent the high electron density (crystalline) domains of the structural unit. The size of the disordered low density domains separating the crystalline domains in the fiber direction is of the order of 60-80 Å.

**Polyester Fibre**

A polyester fibre has been defined by the Federal Trade Commission as "a manufactured fibre in which the fibre-forming substance is a long chain synthetic polymer composed of at least 85% by weight of an ester of a dihydric alcohol and Terephthalic acid". The most common polyester in use throughout the world is that derived from the linear polymer, i.e., Poly(ethylene terephthalate).

![Polyester Fibre Structure](image)

The first recognition of the useful fibre-forming properties of PET was made by Whinfield in 1941 of Calico Printers Association in England. The arrangement of successive ester groupings in trans configuration across both the glycol and the phenyl residue is shown in Figure 1. The chain repeat distance has been shown to be 10.75 Å, which is slightly
Fig. 1.6: Arrangement of Ester Groupings in Poly(ethylene terephthalate)
less than the fully extended length of one chemical unit. The lateral packing of the ester molecules in the unit cell is determined entirely by their geometry, with the projections from one molecule fitting into the hollows of its neighbour.

Polyester fibres became available commercially in the United States in 1953. Polyester is a general term and it is used for the following types of fibres:

From the viewpoint of chemical composition we distinguish polyester fibres:

- based on ethylene glycol and terephthalic acid, such as Terylene, Dijen, Trevira, Tesil, Tergal, Dacron, known as 'PET',
- based on 1,4-bis-hydroxymethyl cyclohexane and terephthalic acid, such as Kodel, Vestan,
- copolymer fibres based on terephthalic acid and isophthalic acid, such as Vycron, Velana,
- copolymer fibres based on terephthalic acid and p-oxybenzoic acid, such as Grilene, and
- copolymer fibres based on terephthalic acid and 5-sulpho-isophthalic acid, such as Dacron 64, and Tesil 31.

The following is the selected list of world producers of polyester fibre.
TABLE 1.1: COUNTRIES PRODUCING POLYESTER FIBRES

<table>
<thead>
<tr>
<th>Country</th>
<th>Names of Trade Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>Terene</td>
</tr>
<tr>
<td>United States (USA)</td>
<td>Dacron, Avlen, Blue C Polyester, Encron, Fortrel, Hystron, Quintess, Vycron, Vytacord, Kodel</td>
</tr>
<tr>
<td>United Kingdom (UK)</td>
<td>Terylene</td>
</tr>
<tr>
<td>German Democratic Republic</td>
<td>Grisuten</td>
</tr>
<tr>
<td>German Federal Republic</td>
<td>Trevira, Vestan, Diolen, Kuraray, Nitisray, Teijin-Tetoron, Toyobo, Toray-Tetoron, Asahi, Nippon</td>
</tr>
<tr>
<td>Japan</td>
<td>Lavsan and Okson</td>
</tr>
<tr>
<td>USSR</td>
<td>Tergal, Trelbe</td>
</tr>
<tr>
<td>France</td>
<td>Wistel, Terital</td>
</tr>
<tr>
<td>Italy</td>
<td>Trevira</td>
</tr>
<tr>
<td>Austria</td>
<td>Terylene</td>
</tr>
<tr>
<td>Canada</td>
<td>Tersuisse, Grilene</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Tesil, Velana</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>Tereelenka</td>
</tr>
</tbody>
</table>

**General Properties of PET**

(a) **Physical Properties**

When quenched rapidly from the melt, the polymer is an amorphous, glassy solid. Differential thermal analysis (DTA) shows a second order transition at 78-80°C, a crystallization endotherm ranging between 125°C and 180°C, and a melting point (DTA) of 255°C. Birefringent melting points are in the neighbourhood at 260-265°C.
The polymer is insoluble in most common solvents. The solvents for PET are phenol, o-chlorophenol, m-cresol, trifluoroacetic acid, nitrobenzene, phenoltetrachloroethane (10:3 by weight) and a mixture of 59 parts phenol, 41 parts trichlorophenol. The weight-average molecular weight of PET fibre lies usually in the range 22,000-27,000 and the number-average in the range 16,000-21,000. The properties of polyester fibre are listed in Table 1.2.

**TABLE 1.2 : PROPERTIES OF POLYESTER POLY(ETHYLENE TEREPTHALATE) FIBRE**

<table>
<thead>
<tr>
<th>Property</th>
<th>Regular Tenacity Filament</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking Tenacity, g/den^\text{10}</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>2.8-5.2</td>
</tr>
<tr>
<td>Wet</td>
<td>2.8-5.2</td>
</tr>
<tr>
<td>Breaking Elongation, %</td>
<td></td>
</tr>
<tr>
<td>Standard</td>
<td>19-40</td>
</tr>
<tr>
<td>Wet</td>
<td>19-40</td>
</tr>
<tr>
<td>Elastic Recovery, %</td>
<td>88-93 at 5% Elongation</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.38</td>
</tr>
<tr>
<td>Moisture Regain (70°F, 65% rh)</td>
<td>0.4</td>
</tr>
<tr>
<td>Melting Temperature, °C</td>
<td>258-263</td>
</tr>
<tr>
<td>Microscopical Appearance^\text{4}</td>
<td>Circular in Cross-section</td>
</tr>
<tr>
<td>Density:</td>
<td></td>
</tr>
<tr>
<td>100% Amorphous</td>
<td>1.335 g/cm^3</td>
</tr>
<tr>
<td>100% Crystalline</td>
<td>1.455 g/cm^3</td>
</tr>
<tr>
<td>Modulus (dynes/cm^2)</td>
<td></td>
</tr>
<tr>
<td>X-ray</td>
<td>7.5 x 10^\text{11}</td>
</tr>
<tr>
<td>Calculate</td>
<td>1.2 x 10^\text{12}</td>
</tr>
<tr>
<td>Fibre</td>
<td>2.2 x 10^\text{11}</td>
</tr>
</tbody>
</table>
TABLE 1.2 (contd.)

<table>
<thead>
<tr>
<th>Property</th>
<th>Regular Tenacity Filament</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weakest Bond</td>
<td>-C-O-</td>
</tr>
<tr>
<td>Bond Energy (ergs/bond)</td>
<td>$3.13 \times 10^{-12}$</td>
</tr>
<tr>
<td>Specific Cohesive Energy:</td>
<td></td>
</tr>
<tr>
<td>(ergs/Å$^2$) : Crystal</td>
<td>$3.5 \times 10^{-13}$</td>
</tr>
<tr>
<td></td>
<td>$3.1 \times 10^{-13}$</td>
</tr>
<tr>
<td>No. of Molecules per Crystal Unit Area (N/cm$^2$)</td>
<td>$4.9 \times 10^{14}$</td>
</tr>
<tr>
<td></td>
<td>$4.5 \times 10^{14}$</td>
</tr>
<tr>
<td>Resiliency</td>
<td>Excellent</td>
</tr>
<tr>
<td>Burning Point</td>
<td>In flame burns slowly with melting; usually self-extinguishing after flame is removed</td>
</tr>
<tr>
<td>Conductivity of:</td>
<td></td>
</tr>
<tr>
<td>Heat</td>
<td>Poor</td>
</tr>
<tr>
<td>Electricity</td>
<td>Poor</td>
</tr>
<tr>
<td>Resistance to Damage from:</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td>Excellent</td>
</tr>
<tr>
<td>Insects</td>
<td>Excellent</td>
</tr>
<tr>
<td>Prolonged Exposure to:</td>
<td></td>
</tr>
<tr>
<td>Sunlight</td>
<td>Good if behind glass</td>
</tr>
<tr>
<td>Acids</td>
<td>Good</td>
</tr>
<tr>
<td>Alkalies</td>
<td>(1) Good to weak alkali, and (2) Fair to strong</td>
</tr>
</tbody>
</table>

CLOTHING COMFORT OF A TEXTILE MATERIAL

The term comfort is a nebulous one which defies definition, but the sensation of comfort is easily recognised by the person experiencing it. Many attempts have been made, without success as yet, to define the state in physical terms, but
none of them provides an objective definition to it. Comfortable clothing has been defined as one which keeps the body in as good working order as possible, which allows freedom of movements, which is not too heavy, which is warm enough for the weather but not too warm, which does not constrict the figure and displace internal organs, and which keeps our skins clean, dry and well ventilated. Wear comfort is the result of harmonious interaction between body, climate and clothing. 'Comfort' is a state of mind which expresses the subjective feeling that a specific garment is satisfactory under given set of environmental conditions. Bekesius adopts subjective approach and quotes comfort as, 'the absence of unpleasantness or discomfort' whereas Goldman takes a non-subjective approach and considers comfort in terms of physiological tolerance to the changes in environmental conditions. Yaglou believes that a satisfactory physical definition of comfort can never be given because it involves human beings who vary in their physiological and psychological aspects and it concerns with environmental conditions of temperature, relative humidity, air motion, radiant heat exchange, etc., which are also variable.

Factors Governing Clothing Comfort

The state of existence of comfort is not easy to define and hence the problem of analysing the factors which influence
comfort is quite complicated\textsuperscript{16}. Clothing comfort is influenced by physical, physiological and psychological factors and therefore it is difficult to define.

In order to understand the physiological behaviour of textiles which lead to comfort, a number of parameters have to be evaluated\textsuperscript{17} and they depend on the physiology of the body structure of various persons. The psychological factors are dependent on the state of the mind of a person which determines whether the fabric is comfortable or uncomfortable in a particular situation. So these two factors, related to the physiology and psychology of a person, influencing the clothing comfort of textile material are very difficult to explain. However, there are other properties like liquid water or moisture sorption and wicking, movement of moisture, air and heat through fabrics, generation of static electricity, soiling and release, aesthetic qualities (viz., hand and drape) etc., discussed in detail in the following sections, are the major factors governing the clothing comfort of a textile material.

\textbf{(1) Absorption and Transport of Liquid Water}

Absorption of water and its transport are important factors in determining the comfort characteristics of a garment under a given set of environmental conditions. Under conditions
where large amount of perspiration is produced, process by which this can be removed involves diffusion of water vapour and transport of liquid water. Transport of liquid water essentially occurs by capillary action. Yarn construction affects the rate of water transport. Wicking with subsequent drying seems to be the mechanism for transfer of perspiration and is independent of regain. However, we know of no fibre in which high regain is coupled with fast drying rate. In considering the movement of liquid water through fabric, two comfort aspects may be identified. Water from an external source, such as rain, should be prevented from reaching the body. On the other hand, water generated at the body surface as perspiration should be removed as quickly and as efficiently as possible if comfort is desired. These two requirements are, of course, diametrically opposed; and it is quiet common for both mechanisms to be needed simultaneously. In addition, these properties are important from the stand-point of aesthetic comfort because both the completeness and uniformity of the dyeing and finishing operations are dependent on the water absorbency. Bechmann has investigated objectively and subjectively the fabric's ability to absorb water on its comfort rating.

(ii) Water Vapour Permeability

The movement of water vapour through a garment is probably the most important factor in governing the clothing comfort.
of textile. When the skin becomes wet with perspiration, the water must be removed, either by wind or by wiping or wicking away in some manner, otherwise the body feels uncomfortable even though the skin temperature is brought back within comfort range. Rapid transport of perspiration in the form of water vapour is an important factor. It depends on the cut of the garment (ventilation through openings in the garment around the collar, through the sleeves, etc.), and on air permeability of the fabric. In the process of evaporation of moisture at the skin and passing it as a vapour through a fabric, the pores of the fabric remain free. So it enables the movement of air through the fabric to continue and allows the heat insulation value of air pockets to be maintained.

On the other hand, if skin moisture is transported to the surface in the liquid phase by wicking action and only evaporates on reaching the air layer at the fabric surface, comfort is reduced in two ways. In the first case the fabric feels clammy and in second case it feels cold because of the less heat insulating capacity of the water filled fabric pores.

(iii) Air Permeability and Porosity

These are very important factors from the comfort point of view. Air permeability controls the convection loss through fabric. It influences the thermal insulation property of clothes so where warmth is desired under cold and windy
Porosity of a textile fabric pertains to the total volume of void space contained within its boundaries, whereas permeability refers to the accessibility of the void space to the flow of air or liquid. Porosity is defined as the ratio of the void spaces to the total volume encompassed by the boundaries of the material. It is also a measure of water holding capacity. The total porosity of fabric can be classified in three components: (a) Intra-fibre porosity, (b) Inter-fibre porosity, and (c) Inter-yarn porosity. (a) and (b) are responsible for the main differences in air permeability. These are defined as "Effective Porosity". Air permeability is not similar but closely related to water vapour permeability, as the former can pass through the yarn whereas the latter can pass through the yarn and fibres both. Air permeability, the rate of air flow through a fabric under a differential pressure across the surface of a cloth, is the property mainly dependent on fabric geometry (construction), on cover factor, on yarn characteristics such as yarn crimp, twist as well as weave and hence can be manipulated by the proper adjustment of these variables. Porosity is also dependent on type and structure of the fibre. Air permeability plays an important role in certain limited end-use requirements such as in parachutes, mosquito nettings,
sails, tentage, etc. Several workers have carried out studies on the measurement of air permeability for correlating it to comfort characteristic of fabric.

(iv) Thermal Comfort and Warmth

Hardy\textsuperscript{16} has defined thermal comfort as the "absence of any unpleasant sensation of being too cool or being too warm, or of having too much perspiration on the skin". This is a major factor in determining the degree of general comfort.

There are six variables influencing the conditions of thermal comfort in a man\textsuperscript{12} viz.,

1. body heat production,
2. the insulation value of clothing,
3. air temperature,
4. mean radiant temperature,
5. relative air velocity, and
6. water vapour pressure in the ambient air.

Transmission of heat through a fabric is the property of paramount importance to thermal comfort, irrespective of whether the particular garment is used for warmth or to protect from heat, because the basic function of clothing is to maintain a uniform temperature in the body of its wearer by protecting the wearer against extremes of environmental temperature.
People, in their activities produce considerable amount of heat which must be removed from the body to some extent to maintain the body temperature i.e., 37°C. The transport of this heat occurs by the phenomena of heat conduction, convection or radiation and depends on the nature and structure of the fabric and on the temperature gradient between the skin and the environment. The total thermal resistance to heat transfer from the body surface to the surrounding air can be divided into the following three components: (a) the thermal resistance to transfer of heat from the body surface to the fabric, (b) thermal resistance of the clothing material, and (c) thermal resistance of the air interlayer. Under a given set of conditions, as volume occupied by fibre is less in comparison to the total volume of the fabric, the thermal resistance of a dry fabric is dependent mostly on fabric thickness and for a given thickness on bulk fabric density. In general, it is observed that thermal insulation value (TIV) increases in proportion to the thickness of fabric for all fibre materials. In calculating heat insulating properties during wear, factors such as air permeability, wind speed and thermal resistance of the garments should be incorporated.

It can be inferred from the above discussion that under hot and humid atmosphere an undergarment would feel more comfortable if it has the following characteristics: (1) Capable of removing water as perspiration from the body surface by
rapid and efficient wicking and evaporation into the air, and
(2) Having enough porosity to allow diffusion of air and
moisture vapour through it to the outer layer.

For greater comfort in a cold and wet climate, the undergarment
should have high heat insulation value by immobilizing a large
amount of air within its pores, and there should be a minimum
area of contact between the fabric and the skin to minimise
heat conduction.

(v) **Static Electricity**

Static electricity is generated by hydrophobic textile
materials. By rubbing with the **synthetic fibres** this electri-
city is observed which leads to various problems such as
clinging of the dresses to the body, the twisting, riding and
bunching of undergarments from adherence of oppositely
charged dirt particles and electrical shocks **while** walking on
carpets which make them uncomfortable. Under a given set of
conditions, both the generation and dissipation of static
electric charge depend on surface hydrophilicity of the
textile material. Higher is the surface hydrophilicity of
the textile material lower will be the generation of static
electric charge and faster will be its decay.

(vi) **Soiling and Soil Release**

Soiling, the unwanted accumulation of materials on the surface,
is the property of textile materials which detracts from the
comfort of garments specially those which are used as underwears. It affects appearance and cleanliness of textile materials and in addition, it shortens the fabric life by the action of frequent cleaning operations. Firm adherence and poor soil release of soils such as odours and colourless salts of perspiration in undergarments often lead to discomfort. Soiling of natural, hydrophilic textile fibres has never given any problem and at the same time, in general, soil removal from these fibres is also easy. However, properties like hydrophobicity, generation of static electric charge and poor wettability of synthetic fibres like polyester give various problems of soiling and soil release and therefore gradual greying of the garments occurs during the course of their wear.

(vii) Aesthetic Comfort

In addition to the objective performance, characteristics of textile materials discussed above, which can be measured in quantitative terms and are independent of personal preferences and psychological experiences, there are other equally important subjective performance characteristics which are not easily measured quantitatively by physical tests and are evaluated at least in part by individual reaction. Such properties are subjective because different persons may feel different degrees of comfort with the same fabric. These factors include hand, stiffness, drape, colour, style, fashion
compatibility of the fabric, etc. Hand of a fabric is an illusive property which expresses personal reaction of the sense of touch when fabric is held in the hand and also a careful analysis of wear-test data shows that the specific preference for or recognition of a "softer-hand" is closely related to the subjective preference. The preference for fabrics with a soft hand was higher. There is a strong correlation between the textile properties of a fabric and how people perceive comfort. If they like the hand, they will feel more comfortable in the garment. A quantitative correlation between hand and fabric surface properties has been obtained with the handle test and it was found that natural staples, such as cotton, wool, and so on are best in tactility because they are produced by nature but they have also limitations. Cotton does not have the durability and ease of care of polyester. "Stiffness of a fabric in terms of Flexural Rigidity is a measure of the resistance offered by the specimen to bending about an axis under its own weight in certain cases", and "drape differs from rigidity in that the weight of the material influences a deformation at some angle to the line of action".

Ghose discusses in general terms how the comfort of hydrophobic fibre garments can be made equal to those of natural fibres and deals with both structure and finishing factors.
REFERENCES


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