The background of the cover is an abstract composition of three main horizontal bands. The top band is a deep blue with lighter, wispy white and light blue patterns, resembling smoke or clouds. The middle band is a solid, vibrant red. The bottom band is a dark, almost black, area with bright green, fibrous or grass-like textures. The title is centered over the red band.

Textile Preparation and Dyeing

A.K. Roy Choudhury

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Science Publishers

Enfield (NH)

Jersey

Plymouth

SCIENCE PUBLISHERS
An Imprint of Edenbridge Ltd., British Isles.
Post Office Box 699
Enfield, New Hampshire 03784
United States of America

Website: <http://www.scipub.net>

sales@scipub.net (marketing department)
editor@scipub.net (editorial department)
info@scipub.net (for all other enquiries)

Library of Congress Cataloging-in-Publication Data

Choudhury, Asim Kumar Roy.

Textile preparation and dyeing / Asim Kumar Roy Choudhury.
p. cm.

Includes bibliographical references and index.

ISBN (Hard Cover) 1-57808-402-4 [10 digits]

978-1-57808-402-9 [13 digits]

ISBN (Paperback) 1-57808-404-0 [10 digits]

978-1-57808-404-3 [13 digits]

1. Dyes and dyeing--Textile fibers. 2. Textile finishing. I. Title.

TP897.C575 2006

667'.3--dc22

2005056310

ISBN 1-57808-402-4

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Published by Science Publishers, Enfield, NH, USA
An Imprint of Edenbridge Ltd.
Printed in India

Preface

Any aspiring technologist who sets out for a career in dyeing technology, whether it be in industry, teaching or research, must have realised the non-availability of a textbook which is comprehensive yet not too bulky. The situation has become more difficult now as the present syllabus encompasses several new subjects and each subject has become voluminous with tremendous advancements in each field. The need of the day is for a single comprehensive book which covers all aspects in a well-balanced manner. Since I have a teaching experience of more than 20 years, I understand necessity of a standard textbook which students can use as the chief source of information on all aspects of dyeing. New entrepreneurs or fresh technicians in the textile processing industry who are desirous of having first hand knowledge of the subject also need similar consolidated information.

The book mainly deals with the classical processes for textile dyeing as well as preparation of the material before dyeing and includes recent technological developments. Both the theories and the practical aspects are discussed precisely in order to enable the students and the technicians to understand the processes clearly.

The first chapter deals with the chemical and physical structures and the properties of various natural, regenerated and synthetic textile fibres. Identification techniques of various textile fibres have been discussed briefly, as satisfactory dyeing is possible only when the composition of textile material is known.

Water quality is the single largest factor which decides the success of the dyeing processes. The second chapter broadly discusses the water sources, qualities, requirements and treatments. Standard norms for water quality required for various textile processes are mentioned. Today there is global concern about water and air pollution caused by effluents/emissions from industries. Air pollution caused by textile industries is similar to the pollution from other industries and is not specific to this industry alone. However, water pollution is another story as this industry uses copious quantity of water, combines it with chemicals and the wastewater is then discharged as effluent. The treatment of effluents before discharge is discussed in detail.

The third chapter discusses various aspects of surface activity and surface-active agents. Such compounds play a vital role at various stages of textile processing. Special emphasis has been given while discussing soaps and detergents, emulsifying agents and wetting agents which are very important for textile dyeing and preparatory steps.

The fourth chapter spells out the preparatory processes for removal of impurities from textile materials before dyeing and printing. Natural fibres are broadly of two types. Cellulosic fibres such as cotton, jute etc. have similar properties and their preparatory processes are more or less identical. However, the natural protein fibres, namely wool and silk, are very different from cellulosic fibres and they require entirely diverse pretreatments. Regenerated and synthetic fibres are factory-made, hence the impurity content in these fibres is much lower. Their methods of preparation are much simpler than that of natural fibres.

The fifth chapter deals with whitening techniques. Perfect whiteness is required for the materials to be sold as white goods. This is achieved in two ways. Firstly, the materials are bleached to remove colouring matters present in the form of impurities. For further whitening, the materials are treated with blue or violet colorants or optical whitening agents.

The sixth chapter clarifies the perception of colour and the chemistry behind colour generation. Visual and instrumental colour measurement methods are given in detail. Properties and classification of textile dyes are also elaborated.

The seventh chapter deals with the dyeing machinery used for textile dyeing operations.

The eighth chapter discusses various dyeing methods for the materials composed of cellulosic fibres, namely the natural fibres like cotton, jute, etc. and the regenerated fibres like viscose.

The ninth chapter describes dyeing methods of protein fibres like wool and silk.

The tenth chapter comprises of dyeing methods for the synthetic fibres namely polyester, nylon, acrylic etc. and their blends.

The eleventh chapter discusses eco-friendly textiles. A large number of dye-intermediates used for the manufacture of dyes and several commercial dyes have been banned recently due to their adverse effects on health. A comprehensive list of such products has been incorporated to create awareness among users. German bans, and the methodology of testing and eco-auditing has been discussed. The use of eco-friendly natural dyes as an alternative to synthetic dyes has been covered in brief.

I wish to convey my sincere gratitude to Dr. Richard Aspland, Professor, School of Textiles, Clemson University (USA) and Dr. M.L. Gulrajani,

Professor, Textile Department, Indian Institute of Technology (New Delhi, India) for their valuable suggestions and for augmenting my efforts in making this book as an appropriate work of reference. I am thankful to my colleague, Dr. P.K. Majumder, for his suggestions.

I also wish to dedicate the book to my beloved mother, late Usha Roy Choudhury, who sacrificed her life for our upbringing.

Asim Kumar Roy Choudhury

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Chemistry of Textile Materials

1.1 INTRODUCTION

The dyeing and printing processes are basically chemical processing of textile materials. Textile materials called *fabrics* or *cloths* are prepared by *weaving* (i.e. woven fabrics) or by *knitting* (i.e. knitted fabrics) with continuous strands of textile materials called *threads* or *yarns*. Yarns are prepared from short-length materials called *staple fibres* or continuous materials called *filaments*. Fabrics called non-woven are prepared from fibres directly (without making yarn) by special methods.

For successful chemical processing, thorough knowledge of the chemical constitution, physiochemical structure and chemical properties of the textile materials is extremely essential. One may wonder at the many and varied properties of fibres, yarns and fabrics that have been produced, particularly since the advent of man-made fibres. One may ask what makes a material suitable for use as a textile fibre. Why fibre properties like strength, elasticity, moisture absorbency, thermal properties, dyeability, resistance to chemicals vary so widely. To answer all these questions, one must closely examine the structure of textile fibres.

1.2 TEXTILE FIBRES

Textile fibres are defined as units of matter characterised by flexibility, fineness and a high ratio of length to thickness. They should have sufficient strength to resist breakage due to stress applied during manufacture and use. They should also possess enough thermal and chemical stability to withstand the environment to which the fibres are exposed. Moreover, an extensibility of 5–50% is required, depending on the end-use of the final product.

Until the introduction of man-made fibres, one had to rely on fibres from natural sources. Not all of these fibres were suitable for use as textile fibres, because they lacked certain characteristics, for example, many were not long,

flexible or strong enough. Soil, feed and other climatic and environmental conditions affect natural fibres. These result in non-uniform properties of natural fibres. Man-made fibres are not much influenced by these factors and greater control can be exercised over their production. However, even with greater control, slight variations in the production of man-made fibres can give rise to significant variation in dyeability, strength and some other properties.

Each individual fibre is made of millions of individual long molecular chains of discrete chemical structure. The morphology, i.e. the arrangement and orientation of these molecules within the individual fibre as well as the gross cross-section and shape of the fibre influence the fibre properties. However, the basic physical and chemical properties largely depend on the chemical structure of the long molecular chains constituting the fibre. The total number of units that repeat themselves in a chain vary from a few units to several hundreds and is termed as the *degree of polymerisation* (DP) for molecules within the fibre.

Cotton, for example, has a DP of about 10,000 and viscose rayon, a regenerated fibre, about 300–350. The DP of man-made fibre is determined by various factors during production of these fibres.

1.3 FIBRE STRUCTURE

With the exception of a few speciality fibres based on inorganic substances like glass, asbestos etc., fibres are a class of solid organic polymers that are distinguished from other polymers by their physical properties and by their characteristic geometric dimensions. A fibre is readily identifiable as a substance that is extremely long with respect to its width or diameter, is flexible and has high anisotropic physical properties. However, fundamental difference between fibres and other solid substances is in their molecular structure, which in turn, decides the differences in their chemical and physical properties.

For a complete description of fibre structure, it is useful to consider three levels of molecular structure, each relating to certain aspects of fibre behaviour and properties. The *organochemical* structure defines the structure of the repeating unit in the base polymer and the nature of polymeric link. This is directly related to chemical properties, dyeability, moisture adsorption, swelling characteristics and indirectly to all physical properties. The *macromolecular* structure describes the family of polymer molecules in terms of chain length, chain length distribution, chain stiffness, molecular size and molecular shape. A *supermolecular* structure provides a description of the arrangement of the polymer chains, primarily in terms of factors like orientation, crystallinity and fibrillar structure.

In general, all fibres that are useful in textile applications are semi-crystalline, irreversibly oriented polymers. This means that the fibres have certain regions in which the molecular chains are highly oriented, closely packed and near-perfectly arranged. These regions are usually referred to as crystalline regions or crystallites. The degree of orientation and the degree of crystallinity are important quantities that strongly influence the physical properties of fibre. In other regions, the molecular chains are not well ordered, tending to a random-coil configuration and these are usually referred to as amorphous region. In the case of natural fibres, there are various identifiable aggregates of polymer chains, which are very often referred to as micelles, fibrils, microfibrils and also macrofibrils [1].

1.4 POLYMER SYSTEM

The basic unit of the textile fibre is a molecular segment called *monomer* (mono = one, mer = unit) which is repeated a large number of times to form a long chain or a molecule called *polymer* (poly = many). A polymer may also be formed from two or more different monomers. Such polymers are called *copolymer*. There is no definite regularity in the order of monomers, which make up a copolymer. Some fibres may contain additional monomers, which do not form part of the polymer chain and are incorporated to improve certain properties of the fibre such as dye affinity (e.g., an acrylic fibre called Zefran). Those are grafted onto the polymer chain as side group or branch. In Figure 1.1, a rectangle, a circle and a triangle are symbolically representing the chemical structure of three monomers. The homopolymers, copolymers and grafted polymers, which can be prepared from the three monomers, are symbolically shown in the figure [2].

1.5 ESSENTIAL PROPERTIES OF FIBRE

It was realised long back that the natural fibres consist of polymers held together by various links or forces. The first step in the development of man-made fibre was the manufacture of regenerated fibre using natural fibrous raw materials. For example, cellulosic materials from plants or trees are regenerated into *viscose*, which can be spun into yarn. The next step was to produce chemicals, which have the ability to form links giving rise to polymers called *synthetic fibres*. It must be realised that only a few of organic chemicals can be used in the production of synthetic fibres. The properties of the polymer necessary for fibre formation are as follows:

1. Molecular weight – a polymer should have high molecular weight, which consequently results in considerably longer fibre. The length of

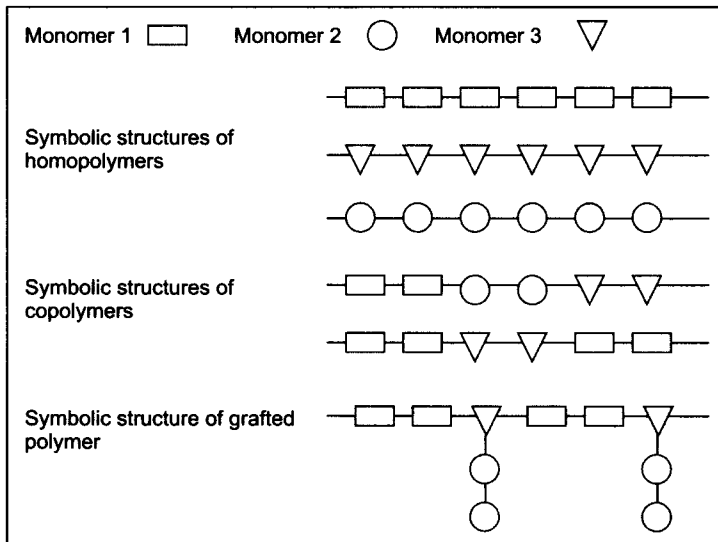


Fig. 1.1 Symbolic structures of different types of polymers

polymer contributes to the strength of the fibre by holding crystalline regions together. To produce a fibre of adequate strength, the length of a polymer molecule in the range of 100 nm (minimum) is required ($1 \text{ nm} = 10^{-9}$ metres). Many naturally available cellulosic materials can not be used as textile fibres as they are much shorter in length.

2. **Linearity** – only predominantly linear polymers will form sufficient crystalline regions, permitting an adequate number of inter-chain forces of attraction to occur within the polymer system. The molecular chains, which are bulky and/or branched, cannot pack closely enough together to form a crystalline region resulting in a weak fibre.
3. **Inter-fibre forces of attraction** – there should be a sufficient degree of inter-molecular links or bonds of one or more of the following types:
 - (i) *Hydrogen bonds*, which occur between positively charged hydrogen atoms in one polymer molecule and negatively charged oxygen, nitrogen or chlorine atoms in an adjacent polymer molecule. Natural fibres are rich in hydrogen bonds.
 - (ii) *Van der Waals' forces* are similar but weaker than hydrogen bonds. They occur when polar groups are absent. The polymers are to be closely packed so that attraction can occur between slight charges of opposite character in the polymer chains. Both the hydrogen bonds and Van der Waals' forces of attraction are weak, but the presence of these forces in large numbers in case of closely packed polymers significantly contributes to its strength.

- (iii) Strongest and chemically most stable *covalent bonds* or *cross-links* are formed when any two atoms share a pair of electrons. The greater the number of cross-links, the more rigid the fibre becomes. However, a low degree of cross-links, as in case of wool (disulphide bond) or elastomeric fibres, imparts a good to excellent elasticity.
 - (iv) *Ionic bonds* are formed between oppositely charged polar groups in polymers and are stronger than hydrogen bonds and Van der Waals' forces. They occur principally in protein fibres like wool and silk, and polyamide fibres like nylons.
4. Orientation – a fibre consists of a large number of individual polymer chains arranged in either highly ordered and highly oriented form called *crystalline region* or randomly called *amorphous region*. In a fibre, the extent and proportion of crystalline and amorphous regions may vary – in natural fibres, the variation is created by nature and in case of man-made fibres, the variation can be controlled during production. In some polymers, the crystalline regions are formed during extrusion and subsequent drawing process merely aligns the crystalline regions parallel to the fibre axis; whereas in other systems, the polymers are first formed in amorphous state and become crystalline during drawing. There is a limitation on the extent to which drawing is carried out on textile fibres. Highly crystalline fibres have harsh handles and poor abrasion resistance, i.e. quickly damaged on rubbing.
 5. Melting point – when a polymer is highly crystalline or when the intermolecular attraction between the polymer molecules is strong, its resistance to heat will be high. Most textile fibres are subjected to heat treatment during production (e.g., during heat setting, dyeing or finishing) or during use (e.g., during ironing, washing etc.). Hence, the fibres should have high resistance to heat. Synthetic fibres have specific ranges of temperature during which they melt, depending on the chemical structure, molecular weight and the degree of crystallinity of the polymer. Natural fibres do not melt as they have strong inter-chain bonding and long chain-length. However, they turn yellow and are damaged above certain temperature depending on the chemical structure of the fibre.

1.6 CLASSIFICATION OF FIBRE PROPERTIES

Fibres have wide variations in chemical, electrical, mechanical, optical and other properties, and the properties of a fibrous product naturally depend on the properties of the fibres of which it is composed. Not only the average values but also the range or statistical distribution is important. A

typical classification of such fibre properties with some examples is given below [1]:

1. Geometric
 - (i) Length
 - (ii) Cross-section
 - (iii) Crimp
2. Physical
 - (i) Density – linear, bulk
 - (ii) Thermal – melting, transitions, conductivity
 - (iii) Optical – birefringence, refractive index, lustre and colour
 - (iv) Electrical – dielectric constant, resistivity
 - (v) Surface – roughness, friction
 - (vi) Mechanical – tension, compression, torsion, bending, shear
3. Chemical
 - (i) Response to acids, alkalis, oxidation, reduction and heat
 - (ii) Sorption – moisture, dyes
 - (iii) Swelling – anisotropy

1.7 CLASSIFICATION OF TEXTILE FIBRES

As the physical and chemical properties differ largely among fibres of different origin, it is necessary to classify textile fibres based on the source of origin. The types of textile fibres available globally are exceedingly large and apparently, it is very difficult to categorise them under a few classes.

Textile fibres are broadly divided into two classes – *natural* and *man-made*. Nature provides us a large number of excellent fibrous materials that can be used directly for yarn and fabric manufacture. Natural fibres may be obtained from plant, animal or mineral sources. All plant fibres are composed of primarily cellulose and secondarily other components like hemicellulose, lignin, etc. Plant fibres can be further divided into various sub-groups depending on the portion of the plant from where the fibre is obtained e.g., seed (cotton), stem or bast (flax, jute, etc.) or leaf (Sisal).

Fibres obtained from animals are mostly composed of amino acid residues or protein. The most important animal fibres are silk and wool. In addition, there are a large number of lesser-known hair fibres such as camel hairs, goat hairs, rabbit hairs, etc.

The fibre obtained from mineral is asbestos.

Man-made fibres can be subdivided into three sub-classes:

1. *Regenerated fibres* are manufactured by dissolving natural fibre-forming polymers and regenerating the polymer in the form of fibre