Natural Polymer Characterization

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Summary: A review about the characterization of natural polymers is given, describing the polymers found in Nature, methods to distinguish natural from syntheticpolymers, and what modern Polymer Science can learn from Nature

Keywords: balance; natural polymers; renovation cycles; sustainalbility; synthetic polymers

Polymers in Nature

When one takes a critical look at the polymers prepared by Nature within the vegetal and the animal domains, one can understand that the special properties present in the polymer materials should have been the main reason for the inclusion of such products in the biogenetic routes.

In fact, the preservation of human life requires provision of food, clothing and housing. Among the important qualities demanded by the living beings, especially when evolution reaches the top species, energy reserve as well as high resistance to weather and to mechanical forces shall be included. The body structure of vegetals and animals require such characteristics, not found in the chemical products of low molecular weight.

It is interesting to observe that natural polymers from vegetal origin are basically different from animal polymers. The principal chemical functions found in the organic polymer chains from vegetal origin are mainly five: hydrocarbon, phenol, acetal, amide and ester. From animal origin, are only two: acetal and amide.

Polyhydrocarbons from vegetal origin are unsaturated and distributed in two groups: polyisoprenes and terpene resins. *cis*-Polyisoprene is produced by rubber trees, like *Hevea brasiliensis*, while *trans*-polyisoprene is obtained from guta-percha and balata trees. Terpene resins result from the polymerization of alicyclic unsaturated monomers known as terpenes, which are dimers of isoprene, found in essential oils, especially from pine trees. Polyphenols also are composed of two groups: lignan resins and lignins, which are indeed macromolecules, not polymers.

Polyacetals include all polysaccharides; cellulose and starch are the most important. Cellulose is the fundamental component of wood, leaves, fibers, etc. Starch composes grains, like wheat, roots, like cassava, tubercles, like potatoes, etc. Vegetal fibers are collected from different parts of the plant: trunk, leaves, seeds. The purest fibers, like cotton and kapok, come from the threads that cover the skin of seeds. The coarser come from palm-tree trunks, like piassava.

Vegetal fibers have cellulosic chemical structure. Represent over half the total fibers consumed by men. Industrial fibers, both natural and synthetic, represent a large part of the polymer consumption in the world, annually about 18 million ton of natural fibers and 16 million ton of synthetic ones. They have quite a great importance as far as sustainable development is concerned. The larger application is in textile industry; the coarse fibers find use in the manufacture of cordage, burlap, rugs, ropes, brushes and mobs.

Besides polysaccharides, some vegetals like wheat, soybean, corn and peanut, also contain a certain quantity of proteins, namely gluten, glycinine, zein, arachyn, etc. The aminoacids residues which compose

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such proteins are important components in a vegetarian diet.

Finally, in minor proportion, there are the polyesters, which are polyhydroxyalkanoates of short carbon chain.

The polyamides, precursors of the proteins, are all of 2-polyamide type, that is, polycondensation products from 2-aminocarboxylic acids in which there is a substituent in 2-carbon atom. It is curious to remark the inexistence of similar synthetic polyamides among the important industrial products. Synthetic fibers are polyesters, polyamides or acrylonitrile polymers. The so-called modified celluloses are regenerated cellulose and cellulose acetate.

The polysaccharide commonly found in animals in Nature is chitin. Fibers from animal origin, like silk and wool, are proteins and have higher cost, being mostly absorbed by the textile industry.

So, polyacetals, that is, polysaccharides, are predominant within the vegetals and animals, while polyamides - that is, proteins - are found mainly in animals.

Polymers related to life - that is, biopolymers - are extremely important for living beings. On the other hand, from technological standpoint, the natural origin polymers are remarkable by their industrial importance as food, fibers and rubber.

The most important natural fibers are from vegetal or animal origin; mineral fibers, like asbestos, have restrict application.

It is interesting to notice that the dominant amount of natural polymers of industrial importance correspond to the materials that have better mechanical characteristics. The most abundant natural polymer is cellulose, produced by plants; the second important presence is chitin, which is a modified cellulose forming the shell of animals. Both polymers have the role of providing resistance to the skeleton of plants or making the external protective layer of invertebrates.

How to distinguish between natural and synthetic polymers

Natural polymers generally occur as fibers or grains (Table 1). The general characteristics of those fibers are presented in Table 2. It is interesting to observe that vegetal fibers come from several botanical families as well as from different parts of the plant, while animal fibers are only two types, silk and wool, from quite different zoological species.

Optical microscopy is a simple procedure for the immediate identification of the

Table 1.
General characteristics of natural fibers and modified natural fibers

Common name	Origin	Systematic classification		Type of source	Part of source
		Gender and species	Family		
Cotton	Vegetal	*Gossipium herbaceum*	*Malvaceae*	Shrub	Seed
Flax	Vegetal	*Linum usitatissimum*	*Linaceae*	Herb	Stalk
Jute	Vegetal	*Corchorus capsularis, C. olitorius*	*Tiliaceae*	Shrub	Stalk
Sisal	Vegetal	*Agave sisalana*	*Agavaceae*	Short-stem plant	Leaf
Ramie	Vegetal	*Bohemeria nivea*	*Urticaceae*	Shrub	Stalk
Wool	Animal	*Ovis áries*	*Bovidae*	Sheep	Hair
Silk	Animal	*Bombyx mori*	*Bombycidae*	(Silk-worm) Cocoon	Moth
Viscose	Vegetal with chemical modification	Cotton *(Gossipium herbaceum)*	*Malvaceae*	Shrub	Seed (linter
Cellulose acetate	Vegetal with chemical modification	Cotton *(Gossipium herbaceum)*	*Malvaceae*	Shrub	Seed (linter)

Table 2.
Natural fiber identification through optical microscopy

Common name	Optical microscopy	
	Longitudinal sight	Cross section
Cotton	Collapsed pipe with wide folds and longitudinal grooves	Section with "C" format, lumen also with "C" format
Flax	Segmented pipe with longitudinal grooves	Polygonal section with roundish corners, with hyphen format lumen
Jute	Coarse stick resembling a lop	Polygonal section, irregular fiber accumulations, with circular lumen
Sisal	Coarse stick resembling a lop	Polygonal section, irregular fiber accumulations, with elliptical lumen
Ramie	Almost regular, segmented coarse stick, with longitudinal grooves	Polygonal section, irregular fiber accumulations, with hyphen format lumen
Wool	Scaly, segmented stick	Circles of varied dimensions, some showing dividing line; absence of lumen
Silk	Almost regular stick, with longitudinal grooves	Rounded off triangles, to the pairs,; irregular accumulations of fiber; absence of lumen
Viscose	Regular stick, with longitudinal grooves	Regular size accumulations of fiber, irregular serrated edges; absence of lumen
Cellulose acetate	Regular stick, with longitudinal grooves	Regular size accumulations of fiber, irregular wavy edges; absence of lumen

natural or synthetic origin of the fiber. Synthetic products show microscopic absolute regularity as a consequence of the process of fabrication and the requirements for quality. On the other hand, natural products exhibit ''irregular'' regularity due to the numerous factors involved in the routes chosen by Nature.

The visual observation of the surface and cross section of the filament with amplification of 200 to 400 times allows to determine if the fiber is vegetal or animal, or artificial, and sometimes even the botanical or zoological species. Natural fibers differ from artificial ones because show irregularity of dimensions and shape, visible at optical microscope. Longitudinal observations may be done directly, with 200 X amplifications, while transversal observations demand a thin plate, cut from the fiber, with amplifications of 200 and 400 X, to enable watching the general shape as well as the details inside the fiber.

All vegetal fibers are cellulosic and have a canal inside, formed after drying the natural fluids present in the plant in the initial phase of formation of the fiber. As the fiber becomes adult, the canal gradually collapses, assuming the characteristic shape of the lumen. The animal fibers are proteic and have no canal. The artificial fibers also do not show canal.

Chemical simple tests indicate if the material is a polysaccharide or a protein (Table 3). No darkening by carbonization after heating directly at open flame shows

Table 3.
Natural fiber identification through chemical reactions

Common name	Reaction with aniline acetate	Pyrolysis with calcium oxide
Cotton	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Flax	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Jute	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Sisal	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Ramie	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Wool	Unchanged aspect	Red litmus paper turns blue, indicating protein
Silk	Unchanged aspect	Red litmus paper turns blue, indicating protein
Viscose	Intense red spot, indicating polysaccharide	Red litmus paper remaining unchanged
Cellulose acetate	Intense red spot, indicating polysaccharide	Material melts, adhering to the pipe wall

immediately the presence of mineral material. Solubility and fusibility may confirm the tests conclusions. Details on the chemical structure may be obtained through infrared absorption spectra or other chemical tests.

Learning from Nature

Along the time, Nature has shown to mankind how to protect the general conditions which are propitious to keep life for the innumerable varieties of animal and vegetal forms.

The complex balance involving such a huge number of variables suggests a ribbon-shaped spiral as a model for the ecosystems. This spiral extends irregular and progressively, with eventual corrections promoted by cataclysms. The excess of some living beings like plants in a forest is removed by burying, allowing gradual degradation. By geological movements, microscopic beings in the bottom of the sea are displaced to other sites in the Earth mantle and decomposed along millenniums. Coal and petroleum deposits were originated from such a Nature correcting events. Dinosaurs extinction may have been a consequence of such ecological balance. These observations would fit adequately within the ideas proposed by James Lovelock as the Gaia Hypothesis.

For millions of years, Nature alone was capable of preserving this equilibrium. Modern society started to create the problem since the Industrial Revolution, when the production of goods rapidly rose to higher and higher levels, with a large increase of the residues. Nowadays, the very fast changes due to the explosive growing of information technology are exposing human life to dangerous conditions. It is urgent to stop it to protect the future of the next generations.

Men should observe how Nature produces its polymers, not so many types as one could expect looking at the fabulous variety of synthetic chemical structures and compositions which are commercially available. There are only five types from vegetal origin and two from animal origin; however, there are several polymer composites.

Composites are multiphase, heterogeneous systems, polymeric or not, in which one of the components, the reinforcing component, discontinuous, provides the main resistance to stress, and the other, the matrix, continuous, avoids the concentration of stresses. These elements neither dissolve each other nor discharacterize completely. Despite of it they act concertedly and the properties of the whole are different from the properties of each individual component.

Examples of vegetal-origin polymer composites are: wood, jarina, coal, palm leaf, etc.

Examples of animal-origin polymer composites are: bone, horn, muscle, tooth, ivory, turtle-shell, mother-of-pearl, leather, etc.

This is the lesson Nature presents to men: it is not necessary to have a large variety of chemical compounds involved in the manufacture of synthetic polymers, with the consequent problems of environment contamination by the residues. Natural routes allow achieving smaller amount of residues, less diversification of structures and easier recycling.

It should be the humanity target: try to imitate the natural renovation cycles, restoring the balance between human development and preservation of the conditions for life in the planet.

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