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A study of the surface properties of cotton fibers by inverse gas chromatography

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Abstract

In the present study, the potential relationships between the microstructure and the surface properties of different cotton fibers are analyzed by inverse gas chromatography (IGC) at infinite dilution. By measuring the retention time of polar and nonpolar gaseous probes into a column containing the fibers, surface characteristics of these fibers, in particular the dispersive component of their surface energy and their surface morphological index, were determined. It is clearly shown that the presence of natural waxes on cotton fibers plays a major role on their thermodynamic surface properties, affecting the surface energy and the acid–base character as well as the morphological aspects of such fibers. Finally, it appeared that IGC is a well appropriate method for the evaluation of the surface characteristics of cotton fibers.

Keywords: Inverse gas chromatography; Surface energy; Index of morphology; Cotton fiber; Cellulose; Extracted cotton fiber

1. Introduction

New ideas have been presented in view of the revolutionary developments in spinning and weaving technologies and in the powerful fiber information systems. These efforts revealed that the market value of cotton has yet to reflect its technological worth. This is man's most important clothing material and also widely used in many medical applications.

Several reasons justify the use of these natural fibers: (i) their excellent mechanical properties; (ii) their variety in terms of morphology, geometry and surface properties, depending on the source; (iii) the possibility to develop comfortable fibers; (iv) their low cost in most instances.

The quality of cotton fiber (*Gossypium hirsutum L.*) is important for all segments of the cotton industry. However, cotton fibers are very complex materials due to their particular structure. It is therefore necessary to carefully analyze the structure and the surface properties of cotton fibers in order to enhance the performances of cotton based materials and fabrics.

The aim of the present study is to determine the thermodynamic surface properties (surface energy) and some surface morphological aspects of cotton fibers by means of inverse gas chromatography (IGC) at infinite dilution. These surface characteristics can be determined by such a technique as recommended by several papers [1,2]. This method is based on the analysis of adsorption of gaseous probes on solid surfaces. If nonpolar probes are used, it leads to the determination of the dispersive component γ_S^D of the surface energy of the solid that describes the potential of this solid surface to establish van der Waals, and more precisely London interactions. Moreover, the use of branched alkanes can lead to the estimation of morphological aspects of the fiber surface. Finally, IGC also allows the estimation of acid–base character of the solid surface by using polar probes.

In this paper, IGC is used to determine the dispersive component of surface free energy, the index of morphology, as well as acid–base properties of cotton fibers before and after solvent extraction. The IGC data are correlated with a surface physico-chemical analysis performed by X-ray photoelectron

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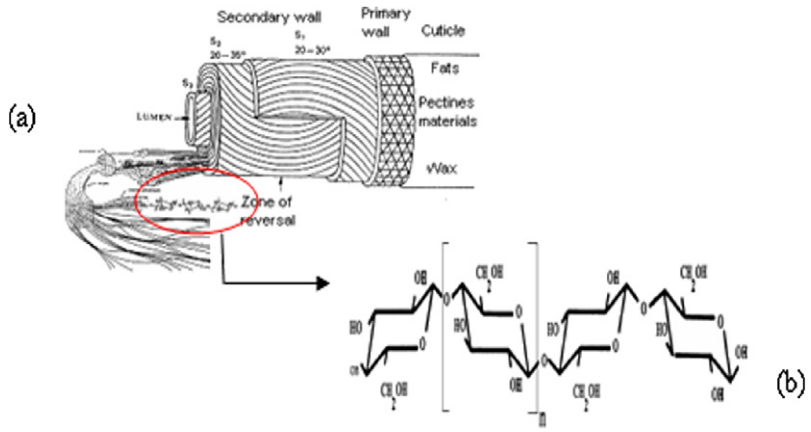

Fig. 1. (a) Schematic representation of the cotton fiber and its components, (b) molecule of cellulose.

spectroscopy (XPS) in order to compare the validity of the various methods for the assessment of extraction method efficiencies.

2. Chemical composition of cotton fiber

Cotton is a remarkably pure and well-defined material based on polysaccharide chains [3], which are packed into regularly arranged crystalline and irregular amorphous regions [4,5].

The macrostructure of cotton fibers [6] is schematically represented in Fig. 1. Current understanding of cotton fiber macrostructure has emerged mainly from research on matured fibers in their dried state. Although the biochemical nature of fiber growth or development has been extensively studied, the fiber macrostructure during growth is not as well understood.

Cotton fibers are composed mostly of α-cellulose (88 to 96.5% w/w) [7]. The rest is noncellulosics that are located on the outer layers and inside the fiber lumen. The specific chemical composition of cotton fibers varies according to their varieties and growth conditions. The noncellulosics include proteins (1 to 1.9% w/w), waxes (0.4 to 1.2% w/w), pectins (0.4 to 1.2% w/w), inorganics (0.7 to 1.6% w/w), and other substances (0.5 to 8% w/w).

3. Theoretical aspects of inverse gas chromatography

3.1. Determination of the dispersive component of the surface energy (γ_S^D)

IGC, under "infinite dilution" conditions, i.e. very high dilution of the probe into the carrier gas (helium), allows the determination of both dispersive and polar surface properties of a solid. The dispersive component γ_S^D of the surface energy of cotton fibers is calculated from the retention times (t_R) of a series of n-alkanes injected into a column containing the fibers. From t_R, one computes the following quantities:

$$V_N = D_c(t_R - t_0), \tag{1}$$

$$\Delta G_a = -RT \ln(V_N), \tag{2}$$

where V_N is the retention volume, t_0 is the retention time of a probe that is not adsorbed on the cotton (i.e. methane), D_c is the helium flow rate, and T is the absolute temperature at which the measurement is carried out. ΔG_a is the standard variation of the free energy of adsorption. ΔG_a of alkanes, when plotted against the number n_C of carbon atoms of these latters, usually leads to straight lines whose slope, $\Delta G_a(CH_2)$, represents an incremental value of free energy corresponding to the free energy of adsorption of a CH_2 group, as shown in Fig. 2.

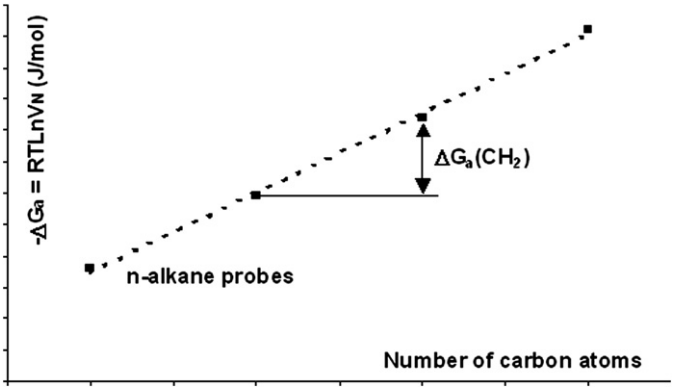

Fig. 2. Variation of the adsorption energy ΔG_a versus the number of carbon atoms (n_C) of the injected n-alkanes probes.

According to Dorris and Gray [8], the dispersive component γ_S^D of the surface energy is then given by

$$\gamma_S^D = \frac{1}{4\gamma_{CH_2}} \left(\frac{\Delta G_a(CH_2)}{N a_{CH_2}} \right)^2. \tag{3}$$

In this relationship, γ_{CH_2} ($\approx$36.5 mJ/m^2 at 20 °C) is the surface energy of a solid entirely composed of methylene groups, i.e. polyethylene, N is Avogadro's number and a_{CH_2} ($\approx$6 Å^2) is the cross-sectional area of an adsorbed CH_2 group.

3.2. Index of morphology

The accessibility of the solid surface for the adsorption of molecular probes depends on both the morphology of the solid surface and the form of the adsorbed molecules.

To characterize the surface morphology of a solid from a molecular point of view concerning the adsorption of gaseous probes, a new morphological index (χ_T) [9] has been recently