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Hygroscopicity and water vapor permeability of Kraft paper impregnated with starch acetate

F.D.S. Larotonda [a], K.N. Matsui [a], P.J.A. Sobral [b], J.B. Laurindo [a,*]

[a] *Departamento de Engenharia Química e Engenharia de Alimentos, CTC, UFSC, Caixa Postal 476, 88040-900 Florianópolis, SC, Brazil*
[b] *Departamento de Engenharia de Alimentos, FZEA-USP, Caixa Postal 23, 13630-000 Pirassununga, SP, Brazil*

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Abstract

This study describes the use of cassava starch acetate (CSA) to impregnate Kraft paper and its influence on the water vapor permeability (K^w). This barrier property depends on the water vapor diffusion coefficient (D_{eff}) and the material hygroscopicity properties (adsorptivity, β). The influences of D_{eff} and β on the K^w value were studied. Kraft paper samples were impregnated at atmospheric pressure and under vacuum. The results showed an important decrease on the K^w values, which was associated with two factors: (a) the partial filling of the Kraft paper superficial and internal pores by the impregnated CSA, reducing the K^w; (b) as CSA is much less hygroscopic than paper, its adsorptivity is reduced significantly by impregnation. This paper demonstrates that CSA impregnation of Kraft paper is an interesting alternative for the improvement of the hygroscopic properties and water vapor permeability of the Kraft paper.

Keywords: Kraft paper; Starch acetate; Water vapor permeability; Hygroscopicity

1. Introduction

Kraft paper is used as a material for the manufacture of low cost packaging, which needs good mechanical properties. It is used as industrial packaging for products of great volume, due its low cost and high mechanical resistance to tearing and to tension forces. These properties are explained by the long cellulose fibers used in its manufacture and gramature of 30–150 g/m^2 (Barroti, 1988).

On the other hand, the hygroscopic properties and the water vapor barrier of the Kraft paper are not suitable for foodstuffs storage in environments with high relative humidity, since this material is hygroscopic and porous (Sobral & Ocuno, 2000). In view of this high hygroscopicity, the paper can absorb water vapor from the environment or from the food, which can cause the loss of its original mechanical properties.

To minimize this problem, several techniques have been used with the aim of to reduce the hygroscopicity and improving the water vapor barrier of papers, with a focus on the impregnation of papers with non-hygroscopic and biodegradable materials, like starch acetate (Narayan, Bloembergen, & Lathia, 1999).

The starch is a natural polymer consisting of two types of molecules: amylose, formed by linear glucose chains, and amylopectin, formed by ramified glucose chains (Buléon, Colonna, Planchot, & Ball, 1998; Whistler & Paschall, 1984). Amongst the agricultural crops that produce starch, one of the most used in Brazil is cassava, Brazil being the second largest worldwide producer of this root, after Nigeria (FAO, 2001).

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[*] Corresponding author. Tel.: +55 48 331 9930; fax: +55 48 331 9687.
E-mail address: joao@enq.ufsc.br (J.B. Laurindo).

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Many studies approach the chemical modification of starch as an alternative way of improving its hygroscopic properties. The acetylation reaction is one of the most interesting. This reaction allows the attainment of a thermoplastic and hydrophobic material (Fringant, Desbrières, & Rinaudo, 1996; Graaf, Broekroelofs, Janssen, & Beenackers, 1995). Part of the hydroxyl groups of glucose monomers is converted into other chemical groups, modifying the molecular structure and consequently the properties and applications of starch (Feuer, 1998; Treadway, 1946). The degree of substitution (DS) of the acetylated starch indicates the average number of substitutions of hydroxyl groups (OH) by acetyl groups, per anhydroglucose unit of starch. The highest possible DS is 3 because there are three hydroxyl groups (OH) available per anhydroglucose unit (Miladinov & Hanna, 2001). Narayan et al. (1999) have shown that starch acetates with a DS between 1.2 and 1.7 had the preferred balance of mechanical properties, water resistance, processability and rate of biodegradation under composting conditions. Recently, there has been renewed interest in intermediate (1–2) and high (3) starch acetate DS for applications such as biodegradable films and molded articles (Bloembergen & Narayan, 1995; Borchers et al., 1993), foams (Altieri & Tessler, 1996; Shogren, 1996) and coatings for paper (Fringant, Rinaudo, Gontard, Guilbert, & Derradji, 1998). In this latter application, the starch acetate has been studied with a view to reducing the sensitivity of hydrophilic materials, coating expanded starch trays, wheat gluten films and papers to water (Fringant et al., 1998).

Steady state mass transfer through flexible films: The steady state mass flux (J_{WZ}) through a film with a specific thickness (δ), for a moisture difference ($X_1 - X_2$) between their surfaces, can be calculated by Fick's Law, Eq. (1) (Cussler, 1984).

$$J_{WZ} = \rho^{s} D_{\mathrm{eff}} \frac{X_1 - X_2}{\delta} \tag{1}$$

where X_1 and X_2 are the surface moisture contents on a dry weight basis [kg water/kg dry solid], with $X_1 > X_2$, ρ^{s} is the specific gravity of the dried film [kg dry solid/m^3], D_{eff} is the effective water diffusion in the film [m^2/s] and δ is the film thickness.

The mass transfer through an initially dried film, submitted to different relative humidities, takes place in three steps: (i) adsorption of water molecules on the film surfaces; (ii) movement of the water molecules from higher to lower moisture; (iii) desorption of water molecules from the film surface with the lower moisture (Sobral & Roques, 1992). Therefore, this mass transfer process depends on the two properties of the film material, i.e., the affinity between the film material and water and the resistance presented by the polymeric network to water molecule movement in its matrix, expressed in terms of an effective diffusivity (Crank & Park, 1968; Sobral & Ocuno, 2000).

At thermodynamic equilibrium, the values of X are related with the water activity in the air by the film sorption isotherm. Usually, the isotherms of cellulose based material present a initial almost linear part, for low water activities (a_{w}), and another non-linear part, for higher water activities. For the linear part, the material moisture can be related to the water activity (a_{w}) by Eq. (2).

$$\beta^{*} = \tan(\theta) = \frac{X}{a_{\mathrm{w}}} \tag{2}$$

where β^{*} [kg water/kg dry solid] is the water adsorptivity in the solid material. It is more usual to define the adsorptivity in terms of [g water/kg dry solid × Pa], which can be obtained by dividing β^{*} by the water vapor saturation pressure at the isotherm temperature ($p_{\mathrm{s}}(T)$), Eq. (3).

$$\beta = \frac{X}{p_{\mathrm{s}} a_{\mathrm{w}}} \tag{3}$$

From Eqs. (1) and (3), the equation representing the water flux through the film, in terms of water activity differences is given by Eq. (4).

$$J_{WZ} = (\rho^{s} \beta D_{\mathrm{eff}}) \frac{a_{\mathrm{w1}} - a_{\mathrm{w2}}}{\delta} p_{\mathrm{s}} \tag{4}$$

The term in parenthesis in Eq. (4) is the water permeability (K^{w}) of the film, usually represented as [g water × mm/m^2 × Pa × h], were h is hour, Eq. (5).

$$K^{\mathrm{w}} = \rho^{s} \beta D_{\mathrm{eff}} \tag{5}$$

Therefore, the water transfer rate through a film (W) with area S and thickness δ, given in [g w/h], can be written as in Eq. (6).

$$W = K^{\mathrm{w}} S \frac{a_{\mathrm{w1}} - a_{\mathrm{w2}}}{\delta} p_{\mathrm{s}} \tag{6}$$

Eq. (6) can be used to determine K^{w} experimentally, from the mass variation over time of a diffusion cell (Crank & Park, 1968).

On the other hand, the material sorption isotherm can be represented by the extensively used the GAB model (Guggenheim, Anderson, de Boer), given in Eq. (7).

$$X = \frac{CkX_0 a_{\mathrm{w}}}{[(1 - ka_{\mathrm{w}})(1 - ka_{\mathrm{w}} + Cka_{\mathrm{w}})]} \tag{7}$$

where C, X_0 and k are constants, with X_0 representing the monolayer moisture content, on a dry basis.

Differentiating Eq. (7) in relation to a_{w} and dividing the result by p_{s}, the water adsorptivity in the film, β [kg water/kg dry solid × Pa], can be given by Eq. (8), which is valid for the whole isotherm.

In this way, it is possible to determine β from the GAB model derivative, since the constants of the model are well-known, for a given temperature. In this way, the

$$\beta = \frac{CkX_0}{\rho_s}\left[\frac{1}{(1-ka_w)(1-ka_w+Cka_w)} - \frac{a_w}{[(1-ka_w)(1-ka_w+Cka_w)]^2}[-k(1-ka_w+Cka_w)+(1-ka_w)(-k+Ck)]\right] \tag{8}$$

effective diffusion coefficient (D_{eff}) of water for the film material, for every situation, can be estimated from β and the experimental data for K^w, ρ^s, using the Eq. (5).

The primary objective of this work was to study the modification of the hygroscopic and water permeability properties of Kraft paper following its impregnation with cassava starch acetate produced in the laboratory. A second goal was to understand how the properties β and D_{eff} influence the Kraft paper permeability, before and after the impregnation.

2. Material and methods

2.1. The Kraft paper and cassava starch acetate (CSA) production

The Kraft paper (75 g/m^2) used in the experiments was purchased commercially in Florianópolis, SC, Brazil. The cassava starch was provided by Amifar Ind. (Brazil), and contains 17% amylose.

The CSA used for the impregnation of the samples was produced in the laboratory, according to US Patent no. 5,710,269 (Feuer, 1998), with the substitution of catalytic agent MSA (methane sulfonic acid) for concentrated sulfuric acid.

In order to obtain CSA, cassava starch was mixed with acetic anhydride and glacial acetic acid, and this mixture was heated to 40 °C under agitation. When the mixture reached 40 °C, the catalytic mixture (concentrated sulfuric acid/glacial acetic acid) was added carefully and gradually during the first 10 min of the reaction. After that, the solution was heated to 80 °C and kept at this temperature for two hours. At the end of the reaction, cold water (5–6 °C) was added to the solution for the precipitation of starch acetate. The precipitate was washed with distilled water and dried in a ventilated oven for 12 h at 60 °C.

The synthesized CSA was evaluated in relation to the degree of substitution (DS) (or degree of acetylation). The method utilized to evaluate the degree of substitution was based on Wurzburg (1964), who developed the following methodology: a sample of 1.00 g of the polymer is hydrated by boiling it in 50 mL of an alcoholic solution (75% v/v) and the polymer is saponified with 40 mL of a 0.5 N sodium hydroxide (NaOH) solution, the excess NaOH then being back titrated with hydrochloric acid (HCl) 0.5 N.

The cassava starch acetate DS used in these experiments was 1.41 (Matsui et al., 2004).

2.2. Kraft paper impregnation

Discs with 90 mm diameter were cut out of the Kraft paper sample using a pair of scissors. The thickness of the samples was measured (±0.001 mm) using a Digimatic digital external micrometer (Mitutoyo Co., Japan). Measurements of thickness were made at four different points on each disk, and these were used to calculate the average values. Paper samples were dried in an oven at 50 °C for 24 h. The solution used in the Kraft paper impregnations was prepared from the solubilization of starch acetate in chloroform at the ratio of 1:5. At this ratio a homogeneous solution without precipitate was obtained, because CSA is soluble in chloroform. This solution was placed in a container that in turn was placed in a desiccator, where the samples of Kraft paper were immersed and kept for 10 min, with the aid of a screen and a weight to prevent the samples from floating. Depending on the case, a vacuum of 600 mmHg, produced by a vacuum pump (model TE-058-Tecnal-Brazil), was used. After impregnation, samples were dried in an oven at 50 °C for 24 h. A diagram of the Kraft paper impregnation procedure is presented in Fig. 1.

Before mechanical characterizations, all the impregnated and non-impregnated samples were conditioned for seven days at 25 °C in desiccators with a saturated solution of sodium chloride, producing an RH of 75%. The samples were codified in accordance with the following: Kraft paper (KP), impregnated Kraft paper (IKP) and vacuum impregnated Kraft paper (VIKP).

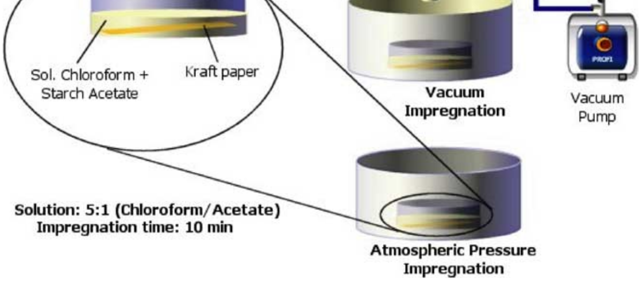

Fig. 1. Diagram of Kraft paper impregnation procedures, with and without vacuum application.

2.3. Scanning electron microscopy (SEM)

Micrographs of the samples were obtained using a Philips XL-30 scanning electron microscope. The samples were coated with a fine gold layer before the obtention of the micrographs. All samples were examined using an accelerating voltage of 20 kV.

2.4. Specific superficial area, pore volume distributions and specific gravity

Before specific area (m^2/g) and mass gravity (kg/m^3) determinations, samples of original and impregnated Kraft paper were dried at 105 °C for 24 h and weighed on a weighing scale with a precision of 0.001 g.

The specific area and pore volume distribution was determined by the N_2 adsorption using equipment from Quantachrome Instruments, model Autosorb®-1-C. Specific area was determined by BET method, while pore volume as a function of pores diameter was determined by BJH method (Barrett, Joyner, & Hallena, 1951).

The specific gravity was determined by the relation $\rho = \frac{m}{S \times \delta}$, where m is the dried sample weight; S and δ are the sample area and average thickness, respectively.

2.5. Water sorption isotherms

Water sorption isotherms were determined by the gravimetric method. Samples with dimensions of 30 × 30 mm were previously dried at 105 °C/24 h. The samples were then placed in desiccators with different relative humidities, imposed by the use of saturated saline solutions. The experiment was carried out at 38 °C. The samples were weighed periodically until they reached constant weight, after which the sample moistures were determined by the gravimetric method. The GAB model (Eq. (7)) was used to represent the experimental sorption data.

2.6. Water vapor permeability

The water vapor permeabilities (K^w) were determined gravimetrically at 38 °C, based on ASTM standard method E96 (ASTM, 1996). The samples (discs of paper, 90 mm diameter) had been previously conditioned under the three relative humidities used, at 38 °C for 24 h. After this pre-conditioning, the samples were placed in permeation cells with saturated saline solutions (lower a_w) and hermetically stamped on the edges with a mixture of refined paraffin and microcrystalline wax. These permeation cells (capsules) were placed in a glass chamber of dimensions 400 × 400 × 250 mm, with another saturated saline solution (higher a_w). A small fan was installed inside the chamber, to promote circulation of internal air and to maintain a homogeneous a_w in this space. The chamber with the permeation cells was placed in an oven and maintained at 38 °C. The experimental conditions used to determine the water vapor permeabilities of each sample are presented in Table 1.

Table 1
Experimental conditions of essays performed to determine water vapor permeabilities of KP, IKP and VIKP

a_w	Interior of diffusion cell	Exterior of diffusion cell (chamber)
0.02–0.33	Calcium chloride ($CaCl_2$)	Magnesium chloride ($MgCl_2$)
0.33–0.62	Magnesium chloride ($MgCl_2$)	Sodium nitrite ($NaNO_2$)
0.62–0.90	Sodium nitrite ($NaNO_2$)	Barium chloride ($BaCl_2$)

The water vapor transfer through the area of a sample was measured by the weight gain of the capsule as a function of time. The capsules were weighed at the beginning of the experiment and then every two hours, for twelve hours. Three samples of each group (KP, IKP and VIKP) were analyzed in the experiments. The water vapor transfer rate, in [g/h], was calculated by Eq. (9).

$$W = \frac{\Delta m}{\Delta t} \tag{9}$$

where ($\Delta m/\Delta t$) is the capsule mass variation over time, under the steady state condition, which was calculated by the linear regression of the experimental mass transfer data. With the values for W, the water vapor permeabilities (K^w, [g mm/h m^2 Pa]) were calculated by Eq. (10).

$$K^w = \frac{W \times \delta}{p_s \times S \times (a_{w1} - a_{w2})} \tag{10}$$

where δ is the average thickness of the samples, p_s is the saturation pressure of the vapor at the experimental temperature 38 °C, and a_{w1} and a_{w2} are the water activities in the interior of the chamber and in the interior of the capsule, respectively.

3. Results and discussion

3.1. Scanning electronic microscopy (SEM)

Micrographs of samples KP, IKP and VIKP, obtained with a magnification of 100×, are presented in Fig. 2. The starch acetate coating the surface of the Kraft paper can be clearly observed, and the presence of fissures in the starch acetate film formed on the paper surface is also evident and is showed by white arrows. These results suggest that impregnated samples will have decreased hygroscopicities, because starch acetate is less hygroscopic than Kraft paper. Furthermore, if the starch acetate penetrated into the internal paper pores,

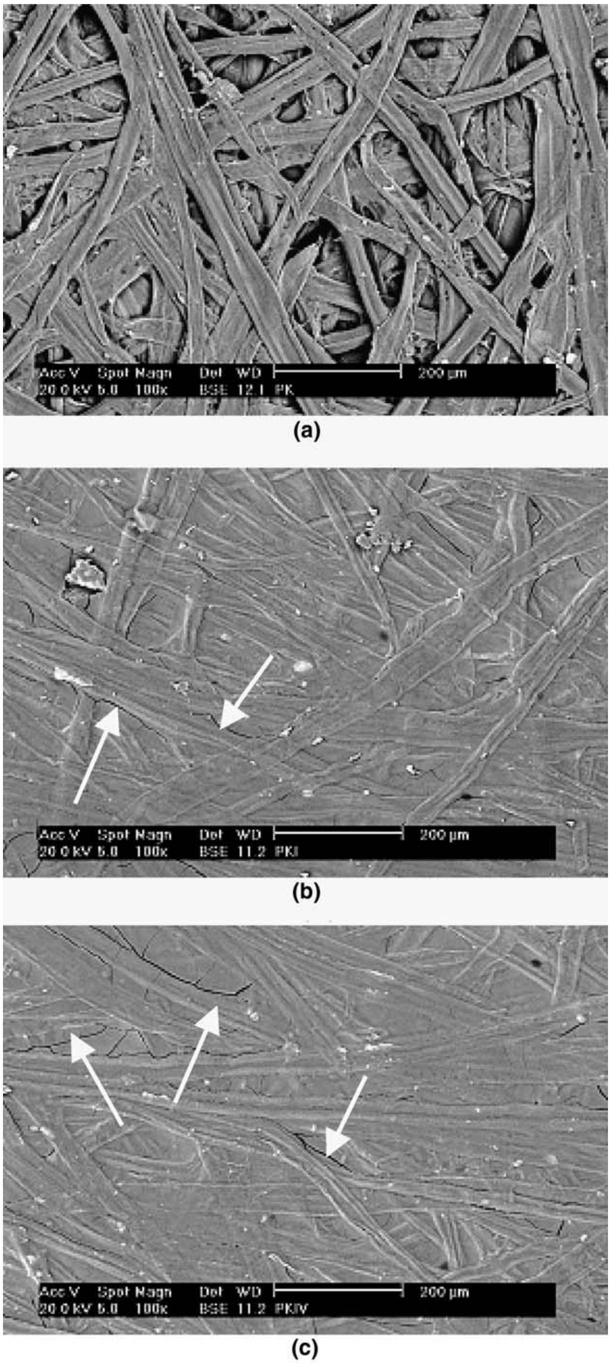

Fig. 2. Micrographs (100×) of Kraft paper samples: (a) non-impregnated, (b) impregnated at atmospheric pressure and (c) impregnated under vacuum conditions. The white arrows indicate the fissures in the starch acetate film.

it is expected that water movement would be more difficult, decreasing the paper permeability. A micrograph of a fractured section of impregnated Kraft paper was obtained, but it was not elucidative, because it was not possible to visualize starch acetate on this fracture. Specific superficial area and specific gravity results, presented in 3.2, were more effective to show the extension of the starch acetate penetration inside the Kraft paper.

3.2. Specific superficial area and specific gravity

The specific gravity values of KP, IKP and VIKP were 0.637 ± 0.032, 0.870 ± 0.037 and 0.919 ± 0.030 g/cm^3, respectively. The specific superficial areas of samples, obtained by the BET method, were 2.999, 0.952 and 1.084 m^2/g, for KP, IKP and VIKP, respectively.

Starch acetate impregnation promoted an increase of around 40% in the paper specific gravity, while the specific superficial area of impregnated samples decreased to a third of the value of the original Kraft paper, due to the reduction of its internal and superficial porosity. These results are in agreement with the pictures obtained by SEM, indicating the filling of a considerable fraction of the Kraft paper pores.

3.3. Water sorption properties

Moisture sorption isotherms of KP, IKP and VIKP at 35 °C are presented in Fig. 3, together with the GAB model fitted for each material. The GAB parameters and the correlation coefficients are given in Table 2. In general, the GAB model represented the experimental isotherm data very well.

The cassava starch isotherm presented the sigmoidal form (type II isotherm), while the isotherm of starch acetate presented a form characteristic of a type III isotherm, related to hydrophobic materials, where there is not the adsorbed molecular monolayer. This behavior also appears in the samples of impregnated Kraft papers IKP and VIKP, which were less hygroscopic than the original Kraft paper, although more hygroscopic than the starch acetate. Similar isotherms for cellulose and starch fractions were reported by Fringant, Desbrières, Milas et al. (1996).

There was a synergic effect between starch acetate and the porous matrix of KP that caused a great decrease of the paper moisture content at equilibrium.

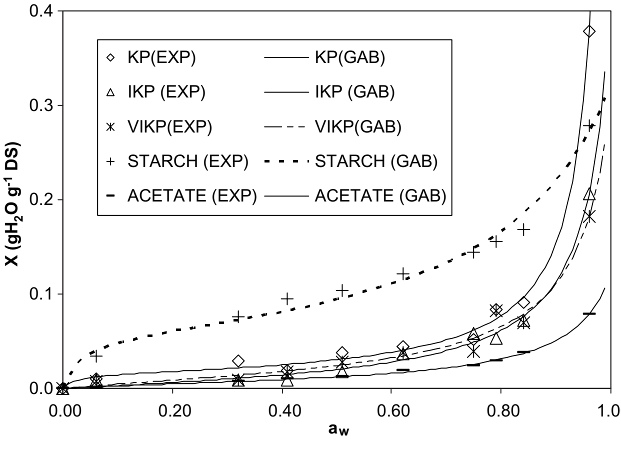

Fig. 3. Experimental data for KP, IKP and VIKP moisture sorption isotherms and the respective fitted GAB curves.

Table 2
GAB parameters for moisture sorption isotherms for cassava starch, cassava starch acetate, Kraft paper (KP), impregnated Kraft paper (IKP) and vacuum impregnated Kraft paper (r is the correlation coefficient)

Sample	GAB parameters			
	X_0	C	k	r
Starch	0.057	34.88	0.821	0.9940
Cassava Starch Acetate	0.009	3.53	0.929	0.9994
KP	0.016	44.86	0.999	0.9982
IKP	0.016	1.87	0.962	0.9956
VIKP	0.018	2.79	0.942	0.9861

For example, at $a_w = 0.95$ the equilibrium moisture content of starch acetate, KP, IKP and VIKP were estimated by GAB equation as 0.3137, 0.007385, 0.1769 and 0.1644 gwater/g dry solid, respectively. On the other hand, the equilibrium moistures contents of IKP and VIKP calculated by means of a simple mixture law were 0.3278 and 0.3190 g water/g dry solid, respectively. The decrease of the superficial area of impregnated samples for a third of KP superficial area value can explain partially this behavior, given that starch acetate solution penetrated and filled a great number of the paper pores. KP and VIKP adsorption cumulative pore volumes, before and after impregnation, are presented in Fig. 4. These results showed that KP pores in the whole range of KP and VIKP pore diameters were filled by starch acetate, which decreased the total pore volume from 5.035×10^{-3} to 2.980×10^{-3} cm^3/g.

These results corroborate that Kraft paper impregnation with cassava starch acetate is a good alternative for obtaining a waterproof paper, as has been previously reported (Larotonda, Matsui, Paes, & Laurindo, 2003).

The behavior of the water adsorptivity (β) of Kraft paper in relation to the water activity is presented in Fig. 5. For original Kraft paper, a value close to 1×10^{-4} [g water/g dry solid × Pa] was calculated, for water activity values tending toward zero. With the formation of the adsorbed molecular monolayer, typical of type II isotherms, the adsorptivity falls to values close to 5×10^{-6} [g water/g dry solid × Pa], coinciding with the isotherms of IKP and VIKP, until a_w values close to 0.63. From this point, the Kraft paper (KP) isotherm differentiates from the isotherms of IKP and VIKP, evidencing it greater adsorptivity. These behaviors will be useful in identifying the relative influences of β and D_{eff} on the water vapor permeability of the Kraft paper studied.

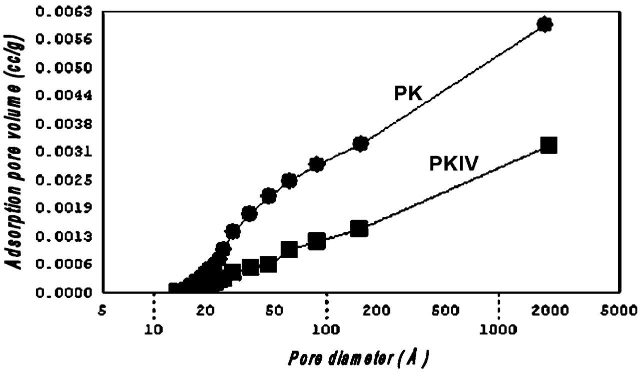

Fig. 4. KP and VIKP adsorption cumulative pore volumes before and after impregnation, determined by BJH method.

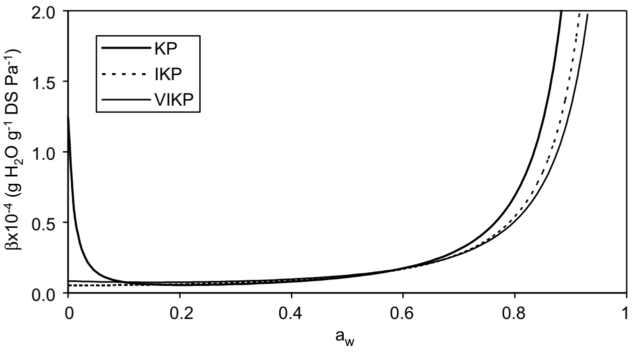

Fig. 5. Adsorptivity (β) values of KP, IKP and VIKP.

3.4. Water vapor permeability, adsorptivity and effective diffusion coefficient

The weight gain curves (triplicate results) of the diffusion cells under the different experimental conditions (different a_w gradients) are presented in Fig. 6. The linearity of the curves, from the beginning of the experiments, is the result of the sample pre-conditioning before carrying out the experiments (Sobral & Ocuno, 2000).

The values for the water vapor permeability of the samples are presented in Fig. 7. They represent average values for each sample group (KP, IKP and VIKP), calculated from the results of the diffusion cell weight gains. The KP permeability was always larger than the IKP and VIKP permeability and increased by around 17% when a_w increased from 0.02–0.33 to 0.33–0.62 and about 20% when a_w increased from 0.33–0.62 to 0.62–0.90. The overall increase in K^w, when a_w increased from 0.02–0.33 to 0.62–0.90 was around 40%. The water vapor permeability for IKP and VIKP also increased with the increase in water activity, but they did not significantly differ from each other. It can be observed that the KP permeability was about 4.2 and 3.7 times greater than the IKP and VIKP permeability, respectively, for the experiment using a_w values of 0.02 and 0.33. This difference decreased with increasing a_w values, in the other experiments. For the experiments carried out with a_w values of 0.33 and 0.62, the KP permeability was around 1.75 and 1.96 times greater than the IKP and

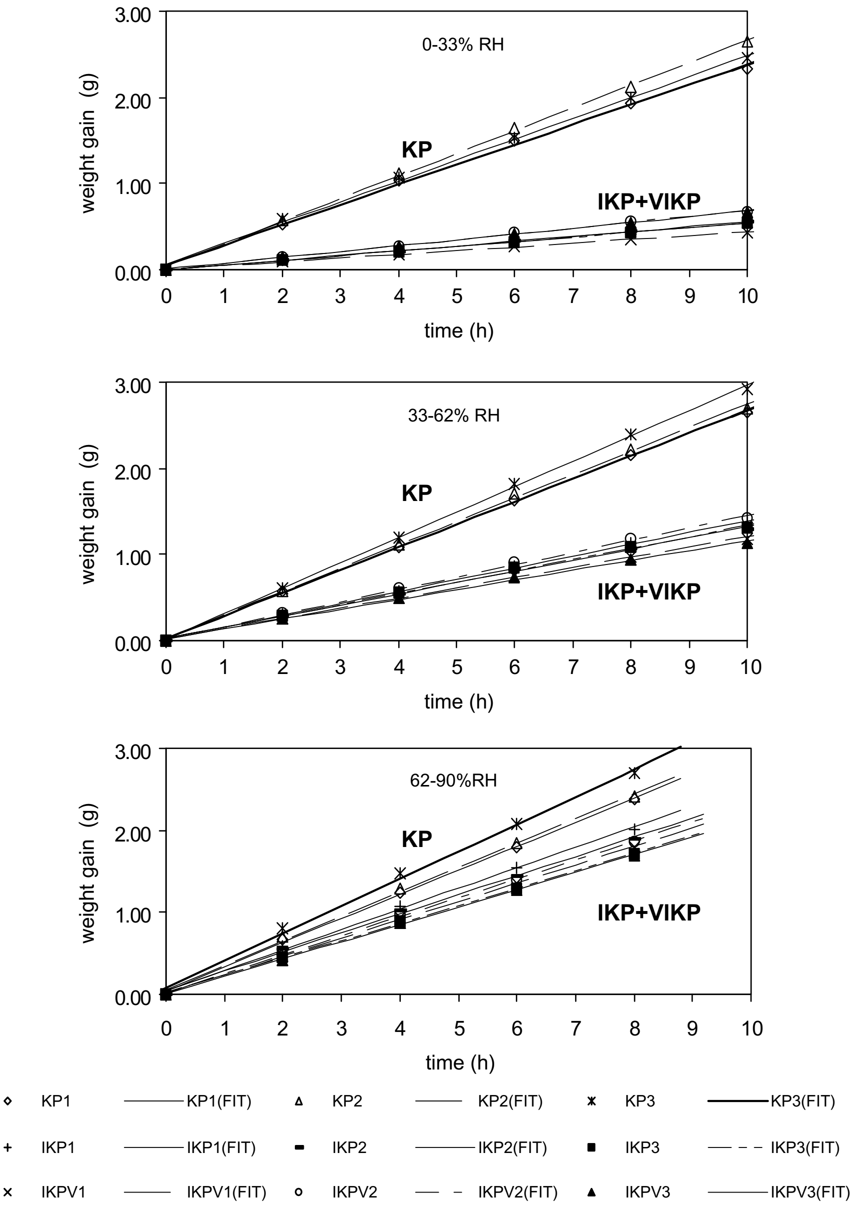

Fig. 6. Mass variation of permeation cells over time for different a_w values.

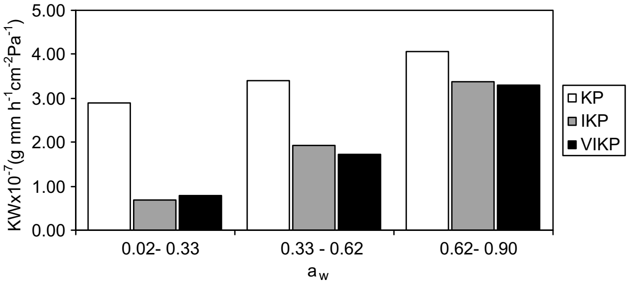

Fig. 7. Comparison of average water vapor permeabilities of KP, IKP and VIKP, determined at different a_w ranges.

VIKP permeability, respectively. For the essays with a_w values of 0.62 and 0.90, KP permeability is about 1.20 and 1.24 times greater than the IKP and VIKP permeability, respectively.

The effective mass diffusivity values calculated from the adsorptivity values and permeability data are presented in Table 3. The D_{eff} value for KP is around 1.8 times the D_{eff} for IKP and VIKP. The calculation of D_{eff} was performed with the average value of the adsorptivity ($\bar{\beta}$), were β presented a large variation. Therefore, the numeric value of D_{eff} needs to be analyzed carefully, in order to understand the mechanisms that control the Kraft paper permeability variation with moisture content and with the starch acetate impregnation. For the values of a_w used in the diffusion cell (0.02–0.33), the reduction in Kraft paper permeability after impregnation was due to the great decrease in its adsorptivity

Table 3
Permeabilities, adsorptivity values and effective diffusion coefficient values for KP, IKP and VIKP

a_w	Sample	K^w (10^{-7} g w mm h^{-1} cm^{-2} Pa^{-1})	$\bar{\beta}$ (10^{-5} g w g^{-1} dm Pa^{-1})	D_{eff} (10^{-11} m^2 s^{-1})
0.02–0.33	KP	2.901	2.201	5.791
	IKP	0.694	0.643	3.475
	VIKP	0.795	0.838	2.890
0.33–0.62	KP	3.398	1.296	11.521
	IKP	1.935	1.300	4.806
	VIKP	1.732	1.366	3.864
0.62–0.90	KP	4.073	14.556	1.229
	IKP	3.385	8.750	1.245
	VIKP	3.295	7.500	1.339

and also to a D_{eff} decrease, which was due to the Kraft paper impregnation with starch acetate.

When a_w values of 0.33 and 0.62 were used for the diffusion cells, the KP, IKP and VIKP $\bar{\beta}$ values were very close to each other (Table 3). However, the D_{eff} value for IKP and VIKP was around 42% lower than that for KP. Therefore, for these a_w values, the Kraft paper permeability reduction was due to the filling of the paper internal pores with starch acetate, reducing the area available for water diffusion and consequently reducing D_{eff}.

When KP, IKP and VIKP samples were submitted to the a_w of 0.62 and 0.90 in the permeation cells, the results indicated clearly that the adsorptivity reduction promoted by impregnation controlled the paper permeability to water vapor. As shown in Table 3, there are no significant differences between the effective diffusion coefficient (D_{eff}) values for KP, IKP and VIKP, while the average adsorptivity ($\bar{\beta}$) decreased by around 80% (from 14.56×10^{-5} to 8.1×10^{-5} g water g^{-1} dm Pa^{-1}), due to impregnation.

4. Conclusions

The results obtained in this work showed that significant reductions in water adsorptivity and water vapor permeability of Kraft paper might well be achieved through starch acetate impregnation, mainly in low relative humidity conditions. This is associated with two factors: (a) the partial filling of the Kraft paper superficial and internal pores by the starch acetate impregnated, reducing the water vapor permeability; (b) as starch acetate is much less hygroscopic than paper, its adsorptivity is reduced significantly by impregnation.

The K^w values obtained varied greatly with a variation in a_w, showing the importance of carrying out permeability essays with the diffusion cells simulating the atmospheric conditions close to the real case. Otherwise, large errors may be made.

Therefore, the starch acetate impregnation of Kraft paper demonstrated here offers an interesting alternative for the improvement of the hygroscopic properties and water vapor permeability of the Kraft paper. Moreover, the use of starch acetate in the impregnation of hygroscopic materials reveals an interesting alternative for the use of starch, adding value to this raw material and providing an incentive for agricultural producers.

Acknowledgement

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