

Kinetic study of the extraction of hemicellulosic carbohydrates from sugarcane bagasse by hot water treatment

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ABSTRACT

Sugarcane bagasse is a lignocellulosic agro-industrial waste, which is usually burned in the sugar and bio-ethanol mills to produce heat and electricity. This work presents the kinetic study of the carbohydrates extracted from the mild hot water pretreatment of sugarcane bagasse, to explain the variation of hemicellulosic carbohydrates during the treatment. This could allow the selection of optimum conditions to obtain the desired products in spent liquors, as high concentration of xylans and low concentrations of fermentation inhibitors. Sugarcane bagasse was hydrothermally treated under isothermal conditions at 160, 170, and 180 °C, using a liquid to solid ratio of 14:1. Glucans, xylans, arabans, xylose, glucose, arabinose, acetic acid, formic acid, HMF and furfural were first identified in the spent liquor. A kinetic model was applied, considering the direct extraction of xylose and oligomers from the solid, xylose production from the oligomers, and furfural generation from xylose. It was supposed that the reaction rate constants have first-order kinetics. The fractionation by hydrothermal treatment has proven to be effective for hemicelluloses removal. Most glucans were retained in the solid, and a partial delignification (at 180 °C, 9.8% and 36.3% of the initial lignin at 20 and 240 min, respectively) was achieved. The maximum concentration of xylans in spent liquors with the low furfural content (0.5% on oven dry bagasse) was achieved at 180 °C and 20 min of treatment (17.6% on oven dry bagasse, about 74% of the initial amount). An activation energy of 128.8 kJ mol⁻¹ has been obtained for the fast hydrolysis of xylans from sugar cane bagasse. The maximal concentration of xylans + xylose in liquors was obtained with a P-factor of 800.

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1. Introduction

Lignocellulosic biomass is an important sustainable resource of carbohydrates (cellulose and hemicelluloses) due to its renewable nature. Its use allows the production of fuels, cellulosic pulp, biomaterials and a variety of chemicals. Lignocellulosic residues generated by agroindustry are available in large quantities at low cost. The fractionation of this waste in its main components would allow the production of chemical intermediates for the manufacture of various products.

Sugarcane bagasse is an important lignocellulosic waste in South America which account about 50% of the world's sugarcane production (about 0.8 billion tonnes in 2012) (FAO, 2014).

Bagasse is usually burned in sugar or bioethanol mills to produce heat and electricity. It is composed of 32–45% cellulose, 19–24% lignin, 27–32% hemicelluloses (mainly xylans) and minor amounts of extractives and inorganic compounds (Novo et al., 2011; Area et al., 2009; Vallejos et al., 2012). It can, therefore, be an adequate source of glucose for the production of second-generation ethanol and xylose for xylitol (Garrote et al., 1999).

Conventional pulping processes fractionate biomass to obtain a pulp rich in cellulose, and energy through burning lignin and other chemical components. An alternative to further enhance value is to separate all components using sequential processes, and produce high value products that can be used in different applications to improve the profit. This is the conceptual background of the technologies based on the bio-refinery concept.

The commonly used pretreatments to fractionate lignocellulosic biomass are essentially hydrolytic either in acidic or basic media, or catalyzed by enzymes.

Xylans can be depolymerized and extracted from biomass in a strong alkali media, but the reaction products are highly degraded,

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completely deacetylated and their solubility in water is limited (Patil, 2012; Li Jansson and Brannvall, 2011). On the contrary, autohydrolysis occurs in mild acid medium due to the partial breakdown of acetyl groups, and acetic acid release. Moreover, the autohydrolysis at mild temperatures produce high molecular weight xylo-oligosaccharides, without substantially modifying the cellulose and lignin, which allows their recovery for further processing (Garrote et al., 1999). Fractionation by hot water is environmentally friendly since uses pressurized hot water at moderate times and temperatures. It has proven to be effective and selective to remove hemicelluloses present in the lignocellulosic material, as is extensively discussed in the literature (Garrote et al., 1999; Allen et al., 1996).

Water is the best green solvent to be used in biorefinery because of its environmental benefits, safety and low cost. It has been classified recently as a recommended solvent by a survey of solvent selection guides (Prat et al., 2014; Amidon and Liu, 2009). Hot water treatment avoids the use of corrosive reagents for the hydrolysis of xylans to reducing sugars. In addition, autohydrolysis at mild conditions (short times and temperatures under 200 °C, without catalyst) does not modify cellulose and lignin substantially, which can allow their recovery for further treatments and utilization (Qing et al., 2013).

After the hydrolytic pretreatment, the solid fraction (mainly cellulose) is filtered to separate the liquid fraction (spent liquor), rich in xylo-oligomers and sugars derived from hemicelluloses (xylose and arabinose). The chemical and porosity of the solid fraction (lignocellulosic material) has been modified, allowing for a more efficient delignification. Treating the material with adequate reagents in subsequent biorefinery processing, allow to obtain cellulose and lignin fractions of higher added value than the currently available industrial ones (Bujanovic et al., 2012; Bozell and Petersen, 2010).

In the autohydrolysis processes using pressurized hot water, hydronium ions from generated compounds (acetic, uronic, and phenolic acids) catalyze the hydrolysis of the hemicelluloses (Garrote et al., 1999). These processes increase cellulose accessibility, and allow pentosans recovery ($\geq 90\%$), producing hydrolysates almost free of fermentation inhibitors. Hemicelluloses structure and composition vary according to the origin of the lignocellulosic material and in different parts within the same material. The hydrolysis reactions generate a random cleavage of the hemicelluloses, depending of their chemical structure, so the understanding of differences in the hydrolysis reactions allows maximization of biomass use.

Modelling of the changes in the composition of the lignocellulosic materials during the hydrolysis treatment is applied to design and optimize the conversion processes. Kinetic models and severity parameters are different mathematical methods to describe the hydrolysis of hemicelluloses. Severity parameters have been used to compare different pretreatment strategies, whilst kinetic models have been applied to describe the changes of hemicelluloses by hydrolysis in function of treatment conditions (Sixta et al., 2006; Wang et al., 2011).

The effect of time and temperature on the intensity of the hot water treatment can be described by the prehydrolysis factor (*P*-factor) based on the Arrhenius equation. *P*-factor is used to compare the hot water treatments performed at different temperatures and to predict the solubilisation of hemicellulosic components during acid treatments. This factor is similar to the *H*-factor used in the pulp and paper industry (Sixta et al., 2006).

The kinetics of the hydrolysis reaction for extraction of hemicelluloses from sugarcane bagasse using diluted sulphuric acid has been widely studied due its high reaction rates and high extraction yields (Aguilar et al., 2002; Ávila Rodrigues and Guirardello, 2008; Sasikumar and Viruthagiri, 2008; Canilha et al., 2011; Cardona et al.,

2010). However, this pretreatment has some drawbacks, as: (i) its high cost, (ii) its high liquid-solid ratio, making necessary a subsequent concentration of sugars for their recovery, and (iii) the high formation of degradation products, inhibitors of the fermentation (Cardona et al., 2010).

Several kinetic models for autohydrolysis have been proposed to describe the hydrolysis reactions of wood and grass species, and to optimize the production of xylo-oligosaccharides and xylose. Nevertheless, no works on kinetic of autohydrolysis reactions of sugarcane bagasse have been found (Kabel et al., 2002; Nabarlatz et al., 2004; Gullón et al., 2009; Carvalheiro et al., 2004; Garrote et al., 2001; Zhuang et al., 2009).

This work presents the kinetic study of mild hot water pretreatment of sugarcane bagasse, to explain the variation of hemicellulosic carbohydrates released during the treatment. This could allow the selection of optimum conditions to obtain the desired products in spent liquors, as high concentration of xylans and low concentrations of fermentation inhibitors.

2. Experimental

2.1. Raw materials

Sugar cane bagasse was supplied by a local mill (San Javier Sugar Mill, Misiones, Argentina). Bagasse pith was removed in two stages. In the former, bagasse was wet-depithed to break its structure in a Bauer disc refiner (plate gap of 0.01 in), after which the bagasse pith was removed by screening, using a plate with 2 mm wide slits (Wenmber). Finally, depithed bagasse was centrifuged and preserved in a refrigerator. The pretreatments were performed in a MK digester with a capacity of 7 L using 350 g OD of bagasse.

2.2. Hot water pretreatment

The conditions of hydrothermal pretreatments were: water/dry bagasse ratio: 14/1, maximum temperatures: 160, 170 and 180 °C, maximum time at temperature: 4 h.

As a fraction of the hemicelluloses (mainly xylans) was hydrolyzed in the pre-heating step (time to reach the maximum temperature), the initial time (0 min) for the isothermal process was set after the initial 60 min.

Samples of liquor were obtained at different times of treatment, and the content of organic compounds was determined. The remaining xylans in the solid were calculated by subtracting the xylans, xylose and furfural present in the liquor (all species expressed as xylose) to the xylans content (expressed as xylose) in raw material.

2.3. Analysis of liquor samples

The samples were characterized by the determination of sugars content (glucose, xylose, and arabinose) and degrading products: furfural, 5-hydroxymethylfurfural and organic acids (formic and acetic), according to Technical Report NREL/TP-510-42623 (January 2008) "Determination of Sugars, Byproducts, and Degradation Products in Liquid Fraction Process Samples", National Renewable Energy Laboratory.

The quantification of sugars, organic acids and degradation products was carried out by HPLC liquid chromatography (Waters HPLC System), using an Aminex-HPX87H column (BIO-RAD) with the following chromatographic conditions: H_2SO_4 4 mM as eluent, 0.6 mL min^{-1} , 35 °C and refractive index and diode array detectors. The structural carbohydrates in the raw material and in the pretreated solid (glucans, xylans, arabans and acetyl groups) were

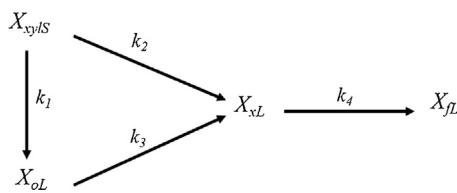


Fig. 1. Xylan solubilization during hot water pretreatment proposed for Mittal et al. (2009a).

determined following the Technical Report NREL/TP-510-42618 (April 2008) National Renewable Energy Laboratory.

2.4. Kinetic model and data analysis

The kinetic of the reactions generating products in the liquor, from the xylans in the solid material, was determined by adapting the model proposed by Mittal et al. (2009a) for hardwoods. The authors have deduced the parameters of the Arrhenius equation by working at different temperatures, assuming a first order kinetics and defining four kinetic constants (k_1 – k_4). The model set up the formation of xylose in the liquor (X_{xL}) along two parallel paths, namely (Fig. 1 and Eqs. (1)–(4)):

- The xylose extracted directly from the hydrolysable fraction of xylans in the raw material (X_{xyLS}), and
- The xylose produced by the hydrolysis of oligomers (X_{oL}) in the liquid phase.

Xylose in the liquor (X_{xL}), in turn, is degraded to furfural (X_{fL}) in a greater or lesser extent depending on the conditions of treatment.

The hydrolysable fraction of xylans (X_{xyLS}) is obtained by multiplying the total amount of xylans in the raw material (X_{xyLS}^{RM}) by the parameter α ("susceptible fraction").

$$\frac{d[X_{xyLS}]}{dt} = -(k_1 + k_2)[X_{xyLS}] - (1 - \alpha)[X_{xyLS}]^{RM} \quad (1)$$

$$\frac{d[X_{oL}]}{dt} = k_1[X_{xyLS}] - (1 - \alpha)[X_{xyLS}]^{RM} k_3[X_{oL}] \quad (2)$$

$$\frac{d[X_{xL}]}{dt} = k_2[X_{xyLS}] - (1 - \alpha)[X_{xyLS}]^{RM} + k_3[X_{oL}] - k_4[X_{xL}] \quad (3)$$

$$\frac{d[X_{fL}]}{dt} = k_4[X_{xL}] \quad (4)$$

The kinetic parameters α and k_i , were obtained using the integrated version of the Eqs. ((1)–(4)) for 160, 170, and 180 °C for the four hours of treatment. The iteration was performed by the SOLVER complement of the Excel software. The activation energies (E_{ai}) for the kinetic reactions were calculated from the Arrhenius equations,

Table 1
Composition of liquors extracted at different times of the pre-treatment at 160 °C (% o.d.b.).

Time(min)	Glucose	Xylose	Arabinose	Formic acid	Acetic acid	HMF	Furfural	Glucans	Xylans	Arabans
0	0.00	0.04	0.21	0.00	0.14	0.00	0.02	1.22	0.54	0.12
5	0.00	0.00	0.38	0.00	0.19	0.00	0.02	1.51	1.20	0.18
10	0.00	0.09	0.54	0.03	0.27	0.00	0.03	1.86	2.29	0.27
20	0.00	0.16	0.71	0.06	0.41	0.00	0.04	2.30	4.59	0.38
40	0.00	0.42	0.92	0.06	0.97	0.01	0.10	2.98	10.4	0.53
60	0.00	0.88	1.03	0.12	1.38	0.01	0.20	3.17	14.2	0.55
90	0.00	1.86	1.08	0.16	1.79	0.07	0.39	2.93	15.5	0.44
120	0.00	3.24	1.09	0.25	1.80	0.07	0.63	2.88	15.2	0.33
180	0.00	7.21	1.04	0.27	2.60	0.06	1.52	2.95	12.2	0.27
240	0.15	10.9	0.98	0.68	3.31	0.10	2.57	2.86	7.91	0.17

Table 2
Composition of liquors extracted at different times of pre-treatment at 170 °C (% o.d.b.).

Time(min)	Glucose	Xylose	Arabinose	Formic acid	Acetic acid	HMF	Furfural	Glucans	Xylans	Arabans
0	0.00	0.10	0.54	0.04	0.28	0.00	0.01	1.84	2.52	0.27
5	0.00	0.16	0.66	0.04	0.40	0.00	0.03	2.25	5.20	0.40
10	0.00	0.28	0.80	0.09	0.57	0.00	0.06	2.72	8.37	0.49
20	0.00	0.63	0.95	0.08	0.91	0.01	0.14	3.03	13.5	0.54
40	0.00	1.90	1.07	0.14	1.50	0.02	0.44	3.19	17.4	0.48
60	0.00	3.59	0.98	0.18	1.85	0.04	0.75	3.22	17.4	0.46
90	0.00	7.98	1.01	0.28	2.82	0.08	1.89	3.18	12.7	0.26
120	0.16	11.3	0.89	0.35	3.64	0.12	3.17	3.03	7.52	0.21
180	0.66	12.0	0.65	0.50	4.36	0.26	5.77	2.43	1.62	0.11
240	1.45	9.50	0.53	0.59	4.43	0.39	7.27	1.39	0.00	0.03

Table 3
Composition of liquors extracted at different times of pre-treatment at 180 °C (% o.d.b.).

Time(min)	Glucose	Xylose	Arabinose	Formic acid	Acetic acid	HMF	Furfural	Glucans	Xylans	Arabans
0	0.00	0.19	0.62	0.09	0.49	0.00	0	2.18	5.88	0.37
5	0.00	0.39	0.73	0.14	0.80	0.00	0.09	2.62	11.1	0.48
10	0.00	0.75	0.81	0.18	1.09	0.00	0.20	2.96	15.1	0.50
20	0.00	1.86	0.84	0.28	1.56	0.02	0.50	3.06	17.6	0.44
40	0.00	5.83	0.78	0.43	2.23	0.06	1.75	2.94	13.7	0.26
60	0.00	9.56	0.66	0.73	3.12	0.12	3.54	2.98	7.32	0.19
90	0.50	9.31	0.41	0.82	3.80	0.24	5.86	2.29	1.45	0.20
120	1.31	6.99	0.33	1.06	4.19	0.34	7.55	1.20	0.00	0.12
180	1.72	3.25	0.28	1.49	4.50	0.83	9.13	0.00	0.00	0.00
240	1.59	1.66	0.16	1.62	4.58	1.15	9.30	0.00	0.00	0.03

Table 4

Constants of the kinetic equations for the studied temperatures.

	160 °C	170 °C	180 °C
α	0.921	0.925	0.917
k_1	0.932	2.274	5.698
k_2	0.048	0.075	0.099
k_3	0.305	0.597	1.292
k_4	0.255	0.367	1.062

using the constants of the regression equations at the three studied temperatures.

2.5. P-factor

P-factor or prehydrolysis factor allows the controlling the prehydrolysis step. P-factor is calculated from the relative rate of prehydrolysis for any desired temperature using activation energy typical for the cleavage of glycosidic bonds of the carbohydrate material in the wood and assuming that the rate constant at 100 °C is 1 (Sixta et al., 2006). P-factor expressing the prehydrolysis time and temperature relationship is defined as (Eq. (5)):

$$P = \int_{t_0}^t k_{\text{rel}} dt = \int_{t_0}^t \frac{k_{H(T)}}{k_{100^\circ\text{C}}} dt = \int_{t_0}^t \text{Exp}\left(\frac{E_A}{373.15 \times R} - \frac{E_A}{T \times R}\right) dt \quad (5)$$

3. Results and discussion

The chemical composition of the sugar cane bagasse used in this work (as a percentage by weight on oven-dry bagasse, % o.d.b.) involved: 43.1% glucans, 23.8% xylans, 1.7% arabans, 1.7% acetyl groups, 21.3% lignin, 2.1% extractives in alcohol-benzene, 2.7% extractives in hot water and 1.5% of ashes.

Main compounds in spent liquors were xylans, xylose, acetic acid, and furfural (generated by the degradation reaction of xylose and arabinose). The composition of the liquors extracted at different times is presented in Tables 1–3.

The hot water pretreatment of bagasse had little effect on cellulose hydrolysis, as it remained almost entirely in the fibrous material. A small fraction of glucans was hydrolyzed during the treatment (the maximum release of glucans was 7.5% of their initial content at 170 °C).

Hemicelluloses were almost fully hydrolyzed to oligomers and sugars (xylans to xylose and arabans to arabinose) and consecutively to furfural, after 240, 90, and 40 min at 160, 170, and 180 °C, respectively. Xylose and arabinose concentrations decreased after 120 and 60 min at 170 and 180 °C, respectively, because of their progressive degradation. Maximum concentrations of pentosans (xylans + arabans) in spent liquors were 15.9, 17.9 and 18.0% o.d.b. (oven-dry basis) at 90, 40, and 20 min for 160, 170, and 180 °C, respectively (Tables 1–3).

These values represent about 62% of the initial amount of pentosans for 160 °C, whereas it is about 70% for 170 and 180 °C. HMF and furfural generation were maximal at 180 °C and 240 min (1.15% and 9.30% o.d.b., respectively).

To adjust the models, only data obtained under isothermal conditions were considered. The kinetic parameters α and k_i for 160, 170, and 180 °C are shown in Table 4.

The value found for the susceptible xylans fraction α (0.92) is high, indicating that almost the total amount of xylans present in the solid are susceptible to hydrolysis in bagasse.

This α value is greater than those obtained for the hydrothermal treatment of corncob (Garrote et al., 2001) (0.850–0.891) and sugar maple (Mittal et al., 2009a) (0.780–0.870), being similar to those obtained for the acid pretreatment of bagasse at 122 °C (Aguilar et al., 2002). The lack of correlation between the α value and tem-

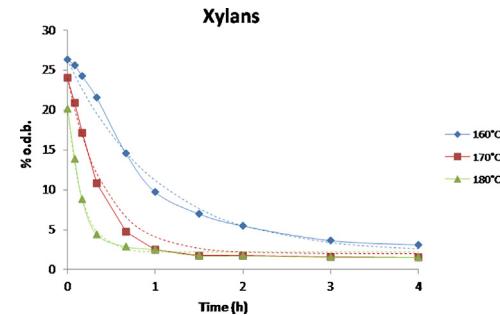


Fig. 2. Xylans solubilisation from bagasse by hot water pretreatment at different temperatures (points: experimental data; dotted line: fitted model).

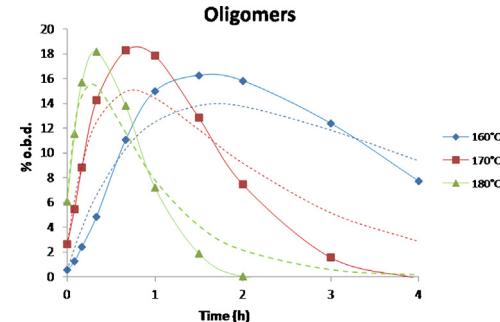


Fig. 3. Oligomers released in liquors by hot water pretreatment of bagasse at different temperatures (points: experimental data; dotted line: fitted model).

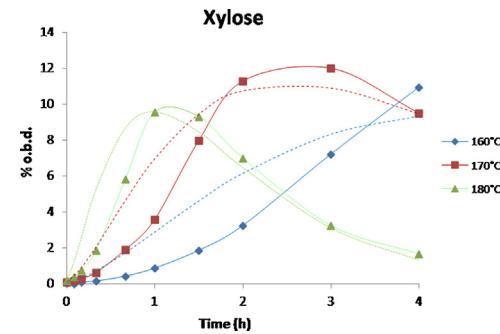


Fig. 4. Xylose released in liquors by hot water pretreatment of bagasse at different temperatures (points: experimental data; dotted line: fitted model).

perature was already found by other authors working with bagasse (Aguilar et al., 2002).

The experimental and theoretical evolutions of xylans extraction and the different products released in liquors are shown in Figs. 2–6.

The experimental data of xylans removal from the raw material showed an almost perfect fit to the theoretical ones, at all temperatures (Fig. 2), whereas experimental values of oligomers in liquors are slightly higher than theoretical ones (about 2–3% o.d.b. at the time of maximum extraction), (Fig. 3). The disappearance of the oligomers from the liquors responds to their conversion to xylose –and further to furfural–, and is more pronounced at higher temperatures.

Xylose in liquors shows similar behaviour (Fig. 4), but in this case the shape of the curves is somewhat different, mainly at 160 °C. Fig. 5 shows the good fit of the equations corresponding to all the components containing xylose.

The activation energies E_{ai} for the kinetic reactions were calculated from the Arrhenius equations, using the constants of the regression equations at all temperatures (Table 4), as shown in

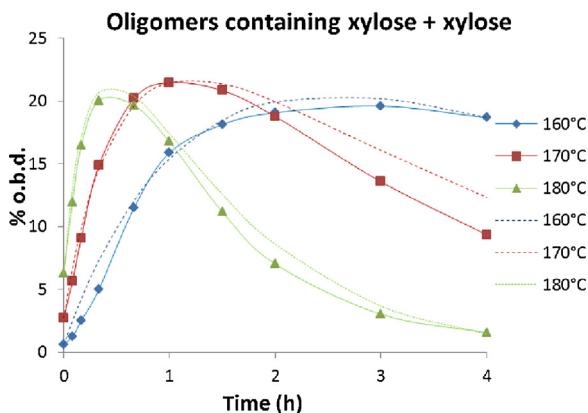


Fig. 5. Oligomers containing xylose plus xylose released in liquors by hot water pre-treatment of bagasse at different temperatures (points: experimental data; dotted line: fitted model).

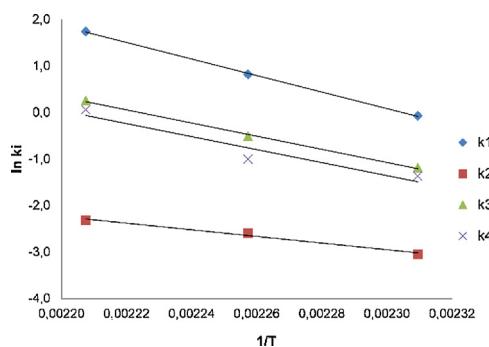


Fig. 6. The activation energies of the kinetic reactions calculated from the Arrhenius equation are shown in Table 5.

Table 5
Activation energies of the kinetic reactions calculated from the Arrhenius equation ($k_i(T) = k_{0i} \exp[-E_{ai}/(RT)]$).

Kinetic coefficient	$\ln k_{0i}^*$	E_{ai} (kJ mol ⁻¹)	R^2
k_1	40.9	148	0.99
k_2	13.5	60	0.99
k_3	31.4	118	0.99
k_4	30.7	116	0.92

Fig. 6. The activation energies of the kinetic reactions calculated from the Arrhenius equation are shown in Table 5.

According to the activation energies, the fastest reaction is the conversion of xylans in the raw material to xylose, and the slowest is their dissolution as oligomers.

These results are close to those obtained when chips (Mittal et al., 2009b) and milled wood (Mittal et al., 2009a) are treated, although they highlight difficulties in the mass transfer for the solubilisation of the polymer in bagasse.

The rate of conversion of oligomers to xylose is very similar to the conversion of this last one to furfural. Furfural generated in liquors shows lower experimental values than theoretical ones from the model at long times of treatment (Fig. 7).

This behaviour evidences that furfural is degraded to other components almost simultaneously with its formation, and that this degradation increases with the treatment temperature. These degradation products, not considered in the equations, are present in the chromatograms and could even include the degradation of xylose to formic acid and humines (Lau et al., 2014; Zhang et al., 2013). The furfural can also disappear from the system due to resinification and condensation reactions, but these reactions are negligible to the temperatures of this work (Zeitsch, 2000).

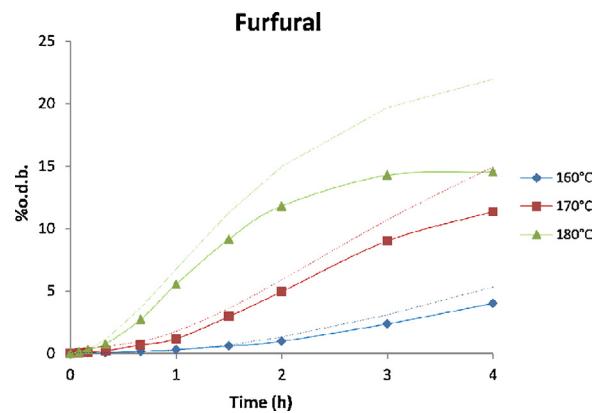


Fig. 7. Furfural generated from xylans dehydration in liquors by hot water pretreatment of bagasse at different temperatures (points: experimental data; dotted line: fitted model).

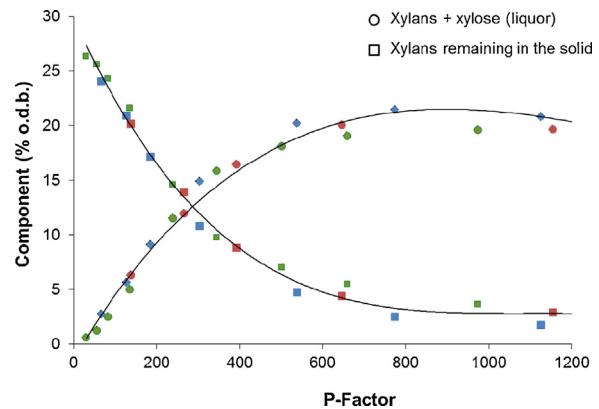


Fig. 8. Xylans + xylose composition in the liquors and xylans remanent in the solid, both evolutions as function of P-factor (green: 160°C, blue: 170°C and brown: 180°C). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

In accordance with the above, another reaction representing the degradation of furfural, or another byproduct generated by xylose, should be incorporated to the model. Other authors used different models for another kind of raw material (Gullón et al., 2009), but they could adapt well to hot water treatment of bagasse. Once identified, the kinetic equations of decomposition products should be included in the model.

P -factors were calculated for all conditions (Fig. 8). The activation energy, E_A , for the fast-reacting xylans from sugarcane bagasse was determined in the present study from the slopes of the curves in Fig. 2, in the bulk step. In this way, an activation energy of 128.8 kJ mol⁻¹ has been obtained for sugar cane bagasse, and it was applied for the calculation of the P -factor as shown in Eq. (6) (Sixta and Potthast, 2006).

$$P = \int_{t_0}^t \frac{k_{H(T)}}{k_{100^\circ\text{C}}} dt = \int_{t_0}^t \text{Exp}(41.52 - \frac{15439}{T}) dt \quad (6)$$

P -factor (similar to H -factor) expresses the hydrolysis time and temperature as a single variable in batch reactors. It is mainly based on empirical models. The authors consider that it is applicable to control the extent of the prehydrolysis process due to its simplicity and ease of implementation. Hemicelluloses removal from lignocellulosic material is strongly controlled by temperature and to a lesser extent by acetic acid concentration. It is possible to consider the variation of acid concentration along the prehydrolysis in the P -factor formula. However, the improvements that can be introduced by the slight change of pH on the autohydrolysis treatment (in this

work, from pH 4.4 to 3.4) do not justify the use of a more complex modified *P*-factor concept (Sixta and Potthast, 2006).

An activation energy of 128.8 kJ mol⁻¹ has been calculated in this work for the fast hydrolysis of xylans from sugar cane bagasse. It is slightly higher than the value found by Sixta et al. (2006) for eucalyptus. The maximal concentration of xylans + xylose in liquors can be obtained with a *P*-factor of 800, as shown in Fig. 8. At that point, xylans (expressed as xylose) and xylose content in spent liquors represented about 70–80% of the xylose in the raw material.

4. Conclusions

Xylans were almost fully hydrolyzed to oligomers and sugars (xylans and arabans, xylose and arabinose) and to furfural, after 240, 90, and 40 min at 160, 170, and 180 °C, respectively.

The adopted model represented well the evolution of most components in liquors. The experimental data of xylans removal from the raw material showed an almost perfect fit to the theoretical ones at all temperatures.

Furfural generated in liquors shows lower experimental values than theoretical ones from the model at long times of treatment. This behaviour might evidence that xylose or furfural, are degraded to other components.

Maximum concentrations of pentosans (xylans + arabans) in spent liquors were 15.9, 17.9 and 18.0% o.d.b. (oven-dry basis) at 90, 40, and 20 min for 160, 170, and 180 °C, respectively.

An activation energy of 128.8 kJ mol⁻¹ has been obtained for the fast hydrolysis of xylans from sugar cane bagasse. The maximal concentration of xylans + xylose in liquors was obtained with a *P*-factor of 800.

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