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The Viscosity of Aqueous Suspensions of Cellulose Fibres. Part 3. Influence of pH

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Abstract. The viscosity of aqueous suspensions of cellulose fibres from eucalipt and pine bleached kraft pulps has been measured at 25ºC as a function of consistency and pH. The measurements cover the range of 0.05 up to 1.00 mass per cent consistency and span the pH interval from about 2 to about 12. Empirical correlations have been established between the viscosity of the suspensions and the above mentioned properties.
Key words: viscosity; suspensions; eucalypt; pine; consistency; fibre length; pH

Sumário. Mediu-se a viscosidade de suspensões aquosas de fibras celulósicas de pastas kraft branqueadas, de eucalipto e de pinho, a 25ºC, em função da consistência e do pH. O intervalo de consistência considerado foi de 0,05 até 1,00% e o de pH desde 2 até cerca de 12. Estabeleceram-se correlações para a variação da viscosidade das suspensões em função das propriedades anteriormente referidas.
Palavras-chave: viscosidade; suspensões; eucalipto; pinho; consistência; comprimento das fibras; pH

Resumé. La viscosité des suspensions aqueuses de fibres de cellulose provenants de pâtes d'eucalyptus et de pin a été mesurée en fonction de leur consistance et du pH à 25ºC. Le pH est changé entre 2 et 12 pour les suspensions de consistances de 0.05 à 1.00 pour cent. Des corrélations ont été établies pour décrire la variation de la viscosité des suspensions en fonction de la consistance et du pH.
Mots clés: viscosité; suspensions; eucalyptus; pin; consistence; longueur des fibers; pH

Introduction

The viscosity of cellulose fibre suspensions is an important variable in the pulp and papermaking processes, either for equipment design or in controlling its operation. In spite of this measured values for that property are scarce in the literature. We have recently reported on the influence of consistency and fibre length on the viscosity of aqueous suspensions of cellulose fibres from eucalypt and pine kraft bleached pulps (SILVEIRA *et al*., 2002), and also on the

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dependence of the viscosity of such suspensions on temperature and on the relative amount of fibres of the two species (FERREIRA *et al.*, 2002). This paper is yet a further contribution to the same field of research. Here we report on the influence of consistency and pH on the viscosity of fibre aqueous suspensions from the same origin. As far as we are aware no previous results in this line have been reported in the literature.

Experimental

Eucalypt and pine kraft bleached pulps (from Celulose do Caima and Georgia-Pacific mills, respectively) were used in the preparation of aqueous cellulose fibre suspensions. The humidity of the original samples was previously determined according to standard procedures (NF Q03-003). A value of (9.55 ± 0.05) weight per cent humidity was obtained for both samples. This value has been taken into account in the preparation of the aqueous suspensions. To obtain the cellulose fibre material necessary to prepare the suspensions the raw pulps were desintegrated using a Buchell device (model BK 111c) following adequate standards (NF Q50-002). The average mass length l_w of the fibres as determined with the Galai analyser (model Cis-100, equiped with Fiblen informatics) gave values of 0.931 and 3.124 mm for the eucalypt and pine samples, respectively, this quantity being defined as (BENTLEY *et al.*, 1994; CARVALHO *et al.*, 1997; ROBERTSON *et al.*, 1999):

$$l_w = \left(\sum_i n_i\, l_i^3\right) / \left(\sum_i n_i\, l_i^2\right)\ , \qquad (1)$$

where n_i is the average number of fibres of average length l_i. The rheological behaviour of the suspensions of consistency C ranging up to 0.85 mass per cent prepared from these fibres was examined at (25 ± 0.1) ºC by changing the rotation speed ω of the spindle of a Brookfield digital viscometer (model DV-II) with which the subsequent measurements were made. Above C = 0.15 per cent the suspensions behaviour is non-newtonian, pseudoplastic. For the more concentrated suspensions of both species, however, the viscosity becomes independent of spindle rotation somewhat below 60 s^{-1} (SILVEIRA *et al.*, 2002). For this reason it was decided to carry out all the measurements at 1 Hz. This means that the results reported here should be regarded as apparent viscosities. To avoid fibre floculation ultrasound was applied to the suspensions just before the viscosity measurements were made. To obtain the adequate pH value to perform each experiment a few drops of aqueous HCl or NaOH solutions were added to the original sample suspension, covering the range from about 2 to about 12 pH unities. Moreover, the viscometer was calibrated using Brookfield standards of viscosity 4.3, 9.2, and 49.0 mPa.s, and measurements were made on these standards at regular intervals between experiments to test the results obtained for the aqueous fibre suspensions.

Results and discussion

The viscosity of each of the suspensions was measured at (25.0 ± 0.1) ºC during five minutes at half minute intervals. The results are shown in Tables 1 and 2 for eucalypt and pine, respectively. These tables also include the standard deviation σ_η of the viscosity readings. C is the consistency defined as one hundred times the mass of fibres divided by the sum of the mass of fibres plus the mass of water in each suspension.

The results show that the viscosity of the aqueous fibre suspensions is clearly dependent on pH: for acid suspensions η decreases when pH increases, while it increases with pH in basic medium. Linear correlations were tried to take account of these variations. This means that by considering

$$\eta = a + b(\text{pH}) \,, \qquad (2)$$

parameter b would be negative if the suspensions are acid, and positive if they are basic. The results of the statistical treatment are registered in Tables 3 and 4.

Since, of course, both parameters a and b should also depend on consistency C, linear correlations of the form

$$a = a_0 + a_1 C \qquad (3.a)$$

$$b = b_0 + b_1 C \qquad (3.b)$$

were tried the results of which have been summarized in Table 5.

Both the experimental results and those obtained from the correlations established in this way are shown in Figures 1 and 2.

Table 1 – Viscosity η (in mPa.s) at (25.0 ± 0.1) ºC of aqueous eucalypt fibre suspensions of consistency C (in mass per cent) as a function of pH. σ_η is the standard deviation of the viscosity measurements

C (%)	**pH**	**($\eta \pm \sigma_\eta$) / (mPa.s)**	**C (%)**	**pH**	**($\eta \pm \sigma_\eta$) / (mPa.s)**
0.05	1.91	6.05 ± 0.40	0.60	1.11	29.19 ± 0.44
	2.89	4.66 ± 0.51		2.17	25.09 ± 0.38
	3.97	3.36 ± 0.52		4.07	15.13 ± 0.35
	6.13	1.20 ± 0.14		6.18	6.03 ± 0.27
	8.13	1.88 ± 0.16		6.52	7.78 ± 0.35
	9.06	3.03 ± 0.45		8.23	9.90 ± 0.29
	10.24	4.23 ± 0.42		10.31	10.60 ± 0.44
	11.16	5.01 ± 0.38		12.21	12.02 ± 0.64
	11.96	5.50 ± 0.40			
0.20	1.22	9.35 ± 0.36	0.80	1.38	39.19 ± 2.18
	2.08	8.13 ± 0.35		2.54	30.00 ± 2.73
	4.23	3.77 ± 0.32		3.56	27.12 ± 2.15
	5.93	1.76 ± 0.05		5.47	12.99 ± 0.58
	7.12	2.41 ± 0.22		6.45	18.00 ± 0.44
	8.40	4.03 ± 0.10		8.41	20.44 ± 1.58
	10.26	5.99 ± 0.40		9.52	23.47 ± 1.05
	11.94	7.14 ± 0.70		10.48	24.76 ± 0.79
				11.36	26.04 ± 0.62
0.40	1.87	11.02 ± 0.29	1.00	1.56	45.96 ± 1.40
	3.03	9.02 ± 0.36		2.21	44.76 ± 0.48
	3.86	5.08 ± 0.35		3.21	39.58 ± 1.70
	5.48	2.90 ± 0.17		5.55	21.16 ± 0.90
	7.81	5.32 ± 0.34		6.45	30.20 ± 0.82
	9.82	8.29 ± 0.33		8.50	37.37 ± 0.85
	10.87	10.16 ± 0.41		10.50	41.54 ± 1.81
	11.80	10.54 ± 0.24		11.85	47.05 ± 0.69

Table 2 – Viscosity η (in mPa.s) at (25.0 ± 0.1) ºC of aqueous pine fibre suspensions of consistency C (in mass per cent) as a function of pH. σ_η is the standard deviation of the viscosity measurements

C (%)	pH	$(\eta \pm \sigma_\eta)$ / (mPa.s)	C (%)	pH	$(\eta \pm \sigma_\eta)$ / (mPa.s)
0.05	1.93	7.92 ± 0.29	0.60	1.87	40.85 ± 1.04
	2.92	5.06 ± 0.23		2.76	33.31 ± 1.56
	4.00	2.55 ± 0.14		3.90	24.87 ± 0.54
	5.87	1.33 ± 0.14		5.30	13.78 ± 0.35
	6.80	2.67 ± 0.26		5.98	17.96 ± 0.44
	8.85	5.08 ± 0.34		8.01	23.29 ± 1.32
	10.85	6.16 ± 0.29		10.01	30.11 ± 1.21
	12.05	7.03 ± 0.23		12.04	36.87 ± 2.60
0.20	1.91	15.50 ± 0.38	0.80	1.90	45.46 ± 1.64
	2.96	11.63 ± 0.59		2.86	38.99 ± 1.20
	4.01	7.95 ± 0.37		3.87	28.66 ± 1.11
	5.67	4.29 ± 0.28		5.93	18.43 ± 1.11
	6.64	8.96 ± 0.26		8.54	28.95 ± 1.38
	8.29	10.85 ± 0.48		9.99	34.92 ± 0.53
	10.00	13.01 ± 0.48		11.00	37.64 ± 1.09
	12.02	14.19 ± 0.44		12.02	39.48 ± 0.54
0.40	2.01	28.89 ± 0.88	1.00	1.93	50.15 ± 0.68
	2.92	24.26 ± 0.50		2.49	48.26 ± 1.33
	4.01	17.28 ± 0.52		4.03	40.04 ± 1.22
	6.42	9.09 ± 0.16		5.35	26.52 ± 1.05
	8.19	19.91 ± 0.75		6.16	29.38 ± 0.74
	9.95	26.56 ± 0.81		8.00	33.72 ± 2.10
	11.00	27.89 ± 1.64		9.97	37.77 ± 1.50
	12.10	29.47 ± 0.74		11.99	42.70 ± 1.96

Table 3 - Parameters a and b for the viscosity of aqueous eucalypt fibre suspensions linear regression expressed by equation (2). r is the correlation coefficient

C	Acid suspensions			Basic suspensions		
(per cent)	a	b	r	a	b	r
0.05	8.045	-1.135	-0.997	-4.051	0.797	0.983
0.20	11.384	-1.674	-0.994	-3.997	0.947	0.994
0.40	15.405	-2.360	-0.972	-4.305	1.283	0.994
0.60	34.599	-4.653	-0.999	-3.805	1.678	0.951
0.80	47.405	-6.202	-0.991	3.076	2.075	0.978
1.00	58.132	-6.468	-0.986	3.764	3.699	0.972

Table 4 - Parameters a and b for the viscosity of aqueous pine fibre suspensions linear regression expressed by equation (2). r is the correlation coefficient

C (per cent)	Acid suspensions			Basic suspensions		
	a	b	r	a	b	r
0.05	8.082	-1.197	-0.939	-3.553	0.901	0.985
0.20	20.677	-2.979	-0.991	-1.849	1.421	0.933
0.40	37.102	-4.492	-0.989	0.848	2.435	0.964
0.60	50.683	-6.191	-0.957	-1.344	3.149	0.998
0.80	57.626	-6.797	-0.989	3.605	3.046	0.984
1.00	64.767	-6.819	-0.981	12.603	2.656	0.995

Table 5 - Parameters a_i and b_i in equations (3), and their respective correlation coefficients, r_a and r_b.

Nature of fibres	Acidity of suspensions	parameters					
		a_0	a_1	r_a	b_0	b_1	r_b
eucalypt	acid	0.54	56.30	0.980	-0.53	-6.32	-0.977
	basic	-6.20	9.13	0.854	0.36	2.73	0.926
pine	acid	9.27	60.11	0.983	-1.67	-6.06	-0.952
	basic	-5.48	14.16	0.870	1.20	2.10	0.832

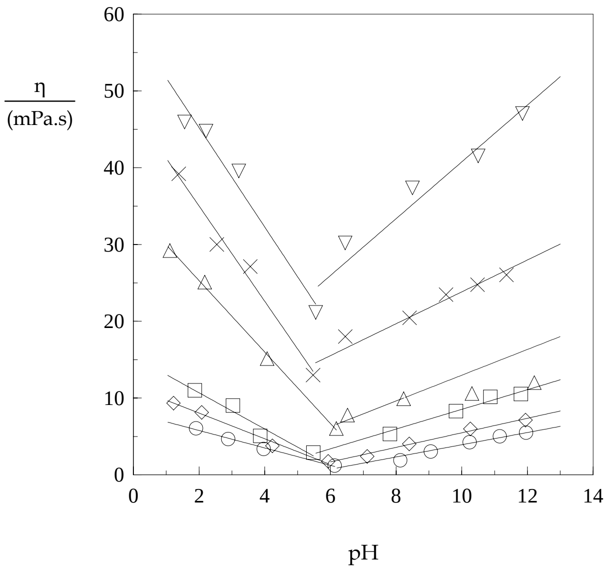

Figure 1 - Viscosity of aqueous eucalypt fibre suspensions as a function of pH and consistency. The symbols are for the experimental measurements and the lines are obtained from equation (2). Legend: ○, C=0.05 %; ◊, C = 0.20 %; □, C = 0.40 %; Δ, C = 0.60 %; ×, C = 0.80 %; ∇, C = 1.00%.

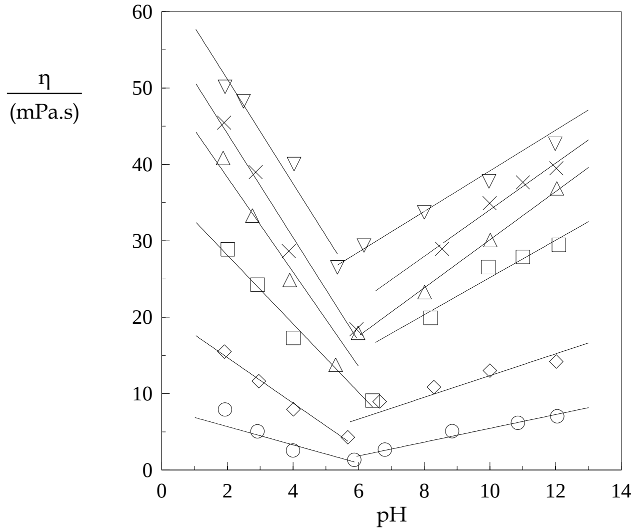

Figure 2 - Viscosity of aqueous pine fibre suspensions as a function of pH and consistency. The symbols are for the experimental measurements and the lines are obtained from equation (2). Legend: ○, C=0.05 %; ◊, C = 0.20 %; □, C = 0.40 %; Δ, C = 0.60 %; ×, C = 0.80 %; ∇, C = 1.00%.

By using the expressions so obtained the straight lines cross at pH = 5.7 ± 0.4 for aqueous eucalypt fibre suspensions, and at pH = 5.4 ± 0.2 for those from pine fibres. It can be concluded from this that aqueous fibre suspensions of both species, eucalypt and pine, show a minimum viscosity between pH values of 5.3 and 5.6. We believe these results can be of use in industrial practice.

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