Silva Lusitana ***11****(1): 61 - 66, 2003*

The Viscosity of Aqueous Suspensions of Cellulose Fibres Part 2. Influence of Temperature and Mix Fibres

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Abstract. Measurements were made of the viscosity of aqueous fibre suspensions of bleached kraft pulps from eucalyptus and pine trees over the temperature range 15 to 75ºC and consistencies from 0.20 to 1.00 mass per cent. In addition, the viscosity of mixed aqueous suspensions of eucalyptus and pine cellulose fibres was measured at 25ºC, varying the mass fraction of short fibres (from eucalyptus) and long fibres (from pine) from 0.25 to 0.75 for consistencies ranging from 0.05 to 0.70 per cent. The viscosities of the mixed suspensions can be shown to be the mass average of the viscosities of the aqueous suspensions of the two species. Correlations describing the dependency of viscosity on temperature and on consistency were established for both species.
Key words: viscosity; suspensions; eucalypt; pine; consistency; fibre length; temperature

Sumário. Foram efectuadas medições da viscosidade de suspensões aquosas de fibras de pasta branqueada de eucalipto e de pinho no intervalo de temperaturas entre 15 e 75ºC e de consistência de 0,20 a 1,00%. Mediu-se também a viscosidade de suspensões aquosas de fibras mistas de eucalipto e pinho, a 25ºC, fazendo-se variar a fracção mássica de fibras curtas (eucalipto) e de fibras longas (pinho) em suspensão entre 0,25 e 0,75, para consistências abrangendo a gama de 0,05 a 0,70 por cento. Concluiu-se que a viscosidade das suspensões de fibras mistas pode ser expressa, com boa aproximação, pela média pesada das viscosidades das suspensões de cada uma das espécies usando como factor de ponderação a fracção mássica. Estabeleceram-se correlações para a variação da viscosidade das suspensões aquosas de ambas as espécies com a temperatura e com a consistência.
Palavras-chave: viscosidade; suspensões; eucalipto; pinho; consistência; comprimento das fibras; temperatura

Résumé. La viscosité des suspensions aqueuses de mélanges de fibres de célulose obtenues de pâtes d'eucalyptus et de pin a eté mesurée en fonction de la température dès 15 jusqu'à 75ºC. On a aussi mesuré la fraction massique de chaque variété dans les mélanges qui change entre 0.25 et 0.75 pour les suspensions de consistences de 0.05 à 0.70 pour cent et la viscosité de chacun de ces mélanges a eté mesurée à 25ºC. La viscosité des suspensions de fibres mélangées a eté obtenue comme la moyenne massique de la viscosité des suspensions aqueuses des deux

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espèces. Des corrélations ont eté etablies pour decrire la variation de la viscosité des suspensions de chaque espèce avec la temperature et la consistance.
Mots clés: viscosité; suspensions; eucalyptus; pin; consistance; longueur des fibres; temperature

Introduction

We have recently reported on the influence of fibre length and consistency on the viscosity of aqueous suspensions of cellulose fibres from eucalypt and pine bleached kraft pulps (SILVEIRA *et al.*, 2002). Although some correlations between these properties were established for each of the two species we have not been able to find one model expressing the suspensions viscosity as a universal function of fibre length, independent of the nature of the cellulose material. In this respect our previous investigation leaves much space for further research, namely for the possible consideration of the role of fibre shape and the relative amount of fines on such correlations. However, since temperature has been long recognized as a major variable directly influencing the viscosity of aqueous solutions and suspensions, we have decided to investigate this aspect of the problem. On the other hand since most of the Portuguese industrial papermaking industries use eucalypt and pine mix charges as raw material we took the oportunity to measure and try to correlate the viscosity of the resulting pulp suspensions to the weight fraction of the two species. In the following sections we report on the results obtained.

Experimental

The equipment and the experimental details for the fibre characterisation and the viscosity measurements have been described in a previous paper (SILVEIRA *et al.*, 2002). Eucalypt and pine kraft bleached pulps (from Celulose do Caima and Georgia-Pacific mills, respectively) were used as raw materials for the preparation of the suspensions. According to standard NF Q03-003 the humidity of the samples was determined as (9.55±0.05) per cent. This humidity has been taken into account in the preparation of the aqueous suspensions. The necessary desintegration of the pulp samples was carried out in a Buchell device (model BK 111C) following NF Q50-002 standard. The Galai analyser (model CIS-100) yield average fibre lengths l_W (as defined in our previous paper) of 0.931 and 3.124 mm for the eucalypt and pine samples, respectively. From each of these samples aqueous suspensions have been prepared covering the consistency range from 0.05 to 0.70 mass per cent (*i e*, one hundred times the mass of dried fibres divided by the total mass of the fibres plus the mass of water in the suspension). The rheological behaviour of the suspensions was tested as described previously (SILVEIRA *et al.*, 2002), and their viscosity has been measured as a function of temperature with a Brookfield digital viscometer (model DV-II) at the spindle rotation of 1 Hz. The viscometer was calibrated using Brookfield standards of reported viscosities 4.3, 9.2, and 49.0 mPa.s. Measurements were made on the adequate standard at regular intervals between experiments to test the results obtained for the suspensions. Each sample of the suspensions was submitted to ultra-sound treatment before its respective viscosity was measured in order to avoid fibre floculation.

The viscosity of eucalypt and pine fibre suspensions prepared in this manner was measured as a function of temperature from 15 to 75ºC at five degrees Celsius increments.

Further, to investigate the influence of the relative amount of the two species on the viscosity of aqueous suspensions made from mix charges of eucalypt and pine fibres adequate portions of both fibre samples were taken. For each value of consistency C aqueous suspensions were prepared in which the relative amount of eucalypt fibres represented 0.25, 0.50, and 0.75 of the total mass fraction amount of cellulose fibrous material in the suspension. The viscosity of these suspensions has been measured at 25ºC.

Results and discussion

The results of the viscosity measurements made on eucalypt and pine fibre suspensions of consistency C ranging from 0.20 to 1.00 mass per cent at temperatures between 15 and 75ºC are shown in Tables 1 and 2, respectively. The quantity σ_η is the standard deviation of the measurements made on each sample during five minutes at half minute intervals.

As expected the viscosity of the suspensions for each consistency increases with the reciprocal of temperature. To represent this dependence an analytical expression of the form

$$\ln \eta = \left(\sum_{i=0}^{3} a_{0i} C^i \right) + \left(\sum_{i=0}^{1} a_{1i} C^i \right) T^{-1} , \qquad (1)$$

where η/(mPa.s) and T/ K have been used. The values of the a_{0i} and a_{1i} parameters obtained by fitting to the experimental data are shown in Table 3. The correlation coefficient is r =0.999 in both cases.

Both the experimental results and their representation using equation (1) are plotted in Figures 1 and 2 as ln η as a function of T^{-1} for consistencies ranging from C= 0.20 to 1.00 per cent. The agreement is much satisfactory especially for the higher consistencies.

Table 1 – Influence of temperature t (in degrees Celsius) on the viscosity η (in mPa.s) of aqueous suspensions of eucalypt samples of consistency C (in mass per cent) ranging from 0.20 to 1.00. σ_η is the standard deviation of the viscosity measurements

t	$(\eta \pm \sigma_\eta)$ / (mPa.s)								
(ºC)	C=0.20%	C=0.30	C=0.40	C=0.50	C=0.60	C=0.70	C=0.80	C=0.90	C=1.00
15	2.14±0.05	2.71±0.03	3.15±0.12	4.10±0.10	6.69±0.26	10.08±0.33	14.83±0.26	21.04±0.33	27.73±0.24
20	1.88±0.07	2.57±0.07	3.07±0.06	4.01±0.19	6.58±0.25	9.94±0.23	14.54±0.30	20.84±0.18	27.55±0.23
25	1.70±0.10	2.46±0.09	2.89±0.06	3.83±0.17	6.32±0.20	9.72±0.15	14.43±0.37	20.73±0.38	27.33±0.32
30	1.66±0.05	2.35±0.9	2.75±0.09	3.62±0.16	6.23±0.13	9.58±0.12	14.22±0.34	20.59±0.36	27.11±0.25
35	1.59±0.06	2.29±0.04	2.54±0.08	3.42±0.19	6.10±0.14	9.27±0.33	14.03±0.29	20.37±0.31	27.03±0.54
40	1.53±0.04	2.11±0.08	2.47±0.12	3.28±0.12	6.03±0.17	9.20±0.23	13.89±0.24	20.28±0.56	26.84±0.35
45	1.42±0.03	1.93±0.02	2.33±0.07	3.15±0.06	5.81±0.18	9.00±0.34	13.73±0.30	20.25±0.61	26.67±0.49
50	1.39±0.09	1.87±0.02	2.25±0.08	3.04±0.15	5.69±0.28	8.81±0.23	13.57±0.33	20.11±0.19	26.55±0.25
55	1.32±0.03	1.73±0.08	2.21±0.05	2.79±0.09	5.67±0.29	8.67±0.24	13.50±0.30	19.92±0.49	26.45±0.29
60	1.26±0.03	1.65±0.02	2.20±0.06	2.76±0.97	5.60±0.25	8.63±0.26	13.43±0.38	19.84±0.19	26.38±0.41
65	1.21±0.04	1.60±0.09	2.16±0.07	2.50±0.18	5.54±0.14	8.56±0.35	13.32±0.31	19.61±0.28	26.34±0.30
70	1.16±0.03	1.57±0.04	2.13±0.10	2.40±0.23	5.48±0.30	8.32±0.40	13.25±0.23	19.52±0.32	26.29±0.29
75	1.12±0.06	1.49±0.08	2.06±0.17	2.30±0.05	5.29±0.27	8.24±0.37	13.24±0.41	19.48±0.72	26.18±0.24

Table 2 – Influence of temperature t (in degrees Celsius) on the viscosity η (in mPa.s) of aqueous suspensions of pine samples of consistency C (in mass per cent) ranging from 0.20 to 1.00. σ_η is the standard deviation of the viscosity measurements

t	$(\eta \pm \sigma_\eta)$ / (mPa.s)								
(°C)	C=0.20%	C=0.30	C=0.40	C=0.50	C=0.60	C=0.70	C=0.80	C=0.90	C=1.00
15	4.68±0.26	7.17±0.19	9.77±0.09	12.60±0.36	15.59±0.55	17.56±0.77	19.97±0.65	23.97±0.47	29.62±1.60
20	4.58±0.27	7.05±0.22	9.72±0.16	12.53±0.29	15.33±0.37	17.41±0.39	19.82±1.02	23.77±0.64	29.33±0.60
25	4.38±0.44	6.90±0.25	9.68±0.24	12.44±0.36	15.16±0.35	17.22±0.35	19.76±1.09	23.52±0.63	29.17±0.95
30	4.33±0.30	6.78±0.22	9.65±0.32	12.37±0.47	15.05±0.67	17.02±0.70	19.64±0.89	23.59±0.68	29.01±1.86
35	4.29±0.33	6.72±0.21	9.49±0.40	12.26±0.35	14.83±0.46	16.93±0.39	19.59±1.00	23.10±0.44	28.87±0.54
40	4.27±0.33	6.63±1.18	9.33±0.38	12.21±0.39	14.79±0.44	16.87±0.76	19.42±0.37	22.87±0.62	28.60±0.73
45	4.15±0.26	6.49±0.30	9.29±0.42	12.18±0.43	14.53±0.51	16.78±0.58	19.30±0.47	22.73±0.58	28.54±0.36
50	4.10±0.25	6.41±0.31	9.23±0.31	12.09±0.55	14.45±0.62	16.55±0.64	19.23±0.50	22.58±0.69	28.37±0.82
55	4.05±0.22	6.31±0.46	9.16±0.38	12.04±0.35	14.40±0.77	16.51±0.36	19.15±0.66	22.37±1.15	28.23±0.61
60	4.03±0.25	6.26±0.13	9.11±0.26	11.98±0.34	14.33±0.56	16.20±0.34	18.95±0.58	22.05±1.01	28.08±0.50
65	3.99±0.19	6.12±0.46	9.08±0.29	11.75±0.44	14.14±0.37	16.09±0.41	18.88±0.82	21.98±0.81	27.93±0.70
70	3.90±0.21	6.10±0.23	8.92±0.32	11.68±0.42	14.06±0.36	15.92±0.36	18.76±0.63	21.85±0.78	27.77±0.50
75	3.88±0.36	6.09±0.87	8.88±0.29	11.65±0.36	14.02±0.35	15.77±0.37	18.50±0.48	21.71±1.05	27.43±0.64

Table 3 – Values of the parameters in equation (1) for aqueous suspensions of eucalypt and pine fibre suspension samples

Nature of the sample	Parameters					
	a_{00}	a_{01}	a_{02}	a_{03}	a_{10}	a_{11}
eucalypt	-3.614	0.872	12.44	-6.425	1354.03	-1347.63
pine	-0.922	9.611	-10.549	4.867	293.34	-185.66

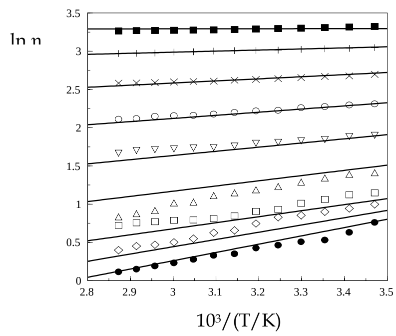

Figure 1 - Plot of the viscosity (expressed as ln η) of eucalypt aqueous suspensions of consistency C as a function of temperature. The straight lines are obtained from eq.(1) and the symbols correspond to experimental data.

Legend: •, C = 0.20 %; ◊, C= 0.30 %; □, C = 0.40 %; Δ, C=0.50 %; ∇, C=0.60 %; ○,C=0.70 %; ×, C= 0.80 %; +, C= 0.90 %; ■, C =1.00 %.

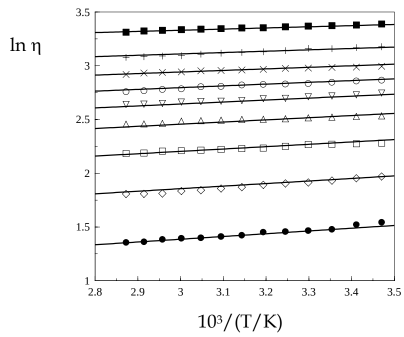

Figure 2 – Plot of the viscosity (expressed as ln η) of pine aqueous suspensions of consistency C as a function of temperature. The straight lines are obtained from eq.(1) and the symbols correspond to experimental data.

Legend: •, C = 0.20 %; ◊, C= 0.30 %; □, C = 0.40 %; Δ, C=0.50 %; ∇, C=0.60 %; ○,C=0.70 %; ×, C= 0.80 %; +, C= 0.90 %; ■, C =1.00 %.

The results of the viscosity measurements made on mix eucalypt and pine fibre aqueous suspensions at 25ºC are shown in Table 4, in which w is the mass fraction of eucalypt fibres in the suspension of consistency C (expressed in mass per cent).

Table 4 - Viscosity η (in mPa.s) at 25ºC of mix aqueous suspensions of eucalypt and pine fibres as a function of consistency C (in mass per cent), for suspensions of relative mass amount of eucalypt w = 0.25, 0.50, and 0.75. σ_η is the standard deviation of the viscosity measurements

C (per cent)	$(\eta \pm \sigma_\eta)$ / (mPa.s)		
	w = 0.25	w = 0.50	w = 0.75
0.05	1.43 ± 0.12	1.46 ± 0.06	1.22 ± 0.06
0.10	2.18 ± 0.14	2.16 ± 0.20	1.68 ± 0.23
0.20	3.71 ± 0.30	3.22 ± 0.47	2.47 ± 0.17
0.30	5.42 ± 0.44	4.77 ± 0.64	3.47 ± 0.27
0.40	7.26 ± 0.51	6.42 ± 0.54	4.60 ± 0.29
0.50	9.56 ± 0.58	8.20 ± 0.82	5.86 ± 0.58
0.60	13.26 ± 0.69	10.92 ± 0.83	8.52 ± 0.69
0.70	16.06 ± 0.61	14.01 ± 1.05	11.35 ± 0.61

To test the results a mass averaged viscosity of the mix suspensions has been assumed:

$$\eta = w\,\eta_e + (1 - w)\,\eta_p\,, \qquad (2)$$

where η is the viscosity of the mix suspensions, and η_e and η_p are, respectively, the corresponding viscosities of eucalypt and pine fibre suspensions of the same consistency; w is the mass fraction of eucalypt fibres. In Figure 3 the experimental results are compared with the values obtained from equation (2) using for η_e and η_p our own experimental values and those obtained from the correlation established in our previous work (SILVEIRA *et al.*, 2002). While the viscosity calculated from equation (2) is in agreement with experimental data, for higher consistencies significant deviations are observed between the data and the values calculated using the above mentioned correlation. This deviation is probably due to the presence of fines in the samples used for the actual measurements made here while the correlation (SILVEIRA *et al.*, 2002) was established for aqueous suspensions of fibrous material previously separated in classes of uniform length (in which fines were absent).

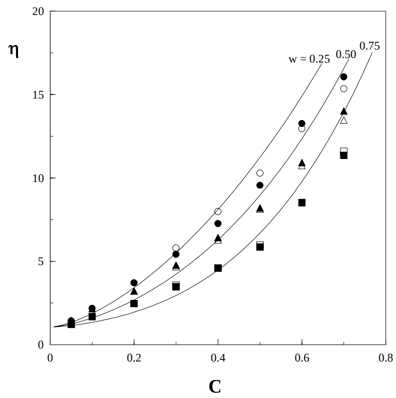

Figure 3 - Viscosity η/(mPa.s) at 25ºC of aqueous suspensions of mix cellulose fibres from eucalypt and pine plotted against consistency C (in percentage). Legend: circles are for w = 0.25; triangles for w=0.50; and squares for w = 0.75. The full symbols are experimental results obtained in this work (Table 4); the open symbols represent the values obtained using equation (2). Lines obtained from equation (2) with η_e and η_p given by the correlation established by (SILVEIRA *et al.*, 2002).

Conclusions

As expected the viscosity η of aqueous fibre suspensions depends on the temperature T and on the consistency C of the suspensions. While ln η varies linearly with T^{-1}, its variation with C can be expressed by simple polynomials.

From Figure 3 one can conclude that the viscosity of suspensions of wood mix fibres from eucalypt and pine can be obtained from the mass averaged viscosity of the corresponding suspensions of the two species with the same consistency. Moreover, the correlation established in a previous work between the viscosity η on one side, and the consistency C, and the fibre length l_w on the other hand, can be used to obtain aproximate values of η from the knowledge of C and l_w. The estimates are better for the suspensions richer in eucalypt fibres.

References

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Entregue para publicação em Julho de 2002
Aceite para publicação em Setembro de 2002