Silva Lusitana ***10***(2): 171 - 178, 2002

The Viscosity of Aqueous Suspensions of Cellulose Fibers Part 1. Influence of Consistency and Fiber Length

Maria Teresa Silveira*, Abel G.M. Ferreira and Lélio Q. Lobo*****
* Adjunct Professor
Escola Superior de Tecnologia. Instituto Politécnico de Tomar, Quinta dos Contadores, Estrada da Serra 2300-313-TOMAR
** Assistant Professor
*** Professor
Department of Chemical Engineering. University of Coimbra, 3030-290 COIMBRA

Sumário. Mediu-se a viscosidade de suspensões aquosas de fibras de celulose provenientes de pastas kraft branqueadas, de eucalipto e de pinho. Investigou-se a dependência da viscosidade das suspensões em relação à consistência e ao tamanho das fibras tendo sido estabelecidas correlações empíricas entre a viscosidade e as referidas propriedades.
Palavras-chave: viscosidade; suspensões; eucalipto; pinho; consistência; comprimento das fibras

Abstract. The viscosity of aqueous suspensions of cellulose fibres from eucalyptus and pine bleached kraft pulps has been measured as a function of consistency and fibre length. 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

Résumé. La viscosité des suspensions aqueuses des fibres de cellulose provenant de pâtes d'eucalyptus et de pin a été mesurée en fonction de leur consistance et de la longueur des fibres. Des corrélations empiriques entre la viscosité et ces proprietés ont été établies.
Mots clés: viscosité; suspensions; eucalyptus; pin; consistence; longueur des fibers

Introduction

At several stages in the pulp and papermaking processes one has to deal with aqueous suspensions of cellulose fibres. Although the viscosity of these suspensions is an important variable both for equipment design and in controlling its operation there is an almost complete lack of measured values for that property in the literature (NICODEMO and NICOLAIS, 1974). As far as we are aware, apart from recent work of general nature (BENNINGTON *et al.*, 1991; HIETANIEMI *et al.*, 1996), the first specific investigation on the viscosity of eucalypt and pine fibre suspensions has been carried out in our laboratory (SILVEIRA, 1994) which is yet to be published. The main reason for the scarcity of such data may come from the non-newtonian behaviour of the

Corresponding Author E-mail: conselhocientifico@fct.uc.pt

suspensions in the range of consistencies encountered in industrial practice, which makes it difficult to assign uniform numerical values to their viscosity. By selecting a particular viscometer and adequate conditions to perform the experiments one can arrive, at least in principle, at numerical values of an apparent viscosity of aqueous fibre suspensions comparable to those obtained using similar experimental conditions and methods. Such results can be of use in industrial practice.

In this work we present the results of an experimental research work carried out in our laboratory with the aim at examining the influence on the viscosity of aqueous cellulose fibre suspensions of a few primary properties: consistency of the suspensions and fibre (nature and) length. Some correlations have been established. The influence of temperature and pH, which was also investigated, is to be reported elsewhere (FERREIRA *et al.*, 2002; SILVEIRA *et al.*, 2002).

Experimental

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. The humidity of the original pulp samples was previously determined according to standard procedures (NF Q03-003). A value of (9.55±0.05) per cent humidity was obtained in both cases. The subsequent, necessary, desintegration of the pulp samples has been carried out in a Buchell device (model BK 111C) following adequate standards (NF Q50-002). Aqueous suspensions prepared from the above mentioned raw materials were fed to a Bauer-McNett classifier in order to separate the cellulose fibres into classes of approximate uniform size. From this operation, accomplished in accordance to SCAN M6:09 standard, eight size groups of fibres (four for eucalypt, and four for pine) were obtained with mass distributions as shown in Table 1.

Table 1 – Yield of the separations of the raw materials (eucalypt and pine pulps) into size classes using the Bauer-McNett classifier

Mesh number	Per cent of sample mass retained	
	Eucalypt pulp	Pine pulp
100	51.35	4.58
48	46.77	8.75
28	1.21	11.90
14	0.67	74.77
Total	100.00	100.00

The separation was repeated a number of times until a mass of fibres in each size class sufficient for the subsequent experiments had been collected. The next step was to determine the average length of the seven main size-groups obtained from them. (The 14-mesh sample derived from eucalypt pulp was neglected in the subsequent experiments in consequence of the relatively small mass collected from the Bauer-Mcnett classifier, insuficient for the preparation of the samples necessary in the suspension viscosity measure-ments). In order to carry out the fibre length characterization as precisely as possible all samples were submitted to measurement in a Galai analyser (model Cis-100, equipped with the FIBLEN infor-matics device). The results expressed as mass average length, l_w, defined as (BENTLEY *et al.*, 1994; CARVALHO *et al.*, 1997; ROBERTSON *et al.*, 1999)

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

where n_i is the average number of fibres of average length l_i, are shown in Table 2. This table also includes the values of l_w of the eucalypt samples measured using an Olympus microscope (model BH2, provided with a CCD camera and the Cue-2 programme).

Table 2 – Mass average length l_w (in mm) of the eucalypt and pine fibre samples

Mesh number	Fibre mass average length, l_w / mm		Analyser
	Eucalypt	Pine	
100	0.820	1.355	Galai
	0.817		Olympus
48	0.988	1.749	Galai
	0.996		Olympus
28	1.119	2.502	Galai
	1.275		Olympus
14	—	3.319	Galai

The average length l_w of the fibre distributions measured by using both techniques are in close agreement with each other. For consistency, the l_w values obtained with the Galai analyser are used throughout this work.

After the average length of each of the sample distributions had been determined, aqueous suspensions were prepared from them in order to measure their viscosities. Firstly the rheological behaviour of suspensions of samples of consistencies C ranging from 0.15 to 0.85 per cent was examined. This was accomplished by registering the measurements made with a Brookfield digital viscometer (model DV-II), covering the range of rotation speeds of the spindle from 0.05 to 1 Hz. The temperature in the sample holder was maintained at (25.0±0.1) degrees Celsius with the aid of a Haake thermostatic circulator (model D8-G). The results of these measurements are shown in Table 3 and Figure 1.

The conclusion to be extracted from these data is that above C=0.15 per cent the rheological behaviour of the suspensions is non-newtonian, pseudo-plastic. However, the viscosity of more concentrated suspensions of both eucalypt and pine becomes independent of the spindle rotation somewhat below about 60 s^{-1}. For this reason it was decided to carry out all the subsequent measurements at 1 Hz. The results reported here ought to be regarded, then, as apparent viscosities. The viscometer was calibrated using Brookfield standards of viscosities 4.3, 9.2, and 49.0 mPa.s. At regular intervals between experiments measurements were made on the adequate standard to test the results obtained for the fibre suspensions. In order to avoid fibre flocculation in the suspensions the samples were submitted to ultra-sound treatment before their respective viscosity was measured.

Results and discussion

From the seven size classes of fibres previously separated (three from eucalypt and four from pine) aqueous suspensions were prepared covering consistency ranges of up to 1.20 mass per cent, at 0.05 per cent increments. The viscosity of each of these suspensions was measured at 25ºC during five minutes at half minute intervals. The results are shown in Tables 4 and 5, which also include the standard deviation σ_η of the viscosity readings.

Table 3 – Dependence of the viscosity η of eucalypt and pine fibre aqueous suspensions on the rotation speed ω of the viscometer spindle. η is in mPa.s, and σ_η is the standard deviation of η. C is the consistency expressed as mass percentage of fibres in the suspensions. The average length l_w of the fibres in these samples is 0.931 mm and 3.124 mm for eucalypt and pine, respectively

Rotation velocity, ω		**($\eta \pm \sigma_\eta$) / (mPa.s)**			
Hz	s^{-1}	C=0.15 %	C=0.30 %	C=0.55 %	C=0.85 %
(a) eucalypt					
0.05	3.67	1.63±0.14	19.88±0.31	46.70±0.56	80.99±1.94
0.10	7.34	1.63±0.13	12.47±0.54	29.61±0.34	55.32±1.22
0.20	14.68	1.63±0.13	8.67±0.27	16.32±0.53	36.39±1.15
0.50	36.71	1.63±0.14	2.64±0.03	4.99±0.11	20.88±0.96
1.00	73.42	1.63±0.14	2.48±0.06	4.75±0.94	18.56±1.55
(b) pine					
		C=0.15 %	C=0.35 %	C=0.60 %	C=0.85 %
0.05	3.67	2.59±0.19	34.70±1.22	66.15±1.37	93.11±1.94
0.10	7.34	2.59±0.18	20.72±0.11	54.35±1.12	74.35±1.12
0.20	14.68	2.59±0.17	12.45±0.16	30.39±0.82	49.61±1.15
0.50	36.71	2.59±0.16	7.16±0.12	18.60±0.59	27.63±0.63
1.00	73.42	2.59±0.17	7.04±0.23	15.86±0.56	25.10±1.02

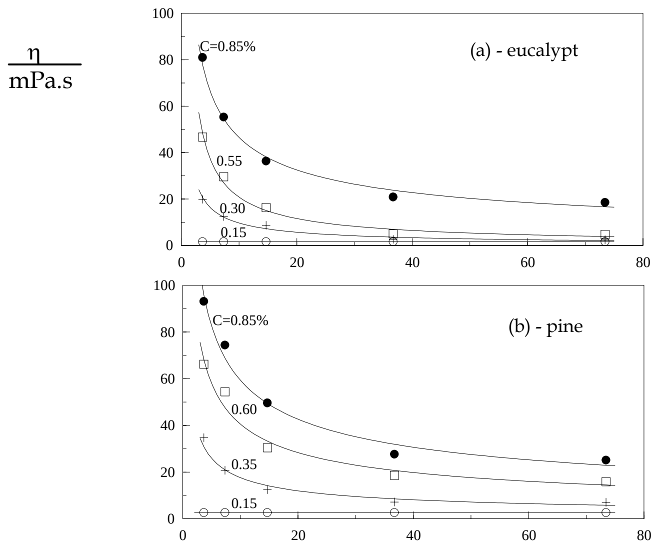

Figure 1 – Viscosity η of aqueous suspensions of consistency C as a function of the rotation velocity ω of the viscometer spindle. C is expressed in mass percentage. (a) eucalypt suspensions; (b) pine suspensions

Table 4 - Viscosity η/ (mPa.s) of aqueous suspensions of eucalypt fibres of consistency C (expressed as the percentage of fibre mass in the suspension). l_w/ mm is the mass average length of the fibre size class sample. Measurements made at 25ºC

C	$(\eta \pm \sigma_\eta)$ / (mPa.s)		
(per cent)	l_w = 0.820 mm	l_w = 0.988 mm	l_w = 1.119 mm
0.00	1.06 ± 0.04	1.06 ± 0.04	1.06 ± 0.04
0.05	1.09 ± 0.06	1.22 ± 0.02	1.51 ± 0.20
0.10	1.18 ± 0.13	1.82 ± 0.21	1.75 ± 0.23
0.15	1.24 ± 0.10	2.40 ± 0.28	2.80 ± 0.19
0.20	1.28 ± 0.11	2.76 ± 0.31	3.11 ± 0.64
0.25	1.42 ± 0.24	3.17 ± 0.28	4.20 ± 0.70
0.30	1.48 ± 0.09	3.63 ± 0.35	5.37 ± 0.49
0.35	1.54 ± 0.05	4.28 ± 0.26	7.13 ± 1.03
0.40	1.88 ± 0.15	4.50 ± 0.34	8.82 ± 0.66
0.45	2.00 ± 0.05	5.01 ± 0.65	10.89 ± 0.97
0.50	2.73 ± 0.24	5.80 ± 0.70	13.33 ± 1.13
0.55	3.66 ± 0.29	6.88 ± 0.41	15.53 ± 0.82
0.60	4.41 ± 0.17	8.18 ± 0.64	21.08 ± 3.42
0.65	5.38 ± 0.40	9.17 ± 0.82	26.03 ± 3.15
0.70	7.20 ± 1.40	10.52 ± 0.91	29.19 ± 3.48
0.75	8.37 ± 1.13	14.35 ± 2.03	32.72 ± 3.91
0.80	11.22 ± 1.01	19.86 ± 3.36	36.86 ± 3.42
0.85	14.56 ± 0.64	24.38 ± 3.24	40.61 ± 3.46
0.90	18.60 ± 2.26	28.03 ± 3.96	43.51 ± 3.74
0.95	21.88 ± 1.78	31.95 ± 2.74	46.97 ± 2.10
1.00	29.12 ± 2.65	37.55 ± 3.37	49.63 ± 1.15
1.05	37.33 ± 3.10		
1.10	42.47 ± 3.70		
1.15	47.55 ± 2.42		
1.20	49.51 ± 2.78		

The viscosity of the suspensions increases with both the consistency and the fibre length. The results were fitted to an expression of the form

$$\eta = \eta_0 + a\, l_w{}^b\, C^{(c+d\, l_w)}, \qquad (2)$$

where a, b, c, and d are parameters obtained by minimizing the viscosity square residuals. The values of these parameters are collected in Table 6. Parameter η_0 = 1.06 mPa.s is, of course, the viscosity of pure water at 25ºC.

Table 5 - Viscosity η/ (mPa.s) of aqueous suspensions of pine fibres of consistency C (expressed as the percentage of fibre mass in the suspension). l_w / (mm) is the mass average length of the fibre size class sample. Measurements made at 25ºC

C (per cent)	$(\eta \pm \sigma_\eta)$ / (mPa.s)			
	l_w = 1.355 mm	l_w = 1.749 mm	l_w=2.502 mm	l_w=3.319 mm
0.00	1.06 ± 0.02	1.06 ± 0.02	1.06 ± 0.02	1.06 ± 0.02
0.05	1.17 ± 0.02	1.30 ± 0.04	1.53 ± 0.11	1.72 ± 0.13
0.10	1.27 ± 0.04	1.39 ± 0.06	2.10 ± 0.14	2.76 ± 0.27
0.15	1.37 ± 0.05	1.81 ± 0.10	2.45 ± 0.23	3.54 ± 0.27
0.20	1.50 ± 0.06	2.19 ± 0.25	3.36 ± 0.36	4.31 ± 0.32
0.25	1.66 ± 0.07	2.62 ± 0.42	4.20 ± 0.29	6.61 ± 0.30
0.30	1.91 ± 0.09	3.30 ± 0.23	5.16 ± 0.28	8.36 ± 0.30
0.35	2.17 ± 0.13	3.88 ± 0.21	6.09 ± 0.37	10.46 ± 0.31
0.40	2.75 ± 0.09	4.59 ± 0.31	7.47 ± 0.54	11.31 ± 0.33
0.45	3.09 ± 0.11	5.52 ± 0.43	8.10 ± 0.30	13.09 ± 0.47
0.50	3.67 ± 0.27	6.29 ± 0.25	9.96 ± 0.51	15.01 ± 0.54
0.55	4.25 ± 0.18	8.10 ± 0.37	11.84 ± 0.51	16.46 ± 0.54
0.60	5.74 ± 0.35	9.73 ± 0.37	13.58 ± 0.60	18.67 ± 0.66
0.65	6.99 ± 0.33	11.88 ± 0.39	14.78 ± 0.44	20.82 ± 0.15
0.70	9.21 ± 0.30	13.46 ± 0.47	16.59 ± 0.39	22.34 ± 1.40
0.75	10.86 ± 0.60	15.73 ± 0.62	19.05 ± 0.77	24.93 ± 1.18
0.80	12.26 ± 0.27	17.81 ± 0.86	20.94 ± 0.90	28.66 ± 1.04
0.85	13.75 ± 0.38	19.62 ± 0.95	22.74 ± 0.88	30.35 ± 0.71
0.90	15.99 ± 0.46	21.14 ± 0.88	24.71 ± 0.94	33.18 ± 0.78
0.95	17.78 ± 0.41	22.56 ± 0.99	27.59 ± 0.92	37.17 ± 0.89
1.00	19.98 ± 0.58	25.05 ± 0.84	30.13 ± 0.96	40.06 ± 1.28
1.05	23.23 ± 1.19	26.76 ± 1.20		
1.10	25.08 ± 1.56	29.85 ± 1.31		
1.15	26.88 ± 1.20			
1.20	30.91 ± 0.95			

Table 6 – Values of the parameters in equation (2) for eucalypt and pine aqueous suspensions

η_{ij}	eucalypt	pine
a	39.4	15.50
b	2.2	0.73
c	10.4	2.86
d	-7.6	-0.43

The correlation coefficients of the fittings are r = 0.993 and r = 0.997 for the eucalypt and pine suspensions, respectively, with standard deviations σ_η= 1.81 and σ_η= 0.81 mPa.s.

Figures 2 and 3 show the results of the measurements for the various samples and also the curves calculated from equation (2). The agreement is much satisfactory. It should be kept in mind that although equation (2) applies both for eucalypt and pine sample suspensions the parameters in this equation are different for the two species. In other words: the parameters in equation (2) depend on the nature of the fibres involved. Possibly, the shape factor of the fibres should have been taken into account but we did not make any attempt on this issue.

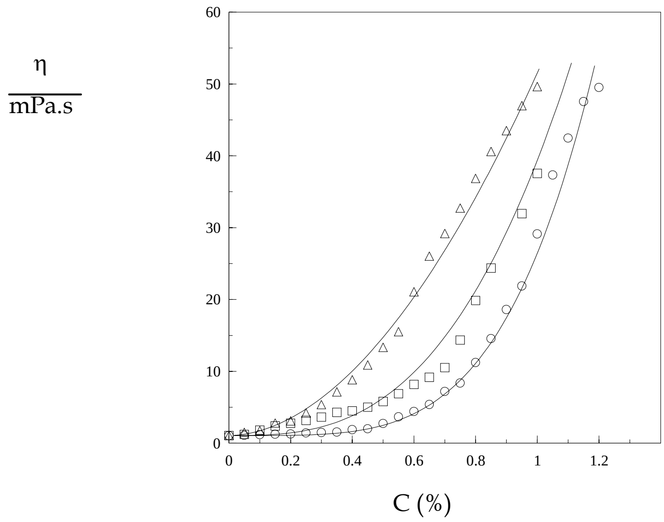

Figure 2 - Viscosity η / (mPa.s) of eucalypt fibre aqueous suspensions of average mass length l_w as a function of consistency C. The curves are obtained from eq. (2), and the symbols correspond to the experimental data. Legend: ○, l_w = 0.820; □, l_w = 0.988; △, l_w = 1.119 mm

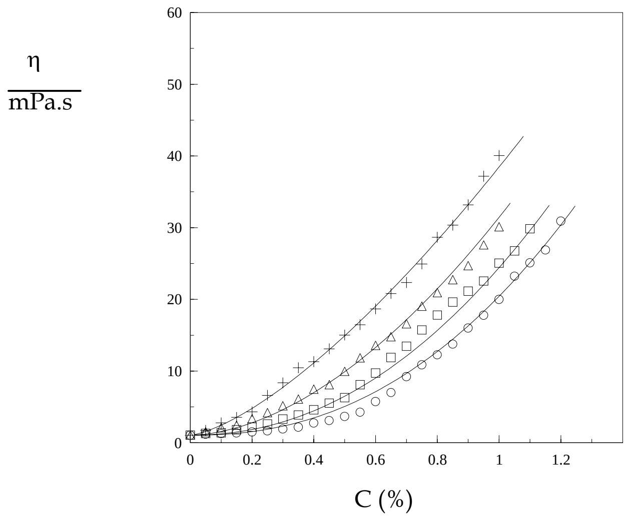

Figure 3 - Viscosity η / (mPa.s) of pine fibre aqueous suspensions of average mass length l_w as a function of the consistency C. The curves are obtained from eq. (2) and the symbols correspond to the experimental data. Legend: ○, l_w = 1.335; □, l_w = 1.749; Δ, l_w = 2.502; +, l_w

=3.319 mm

Conclusion

By chosing adequate experimental conditions and techniques it is possible to measure coherent values of the apparent viscosity of aqueous suspensions of cellulose fibres from eucalypt and pine. The measured viscosity for each species correlates well with both the fibre length and the consistency C of the suspensions (up to about C = 1.20 per cent). Altough the subject deserves further investigation, the results reported and the correlations established here can be of use in industrial practice.

References

BENNINGTON, C.P.J., KEREKES, R.J., GRACE, J.R., 1991. Motion of pulp fibre suspensions in rotary devices. *Can. J. Chem. Eng*. **69** : 252-258.

BENTLEY, R.G., SCUDMORE, P., JACK, J.S., 1994. A comparison between fibre length measurement methods. *Pulp & Paper Canada* **95**(4) : 41-43.

CARVALHO, M.G., FERREIRA, P.J., MARTINS, A.A., FIGUEIREDO, M.M., 1997. A comparative study of two automated techniques for measuring fiber length. *Tappi J*. **82**(2) : 137-142.

FERREIRA, A.G.M., SILVEIRA, M.T.L., LOBO, L.Q., 2002. The viscosity of aqueous suspensions of cellulose fibres. Part 2. Influence of temperature and mix fibres. *Silva Lusitana* (submitted)

HIETANIEMI, J., GULLICHSEN, J., 1996. Flow properties of medium-consistency fibre suspensions. *J. Pulp & Paper Sci*. **22**(12) : J469-J474

NICODEMO, L.; NICOLAIS, L., 1974. Viscosity of concentrated fiber suspensions. *Chem. Eng. Journal* **8** : 155-156.

ROBERTSON, G., OLSON, J., ALLEN, P., CHAN, B., SETH, R., 1999. Measurement of fiber length, coarsness, and shape with the fiber quality analyser. *Tappi J*. **82**(10) : 93-98

SILVEIRA, M.T.L., 1994. *Estudo da viscosidade de suspensões de fibras de celulose*. Tese de Mestrado. U. Coimbra

SILVEIRA, M.T.L., FERREIRA, A.G.M., LOBO, L.Q., 2002. The viscosity of aqueous suspensions of cellulose fibres. Part 3. Influence of pH. *Cellulose* (submitted)

Submetido para publicação em Março de 2002
Aceite para publicação em Abril de 2002