WOOD RESEARCH doi.org/10.37763/wr.1336-4561/70.4.605617
e-ISSN 2729-8906
70(4): 2025 605-617 pp.

THE INFLUENCE OF PULP BEATING AND PAPERMAKING AGENTS ON THE CHARGE DENSITY OF FIBERS AND COLLOIDAL PARTICLES IN PAPERMAKING WATERS

VLADIMÍR KUŇA, JOZEF BALBERČÁK
PULP AND PAPER RESEARCH INSTITUTE
SLOVAK REPUBLIC

(RECEIVED JULY 2025)

ABSTRACT

The first part of the paper is focused on monitoring the impact of the beating process on the charge density of fibres and colloidal particles in water in the production of tissue papers. Three types of pulps most commonly used were tested: long-fibre pine pulp, short-fibre eucalyptus pulp and short-fibre hardwood birch pulp. In the range of beating degrees from 14°SR to 35°SR, the impact of beating on the charge density of fibres expressed as Zeta potential, the charge density of colloidal particles expressed as PCD value and the conductivity of the paper suspension were evaluated. The paper also evaluates the impact of beating on the physical and mechanical properties of laboratory sheets. The second part of the paper is focused on monitoring the impact of papermaking aids, in the production of tissue papers, on the charge density of fibres and colloidal particles in water. The most significant impact was demonstrated by the agent for increasing the wet strength of paper. In these laboratory tests, pulp mixtures were used that were prepared by separately beating individual pulps to a beating degree of 25°SR.

KEYWORDS: pulp, beating, fibre, charge density, Zeta potential, PCD, conductivity, physical-mechanical properties, papermaking aids, colloidal particles in water, retention system.

INTRODUCTION

In Slovakia in 2022, the specific electricity consumption was 700 kWh/t, the specific heat consumption was 17 GJ/t and the specific water consumption was 43 m^3/t of paper. Growing competition in the production of tissue paper creates the pressure for economization and greening of production, thus also for reducing the costs of input raw materials, water and energy (de Assis et al. 2018, Balberčák et al. 2022, Balberčák and Kuňa 2024, Kuňa et al. 2018, 2021, Mašura et al. 2019, Pažitný et al. 2017). Based on the determination of the charge density of fibres and colloidal particles in technological waters, it is possible to optimize the application of papermaking aids, the process of fibre preparation and processing, the speed of dewatering the suspension on the paper machine screen, and the energy consumption during fibres beating and paper drying (Kuňa et al. 2016).

Zeta potential is an electrical charge which is created at the phase interface between solids and liquids (Kamble 2022). In papermaking industry, it represents the electrokinetic potential that is created at the interface between the surface layer of fibres or a particle and the surrounding aqueous environment. Moreover, it is a reliable tool for evaluating the effectiveness of the agents used (Ordaz-Díaz et al. 2017). The electrical charge created on the surface is the consequence of free electrons in the solution, which have the ability to rearrange into a region with a non-zero charge that exists near the fibre-liquid interface. Zeta potential indicates the potential stability of a colloidal system. If all the particles in a suspension have the large negative or positive Zeta potential, then they will tend to repel each other and the particles will not tend to connect. However, if the particles have the low values of Zeta potential, then there will be no force to prevent the particles from connecting and flocculating. The general dividing line between stable and unstable suspensions is generally taken to be either +30 or -30 mV. The particles with the Zeta potential more positive than +30 mV or more negative than -30 mV are normally considered stable (Nasser 2014).

The charge density of colloidal particles dissolved in water is expressed by the specific anion or cation consumption. It is determined on a PCD (Particle charge detector) device. The measurement of the particle charge is based on the principle of a combination of current potential and polyelectrolytic titration. Polydiallyldimethylammonium chloride (PDADMAC) is usually used as a cationic polyelectrolyte and potassium polyvinyl sulphate (KPVS) is used as an anionic polyelectrolyte. If the system is in electrostatic equilibrium, the charge of colloidal particles is balanced by the opposite charge of the surrounding environment. The separation of counterions by oscillatory motion causes the charge violation, and an electrokinetic phenomenon occurs, generating a current potential. The induced current potential depends on many factors such as specific conductivity, particle size and shape, viscosity, pH value and temperature. The magnitude of the charge density is measured indirectly by polyelectrolytic titration of the released ions with a standard with the opposite charge. The applied polyelectrolyte neutralizes the charge of the colloidal particles, forming a polymer complex. This point of neutral charge is called the isoelectric point and is also the end of the titration (Lužáková and Marcinčinová 1993, Sundberg et al. 1993, Gruber and Ott 1995, Valto et al. 2010, Holmbom and Sundberg 2003).

Electrical conductivity is a physical quantity describing the ability of electrolyte solutions to conduct electric current, which is also used in the pulp and paper industry. The greater the conductivity, the stronger the electric current passes through the solution, at the same voltage. In the case of electrolyte solutions, the presence of free moving particles (electrons, ions) that exchange electric charge is a necessary condition. Electrolyte solutions are substances containing ions, i.e. solutions of ionic salts or compounds that ionize in solution. The ions formed in the solution are responsible for conducting electric current. Electrolytes include acids, bases and salts and can be strongly or weakly conductive (Weitao et al. 2020).

The aim of this research is to monitor in the laboratory the effect of beating as well as papermaking agents on the charge density of fibres and colloidal particles in water, under conditions close to the production of tissue papers, by measuring the above-mentioned values of Zeta potential, PCD and conductivity.

METHODS AND MATERIAL USED

Pulp

For laboratory testing, pulps that are used the most often used in production of tissue paper were selected. Pulp samples were pulped on an Escher-Wyss laboratory pulper under the standard conditions for 5 min. Pulp beating was performed on a Valley Hollander laboratory device, at a consistency of 2% and a suspension volume of 22.5 dm^3. During beating, when the appropriate beating degree was reached in the range from 14°SR to 35°SR, samples of water suspension were taken to determine the values of the Zeta potential of the fibres, the charge density of colloidal substances in PCD waters and conductivity. In the second part of the research, when determining the influence of papermaking agents, individual pulps were beating uniformly at 25°SR, to achieve the most suitable parameters for the production of tissue paper. The pulps prepared in this way were mixed and homogenized for 10 min. Part of the evaluation of the quality of the fibres suspension was the determination of the arithmetic and weighted fibres length on the ADV3 device (Ihnát et al. 2021).

The determination of physical and mechanical properties

From the prepared fibres suspension, laboratory sheets with the basis weight of 70 g/m^2 were formed on a Rapid–Köthen sheeter according to DIN 54358-1 (1981) and ISO 5269-2 (2004). After 24 h of conditioning under standard conditions (23°C, 50% RH), the following were determined: tensile strength according to ISO 1924-2, 2008, stiffness according to ISO 5628 (2019), stiffness according to ISO 2758 (2014), water absorption according to ISO 5637 (1989) and porosity according to TAPPI Test method T460 and ISO whiteness according to STN ISO 2470-1, ISO 3688.

Papermaking agents

The following were used for laboratory tests: a dry strength agent, Acefloc DSR CS1 (starch-based biopolymer), a wet strength agent, Kymene 217 LXE (epichlorohydrin resin), and a two-component retention system, Acefloc 20902LB and Acefloc SA540, consisting of a long-chain, low-charge cationic polymer based on polyacrylamide and a high-charge, short-chain, cationic micropolymer based on polyamine.

Testing the influence of papermaking agents on the charge density of fibres and colloidal particles in water

On two pulp mixtures: Mixture 1: 50% long-fibre softwood pulp pine + 50% short-fibre hardwood pulp birch and Mixture 2: 50% long-fibre softwood pulp pine + 50% short-fibre eucalyptus pulp, three types of chemicals were tested: a dry strength agent: Acefloc DSR CS1, a starch-based biopolymer, dosage 1- 5 kg/t pulp, a wet strength agent: Kymene 217 LXE, epichlorohydrin resin, dosage 10 - 50 kg/t pulp and a two-component retention system: Acefloc 20902LB and Acefloc SA540, consisting of a cationic polymer based on polyacrylamide and a cationic micro polymer based on polyamine, dosage 100 - 300 g/t pulp. Zeta potential, PCD and conductivity values were determined on the water suspension.

The used methods

The charge density of the fibres was expressed by determining the Zeta potential and the charge density of the colloidal particles by determining the PCD. The Zeta potential was determined on a Fibres Potential Analyzer and the PCD value was determined on a Charge Analysing System CAS-II from AFG Analytic GmbH, the conductivity was determined on a Fibres Potential Analyzer.

RESULTS AND DISCUSSION

The determination of the properties of aqueous suspensions with the required beating degree and the determination of the physical and mechanical parameters of laboratory sheets with a basis weight of 70 g/m^2 are summarized in Tabs. 1 to 3.

Tab. 1: Analysis of the properties of long-fibre softwood pulp - pine.

Beating degree, °SR	14	20	25	30	35
Zeta potential, mV	-37,2	-15,4	-13,1	-12,6	-12,2
PCD, μeq/l	-14	-15	-16	-18	-21
Conductivity, mS/cm	0,532	0,579	0,604	0,607	0,611
Fibres length – arithmetic mean, mm	1,04	1,22	1,24	1,16	1,06
Fibres length – weighted mean, mm	2,26	2,72	2,82	2,7	2,58
Basic weight, g/m^2	70	70	70,6	70,2	70,6
Tensile strength, kN/m	2,3	5	6,1	6,6	7
Stiffness, mN	58	71	82	87	84
Porosity Gurley, s	0,7	9,6	21	35	49
Burst strength, kPa	55	300	363	392	400
Water absorption, %	380	270	230	215	205
Whiteness ISO, %	84,9	82,4	82	81,8	81,6

Tab. 2: Analysis of the properties of short-fibre eucalyptus pulp.

Beating degree, °SR	17	20	25	30	35
Zeta potential, mV	-42,2	-28,9	-23,5	-22,6	-21,1
PCD, μeq/l	-9	-11	-15	-19	-22
Conductivity, mS/cm	0,57	0,606	0,622	0,634	0,642
Fibres length – arithmetic mean, mm	0,89	0,96	0,94	0,9	0,88
Fibres length – weighted mean, mm	1,56	1,65	1,47	1,35	1,29
Basic weight, g/m2	70,6	70,2	70,4	70,9	70,7
Tensile strength, kN/m	2,5	4,1	5	5,6	5,9
Stiffness, mN	67	75	82	86	83
Porosity Gurley, s	1,4	2,4	5,4	11	20,4
Burst strength, kPa	67	150	229	283	304
Water absorption, %	429	325	270	252	245
Whiteness ISO, %	86,8	86,1	85,6	85,2	84,9

Tab. 3: Analysis of properties of short-fibre hardwood pulp - birch.

Beating degree, °SR	16	20	25	30	35
Zeta potential, mV	-33,8	-23,6	-18	-17,2	-17
PCD, µeq/l	-15	-16	-20	-23	-25
Conductivity, mS/cm	0,515	0,565	0,582	0,59	0,601
Fibres length – arithmetic mean, mm	0,88	0,94	0,97	0,93	0,9
Fibres length – weighted mean, mm	1,53	1,63	1,54	1,48	1,42
Basic weight, g/m2	70	70,1	70,2	70	70,2
Tensile strength, kN/m	2,4	4,7	5,5	6,1	6,5
Stiffness, mN	62	74	80	84	82
Porosity Gurley, s	1	3,7	13	24	45
Burst strength, kPa	63	209	297	356	365
Water absorption, %	356	248	214	207	203
Whiteness ISO, %	86,8	85,3	85,1	84,6	83,9

The effect of beating on the charge density of fibres and colloidal particles

The effect of the beating degree on the values of Zeta potential, PCD and conductivity are shown in Fig. 1. The measured values show that by increasing the beating degree, the value of Zeta potential increases, too what corresponds to the research of Bhardwaj et al. (2004). The largest increase is up to the beating degree of 25°SR, when the increase in values is significant. Increasing the beating degree from 25°SR to 35°SR caused only a minimal increase in Zeta potential. The lowest values were measured for short-fibre eucalyptus pulp and the highest values for long-fibre pine pulp. The charge density of fibres (PCD value) decreases directly proportionally with increasing the beating degree. The lowest values were measured for the short-fibre birch pulp. The PCD values of eucalyptus and pine pulps are in the same range from -10.0 µeq/l to -25.0 µeq/l. The measured conductivity values are closely correlated with the measured Zeta potential values and increase with increasing grinding degree.

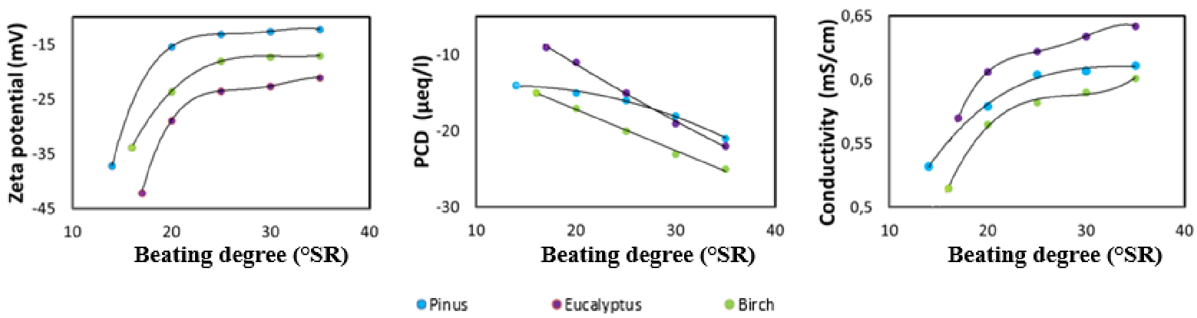

Fig. 1: The effect of beating on Zeta potential (a), PCD (b) and conductivity (c).

The effect of beating on the length of fibres

The effect of the beating process on the length of the fibres of the analysed pulp types is shown in Fig. 2. The measured results show that in the first phase of pulp beating on the Valley Hollander device, mainly fibres fibrillation occurs, which is reflected in an increase in the length of the fibres to a beating degree of 20 to 25°SR. Further beating already shortens the fibres, which is reflected in the decrease in the values of the arithmetic and weighted length (Fišerová and Gigac 2011). The longest fibres length of the monitored pulps was long-fibered softwood pulp - pine, and the shortest fibres length was eucalyptus pulp.

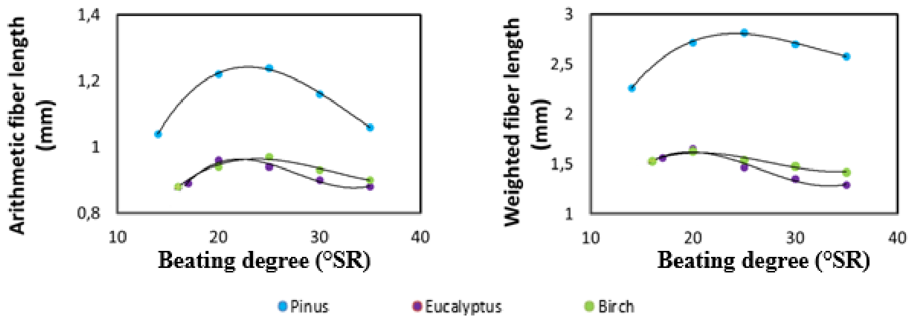

Fig. 2: Effect of beating on arithmetic fibres length (a) and weighted fibres length (b).

The influence of pulp beating on physical and mechanical properties

The influence of the beating degree on the values of the tensile load is shown in Fig. 3a. The measured values show that the tensile values of all three pulps increases in the entire beating range from 14°SR to 35°SR. The highest values were measured for long-fibre pine pulp. The lowest value of the tensile values was achieved by eucalyptus pulp. The influence of the beating degree on the stiffness values of selected pulp types is shown in Fig. 3b. The measured values show that the stiffness increases up to a beating degree of 30°SR and then has a decreasing tendency. The highest stiffness values were achieved by long-fibre pine pulp and the lowest values by short-fibre birch pulp. The dependence of the compressive strengths on the beating degree of the studied pulps is shown in Fig. 3c. The curve of the increase in compressive strength is steepest up to the beating degree of 30°SR. With a further increase in the beating degree, the increase in parameters is more moderate. The highest values of compressive strength were achieved by long-fibre pine pulp, and conversely, the lowest values were measured for eucalyptus pulp. Pokhrel (2010) also points out the better strength properties of pine pulp compared to birch or eucalyptus pulp, based on the evaluation of laboratory sheets.

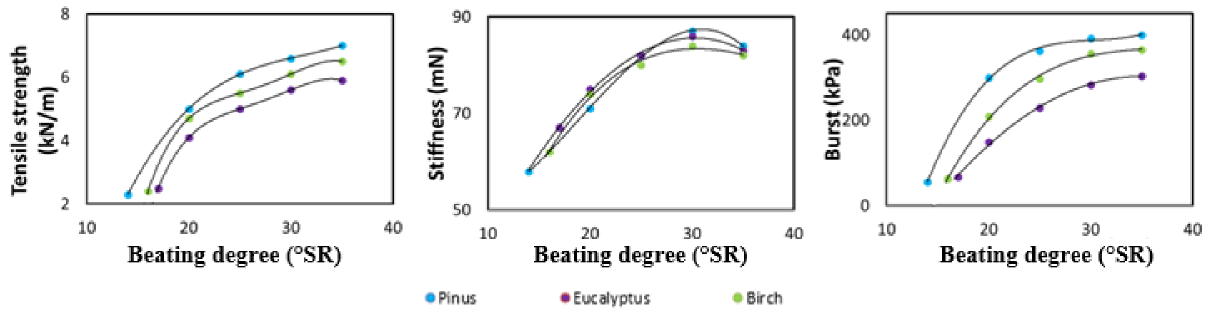

Fig. 3: The effect of beating on tensile strength (a), stiffness (b) and Burst strength (c).

The air permeability of laboratory sheets, Fig. 4a, was determined by measuring the Gurley porosity. As the beating degree increases, the air permeability decreases, i.e. the Gurley porosity increases. The highest air permeability is for short-fibre eucalyptus pulp and the lowest for long-fibre pine pulp. The ability of laboratory sheets to adsorb water is expressed by the water absorption value. As the beating degree increases, the ability of pulps to adsorb water decreases, Fig. 4b, with the decrease curve being steepest up to a beating degree of 25°SR, after which the decrease in values is more moderate. The relationship of the absorption capacity with respect to Gurley porosity shows a negative correlation (Ferreira et al. 2018). Of the pulps analyzed, eucalyptus pulp showed the highest water absorption and birch pulp the lowest. The effect of beating on the whiteness of laboratory sheets is shown in Fig. 4c.

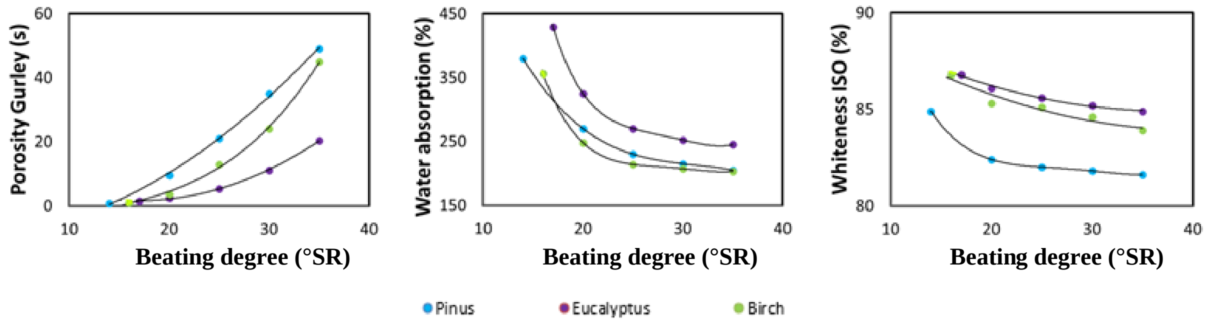

Fig. 4: The effect of beating on porosity (a), absorbency (b) and whiteness (c) values.

With increasing beating degree, whiteness decreases (Fišerová et al. 2019). Of the pulps monitored, short-fibre eucalyptus pulp and short-fibre birch pulp showed the highest whiteness. Long-fibre pine pulp had the lowest whiteness. Within the range of the monitored beating degree, long-fibre pine pulp had the highest decrease in whiteness by 3.3%, short-fibre birch pulp by 2.9%, and the smallest decrease was in short-fibre eucalyptus pulp by 1.9%.

The influence of papermaking agents on the charge density of fibres and colloidal particles in waters

The results of laboratory testing of the influence of papermaking agents on the charge density of fibres and colloidal particles in water are summarized in Tabs. 4 and 5.

Tab. 4: Mixture 1, 50% long-fibre Pine (25°SR) + 50% short-fibre Birch (25°SR).

Sample	Zeta potential (mV)	Conductivity (mS/cm)	PCD (μeq/l)	Amount	
1 DSR	-22,2	0,8	-17	1kg/t	CS1
2 DSR	-20,9	0,795	-16	2kg/t	
3 DSR	19,4	0,79	-15	3kg/t	
4 DSR	18,4	0,785	-14	4kg/t	
5 DSR	-17,5	0,78	-13	5kg/t	
10 KYM	-17,3	0,79	-11	10kg/t	217LXE
20 KYM	-12,6	0,8	-10	20kg/t	
30 KYM	-6,2	0,81	-8	30kg/t	
40 KYM	0,6	0,82	-6	40kg/t	
50 KYM	7,7	0,83	2	50kg/t	
				A20902LB	ASA540
100 RET	-21,7	0,74	-15	100g/t	200g/t
150 RET	-21,5	0,755	-15	150g/t	200g/t
200 RET	-21,3	0,77	-15	200g/t	200g/t
250 RET	-21,1	0,78	-14	250g/t	200g/t
300 RET	-21	0,79	-14	300g/t	200g/t

Tab. 5: Mixture 2, 50% long-fibre Pine (25°SR) + 50% Eucalyptus (25°SR).

Sample	Zeta potential (mV)	Conductivity (mS/cm)	PCD (μeq/l)	Amount
1 DSR	-24,5	0,84	-19	1 kg/t
2 DSR	-22,5	0,83	-17	2kg/t

3 DSR	-20,9	0,82	-16	3kg/t	
4 DSR	-19	0,81	-15	4kg/t	
5 DSR	-17,2	0,8	-14	5kg/t	
10 KYM	-16,2	0,8	-12	10kg/t	
20 KYM	-8,9	0,81	-11	20kg/t	
30 KYM	-0,6	0,82	-9	30kg/t	
40 KYM	4	0,83	-4	40kg/t	
50 KYM	12,4	0,85	3	50kg/t	
				A20902LB	ASA540
100 RET	-24,8	0,79	-15	100g/t	200g/t
150 RET	-24,6	0,8	-14	150g/t	200g/t
200 RET	-24,4	0,81	-14	200g/t	200g/t
250 RET	-24,3	0,82	-14	250g/t	200g/t
300 RET	-24,2	0,83	-14	300g/t	200g/t

The effect of dry strength agent on charge density

A starch-based biopolymer is used to increase the dry strength of tissue papers (Balberčák and Kuňa 2024). Depending on the type of production program and the basis weight of the paper being produced, it is used in an amount from 1.0 kg/t to 5.0 kg/t of paper. The results of the laboratory application of Acefloc DSR CS1 agent to various pulp suspensions and its effect on Zeta potential, PCD value and conductivity are shown in Fig. 5.

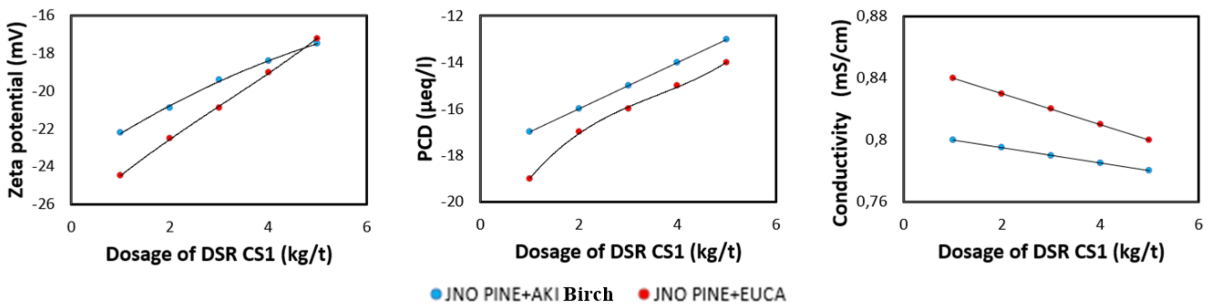

Fig. 5: The effect of starch dosage on Zeta potential (a), PCD value (b) and conductivity (c).

The addition of a starch-based dry strength enhancer increases the Zeta potential of the fibres (Fig. 5a). For the sample labelling Mixture1, in the given starch dosage range, the Zeta potential value increased by 4.7 mV, for the sample labelling Mixture2 by 7.3 mV. The charge density of colloidal particles, expressed as the PCD value, increases with increasing starch dosage, with a higher increase in the sample labelling Mixture2. The conductivity values decrease with increasing starch addition. This is due to the fact that starch absorbs anionic interfering substances from water and binds them to the pulp fibres (Khoo et al. 2023).

The effect of a wet strength agent on the charge density

Epichlorohydrin resins are used to increase the wet strength of tissue papers (Ntifafa et al. 2024). Depending on the type of production program and the basis weight of the paper produced, their dosage ranges from 10.0 kg/t to 50.0 kg/t of paper. In laboratory testing, we used Kymene 217LXE as a means of increasing wet strength. The results of laboratory application to various pulp suspensions and its effect on Zeta potential, PCD value and conductivity are shown in Fig. 6.

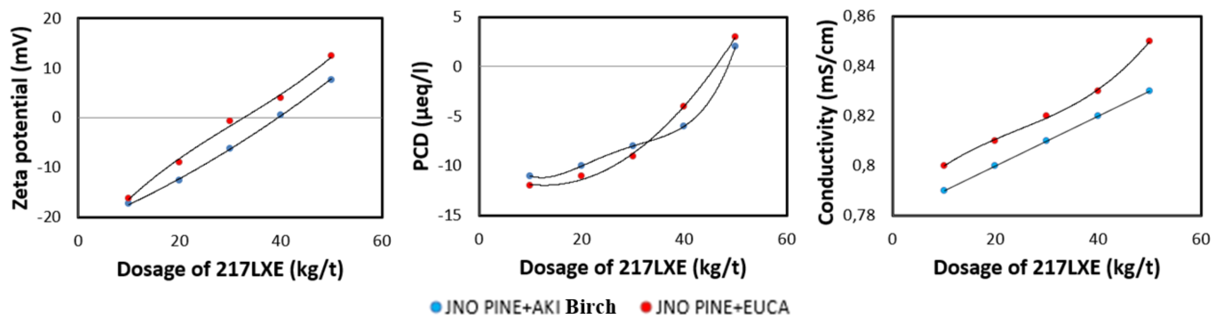

Fig. 6: The effect of wet strength agent on Zeta potential (a), PCD value (b) and conductivity (c).

By adding a wet strength agent (PPzM), the Zeta potential values of the fibres increase (Fig. 6a). At a PPzM dose above 40 kg/t of pulp, the Zeta potential changes from negative to positive. The charge density of colloidal particles in PCD waters increases with increasing PPzM addition and at a dose of 50 kg/t of pulp, it passes into the positive range. By increasing the PPzM addition, the conductivity of the waters also increases. This is due to the fact that only a part of the PPzM binds to the fibres and the other part remains dissolved in the waters. The conductivity of individual pulp mixtures increased in the range of 0.04 - 0.05 mS/cm.

The influence of the retention system on the charge density

Multi-component retention systems are used in tissue production to improve the WRV of water bodies (Kuňa et al. 2016). In this work, a two-component retention system was used, consisting of the micro polymer Acefloc SA540 and the long-chain polymer with low charge density Acefloc 20902LB (Fig. 7). The dosage of the micro polymer was constant at 200 g/t pulp and the dosage of the long-chain polymer varied in the range from 100 g/t to 300 g/t.

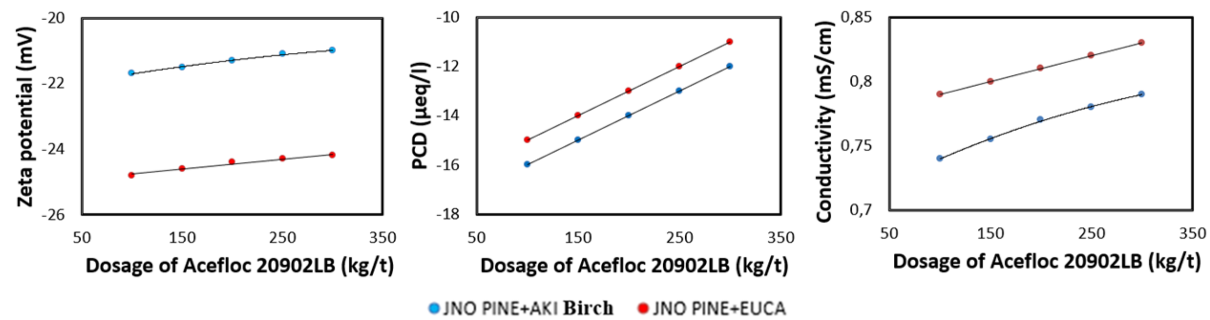

Fig. 7: The effect of retention system on Zeta potential (a), PCD value (b) and conductivity (c).

The influence of the two-component retention system on the charge density of the fibres is only minimal. It slightly increases the Zeta potential. For the suspension labelling Mixture1, it represents an increase of 0.7 mV, for the suspension labelling Mixture2, the increase was 0.6 mV. The charge density of colloidal particles in water, expressed as the PCD value, increases slightly due to the increase in the dose of the retention system. The increase in the PCD value was 4 μeq/l for the given dosage range. The increase in the conductivity values of the fibres suspension also increased due to the increase in the dose of the retention system. The increase in the conductivity values was only minimal. For the sample Mixture1, the increase was 0.05 mS/cm, for the sample Mixture2 it was 0.03 mS/cm.

CONCLUSIONS

The measured values of the fibre length show that in the first phase of beating, mainly fibres fibrillation occurs, which is reflected in the increase in fibre length to a beating degree of 20 to 25°SR. With further beating, fibre shortening occurs, which is reflected in the decrease in the values of arithmetic and weighted length. The longest fibre length of the monitored pulps was in long-fibre pine pulp and the smallest in eucalyptus pulp. The results show that increasing the beating degree increases the value of the Zeta potential. The largest increase is up to a beating degree of 25°SR. Increasing the beating degree from 25°SR to 35°SR caused only a minimal increase in the Zeta potential. The lowest values were measured in short-fibre eucalyptus pulp and the highest values in long-fibre softwood pulp - pine. The charge density of colloidal particles in water, the PCD value, decreases with increasing beating degree. The lowest values were measured for short-fibre birch pulp. The PCD values of eucalyptus and pine pulps, in the beating degree range up to 35°SR, are in the range from -10.0 μeq/l to -25.0 μeq/l. The tensile strength and compressive strength increase throughout the beating range, while the stiffness only up to 30°SR and then has a decreasing tendency. Of the pulps studied, long-fibre pine pulp has the highest strength parameters. Gurley porosity values increase throughout the beating range, which means that the paper becomes less permeable. The absorbency of pulps decreases due to beating, with the largest decrease being up to a beating degree of 25°SR. Then the decrease in values is more moderate. The whiteness of pulps decreases due to beating. For the pulps studied, the decrease in whiteness in the beating range is 1.9 to 3.3%.

In the laboratory testing of the influence of papermaking auxiliaries on the charge density of fibres and colloidal particles in waters from the studied systems, the most significant influence on the charge density values is exerted by the agent for increasing the wet strength of paper. At high doses, above 40 kg/t of pulp, the Zeta potential and PCD value change from negative to positive. The excess amount of PPzM no longer binds to the fibres, but remains dissolved in the waters, which is also confirmed by the increase in conductivity values. The agent for increasing the dry strength increases the Zeta potential of the fibres and the value of colloidal particles, but significantly less than PPzM. In the studied starch dosage range, the studied values remained in the negative range. The conductivity values decrease with increasing starch addition. This is due to the fact that starch absorbs anionic interfering substances from water and binds them to pulp fibres. The two-component retention system had the least significant effect on the charge density of fibres and colloidal particles of the monitored systems. Since it is a cationic system, its influence caused a slight increase in Zeta potential, PCD and water conductivity.

ACKNOWLEDGEMENTS

This work was supported by the Slovak Research and Development Agency under contract No. APVV-23-0623.

REFERENCES

1. Bhardwaj, N.K., Kumar, S., Bajpai, P.K. (2004). Effects of processing on zeta potential and cationic demand of kraft pulps. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 246(1-3), 121-125.
2. Balberčák, J., Kuňa, V., Boháček, Š., Ihnát, V., 2022: Reduction of the softwood long fibre pulp addition in tissue production. Case study. Wood Research 67(3): 447-459.
3. Balberčák, J., Kuňa, V, (2024). Modified starches as a mean of increasing the dry strength of tissue papers. Wood Research, 69(1), 60-71.
4. de Assis, T., Reisinger, L.W., Pal, L., Pawlak, J., Jameel, H., Gonzalez, R.W., 2018: Understanding the effect of machine technology and cellulosic fibers on tissue properties – A review. BioResources 13(2): 4593-4629.
5. DIN 54358-1, 1981: Testing of pulps; preparation of laboratory sheets for physical testing; Rapid-Köthen method.
6. Ferreira, J.C., Evtuguin, D.V., Rebola, S.M., Jorge, S.R., Margalho, L. (2018). Production factors affecting the performance of eucalypt kraft pulp for tissue papers. XXIV TECNICELPA - International Conference on Forestry, Pulp and Paper 11-12 October – Aveiro, Portugal, 8 p.
7. Fišerová, M., Gigac, J. (2011). Comparison of hardwood kraft pulp fibre characteristics and tensile strength. Cellulose Chemistry and Technology, 45(9), 627.
8. Fišerová, M., Gigac, J., Stankovska, M., Opálená, E. (2019). Influence of bleached softwood and hardwood kraft pulps on tissue paper properties. Cellulose Chemistry &Technology, 53(5-6), 469-477.
9. Gruber, E., Ott, T. (1995). Determination of ionic groups in cationic pulps – Colorimetric analysis and polyelectrolyte titration, Papier 49(6), 289-290, 292-294, 296.
10. Holmbom, B., Sundberg, A. (2003). Dissolved and colloidal substances accumulating in papermaking process waters. Wochenblatt Papierfabrikation 131(21), 1305-1311.
11. Ihnát, V., Fišerová, M., Opálená, E., Russ, A., Boháček, Š. (2021). Chemical composition and fibre characteristics of branch wood of selected hardwood species. Acta Facultatis Xylologiae Zvolen res Publica Slovaca, 63(2), 17-30.
12. ISO 5269-2, 2004: Pulps. Preparation of laboratory sheets for physical testing. Part 2: Rapid-Köthen method.
13. ISO 5264-3, 1979: Pulps. Laboratory beating. Part 3: Jokro mill method.
14. ISO 5637, 1989: Paper and board. Determination of water absorption after immersion in water.

15. ISO 5628, 2019: Paper and board. Determination of bending stiffness. General principles for two-point, three-point and four-point methods.
16. ISO 1924-2, 2008: Paper and board. Determination of tensile properties. Part 2: Constant rate of elongation method (20 mm/min).
17. ISO 2758, 2014: Paper. Determination of bursting strength.
18. Kamble, S., Agrawal, S., Cherumukkil, S., Sharma, V., Jasra, R.V., Munshi, P. (2022). Revisiting zeta potential, the key feature of interfacial phenomena, with applications and recent advancements. ChemistrySelect, 7(1), e202103084.
19. Khoo, P.S., Ilyas, R.A., Uda, M.N.A., Hassan, S.A., Nordin, A.H., Norfarhana, A.S., Rafiqah, S.A. (2023). Starch-based polymer materials as advanced adsorbents for sustainable water treatment: current status, challenges, and future perspectives. Polymers, 15(14), 3114.
20. Koljonen, K., Mustranta, A., Stenius, P. (2004). Surface characterisation of mechanical pulps by polyelectrolyte adsorption. Nordic Pulp & Paper Research Journal, 19(4), 495-505.
21. Kuňa, V., Balberčák, J., Boháček, Š., Ihnát, V. (2021). Elimination of adhesive impurities of the recovered paper in flotation process. Wood Research, 66(2), 221-230.
22. Kuna, V., Balbercak, J., Pazitny, A., Russ, A., Bohacek, S., Ihnat, V. (2018). Tackiness reducing of the stickies surfaces by inorganic agents and organic polymers. Wood Research, 63(6), 1013-1020.
23. Kuňa, V., Balberčák, J., Opálená, E., Pažitný, A., Russ, A., Schwartz, J. (2016). The effect of multi-component retention systems on the properties of the paper suspensions. Wood Research, 61(5), 767-776.
24. Lužáková, V., Marcinčinová, T. (1993). Využitie metódy merania náboja častíc pri riešení ekologických problémov výroby papiera. Zborník z odborného seminára: Environmentálne program v chemickej technológii dreva, celulózy a papiera (The use of particle charge measurement methods in solving ecological problems of paper production. Proceedings of seminar: Environmental Program in the Chemical Technology of Wood, Cellulose and Paper). September, 23-24, Bratislava (in Slovak language).
25. Mašura, V., Balberčák, J., Kuňa, V., Mikulášik, R. (2019). Reaction phases of the wood constituent's degradation during Kraft cooking of spruce chips. Wood Research, 64(6), 975-985.
26. Nasser, M.S. (2014). Characterization of floc size and effective floc density of industrial papermaking suspensions. Separation and Purification Technology, 122, 495-505.
27. Ntifafa, Y., Ji, Y., Hart, P.W. (2024). Polyamidoamine epichlorohydrin (PAAE) wet-strength agent: Generations, application, performance, and recyclability in paperboard and linerboard. BioResources, 19(2), 3895.
28. Ordaz-Díaz, L.A., Valle-Cervantes, S., Rodríguez-Rosales, J., Bailón-Salas, A.M., Madrid-Del Palacio, M., Torres-Fraga, K., Luis, A. (2017). Zeta potential as a tool to evaluate the optimum performance of a coagulation-flocculation process for wastewater internal treatment for recirculation in the pulp and paper process. BioResources, 12(3), 5953-5969.

29. Pažitný, A., Boháček, Š., Medo, P., Balberčák, J., Schwartz, J., Kuňa, V., Ihnát, V. (2017). Possibilities of removing condensate from a heat recovery unit utilizable in paper industry. Wood Research, 62(2), 273-282.
30. Pokhrel, C. (2010). Determination of strength properties of pine and its comparison with birch and eucalyptus. Bachelor's Thesis. Saimaa University of Applied Sciences. Finland, 60 p.
31. Sundberg, A., Ekman, R., Holmbom, B., Sundberg, K., Thornton, J. (1993). Interactions between dissolved and colloidal substances and a cationic fixing agent in mechanical pulp suspensions. Nordic Pulp & Paper Research Journal 8(1), 226-231.
32. Valto, P., Knuutinen, J., Alén, R., Rantalankila, M., Lehmonen, J., Grönroos, A., Houni, J. (2010). Analysis of resin and fatty acids enriched in papermaking process waters. BioResources 5(1), 172-186.
33. Weitao, Z., Xia, Ch., Yan, W., Lianying, W., Yangdong, H (2020). Experimental and modeling conductivity measurement for systems with electrolytic solutions. ACS Omega 2020 5(35), 22465-22474.

VLADIMÍR KUŇA*, JOZEF BALBERČÁK
PULP AND PAPER RESEARCH INSTITUTE
DÚBRAVSKÁ CESTA 14, 841 04 BRATISLAVA
SLOVAK REPUBLIC
*Corresponding author: kuna@vupc.sk