Measurement of the electrical specific conductivity of a wet pulp web

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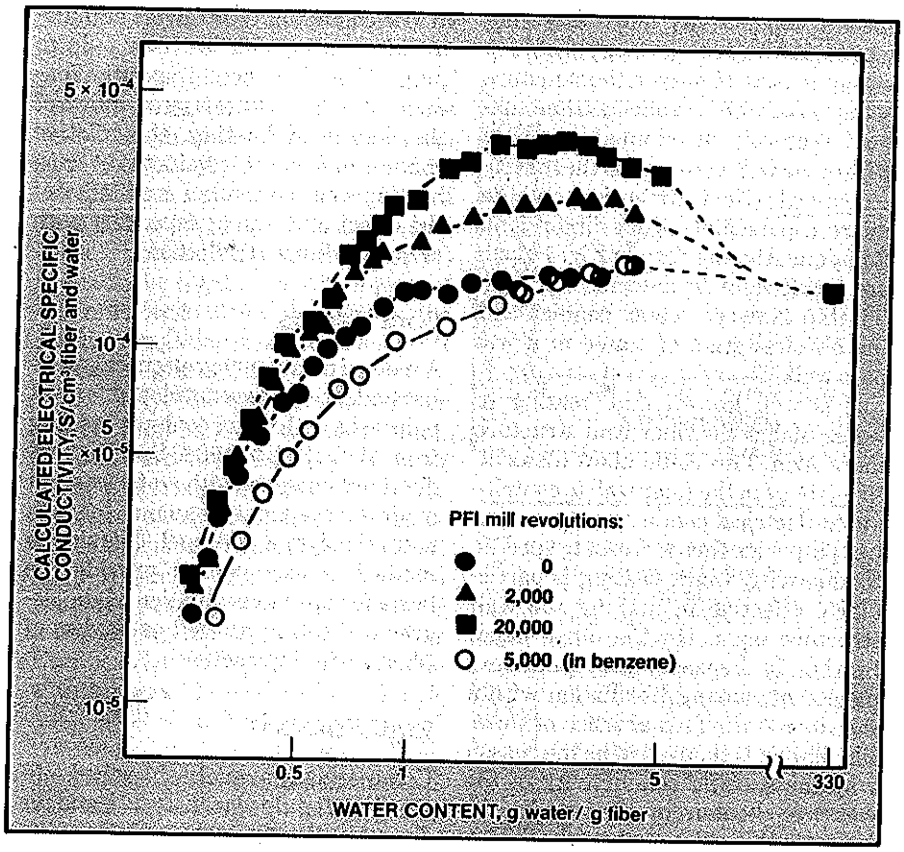
Wood pulp fibers generally contain electrolytes and dissociative groups, such as the carboxyl group (*1*). The dissociation of these groups depends on the physical state of water within the pulp web. Therefore, the relationship between the electrical conductivity and the amount of water in the wet pulp web can be expected to characterize the state of the water in the pulp web.

There has been a great deal of research into the electrical conductivity of paper in the *z*-direction under conditions ranging from dry to moist. Most of this research has been related to the production of electrical insulating paper (*2, 3*). However, there are no available data regarding the electrical conductivity of wet pulp webs, with the exception of Stamm's experiments, in which the electrical conductivity of paper containing a dilute salt solution was measured (*4*).

This article describes the measurement of the electrical specific conductivity of wet pulp webs with water contents (g water/g fiber) ranging from about 30% to about 400%. The method used is one that was developed primarily for electrolyte solutions. This method uses an alternating-current bridge and is suitable for wet pulp webs because it avoids polarization at the electrodes. The experimental results show that specific conductivity can be used to evaluate the degree of pulp beating.

1. Logarithmic plot of calculated electrical specific conductivity (S/cm^3 fiber and water) as a function of water content (g water/g fiber) for fines-free bleached kraft pulp wet webs.



Results and discussion

Both the fibers and the water in a wet pulp web participate in conduction of electricity through the wet web. Consequently, the electrical specific conductivity per volume of fiber and water (S/cm^3 fiber and water) is calculated from the mass of fibers and water and the measured electrical resistance. Densities for the fiber wall and water are assumed to be 1.5 g/cm^3 and 1.0 g/cm^3, respectively. This conductivity, known as the "calculated electrical specific conductivity," is hereafter referred to as the "specific conductivity."

The logarithmic relationship between specific conductivity and water content is shown in **Fig. 1**. Regardless of the degree of beating, the specific conductivity of a pulp suspension is the same as that of the water itself. In pulp suspensions, the specific conductivity depends only on the purity of the tap water. Figure 1 shows that fiber condition has no effect on the specific conductivity of a pulp suspension.

As the consolidation proceeds, the specific conductivity of the beaten wet pulp web increases to a maximum and then decreases. The lower the water content below a value of about 100%, the more the specific conductivity decreases. Similar behavior for specific conductivity vs. water content was reported for natural polymer hydrogels, such as agar gel, by Mizuguchi *et al.* (*5*). According to these authors, the increase in electrolyte and dissociative-group consistency resulting from sample drying should increase the specific conductivity. However, below a water content of about 100%, the physical state of water in the wet web is different from that of free water, i.e., the dissociative function of water in the wet pulp web is less than that of free water.

Because wood pulp fibers and agar belong to a similar group of natural polymers, it would seem that Mizuguchi *et al.*'s observations regarding specific conductivity and water content would be generally applicable to wet pulp webs. However, the structure of the paper web complicates the situation. Water is distributed unevenly within the wet web on both the macroscopic scale (fiber dimension) and the microscopic scale (micelle dimension). Consequently, the data in Fig. 1 alone are insufficient to describe the relationship between water content and the physical state of water in a wet pulp web.

It is well known that beating in water makes the fiber wall structure more open. This could allow dissociative groups in the fiber wall to contribute to electrical conduction through a wet pulp web, thus increasing specific conductivity. Light beating is particularly effective in making the wall structure open. On the other hand, beating in benzene cuts the fibers instead of causing fibrillation within the fiber wall. This absence of inner fibrillation is thought to be the reason why the specific conductivity of the wet web beaten in benzene is the lowest in the series of wet webs in Fig. 1.

The basic properties of the four pulps in Fig. 1 are presented in **Table I**. The relationship among these pulp properties is consistent with the relationship evident in Fig. 1 between specific conductivity and beating. The freeness and the water-retention values (WRV) are almost identical for the pulp beaten in benzene and the unbeaten pulp. On the other hand, the strength properties of a dry sheet formed from the unbeaten pulp are higher than those of a sheet formed from the pulp beaten in benzene, although the sheet density of the latter is higher than that of the former. In contrast, beating in water causes a large increase in strength properties, as well as in sheet density and WRV. Light beating is particularly effective in this respect, although the decrease in freeness is not large.

I. Basic properties of fines-free bleached kraft pulp

PFI mill revolutions	Freeness, mL CSF	WRV, %	Sheet density, kg/m^3	Tensile index, kN·m/kg	Young's modulus/density, MPa·m^3/kg
		In water			
0	742	72	480	10	2.2
2,000	648	145	690	76	7.0
20,000	12	260	910	108	8.5
		In benzene			
5,000	732	71	540	6	1.8

The content of electrolytes and dissociative groups varies from pulp to pulp. Therefore, while specific conductivity itself is not a good index of the degree of beating, the relative change in specific conductivity with beating would provide a good index of the effect of beating, especially with respect to inner fibrillation.

Conclusions

A method of measuring electrical specific conductivity was developed for wet pulp webs with water contents ranging from about 30% to 400%. Specific conductivity changes with water content in almost the same manner as that of a natural polymer hydrogel. This simple method is expected to provide the basis for on-line evaluation of the degree of beating as well as studies of fiber–water interactions.

Experimental

Commercially available bleached softwood kraft pulp was classified, and the fines fraction was removed. One part of the pulp was beaten in a PFI mill under standard conditions. Thick wet webs with a basis weight of 240 g/m^2 were prepared using a standard handsheet mold (*6*). The water content of the wet pulp web was reduced successively by wet pressing. After wet pressing, the wet pulp web (inserted between wet filter papers) was placed in a polyethylene bag for about 1 h to minimize variations in the water content within the web. A portion of the pulp was beaten in benzene instead of water, then washed with ethanol and water, and finally molded into a wet pulp web. Tap water was used throughout these experiments.

The electrical conductivity of each wet pulp web was measured using an electrical conductivity meter attached to a Shimadzu ZP-10B streaming potential analyzer with a frequency of 60 Hz and a potential of 6 V at 20°C. Measurements were made in the x,y-direction of the web instead of the z-direction, since web thickness during sample drying decreased so much that the conditions of contact between the web and the electrodes could not be kept constant. Specially made clip-type electrodes were used for tests on wet pulp webs; ordinary electrodes were used for tests on pulp suspensions. The validity of Ohm's law was verified by measuring the conductivity of wet filter papers of various sizes.

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