Effect of Birch and Pine Fibre Content and Degree of Beating on the Properties of Bleached Sulphate Pulps

Abstract
Apparent specific volume changes of bleached birch and pine sulphate pulps, as well as their mixtures in correlation with their basic strength properties (i.e. breaking length and tear index in the beating process), were studied. It was found that the greatest decrease in pulp apparent specific volume, and at the same time a great increase in its breaking length, had already taken place at an initial stage of the beating process. Bleached sulphate pine pulp, in both beaten and unbeaten states, has a higher apparent specific volume than bleached birch sulphate pulp. As a result, a mixture of birch pulp (70-90 wt.%) and pine pulp (10-30 wt.%), after having been beaten together to a freeness value of 18-21°SR, also gives a higher apparent specific volume in comparison with birch pulp, although the increase does not exceed 4% rel. A substantial improvement in sulphate pulp apparent specific volume, within a range from 3.3% to 13.3% rel., can be obtained by adding unbeaten or weakly beaten pine pulp in an amount of 10-30 wt.% to beaten sulphate birch pulp (with a freeness value of 20-22°SR). The mixtures thus obtained tend to have a higher tear index (by 6-37% rel.) and a breaking length which is comparable at 10 wt.% pine pulp content and lower (by 9-19% rel.) at 20-30 wt. % content of this pulp in relation to birch pulp.

Key words: bleached sulphate pulps, beating, apparent specific volume (bulk), breaking length, tear index.

Introduction
The dewatering of a formed paper web by exerting mechanical pressure on it in dewatering presses often results in an excessively high degree of densification of the sheet [1]. This phenomenon, which manifests itself as a considerable decrease in the paper’s apparent specific volume and its thickness, is unfavourable, particularly for graphic papers, because it results in a decrease in opacity and bending stiffness coefficient [2]. It can usually be observed when technological changes aimed at achieving a higher content of dry substance in a paper web are introduced.

A considerable effect on the apparent specific volume of pulps and paper is made by the flexibility of fibres as well as their collapsibility; these indices are in general closely interconnected. The stiffier fibres are, and the greater the tendency they show to keep their natural shape, the bulkier will be the structures they form [3]. Table 1 shows the effect of various factors on those properties of bleached sulphate pulps which are now the main fibrous semi-finished products for the production of printing papers [3,4].

Table 1. Effect of various factors on the properties of fibres that determine the structure of a semi-finished product produced from them (+ increase, - decrease, 0 - no changes).

<table>
<thead>
<tr>
<th>Raw material/process</th>
<th>Fibre flexibility</th>
<th>Susceptibility to cross deformation (fibre flattening)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kind and species of wood</td>
<td>+ ++</td>
<td>+</td>
</tr>
<tr>
<td>Pulping (amount of effective alkali)</td>
<td>+</td>
<td>0 (+)</td>
</tr>
<tr>
<td>Bleaching</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Beating</td>
<td>+ + +</td>
<td>+, +</td>
</tr>
<tr>
<td>Drying of pulps before beating</td>
<td>-</td>
<td>- (+)</td>
</tr>
</tbody>
</table>

The number of pluses shows that the kind and species of trees from which the pulps were produced is of great significance. Fibres of the individual tree species differ from each other in both their length and cross dimensions. Especially, there is a considerable difference between the softwood and hardwood fibres. This affects fibre flexibility in that the flexibility index decreases as the cell wall thickness increases and the fibre width decreases [5,6].

Table 1 shows that process operations such as wood pulping, pulp bleaching and above all pulp beating can affect the apparent specific volume of pulp by changing the fibre flexibility and elasticity of the cell walls. The pulping and bleaching processes result first of all in an increase in cell wall elasticity by changing its chemical composition, and a decrease in cellulose degree of polymerisation [7]. Unbeaten pulp fibres are characterised by a relatively high stiffness, which causes such pulps to have high apparent specific volume. However, to develop their strength properties, they have to be treated in a beating process during which they soon lose their initial elasticity and become more and more flexible due to internal and external fibrillation [8]. That is why they can easily intertwine, owing to which both their bonding surface and their bonding strength are increased. The beating process, which results in a considerable increase of fibre flexibility and pulp strength properties, has an adverse effect on their apparent specific volume, as well as on their opacity and brightness.

In the case of an excessive decrease in the apparent specific volume of bleached sulphate pulps, a fibrous semi-finished product containing more stiff fibres is sometimes added. This function can be performed by mechanical or thermo-mechanical pulps, but their excessive lignin content can adversely affect the paper’s brightness and resistance to ageing. It is also possible to improve the paper’s apparent specific volume by adding sulphate pulp with stiffer fibres, for example...
eucalyptus, which according to literature have a higher apparent specific volume at a given tensile strength in comparison with birch sulphate pulps [9].

Fibre curl also affects the apparent specific volume of pulps. The more curled fibres a pulp contains, the higher is the apparent specific volume of the products made of it [10]. The fibre curl may be influenced in the beating process by means of special conditions (above all, the high consistency of slurry). However, in practice this process usually results in a decrease in fibre curl, that is, their ‘straightening’, which additionally reduces the apparent specific volume of the semi-product.

### Aim of Work

The aim of this work was to study in laboratory conditions the effect of the beating process on the apparent specific volume of bleached sulphate birch and pine pulps, and to find methods of improving this important structural property in connection with pulp strength properties.

### Object of Research

For the tests we used bleached sulphate birch and pine pulps (ISO brightness of approx. 90%) delivered by domestic pulp and paper mill in the form of sheets of 93% dryness and never-dried pulps. The never-dried pulps were obtained by pulping industrial wood chips in a laboratory using the sulphate method and by delignifying the produced pulps with oxygen. They were then bleached in a two-stage bleaching process with chlorine dioxide, with an intermediate alkaline extraction to ISO brightness of approx. 90%.

### Experimental

Suitably disintegrated pulps (delivered in the form of sheets) were placed in a water-filled container for 24 hours. Then, after additional disintegration in a laboratory mixer, the pulp was beaten in a Jokro mill, in accordance with standard PN-61/P-50062, at variable times from 1 to 25 min. The beating time and the Schopper-Riegler freeness of the pulp (SR) are specified in Table 2.

In the Rapid-Köthen apparatus, hand-sheets of a basic weight of approx. 75 g/m² were made of unbeaten and beaten pulps. The apparent specific volume and strength properties were determined according to established methods [11]. The mixtures of birch and pine pulps to be beaten together in the Jokro mill were prepared by weighing their appropriate amounts and mixing, followed by short disintegration. The mixtures of birch and pine pulp beaten separately were prepared by replacing a specific volume of birch pulp slurry with an equivalent amount of pine pulp slurry, and by equalising them in a laboratory mixer.

### Discussion of Results

The pulps prepared for studies were beaten; the beating time was selected in such a way as to achieve the highest concentration of points at the initial beating stage (Table 2). This enabled us to determine relatively precisely the effect of this stage of pulp beating process on their apparent specific volume, as well as the breaking length and tear index. The results were presented in Figures 1 and 2.

Figure 1 shows that within the first 4-6 minutes of beating, a very fast decrease in the apparent specific volume of all the tested pulps has already taken place. This is a result of a rapid increase in the flexibility of the almost fully delignified fibres of bleached pulps treated mechanically. A longer beating (above 6 minutes), as is shown in Figure 1, causes a further decrease in the pulp’s apparent specific volume. Table 2. Beating time and freeness values of bleached sulphate pulps used in tests.

<table>
<thead>
<tr>
<th>Pulp type</th>
<th>Schopper-Riegler freeness in °SR for beating time, min</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Birch, dried</td>
<td>15</td>
</tr>
<tr>
<td>Pine, dried</td>
<td>13.5</td>
</tr>
<tr>
<td>Birch, never-dried</td>
<td>15</td>
</tr>
<tr>
<td>Pine, never-dried</td>
<td>14</td>
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</tbody>
</table>

Figure 1. Relationship between the apparent specific volume of birch (B) and pine (P) pulp and beating time in the Jokro mill. Pulp freeness values corresponding to individual points are shown in Table 2. Filled symbols represent the results of tests made on dried pulps; symbols that are unfilled, the results of tests on never-dried pulps.

Figure 2. The tear-breaking length relationship of birch (B) and pine (P) pulps. Consecutive points correspond to beating time and freeness according to Table 2. Filled symbols represent the results of tests made on dried pulps; symbols that are not filled represent the results of tests on pulps that are not dried.
volume, but it is much lower than during the first minutes of the beating process.

Never-dried pulps, both birch and pine, behave like dried pulps; however, the more flexible fibres of the former in the unbeaten state are the cause of their lower apparent specific volume. This is especially evident in the case of birch pulp. As the beating process of dried and never-dried birch pulps progresses, the differences in apparent specific volume between these pulps decrease, and almost disappear in the case of pine pulp. However, there are still differences in the apparent specific volume of the handsheets, which results from the kind of fibres being beaten (softwood, hardwood). The apparent specific volume of handsheets made of pine pulp is higher than that of birch pulp, irrespective of their degree of freeness (Figure 1). This probably results from the greater length and width of pine fibres in comparison to birch fibres, and in consequence, a smaller amount of the former in a pulp mass unit.

The results indicate the following possibilities of increasing the apparent specific volume of pulp and paper:

- Pulp beating to as low a freeness level as possible (defined by reaching the required strength potential), i.e. avoiding pulp 'over-beating' as a result of which the pulp's apparent specific volume is reduced too much, and the strength properties are no longer significantly improved.
- Pine and birch pulps beaten together.
- The addition of unbeaten or weakly-beaten pine pulp to well-beaten birch pulp.

The first of the above-mentioned possibilities for improving apparent specific volume is based on the observation that beating bleached pulps has an adverse effect on their apparent specific volume, so this process should be shortened as much as possible. However, the pulp beating degree depends on the required strength potential which should characterise fibrous semi-finished products to ensure proper formation of a paper web on PM wire, runnability, and the good properties of the finished product.

Figure 2 shows the results illustrating the variation of strength potential in the tested pulps in the beating process. In the initial stage of the beating process, the increase in the strength potential of the birch pulps is almost linear with the increase in beating time, owing to the increase in the breaking length and tear index.

This means that birch pulp must be beaten to develop its strength potential. This considerably limits the possibility of significantly shortening the birch pulp beating process, or its use in an unbeaten condition, thus maintaining its higher apparent specific volume.

Unlike birch pulp, pine pulp is characterised by a high tear index in its already unbeaten condition. Above all, beating improves their breaking length, although it is usually already higher in its unbeaten condition than in the case of birch pulp (in corresponding tests on dried and never-dried pulps, q.v. Figure 2). Tendencies in variation of apparent specific volume, breaking length and tear index of birch and pine pulps (beaten and unbeaten) are presented in Table 3.

The research into the second possibility of improving the apparent specific volume of birch pulp consisted of making mixtures of birch and pine pulps and beating them together, assuming that birch fibres would be the main component, and that the content of pine fibres would not exceed 30 wt. %. Birch pulp is the main semi-finished product used in the production of graphic papers, due to its lower price and better structural properties, e.g. in sheet formation. In these tests dried pulps were used. Pulp mixtures were beaten in a Jokro mill, and then the apparent specific volume and strength properties of the handsheets were determined. The results, illustrated in Fig. 3, show that replacing 10, 20 or 30 wt. % of birch pulp fibres with pine pulp fibres can improve the apparent specific volume of a handsheet; however, the resultant effect is not considerable. For example, in a test in which pulp containing 70% birch and 30% pine was beaten (–for 10 minutes), the apparent specific volume was increased by 4% rel. in comparison with a test in which the pulp was beaten identically and consisted of 100% birch fibres.

The third investigated possibility of improving the apparent specific volume of the handsheets was the addition of unbeaten (13.5°SR) or weakly-beaten pine pulp (14°SR) to birch pulp with a freeness in the range of 20-22°SR. As stated in the experimental section, the operations of beating birch and pine pulps were carried out separately; prior to making the handsheets, 10, 20 or 30 wt. % of beaten birch fibres were replaced with

| Table 3. Properties of bleached sulphate beaten and unbeaten pulps (+ positive effect, − negative effect). |
|---|---|---|---|---|---|
| Types of pulps | Apparent specific volume, cm³/g | Breaking length, m | Tear index, mN m²/g | Evaluation |
| Unbeaten pulps | | | | |
| Birch (B) | Highest values, (+) | Lowest values, (−) | Lowest values, (−) | + − + − + |
| Pine (P) | Highest values, (+) | Lowest values, (−) | High values, (+) | − + − + |
| Beaten pulps | | | | |
| Birch (B) | Considerably lowered values, (−) | High values, (+) | Highest values, (+) | − + − + |
| Pine (P) | Considerably lowered values, (−) | High values, (+) | Considerably lowered values, (−) | − + − + |
unbeaten or slightly beaten pine fibres. The results are shown in Figures 4-7.

Figure 4 shows that in the case of dried birch pulp beaten to 20°SR in which 10, 20 or 30 wt. % of fibres were replaced with unbeaten dried pine fibres, the increase of the handsheets’ apparent specific volume amounted to 4, 6 and 15% rel. in comparison with pure birch pulp. The results were similar when birch pulp of the same freeness level was mixed with pine fibres beaten for a short time (1 min, 14°SR). However, the increase in the apparent specific volume shown in Figure 4 was somewhat lower. Similar tendencies in the apparent specific volume of handsheets were observed during tests made with never-dried pulps. The increase in the apparent specific volume of the handsheets made of never-dried birch pulp with the addition of unbeaten pine pulp (also never-dried) in the amount of 10-30 wt. %, amounted from 3.3% to 13.3% rel.

Figure 5 shows that the breaking length of dried birch pulp after beating is lower than the breaking length obtained for pulp that was never-dried at comparable beating times. These results, first of all due to the irreversible changes to fibre surface that take place during drying, causes the dried fibres to show lower bonding ability. Moreover, the figure shows the breaking length of birch pulps with 10-30 wt. % addition of unbeaten or weakly beaten pine pulps, both dried and never-dried. For example, at 10 wt. % addition of unbeaten pine pulp, the breaking length was comparable to that obtained in tests in which birch fibres consisted 100% of the fibre furnish. At a greater share of unbeaten pine fibres (20 and 30 wt. %), the breaking length was considerably lowered - for dried pulps approx. by 9% and 19% rel., and for never-dried pulps by approx. 5% and 17% rel.

The data illustrated in Figures 4 and 5 shows that the addition of unbeaten pine pulp to beaten birch pulp improves their apparent specific volume and decreases their breaking length. The interrelationship between these two properties is shown in Figure 6 within a breaking length range of 7000 to 11,000 m. According to this data, dried birch pulp and its mixtures with dried pine pulp
have a higher apparent specific volume, but at the same time a lower breaking length than the never-dried pulps. At a definite breaking length level, the mixtures of birch and pine pulps have higher apparent specific volumes than do those of 100% birch pulps.

As for the tear index, Figure 7 shows that the values of this index for birch pulps with the addition of unbeaten or weakly beaten pine pulps are higher (by approx. 6-37% rel., depending on the addition of pine pulp), than the tear index values obtained in the tests in which the birch pulp consisted 100%, and these in the case of both dried and never-dried pulps.

**Summary**

- The greatest decrease in the apparent specific volume of bleached sulphate pulps (by 12-25%) takes place at the initial stage of the beating process (up to 6 min) within a freeness range of 13.5 to 18°SR. In the case of birch pulp, this is accompanied by an increase in both breaking length and tear index, while in case of pine pulp there is above all an increase in breaking length. Further beating of pulps gives only a slight improvement of strength properties, and in the case of pine pulp, even causes a significant decrease in the tear index, along with a further considerable decrease in the apparent specific volume. According to a principle of beating pulp to a definite previously set freeness (most often approx. 30°SR), bleached pulps can be ‘over-beaten’, and for this reason their apparent specific volume is excessively decreased. The beating time of these pulps should be optimised from the point of view of their reaching the expected strength potential.

- Bleached pine sulphate pulp has a higher apparent specific volume in comparison with bleached birch pulp, both beaten and unbeaten. As a result, the apparent specific volume of birch and pine mixtures after beating is included in a range between the values of this characteristic of pure birch and pure pine pulps. At 30 wt. % share of pine pulp in a mixture, the improvement of apparent specific volume achieved amounts to approx. 4% rel., so it is comparatively low.

- A considerably greater improvement in the apparent specific volume of bleached sulphate pulps, within a range from 3.3 to 15% rel., was achieved by the addition (10-30 wt. %) of unbeaten pine pulp to birch fibres which had been beaten to a greater degree. The resultant improvement in the apparent specific volume at a given level of birch pulp beating depends on the amount of unbeaten pine pulp that was added. After adding 20 and 30 wt. % of unbeaten pine pulp, we can expect a decrease in pulp breaking length by approx. 9% and 19% respectively, while tearing resistance is considerably improved by 6-37% rel., depending on the amount of pine fibres.

**References**


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