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SUGAR BEET PULP FIBROUS RESIDUES AS BONDING AGENTS IN PAPERMAKING

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ABSTRACT

Fibrous residues from acid and enzymatic hydrolysis of sugar beet pulp can be applied to increase bonding potential and partial replacement of recovered fibres. The authors investigated the influence of original, chemically and enzymatically modified sugar beet pulp on fibre suspension and paper properties from recovered fibres. With increasing content of sugar beet pulp in a mixture with recovered fibres, drainage time and water retention value increased, weighted average fibre length decreased, tensile and burst index, internal bond strength increased, bending resistance and porosity decreased. The effect of sugar beet pulp on fibre suspension and paper properties increased in the sequence original, chemically and enzymatically modified sugar beet pulp. Optimum input of original sugar beet pulp is 15-20%, of chemically modified sugar beet pulp 10-15% and of enzymatically modified sugar beet pulp 5-10%. Addition of sugar beet pulp to recovered fibres had a similar effect on fibre suspension and paper properties as beating of recovered fibres. However, an increase of internal bonding strength is in comparison with beating of recovered fibres disadvantageous with regard to drainage time, water retention value and porosity. This disadvantage can be eliminated by applying a three-component retention and drainage system. The retention and drainage system improved drainage, reduced COD and BOD_5 of filtrates from a mixture of recovered fibres with addition of sugar beet pulp and increased internal bond strength of paper. By applying a retention and drainage system, it is possible to increase optimal input of original, chemically and enzymatically modified sugar beet pulp in a mixture with recovered fibres approximately by 5%.

KEY WORDS: sugar beet pulp, chemical modification, enzymatic modification, recovered fibres, beating, drainage, retention, paper properties, COD, BOD_5

INTRODUCTION

Sugar beet pulp is a renewable raw material and a cheap source of materials, with special industrial and economic importance. Leached sugar beet pulp is a valuable stock for biotechnology and further processing, for the isolation of components with increased added value (Bonnin et al. 2000). Sugar beet pulp is fractionated by chemical and enzymatic methods in complicated processes, adjusted to the required properties of the final product. Least demanded is the fibrous fraction used as feedstock or food additive, if the pre-treatment was performed under mild conditions. The advantage of the enzymatic treatment is mild solubilisation of biopolymers to a required level with enzymes or microbial cultures containing enzymes produced by exogenic processes. A combination of several treatments is used in practice to isolate the required product which may be feedstock, fibrous material, isolated biopolymers and monosaccharides. The isolated components could be further modified or transformed by chemical, enzymatic or cultivation action (Turquois et al. 1999).

Of all available natural waste materials, sugar beet pulp has the highest L-arabinose content, at least twice higher as alternative sources (Slugeň et al. 2005). Sugar beet pulp is used for preparation of L-arabinose. Simultaneously pectin and fibrous residue consisting of polysaccharides are isolated. Hydrolysis of polysaccharides releases L-arabinose from the matrix of the sugar beet pulp. The applied degree of hydrolysis should assure an effective release of L-arabinose (also in the form of arabinans), with minimum destruction of the basic matrix which is especially important, as a higher content of loading substances (saccharides, pectins, proteins) renders the isolation of L-arabinose impossible.

Sugar beet pulp contains up to 25% of pectin substances. This by-product of sugar manufacture is a potential raw material for pectin manufacture. Sugar beet pectins are complex heteropolysacharides containing mainly galacturonic acid, rhamnose, arabinose and galactose (Micard et al. 1996, Kroon and Villiamson 1996). Sugar beet pectins, however, differ from pectins isolated from apples or citrus fruits by high rhamnose content, by the presence of acetyl groups linked to the α -D-galacturonic acid and by the presence of ferulic acid which is associated almost exclusively with the pectic side chains and is found as ester-linked to either the C-2 of arabinofurance or to the C-6 of galactopyranose residue (Rombouts and Thibault 1986).

Sugar beet pectin, due to physical-chemical properties, can be regarded as a slime or gum substance; these substances are frequently used in paper manufacture as anionic surface active agents. Several authors published surface treatment of paper with pectin and hemicelluloses preparations (Aaltio and Jounikainen 1971, Hernádi and Erdélyi 1971, Guha and Pant 1970). The effect of these substances is specific, depending on the type and amount of applied substance and on pulp grade.

In wet end application, the effect of added substances such as slimes and gums depends on retention or adsorption on fibre surface. Adsorption of these substances is limited by the saturation point which is reached at addition of approximately 1% of the substance on fibres (Kubát and Svatoň 1960). The positive effect of pectin on strength properties of sulphate pulp was confirmed in wet end applications (Maděrová et al. 1973).

The fibre structure of sugar beet pulp is more or less composed of cellulose fibres, depending on processing conditions. The fibrous part of sugar beet pulp released from lipids and pectins can be used for special applications in paper manufacture. Intensive processing with NaOH makes the properties of sugar beet pulp similar to those of microcrystalline cellulose. Such preparations, characterised by a significantly lower aggregation, are more hydrophilic than common celluloses (Dinand et al. 1999).

Well-known is the manufacture of paper with addition of dry micronised sugar beet pulp (Vaccari et al. 1994). In the Cartiera Favina mill of Italy, paper is prepared from recycled fibres with addition of micronised sugar beet pulp (Monagato and Stragliotto 1997). The influence of dry and wet pre-treated sugar beet pulp on recovered fibres suspension and paper properties, as well as the possible sugar beet pulp exploitation in core board manufacture has been investigated on laboratory scale (Fišerová et al. 2007). Wet beaten sugar beet pulp is suitable for increasing specific bond strength as well as a partial substitute of recovered fibres and semichemical pulp in fluting and test liner (Fišerová et al. 2007).

The objective of this investigation was to evaluate possibility of sugar beet pulp fibrous residues utilisation in papermaking and compare the influence of the fiberised original, chemically and enzymatically modified sugar beet pulp addition to recovered fibres on suspension and paper properties with and without retention and drainage aids.

MATERIAL AND METHODS

Recovered fibres (RF) were prepared from the following waste paper classes, according to EN 643: 50% of mixed papers and boards (sorted) and 50% of old corrugated boxes. Recovered fibres were beaten in a laboratory Valley holander to 38, 41, 44, 48 and 51°SR, according to ISO 5264-1.

Original sugar beet pulp (OSBP) extruded and dried (particles of 1-6mm) was fiberised 12 minutes in a laboratory mixer at 4 000 RPM to 0.01-1.5 mm particles after soaking in water for 2 hours.

Chemically modified sugar beet pulp (CMSBP) was prepared from extruded and dried sugar beet pulp by acid hydrolysis in diluted HCL solution of pH 3.5 in the presence of chelaton 3 at 80°C for 1 hour to a yield 87%, and fiberised 8 minutes in a laboratory mixer at 4 000 RPM to 0.01-1.5 mm particles.

Enzymatically modified sugar beet pulp (EMSBP) was prepared from extruded and dried sugar beet pulp by hydrolysis with cellulase and pectinase at 50°C for 8 hours to a yield of 68%, and fiberised 6 minutes in a laboratory mixer at 4 000 RPM to 0.01-1.5 mm particles.

Retention and drainage system (RDS) composition was: 3% crystalline aluminium sulphate (pH 4.6), 0.06% cationic polyacryl amide (Organopol 6480) and 0.02% anionic polyacryl amide (Labufloc A 157) from Ciba Company.

Fibre furnishes were prepared for the experiments from recovered fibres, fiberised 3 minutes in laboratory fiberizer Escher Wys (38°), and fiberised original, chemically and enzymatically modified sugar beet pulps (further referred to as "experimental fibre furnish"). Original, chemically or enzymatically modified sugar beet pulps was added to the experimental fibre furnishes to a final content of 5, 10, 20 and 40%. Handsheets were prepared from the experimental furnishes with addition of sugar beet pulps. We investigated the properties of the fibre suspensions and handsheets.

The beating degree and drainage time were determined according to the ISO 5267-1 standard, and water retention value (WRV) – according to the TAPPI UM 256 method. *Test sheets* (127 g/m^2) of recovered fibres, and original, chemically and enzymatically modified sugar beet pulps were prepared according to the ISO 5269-2. *Tensile index* was determined according to ISO 1924-2 and *burst index* according to ISO 2758 standard. *Internal bond strength* was measured as Scott Bond Energy according to TAPPI method 506 wd-83. Stiffness was determined as *bending resistance* by a two-point method, at a 15° bending angle, 25 mm distance of clamp and blade distance according to TAPPI 556 pm-95 method. Porosity was measured as *air permeance* according to Gurley (ISO 5636-5). *Fibre length distribution* was determined on an ADV-3 instrument developed by the Pulp and Paper Research Institute Bratislava, measuring fibre length in a capillary with a conductivity detector. *Chemical oxygen demand* (COD) and *Biochemical* *oxygen demand* (BOD_5) of filtrates from experimental fibre furnishes were determined according to ISO 6060, respectively EN 1899-1 methods.

RESULTS AND DISCUSSION

Influence of sugar beet pulp modification on fibre suspension and paper properties

Drainage speed of fibre suspension on the wire of a paper machine has a significant influence on paper production. Therefore we investigated the influence of original, chemically and enzymatically modified sugar beet pulp on drainage time of recovered fibres (Fig. 1). Drainage time increased with increasing content of sugar beet pulp in a mixture with recovered fibres, more with addition of enzymatically and chemically modified sugar beet pulp. At 10% content of sugar beet pulp, drainage time of the mixture increased by 7% up to 87%. At 40% content of original sugar beet pulp, drainage time increased by 14%, at addition of chemically modified sugar beet pulp by 153% and at addition of enzymatically modified sugar beet pulp by 215%. As increased drainage time reduces paper machine output, it is necessary to apply lower input of enzymatically and chemically modified sugar beet pulp. The same drainage time (40 s) as at a mixture with 40% content of original sugar beet pulp was observed at a content of 5% of chemically modified and 2.5% enzymatically modified sugar beet pulp.

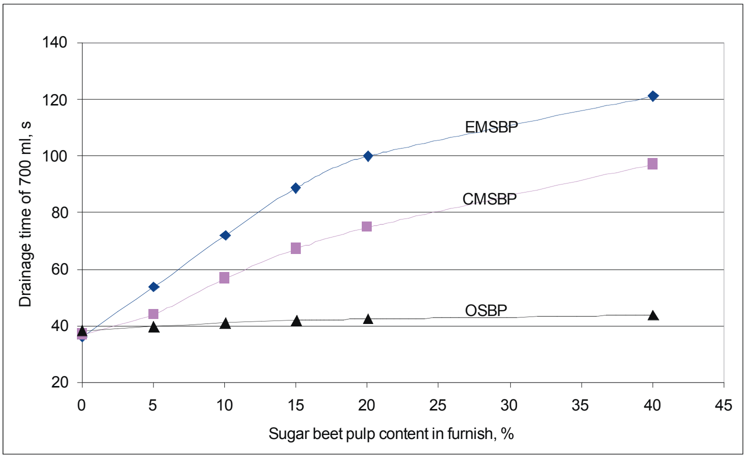

Fig. 1: Increase of drainage time of a mixture of recovered fibres with increasing content of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish

We found in our previous investigation (Fišerová et al. 2007) that fiberised sugar beet pulp in mixture with various fibres increased WRV. With increasing WRV, the dryness of paper web entering the drier part of paper machine decreases, with the result of increased energy demand in drying and lower paper production. A decrease of dryness by 1% represents a reduction of paper machine output by 3-4%. Fig. 2 shows the change of recovered fibres WRV with addition of original, chemically and enzymatically modified sugar beet pulp. With increasing content of sugar beet pulp in the mixture with recovered fibres, WRV increased to larger extent with addition of enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp addition, WRV increased by 12 to 18%. At 40% addition of original sugar beet pulp WRV increased by 68%, at addition of chemically modified sugar beet pulp by 72% and at addition of enzymatically modified sugar beet pulp by 78%. The same WRV (128%) was achieved with addition of 10% original sugar beet pulp, 9% chemically and 7% enzymatically modified sugar beet pulp.

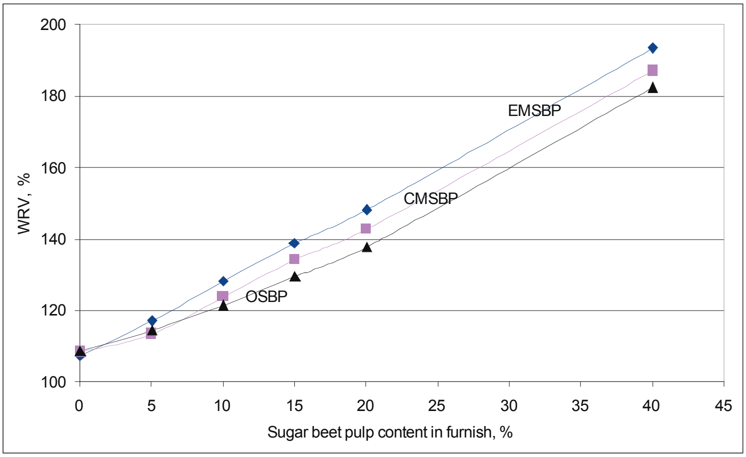

Fig. 2: Increase of WRV of a mixture of recovered fibres with increasing content of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish

Fibre length significantly influences tensile properties of paper and therefore we investigated the effect of addition of original sugar beet pulp, chemically and enzymatically modified sugar beet pulp on weighted average fibre length (Fig. 3). With increasing addition of sugar beet pulp to recovered fibre furnishes, weighted average fibre length decreased more after the addition of enzymatically and chemically modified sugar beet pulp. At 10% content of sugar beet pulp, weighted average fibre length decreased by 3.4 to 6.5%. At 40% content of original sugar beet pulp weighted average fibre length decreased by 10%, of chemically modified sugar beet pulp by 12% and enzymatically modified sugar beet pulp by 14%. The same weighted average fibre length (1.94 mm) as in a mixture containing 10% original sugar beet pulp was found at 8% content of chemically and 6% of enzymatically modified sugar beet pulp.

Strength properties of paper depend on fibrous composition of furnishes. The influence of original, chemically and enzymatically modified sugar beet pulp on tensile and burst index, internal bond strength and bending resistance is presented in figures 4 to 7.

Fig. 4 shows the influence of original, chemically and enzymatically modified sugar beet pulp addition to recovered fibres on tensile index of paper. With increasing addition of sugar beet pulp to recovered fibres, tensile index increased more with enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp content in furnish, tensile index increased by 5 to 25%. At 40% content of original sugar beet pulp tensile index increased by 11.5%, of chemically modified sugar beet pulp by 29.4% and enzymatically modified sugar beet pulp by 41.7%.

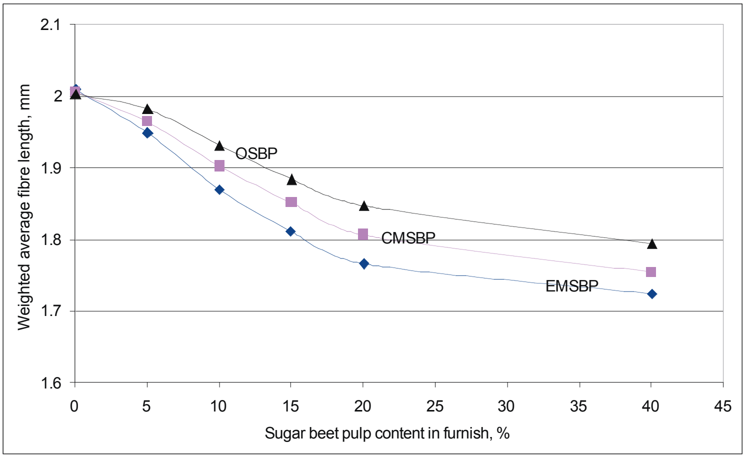

Fig. 3: Dependence of weighted average fibre length of a mixture of recovered fibres on increasing content of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish

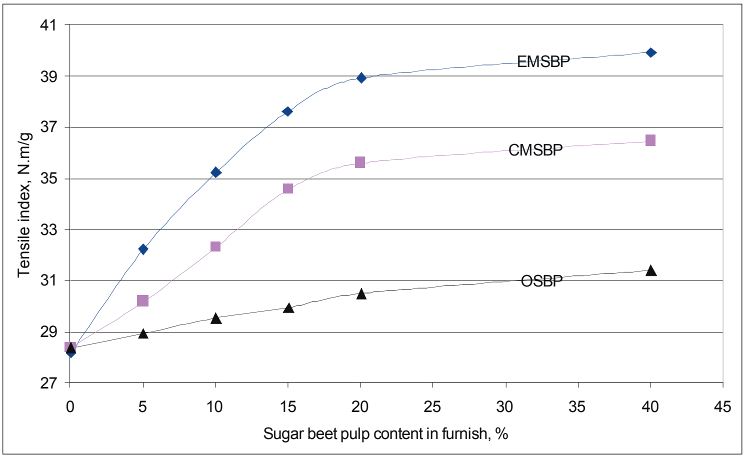

Fig. 4: Influence of original (OSPB), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp content in recovered fibres furnish on tensile index of paper

Fig. 5 shows the influence of original, chemically and enzymatically modified sugar beet pulp addition to recovered fibres on burst index of paper. With increasing content of sugar beet pulp in recovered fibres furnish burst index increased more with enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp content burst index increased by 3.5 to 15.4%. At 40% original sugar beet pulp content burst index increased by 14.3%, of chemically modified sugar beet pulp by 32.7% and enzymatically modified sugar beet pulp by 51.7%.

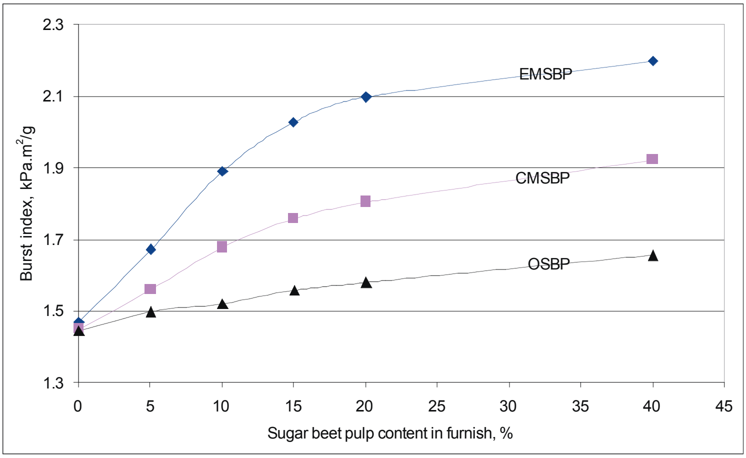

Fig. 5: Influence of original (OSPB), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp content in recovered fibres furnish on burst index of paper

Fig. 6 shows the influence of original, chemically and enzymatically modified sugar beet pulp addition to recovered fibres on internal bond strength of paper. With increasing content of sugar beet pulp in recovered fibres furnish, internal bond strength increased more with enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp content in furnish, internal bond strength increased by 10.3 to 42.2%. At 40% original sugar beet pulp content internal bond strength of paper increased by 96%, of chemically modified sugar beet pulp by 130% and enzymatically modified sugar beet pulp by 147%.

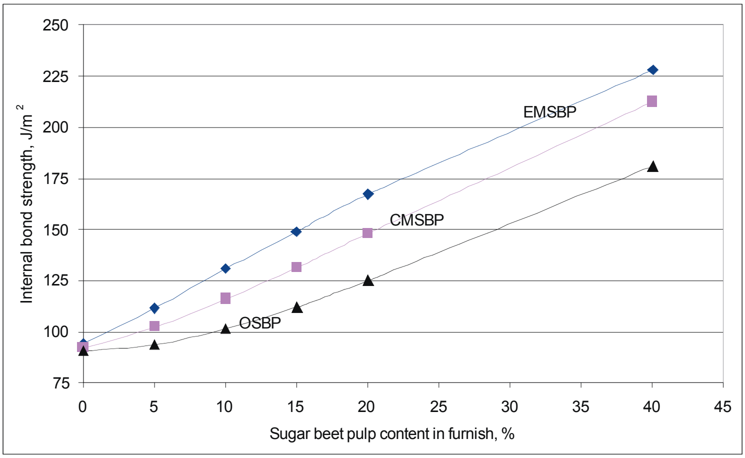

Fig. 6: Influence of original (OSPB), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp content in recovered fibres furnish on internal bond strength of paper

Fig. 7 shows the influence of original, chemically and enzymatically modified sugar beet pulp addition to recovered fibres on bending resistance of paper. With increasing addition of sugar beet pulp to recovered fibres bending resistance decreased more with enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp content bending resistance decreased by 6.8 to 10.9%. At 40% original sugar beet pulp content bending resistance decreased by 19.3%, of chemically modified sugar beet pulp by 24.3% and enzymatically modified sugar beet pulp by 27.7%.

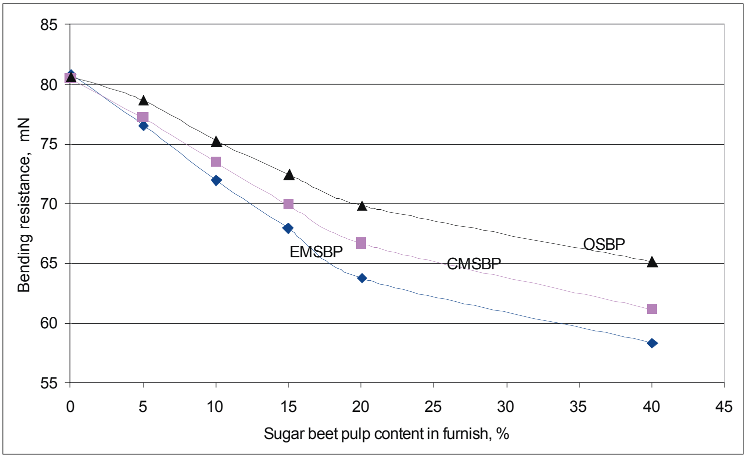

Fig. 7: Influence of original (OSPB), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp content in recovered fibres furnish on bending resistance of paper

Porosity is an important physical property of some paper grades. Porosity is determined as resistance to air permeation. A higher value means that the paper is less porous. At same conditions, porosity is influenced mainly by the radius of pores which decreases with increasing beating degree and increasing content of fillers. Fig. 8 shows the influence of addition of original, chemically and enzymatically modified sugar beet pulp to recovered fibres on air permeation resistance of paper. With increasing addition of sugar beet pulp to recovered fibres, air permeation resistance increased more with enzymatically and chemically modified sugar beet pulp. At 10% sugar beet pulp content air permeation resistance increased by 59 up to 170%. At 40% original sugar beet pulp content air permeation resistance increased by 7.4 times, at addition of chemically modified sugar beet pulp by 8.7 times and at addition of enzymatically modified sugar beet pulp by 11 times.

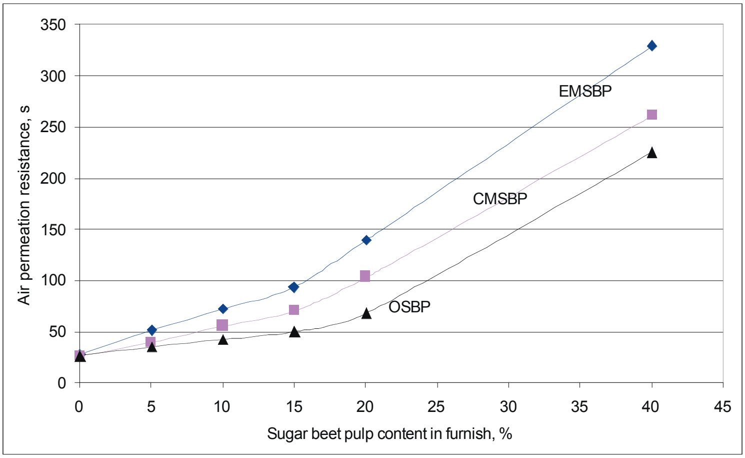

Fig. 8: Influence of original (OSPB), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp content in recovered fibres furnish on air permeation resistance of paper

The results have shown that fiberised original, chemically and enzymatically modified sugar beet pulp can be utilised in paper production as ecological materials for increase paper properties prepared from recovered fibres. Chemically modified sugar beet pulp is a fibrous residue of pectin isolation from sugar beet pulp at moderate acidity; enzymatically modified sugar beet pulp is a fibrous residue of L-arabinose isolation. By the application of these fibrous residues in paper production, a higher valuation of sugar beet pulp is achieved.

The effect of sugar beet pulp on paper properties prepared from recovered fibres increases in the sequence: original, chemically and enzymatically modified sugar beet pulps. Enzymatically modified sugar beet pulp has a highly loosened structure (hydrolysis degree 32%) and has the largest alpha cellulose content (29.5%). Chemically modified sugar beet pulp has a less loosened structure (hydrolysis degree 13%) and lower alpha cellulose content (23%). Hydro mechanical forces in fiberisation influenced properties of original sugar beet pulp to a lesser extent. Original sugar beet pulp had the least accessible structure and lowest alpha cellulose content (18.2%).

The addition of sugar beet pulp worsened the drainage time of suspensions, increased WRV and reduced bending resistance and porosity. Consequently, optimum content of fiberised original sugar beet pulp in a mixture with recovered fibres is 15-20%, of chemically modified sugar beet pulp 10-15% and of enzymatically modified sugar beet pulp 5-10%.

From all tested paper strength properties, sugar beet pulps increased the internal bond strength characterising the energy required to destruct fibre to fibre bonds to the greatest extent. At optimum content of original sugar beet pulp, internal bond strength increased by 20-34%, of chemically modified sugar beet pulp by 27-41% and of enzymatically modified sugar beet pulp by 21.5-40%. From these results it can be concluded that enzymatically modified sugar beet pulp creates more bond between wood fibres than chemically modified and original sugar beet pulp.

Comparison of the influence of sugar beet pulp addition and beating of recovered fibres on properties of suspension and paper

Addition of fiberised sugar beet pulp to various pulps had a similar effect on some suspension and paper properties as beating of pulps. Drainage time and WRV of suspension increased.

In the same way paper strength properties, such as tensile and burst index and internal bond strength, increased with increasing sugar beet pulp content. The influence of recovered fibres beating on internal bond strength of paper was compared with the increase of internal bond strength caused by addition of original, chemically and enzymatically modified sugar beet pulp to recovered fibres (Fig. 9-11).

On Fig. 9, the relationship between internal bond strength of paper and drainage time of recovered fibres suspension containing 0, 5, 10, 15, 20 and 40% original, chemically and enzymatically modified sugar beet pulp is compared with changes caused by beating of recovered fibres to 38, 41, 44, 48 and 51°SR. With increasing drainage time, internal bond strength of paper from recovered fibres increased. The increase of internal bond strength was more marked when increased drainage time was caused by addition of original sugar beet pulp. At same drainage time (45 s), the highest internal bond strength (181.3 J/m^2) was attained by paper containing 40% of original sugar beet pulp, paper from recovered fibres beaten to 45°SR (143 J/m^2), paper containing 5% of chemically modified sugar beet pulp and paper with 2% content of enzymatically modified sugar beet pulp (104 J/m^2).

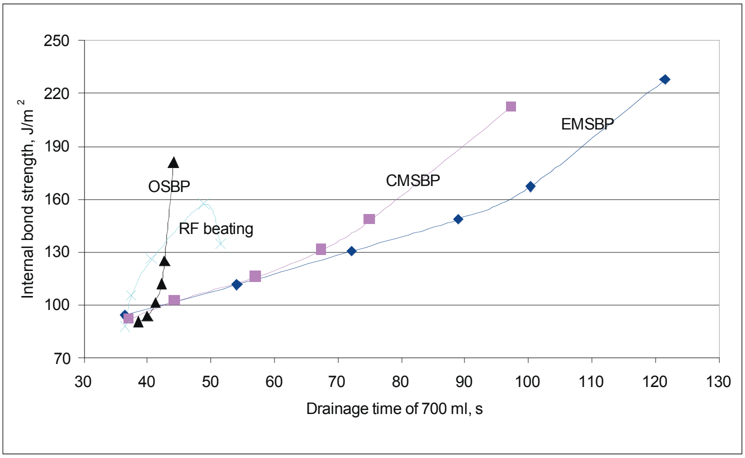

Fig. 9: Relationship between internal bond strength of paper and drainage time of recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish is compared with changes resulting from recovered fibres (RF) beating to 38, 41, 44, 48 and 51°SR

On Fig. 10, the dependence of internal bond strength of paper from recovered fibres on the content of original, chemically and enzymatically modified sugar beet pulp is compared with changes caused by beating of recovered fibres in relation to WRV. With increasing WRV internal bond strength increased more when increased WRV was a result of recovered fibres beating rather than that of addition of sugar beet pulp. At same WRV (120%), the highest internal bond strength had paper from recovered fibres beaten to 48°SR (158 J/m^2), followed by paper containing 6.5% enzymatically modified sugar beet pulp (112 J/m^2), by paper containing 8% of chemically modified sugar beet pulp (112 J/m^2) and by paper containing 9.5% original sugar beet pulp (100 J/m^2).

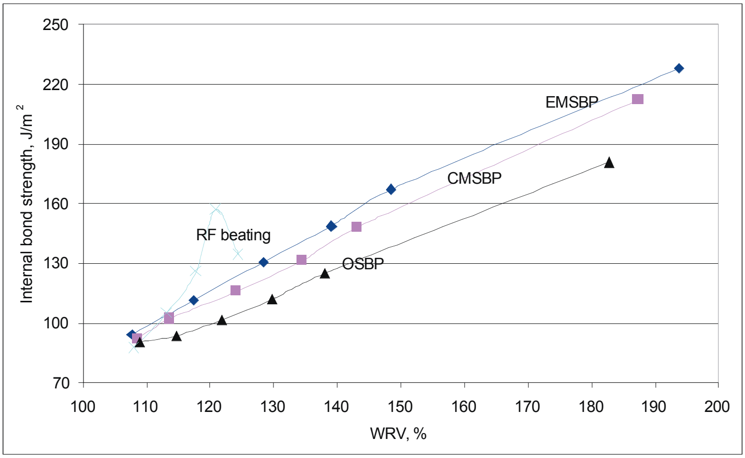

Fig. 10: Relationship between internal bond strength of paper and WRV of recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish is compared with changes resulting from recovered fibres (RF) beating to 38, 41, 44, 48 and 510 SR

On Fig. 11, the relationship between internal bond strength and air permeation resistance of paper from recovered fibres containing original, chemically and enzymatically modified sugar beet pulp is compared with changes caused by beating of recovered fibres. With increasing air permeation resistance of paper, internal bond strength increased more by beating recovered fibres than by addition adding sugar beet pulp. At same air permeation resistance (63 s), the highest internal bond strength (158 J/m^2) was achieved by beating of recovered fibres to 48°SR followed by paper containing 8% of enzymatically modified sugar beet pulp, by paper containing 12% of chemically modified sugar beet pulp and by paper containing 19% of original sugar beet pulp (126 J/m^2).

At same drainage time, WRV and air permeation resistance internal bond strength of paper increased more by beating of recovered fibres resulting in internal and external fibrillation of fibres than by addition of fiberised sugar beet pulp.

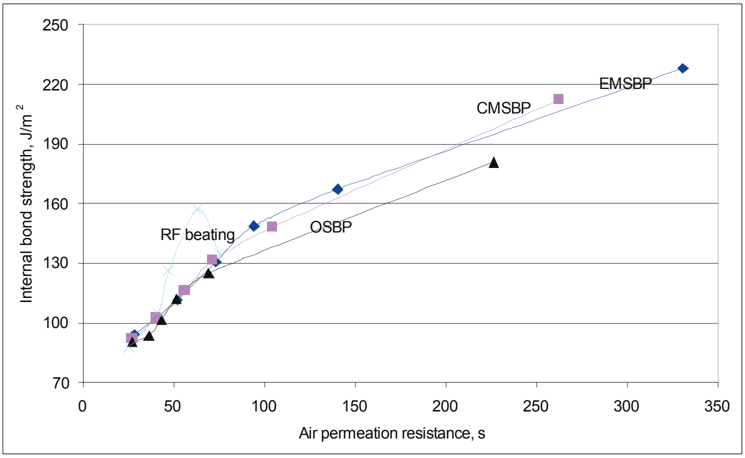

Fig. 11: Relationship between internal bond strength and air permeation resistance of papers prepared from recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish is compared with changes resulting from recovered fibres (RF) beating to 38, 41, 44, 48 and 510 SR

The influence of retention and drainage system on suspension and paper properties

As presented above, drainage time significantly increased with increasing content of original, chemically and enzymatically modified sugar beet pulp. Therefore, attention was given to the improvement of suspension drainage. Based on laboratory experiments, an optimal three-component retention and drainage system was selected for mixtures of recovered fibres with original, chemically and enzymatically modified sugar beet pulps. The retention and drainage system consisting of aluminium sulphate, cationic and anionic polyacryl amide based flocculants improved drainage, strength, formation and porosity of paper from recovered fibres with addition of sugar beet pulp (Gigac and Fišerová 2008).

The influence of the retention and drainage system on drainage time, WRV, air permeation resistance and internal bond strength of paper from recovered fibres with addition of original, chemically and enzymatically modified sugar beet pulp is presented on Fig. 12-14.

Fig. 12 illustrates a significant reduction of drainage time of a suspension consisting of recovered fibres and sugar beet pulp by the retention and drainage system. Higher internal bond strength of paper was achieved at same content of original, chemically and enzymatically modified sugar beet pulp in a mixture with recovered fibres. Drainage time of recovered fibres suspensions with addition of chemically and enzymatically modified sugar beet pulp and application of the retention and drainage system was only slightly longer than of suspensions with addition of original sugar beet pulp. Without application of the drainage and retention system, drainage time differences at same sugar beet content were significantly higher. Significantly lower was the drainage time of mixtures with addition of original sugar beet pulp even without application of the drainage and retention system when compared with addition of chemically and enzymatically modified sugar beet pulps. Drainage time of recovered fibres mixture with enzymatically modified sugar beet pulp was the longest. Drainage time of all mixtures of recovered fibres with sugar beet pulps with the application of the drainage and retention system was shorter than drainage time of recovered fibres without application of the retention and drainage system.

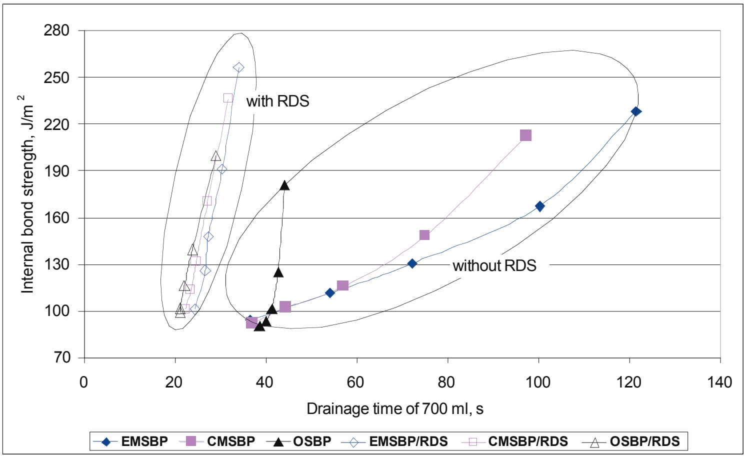

Fig. 12: Relationship between internal bond strength of paper and drainage time of recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish with and without retention and drainage system (RDS)

Fig. 13 shows the change of internal bond strength of paper related to WRV of recovered fibres with addition of original, chemically and enzymatically modified sugar beet pulp and with and without application of the retention and drainage system. At same WRV, internal bond strength of recovered fibres mixtures with sugar beet pulp addition and application of the drainage and retention system is higher when compared with same furnish without the retention and drainage system. Application of the drainage and retention system at same sugar beet pulp content in a mixture with recovered fibres slightly increased WRV. Consequently, same WRV can be achieved with lower sugar beet pulp content in the mixture (by 2%). However, due to higher internal bond strength resulting from the application of the retention and drainage system, approximately the same level of internal bond strength remains even at lower sugar beet pulp content. Original sugar beet pulp increases WRV to lower extent than chemically and enzymatically modified sugar beet pulp.

Fig. 14 shows the relationship between internal bond strength and air permeation resistance of paper from recovered fibres with addition of original, chemically and enzymatically modified sugar beet pulp with and without application of the retention and drainage system. At same air permeation resistance, internal bond strength of papers with application of the retention and drainage system is higher.

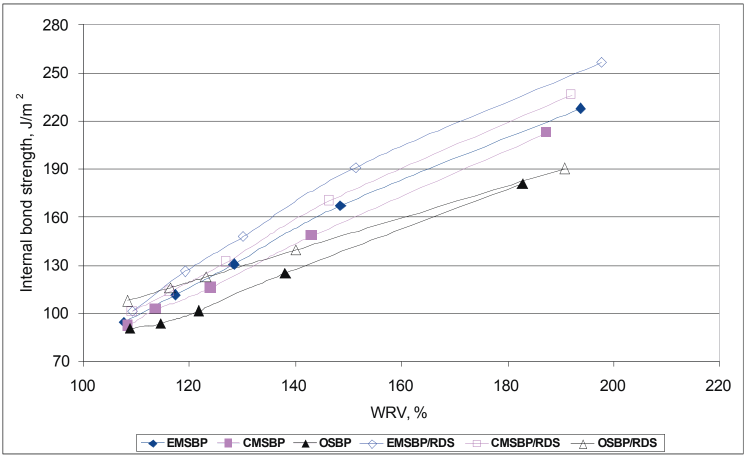

Fig. 13: Relationship between internal bond strength of paper and WRV of recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish with and without retention and drainage system (RDS)

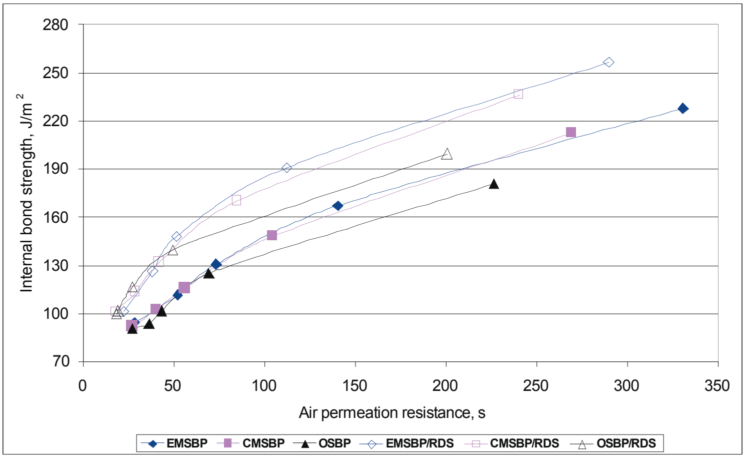

Fig. 14: Relationship between internal bond strength and air permeation resistance of paper from recovered fibres containing 0, 5, 10, 20 a 40% of original (OSBP), chemically (CMSBP) and enzymatically (EMSBP) modified sugar beet pulp in the furnish with and without retention and drainage system (RDS)

The retention and drainage system improved drainage of recovered fibres mixture with addition of original, chemically and enzymatically modified sugar beet pulp. Drainage time of a mixture containing 40% original, chemically and enzymatically modified sugar beet pulp with application of the retention and drainage system was shorter than drainage time of a recovered fibres mixture without application of the retention and drainage system. In case of the retention and drainage system application at same sugar beet pulp content in mixture with recovered fibres, internal bond strength was higher by 10.3-12.5%. Retention of fines had a positive influence on internal bond strength.

The influence of the retention and drainage system on COD and BOD_5

We investigated the influence of the retention and drainage system on the reduction of COD and BOD_5 of filtrates from recovered fibres mixtures with addition of original, chemically and enzymatically modified sugar beet pulp (Fig. 15-17). Application of the retention and drainage system significantly reduced COD and BOD_5 of filtrates from recovered fibres mixtures with addition of original sugar beet pulp (Fig. 15). Consequently, at approximately 15% original sugar beet pulp content in recovered fibres mixture, COD and BOD_5 values are on the same level as filtrates from recovered fibres without the retention and drainage system. At 40% original sugar beet pulp content in recovered fibres mixture application of the retention and drainage reduced COD by 41% and BOD_5 by 31%.

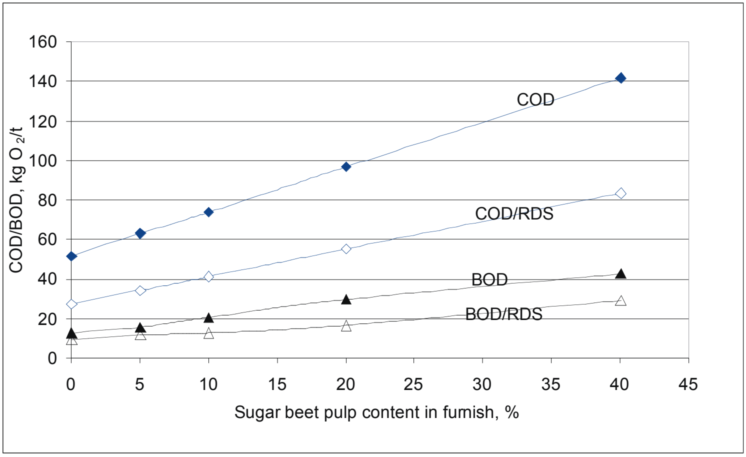

Fig. 15: COD and BOD_5 of recovered fibres filtrates with increasing content of original sugar beet pulp in the furnish with and without retention and drainage system (RDS)

Fig. 16 shows COD and BOD_5 values of filtrates from recovered fibres mixtures with addition of chemically modified sugar beet pulp with and without application of the retention and drainage system. Application of the retention and drainage system significantly reduced COD and BOD_5 of filtrates. Consequently, at approximately 15% chemically modified sugar beet pulp content in recovered fibres mixture, COD and BOD_5 values are on the same level as filtrates from recovered fibres without the retention and drainage system. At 40% chemically modified sugar beet pulp content in recovered fibres mixture, the application of the retention and drainage system reduced COD by 44% and BOD_5 by 32.5%.

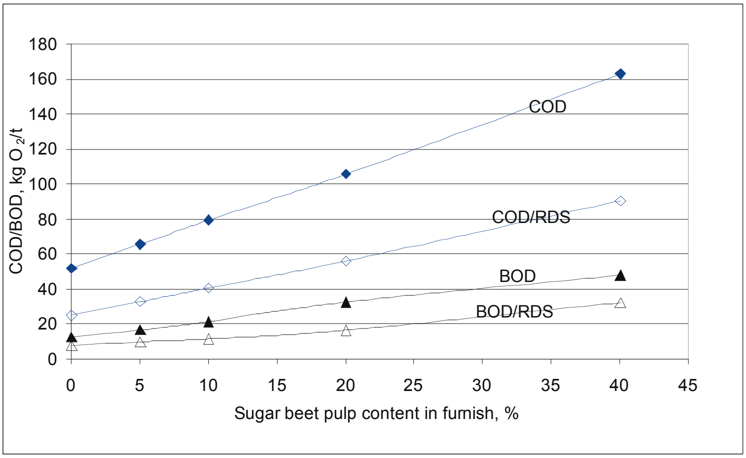

Fig. 16: COD and BOD$_5$ of recovered fibres filtrates with increasing content of chemically modified sugar beet pulp in the furnish with and without retention and drainage system (RDS)

Fig. 17 shows COD and BOD$_5$ values of filtrates from recovered fibres mixtures with addition of enzymatically modified sugar beet pulp with and without application of the retention and drainage system. The application of the retention and drainage system significantly reduced COD and BOD$_5$ of filtrates. Consequently, at approximately 15% enzymatically modified sugar beet pulp content in recovered fibres mixture, COD and BOD$_5$ values are on the same level as filtrates from recovered fibres without the retention and drainage system. At 40% enzymatically modified sugar beet pulp content in recovered fibres mixture application of the retention and drainage system reduced COD by 46% and BOD$_5$ by 34%.

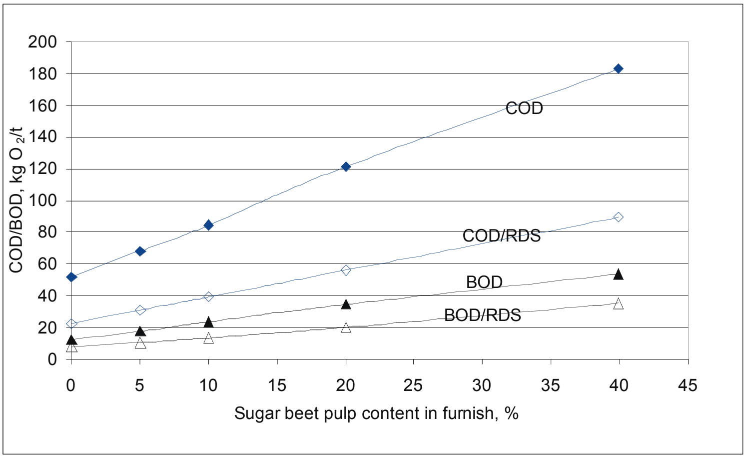

Fig. 17: COD and BOD$_5$ of recovered fibres filtrates with increasing content enzymatically modified sugar beet pulp in the furnish with and without retention and drainage system (RDS)

Increasing addition of sugar beet pulp to recovered fibres significantly increased COD and BOD_5 of filtrates. The highest increase was achieved by addition of enzymatically modified sugar beet pulp. The retention and drainage system reduced COD and BOD_5 of filtrates from suspensions of recovered fibres with addition of sugar beet pulp. The reduction was higher if enzymatically or chemically modified sugar beet pulp was added.

CONCLUSIONS

With increasing content of original, chemically and enzymatically modified sugar beet pulp in recovered fibres mixture, tensile and burst index increased as well as internal bond strength; WRV and drainage time of the mixture increased too. At same sugar beet pulp content, the increase of internal bond strength was the highest. The effect of sugar beet pulp on suspension and paper properties increased in the sequence: original, chemically and enzymatically modified sugar beet pulp.

Exploitation of enzymatically and chemically modified sugar beet pulp for an improvement of paper strength properties is of advantage from economical and ecological point of view, as by this a fibrous residue of L-arabinose and pectin production from sugar beet pulp can be utilised. Differences in the effects of sugar beet pulp are a result of different structure and chemical composition of modified sugar beet pulps which are influenced by the conditions of chemical and enzymatic hydrolysis.

The increase of internal bond strength of paper from recovered fibres with addition of sugar beet pulp is in comparison with beating of recovered fibres of disadvantage as drainage time, WRV and air permeation resistance of paper is increased simultaneously.

The application of a three-component retention and drainage system can partially eliminate the negative effect of sugar beet pulp addition and a significant reduction of COD and BOD_5 of filtrates from recovered fibres mixtures with addition of original, chemically and enzymatically modified sugar beet pulps can be achieved at the same time.

Using the retention and drainage system makes it possible to increase sugar beet pulp content in a mixture with recovered fibres by 5% without a negative influence on suspension and paper properties. Optimum content of original sugar beet pulp in the mixture with recovered fibres is 20-25%, of chemically modified sugar beet pulp 15-20% and of enzymatically modified sugar beet pulp 10-15%. Utilisation of enzymatically and chemically modified sugar beet pulp in papermaking is viable only with simultaneous application of a suitable retention and drainage system.

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