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OXIDATIVE AND REDUCTIVE BLEACHING OF DEINKED PULP

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ABSTRACT

Deinked pulps for hygienic paper production were bleached with hydrogen peroxide and sodium dithionite in single and two-stage bleaching. The brightness gain of high brightness deinked pulp in the peroxide stage was 5.7% ISO and of low brightness 4.4% ISO. In sodium dithionite stage, the brightness gain of high brightness deinked pulp was 4.0% ISO and of low brightness deinked pulp 3.8% ISO. The two-stage oxidative-reductive bleaching sequence resulted in an increase of brightness by 9.7% ISO for high brightness deinked pulp and by 9.1% ISO for low brightness deinked pulp. Brightness gain in the two-stage reductive-oxidative bleaching sequence was 6.7% ISO for high brightness deinked pulp and 5.6% ISO for low brightness deinked pulp. The coordinate b* value and yellowness of deinked pulps decreased in sodium dithionite bleaching stage more than in hydrogen peroxide stage. The two-stage oxidative-reductive bleaching sequence is more preferred than reductive-oxidative sequence regardless of the fibre composition. The tensile index and the tensile energy absorption index of deinked pulps slightly decreased after single-stage and two-stage bleaching sequences, their reduction in the peroxide stage was greater than in the dithionite stage. The fibre strength and fibre length characteristics of deinked pulps decreased after bleaching, while fibre bonding ability increased. The water absorption and bulk softness increased after bleaching, the increase was higher after peroxide stage than dithionite stage.

KEYWORDS: Deinked pulp, bleaching, hydrogen peroxide, sodium dithionite, tensile strength, water absorption, bulk softness

INTRODUCTION

In recent years, the recycled waste paper component in consumer paper products has grown globally, as resource shortages and environmental problems have become more serious. To increase the use of recycled fibres as a raw material source for production of high quality papers, there is a higher requirement for cleaner and brighter deinked pulps. While the deinking process is designed to optimise brightness gains, this process must be frequently supplemented by an additional bleaching stage or sequence. The goal of deinked pulp bleaching is to increase brightness without yellowing and to strip dyes and colours that are present in waste paper furnish (Bhardwaj and Nguyen 2005).

A recycled fibre furnish may contain a variety of pulps, for example, from high quality bleached kraft pulp to unbleached ground woods. Added to the heterogeneity of the fibre composition, the contaminants, paper additives and dyes in the original waste paper as well as the discolouration of the fibre are present as a result of the deinked process. Thus, no single bleaching sequence is sufficient for all deinked pulps.

Environmental pressures together with legislation have led to the replacement of chlorine based bleaching chemicals used in deinked pulp bleaching. The choice of bleaching chemicals depends on the quality of recycled fibres. Besides fibre composition, this also includes different types and proportions of contaminants and detrimental substances, which are present in deinked pulp. Bleaching of deinked pulps can be achieved with oxidizing or reducing agents. Among the oxidative bleaching chemicals that are available, hydrogen peroxide is most commonly used with deinked pulp (Pettit 1992). Hydrogen peroxide and sodium dithionite are used without restriction for all types of fibres. These bleaching agents may be added during deinking or in a separate bleaching stage. However, each of them bleaches the pulp by a different mechanism. The role of hydrogen peroxide in the bleaching is to improve the brightness of the pulp by modifying colour-causing groups within the fibre such as those contained in lignin. The role of sodium dithionite is to act primarily on the dye component of the pulp. Dyes are largely unaffected by peroxide bleaching but many of them can be decolourised by reductive bleaching (Hanchett 1994).

Hydrogen peroxide has the advantage of being compatible with environment, as it decomposes to water and oxygen. Therefore, strong environmental concerns make the product even more attractive as a bleaching agent for deinked pulps. Hydrogen peroxide bleaching of old corrugated containers pulp was studied (Matjacic and Moze 1998). Stabilization of peroxide systems by silicate and calcium carbonate and its application to bleaching of deinked old magazine pulp were studied (Wekesa and Ni 2003). It was found that the residual peroxide content and deinked pulp brightness increased. Hydrogen peroxide usually has little colour stripping ability when is used as deinked pulp bleaching agents (van Lierop and Liebergott 1994, Patt et al. 1996; Magnin et al. 2000).

Reductive bleaching with sodium dithionite or formamidine sulfinic acid (FAS) tends to strip the unwanted colours shades from deinked pulps more effectively than with oxidative bleaching agents (Helming et al. 1986, Naddeo et al. 1991, Angulo 1990, Dumont et al. 1994, Fluet and Shepperd 1997, Magnin et al. 2000, Carré et al. 2000). The reductive effect of the sodium dithionite during bleaching is due to its chemical transformation in aqueous solution into bisulphite ($NaHSO_3$) and into the sodium salt of the unstable formamidine sulphinic acid ($NaHSO_2$) in the presence of reducible substances. The resulting sodium salt of the sulfoxylic acid is the actual bleaching agent because the sodium bisulphide as a weak reducing agent barely influences the bleaching reaction.

The bleaching technologies of deinked pulp have moved from the hydrogen peroxide and sodium dithionite methods to sophisticated multi-stage techniques. Many of these strategies have been in response to the use of waste paper with increasing levels of contaminants and to the use of unbleached pulp grades. The sequential application of oxidative and reductive bleaching has shown promise in improving the optical properties of deinked pulp, which would then be suitable for high-brightness paper production. Two-stage bleaching usually uses an oxidative-reductive sequence (Göttsching and Pakarinen 2000). Single-stage hydrogen peroxide (Heimburger and

Tremblay 1990) and sodium dithionite and two-stage peroxide-dithionite (Joachimides and Hache 1990) were shown to be effective in newsprint and magazine grade recycled fibres. The effects of pH and hydrogen peroxide charges at the oxidative and reductive stages of two-stage bleaching of deinked old newsprint and magazine mixture were studied (Philippakopoulou and Economides 1999).

In operation, the efficiency achievable with different bleaching sequences depends less on the particular bleaching sequence than on the stock processing technology, system integration, and white water circulation and purification. For every installation, decision must be made in which sequence and chemicals bleaching will be used (Göttsching and Pakarinen 2000).

Absorbency, softness and tensile strength are generally as the most important consumer attributes of hygienic paper, the order of significance depends on end use. The properties of hygienic paper are influenced by input raw materials and manufacturing technology. Absorbency and softness are mostly affected by porosity, creping (surface properties) and furnish composition of paper. The other properties are wood species, pulping processes, stiffness, bulkiness, wet strength, basic weight, thickness etc. Several factors contribute to high hygienic paper absorbency, including the type of pulp, wetting agents, and machine adjustments (Escott et al. 1995). Absorption is directly connected to the softness, creping and bulkiness. The molecule of cellulose contains hydroxyl groups which permit it to form hydrogen bonds with water. This is the main reason of paper water absorbency. Moreover there are many microscopic spaces among cellulose fibres, where water can soak up. Softness can be improved by reducing the refining of fibrous raw material. Softness is a combination of surface smoothness, bulk and bending stiffness. Tensile strength is important for high bulk in hygienic paper converting.

The aim of this work was to compare single and two-stage bleaching processes using hydrogen peroxide and sodium dithionite as well as their influence on the properties of two types of deinked pulps, used for the production of hygienic paper.

MATERIAL AND METHODS

Materials

Deinked pulp with high brightness (70% ISO) was prepared in Metsä Tissue Slovakia mill from 80% of waste papers Group No. 3 "High grades" according to EN 643:2014 and 20% of broke from production of hygienic paper from bleached pulp. The total lignin content in deinked pulp was 5.8%.

Deinked pulp with low brightness (58% ISO) was prepared in Metsä Tissue Slovakia mill from 57% of waste papers Group No. 1 "Ordinary grades", 38% of Group No.3 "High grades" according to EN 643:2014 and 5% of cartons. The total lignin content in deinked pulp was 10.5%.

Methods

Peroxide stage (P)

The deinked pulp (DIP) was bleached with 0.5, 1.0, 1.5, 2.0 and 2.5% dosage of H_2O_2 and 0.2% chelating agent on o.d. pulp. The pH was adjusted to value 11 with NaOH. The bleaching was carried out in a sealed glass vessel at 80°C, 10% consistency and reaction time of 90 min. At the end of bleaching, the filtrates pH ranged from 9.5 to 10.5 and the residual concentration of H_2O_2 from 0.22 g L^{-1} to 0.44 g L^{-1}. After washing bleached DIP with distilled water, handsheets were prepared for analyses.

Dithionite stage (Y)

In preparation for sodium dithionite bleaching, the DIP and the vessel holding DIP were flushed with nitrogen. The sodium dithionite solution was prepared and mixed into pulp in nitrogen atmosphere. The DIP was bleached with 0.5, 1.0, 1.5, 2.0 and 2.5% dosage of $Na_2S_2O_4$ on o.d. pulp. The bleaching was carried out in a sealed glass vessel at 80°C, 10% consistency and reaction time of 90 min. At the beginning, the pH ranged from 7.0 to 7.5. After bleaching, pH of the filtrates ranged from 7.1 to 8.0. After washing bleached DIP with distilled water, handsheets were prepared for analyses.

Two-stage PY or YP bleaching

In the single P or Y stage, bleached DIPs with 1.5% dosage of H_2O_2 or $Na_2S_2O_4$ were prepared. These bleached DIPs in single-stages were used in the second bleaching stage P or Y. The conditions in these stages were the same as in the single-stages. At the end of bleaching with $Na_2S_2O_4$ in PY sequence, the pH of the filtrates ranged from 6.7 to 8.2. After bleaching with H_2O_2 in YP sequence, the pH of the filtrates ranged from 9.4 to 10.4 and the concentration of residual peroxide ranged from 0.02 g L^{-1} to 0.07 g L^{-1}. After washing bleached DIP with distilled water, handsheets were prepared for analyses.

Analyses

The content of acid-insoluble (Klason) and acid-soluble lignin in deinked pulp was determined according TAPPI T 222 om-06 and TAPPI UM 250, respectively. The handsheets (60 $g{\cdot}m^{-2}$) from deinked pulp before and after bleaching were prepared according to ISO 5269-2:2004 standard. Brightness was determined according to ISO 2470-1:2016, colour coordinate b* according to ISO 5631-1:2015 and yellowness according to DIN 6167 standard. The tensile index and tensile energy absorption index were determined according to ISO 1924-2:2008. Fibre characteristics such as fibre strength, fibre length and fibre bonding ability, expressed as FS number, L number and B number were measured with the PULMAC INC Zero-Span 1000 instrument according to ISO 15361:2000. Water absorption after immersion was determined according to ISO 5637:2015 and air permeability (Gurley) according to ISO 5636-5:2013 standard. The bulk softness was calculated from the bending stiffness determined at 15° and 10 mm distance between the clamp and the knife-edge according to the TAPPI T 556 pm-95 method.

RESULTS AND DISCUSSION

Comparison of single-stage (P, Y) bleaching

The current trend in the use of recycled fibres for the production of high quality papers requires improvement of the optical properties of deinked pulps (DIP), which is achieved by bleaching. The bleaching of DIP is an important and often vital process stage in the processing of recycled fibres. Waste papers contain different types and levels of bleached and unbleached pulps and were printed with colours of different composition.

The bleaching effect of the oxidizing and reducing agents depends on the pulp type and on the nature of the colour components in the deinked pulp because some of them are removed using oxidizing and other reducing agents.

High brightness (70% ISO) and low brightness (58% ISO) DIPs were bleached with 0.5% up to 2.5% dosages of hydrogen peroxide and sodium dithionite. The effect of hydrogen peroxide and sodium dithionite dosage on brightness is shown in Fig. 1. The brightness increased initially with increasing of bleaching agent dosage, but the gain became insignificant, if the bleaching agent dosage exceeded 1.5%. The reactions of chromophores elimination or formation may be viewed as occurring co-currently with the dissolution of hemicelluloses, which determine the outcome of bleaching (Bhardwaj and Nguyen 2005). With 1.5% hydrogen peroxide dosage, the brightness of high brightness DIP was 75.5% ISO and brightness of low brightness DIP was 62.1% ISO. After sodium dithionite bleaching, the brightness of high brightness DIP was 73.8% ISO and brightness of low brightness DIP was 61.5% ISO.

The brightness gain of the high brightness DIP in the P stage was 5.7% ISO and of low brightness DIP was 4.4% ISO. The brightness gain of the high brightness DIP in the Y stage was 4.0% ISO and of low brightness DIP was 3.8% ISO.

In single-stage bleaching stage of high brightness DIP with optimum 1.5% dosage of hydrogen peroxide, by 1.7% ISO higher brightness was achieved than with sodium dithionite, while when bleaching of low brightness DIP, only by 0.6% ISO higher brightness was achieved (Fig. 1).

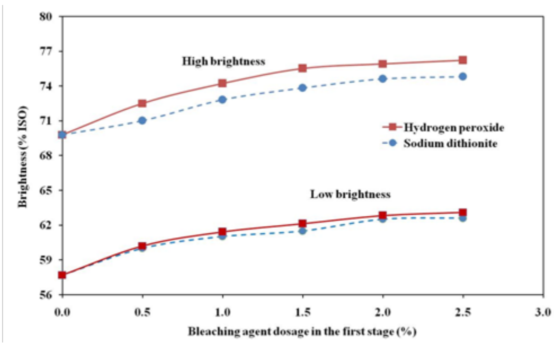

Fig. 1: Effect of hydrogen peroxide or sodium dithionite dosage in the first stage on brightness of high and low brightness deinked pulps.

The paper is able to reflect or absorb the light of certain wavelengths. CIELAB system allows to express colour paper and colour deviation between two papers, as closely as possible to respond visual perception. The colour is defined by the coordinates L*, a* and b*, where the positive value of coordinates b* represents yellow colour and the negative value blue colour.

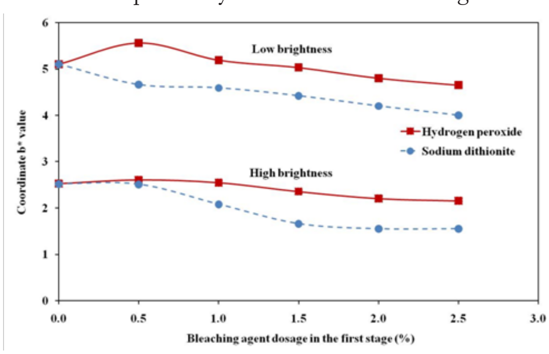

Fig. 2: Effect of hydrogen peroxide or sodium dithionite dosage in the first stage on coordinate b value of high and low brightness deinked pulps.*

High and low brightness DIPs are used for hygienic paper production. The manufacturers are try to get yellow shade of papers from high quality secondary fibres similar to that of papers from pulps, where the coordinate value b* value should be at least +2. The effect of hydrogen peroxide and sodium dithionite on coordinate b* value of DIPs was determined (Fig. 2). The coordinate b* value of high brightness DIP was +2.5 and of low brightness DIP was +5.1. The higher coordinate b* value is associated with the higher content of lignin in the low brightness DIP, as it contains a high proportion of mechanical pulp. The lignin content in the low brightness deinked pulp was 10% while in the high brightness DIP only 5.8%.

With increasing dosage of bleaching agents, the coordinate b* value decreased more with dosage of sodium dithionite than with hydrogen peroxide. The coordinate b* value at 1.5% hydrogen peroxide dosage dropped for high brightness deinked pulp from +2.5 to +2.3 (by 8%) and for low brightness deinked pulp from +5.1 to +4.9 (by 4%). With the same sodium dithionite dosage, the coordinate b* value dropped for high brightness DIP to +1.8 (by 28%) and for low brightness deinked pulp to +4.5 (by 12%). The coordinate b* value decreased more at the same bleaching agent dosage for high brightness DIP than for low brightness DIP.

Yellowness is defined as a result of measurement of the degree to which the colour of a surface is shifted from preferred white (or colourless) towards yellow. High quality DIPs should have a yellowness at least 4% to achieve a shade similar to that of pulp fibres.

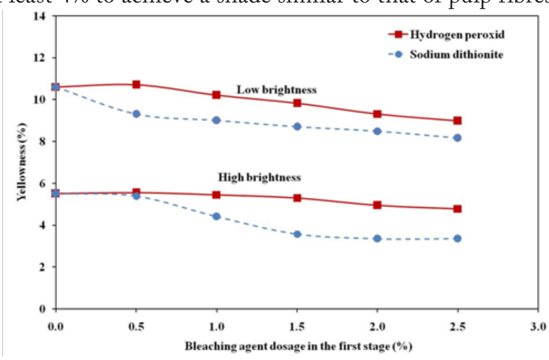

Fig. 3: Effect of hydrogen peroxide or sodium dithionite dosage in the first stage on yellowness of high and low brightness deinked pulps.

In Fig. 3, the effect of hydrogen peroxide and sodium dithionite dosage on yellowness of high and low brightness DIPs is shown. With increasing dosage of bleaching agents, the yellowness decreased more with dosage of sodium dithionite than with hydrogen peroxide, analogously as in the case of coordinate b* (Fig. 2). The yellowness at 1.5% hydrogen peroxide dosage dropped for high brightness DIP from 5.5 to 5.3% (by 4%) and for low brightness DIP from 10.6 to 9.8% (by 7.5%). With the same sodium dithionite dosage, the yellowness for high brightness DIP dropped to 3.6% (by 34%) and for low brightness DIP to 8.7% (by 18%). The yellowness decreased at the same bleaching agents more for high brightness DIP than for low brightness DIP as in the case of coordinate b* value (Fig. 2). The decrease of coordinate b* value and yellowness in dithionite bleaching stage was greater than in the peroxide stage, which is associated with a lower pH as the higher pH promotes the formation of coloured chromophores.

Comparison of two-stage (PY, YP) bleaching sequences

Considering to the heterogeneity of the fibre composition and the presence of various contaminants, such as paper additives and dyes in the waste paper, in many cases the single stage bleaching process is not sufficient. Therefore, two-stage bleaching with hydrogen peroxide and sodium dithionite in different order were tested. For the second bleaching stage, DIPs bleached with 1.5% dosage of hydrogen peroxide or sodium dithionite were used. With increasing dosage of hydrogen peroxide or sodium dithionite in the second stage, the brightness increased more with dosage of hydrogen peroxide than with sodium dithionite, the most to 1.5% dosage (Fig. 4). The brightness increased more in the two-stage PY sequence than in the YP sequence. In the second stage of PY sequence with 1.5% sodium dithionite dosage, the brightness of high brightness DIP increased by 4% ISO and low brightness DIP by 1.8% ISO. In the second stage of YP sequence with 1.5% hydrogen peroxide dosage, the brightness of high brightness DIP increased by 2.7% ISO and low brightness DIP by 1.8% ISO.

The two-stage oxidative-reductive bleaching sequence PY resulted in an increase of brightness of high brightness DIP by 9.7% ISO and of low brightness deinked pulp by 9.1% ISO. The two-stage reductive-oxidative sequence YP resulted in an increase of brightness of high brightness DIP by 6.7% ISO and of low brightness DIP by 5.6% ISO. Based on the achieved brightness, the PY sequence is more advantageous than YP sequence for bleaching process of DIP. The effect of the fibre composition does not play a significant role.

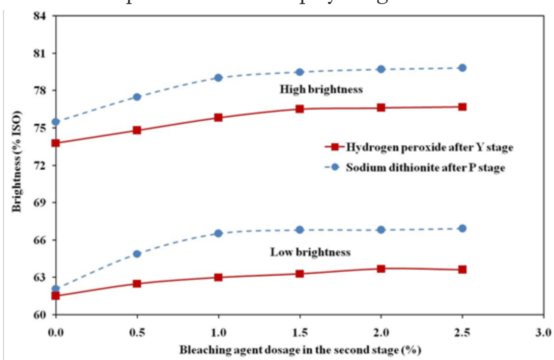

Fig. 4: Effect of hydrogen peroxide or sodium dithionite dosage in the second stage on brightness of high and low brightness deinked pulps.

Fig. 5 presents the effect of hydrogen peroxide and sodium dithionite dosage in the second stage of PY or YP bleaching sequence on coordinate b* value of high brightness and low brightness DIP. The coordinate b* value increased with hydrogen peroxide dosage in the second stage of YP sequence, while with increasing of sodium dithionite in the second stage of PY dosage decreased.

The effect of hydrogen peroxide and sodium dithionite dosage in the second bleaching stage of PY and YP sequences on yellowness of high and low brightness DIPs is shown in Fig. 6. The yellowness increased with hydrogen peroxide dosage while with sodium dithionite dosage decreased analogously as the coordinate b* value (Fig. 5). The increase of yellowness and coordinate b* value in P stage is associated with a higher pH (10) compared to Y stage (7.5).

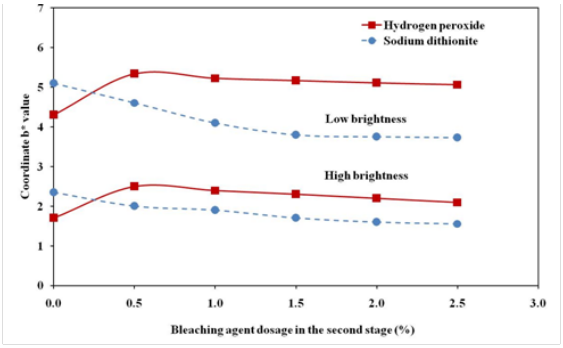

Fig. 5: Effect of hydrogen peroxide or sodium dithionite dosage in the second stage on coordinate b value of high and low brightness deinked pulps.*

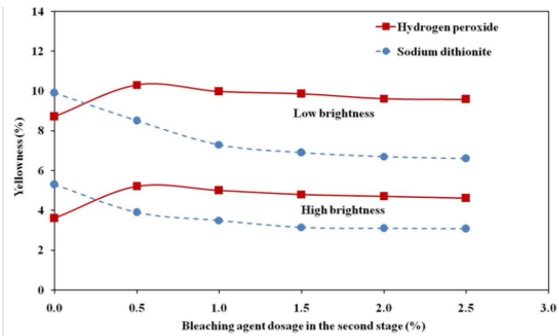

Fig. 6: Effect of hydrogen peroxide or sodium dithionite dosage in the second stage on yellowness of high and low brightness deinked pulps.

Influence of bleaching on properties and fibre characteristics

Comparison of the tensile strength and functional properties as well as the fibre characteristics of high and low brightness DIPs (Reference), intended for the production of hygienic paper, before and after single and two-stage bleaching was performed. In individual stages, 1.5% of bleaching agents dosage was used.

Tensile strength properties

The tensile strength is one of the most important basic physical properties of paper. Tensile strength represents the maximum tensile force developed in a test specimen before rupture on a tensile test carried to rupture under prescribed conditions. The tensile strength depends on fibre strength, fibre length and fibres bonding ability. Fig. 7 shows the tensile index of unbleached and bleached DIPs. The tensile index of high brightness DIP was by 37% lower in comparison with the tensile index of low brightness DIP. Tensile indexes of DIPs decreased in bleaching by 5.8% to 8.9%. Tensile indexes of deinked pulps decreased in the P stage by 1.0 to 1.7% more than in the Y stage.

In Fig. 8, the tensile energy absorption indexes of DIPs before and after single stage as well as two-stage sequences bleaching are compared. Tensile energy absorption represents the work done when a specimen is stressed to rupture in tension under prescribed conditions as measured by the integral of the tensile strength over the range of tensile strain from zero to maximum strain. The tensile energy absorption index of high brightness DIP was by 17% lower than tensile absorption energy index of low brightness DIP. Tensile energy absorption indexes of DIPs decreased in bleaching by 4.5% to 10.0%. Tensile energy absorption indexes of DIPs decreased in the P stage by 3% more than in the Y stage because at alkaline pH there is a more pronounced degradation of polysaccharides than at neutral pH.

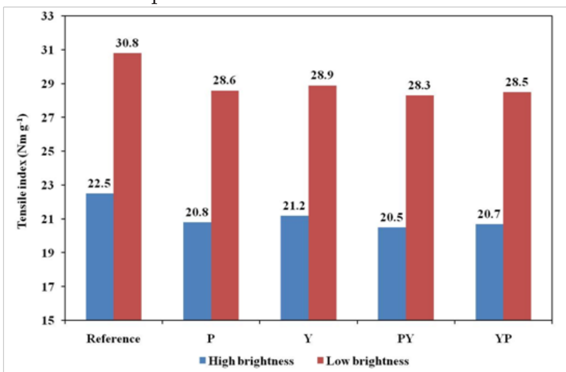

Fig. 7: Tensile index of high and low brightness deinked pulps before (Reference) and after bleaching.

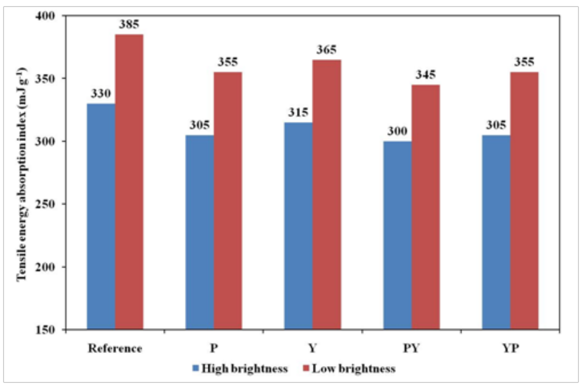

Fig. 8: Tensile energy absorption index of high and low brightness deinked pulp before (Reference) and after bleaching.

The evaluation of tensile index and tensile energy absorption index showed that the tensile strength properties of low brightness DIP were higher than of high brightness DIP. Higher strength properties of low brightness deinked pulp are mainly related to the higher beating degree (30 °SR) compared to high brightness deinked pulp (17 °SR). The high brightness DIP was prepared from wood free waste papers and broke from bleached pulp processing, while low brightness DIP were prepared mainly from lower quality waste papers, such mixed papers, cardboard, smaller proportion of wood free printing papers and documents.

After single (P, Y) and two-stage (PY, YP) bleaching sequence, the tensile index and the tensile energy absorption index of high and low brightness DIP slightly decreased. The tensile strength properties of DIPs decreased more in the P bleaching than in the Y stage.

Fibre characteristics

The evaluation of strength properties of handsheets by conventional methods is not suitable for their detailed specification because the fibre strength and the bonding between the fibres are not determined separately.

The Pulmac zero-span tester was used to determine fibre strength (FS number), fibre length (L number) and fibres bonding ability (B number) of the DIPs before and after bleaching. FS number does not express the true fibre tensile strength but is merely an indicator. L number is also only indicator of fibre length and B number is indicator of fibre bonding ability.

In Fig. 9, the fibre strength (FS number) of the low and high brightness DIPs before and after bleaching is compared. Fibre strength of high brightness DIP was by 4.5% higher than low brightness DIP. Fibre strength of DIPs decreased in bleaching by 3.3% to 9.8%. Fibre strength of DIPs decreased in the P stage by 0.7 to 4.8% more than in the Y stage. Fibre strength decrease in P stage was more pronounced for low brightness DIP.

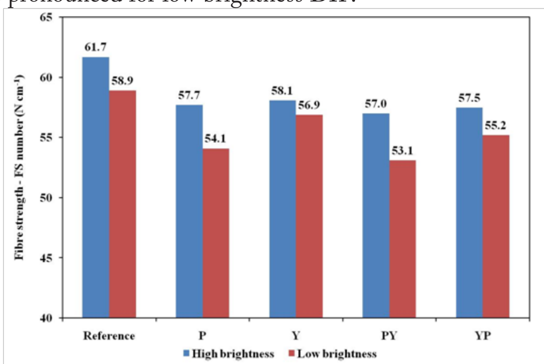

Fig. 9: Fibre strength of high and low brightness deinked pulp before (Reference) and after bleaching.

The influence of bleaching on the fibre length is presented in Fig. 10. The high brightness DIP had by 20% longer fibres than low brightness DIP. Fibre length of DIPs decreased in bleaching by 2.8 to 10.3%. Fibre length of DIPs decreased in the P stage by 2.8 to 3.4% more than in the Y stage. Fibre length decrease in P stage was more pronounced for low brightness DIP, similarly as in the case of fibre strength (Fig. 9). This can be explained by the fact that low brightness DIP has been more degraded, since it was produced from lower quality waste papers as high brightness DIP.

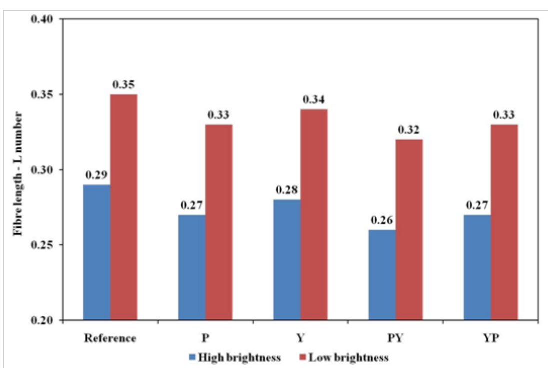

Fig. 10: Fibre length of high and low brightness deinked pulp before (Reference) and after bleaching.

In Fig. 11, the fibre bonding ability (B numbers) of the low and high brightness DIPs before and after bleaching is compared. Fibre bonding ability of low brightness deinked pulp was by 6.2% higher than high brightness deinked pulp. Higher fibre bonding ability of low brightness DIP is mainly related to the higher beating degree (30 °SR) compared to high brightness DIP (17 °SR). Fibre bonding ability of DIPs increased in bleaching by 6.6 to 16.7%. Fibre bonding ability of DIPs increased in the P stage by 3.1 to 3.7% more than in the Y stage. Fibre bonding ability increase in P stage was more pronounced for low brightness DIP.

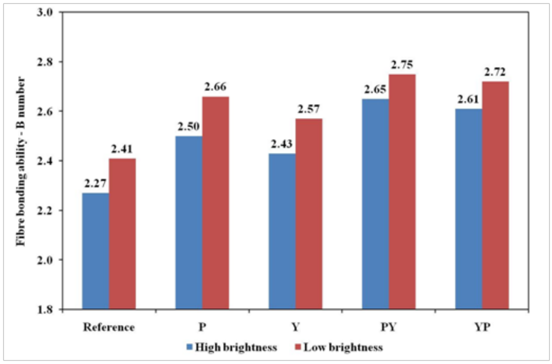

Fig. 11: Fibre bonding ability of high and low brightness deinked pulp before (Reference) and after bleaching.

After bleaching, the fibre strength and fibre length of DIPs decreased, while fibre bonding ability increased. Despite of, that the lower fibre strength and fibre length were partially compensated with higher fibre bonding ability, the tensile strength was slightly decreased. These results are in accordance with those that have been achieved in the bleaching of pulps (Fišerová and Gigac 2010).

Functional properties

The main property of hygienic paper is the absorption. This property is directly related to the softness and bulk, although not always in the same way. The ability to absorb liquids is a common requirement of all creped hygienic products, such as towels, facial tis¬sue, toilet tissue, paper diapers, or hospital bed pads. In Fig. 12, the water absorption of the low and high brightness DIPs before and after bleaching is compared. Water absorption of high brightness DIP was by 6.7% higher than low brightness DIP. Water absorption of DIPs increased after bleaching by 10% to 26%. Water absorption of DIPs increased in the P stage by 10% more than in the Y stage.

After absorption, softness is the most significant property of hygienic paper. Softness is a complex phenomenon, which incorporates many aspects of human interaction with the hygienic product. It is believed to be influenced by both bulk and surface softness. The perception of bulk softness is discerned by gentle crumpling or folding of the hygienic paper, and is inversely related to flexural rigidity or bending stiffness.

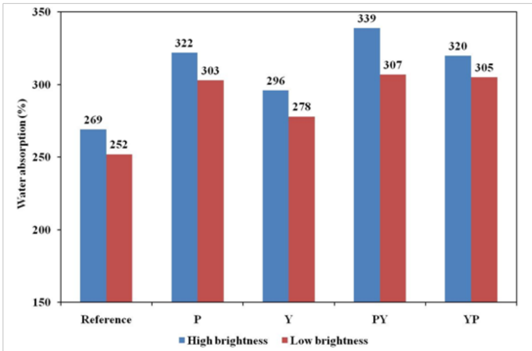

Fig. 12: Water absorption of high and low brightness deinked pulp before (Reference) and after bleaching.

The influence of bleaching on the bulk softness of DIPs is presented in Fig. 13. Bulk softness of high brightness DIP was by 10% higher than low brightness DIP. Bulk softness of DIPs increased after bleaching by 3.6 to 10.3%. Bulk softness increased in the P stage by 0.6 % more than in the Y stage.

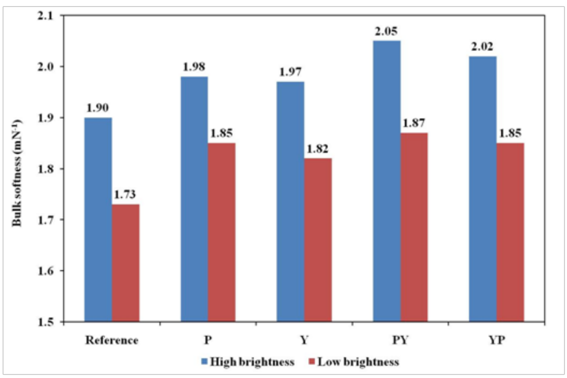

Fig. 13: Bulk softness of high and low brightness deinked pulp before (Reference) and after bleaching.

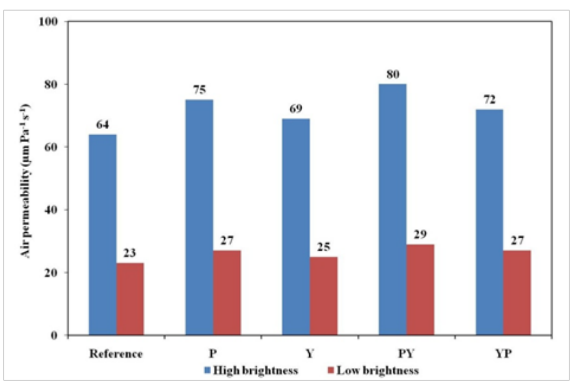

Fig. 14: Air permeability of high and low brightness deinked pulp before (Reference) and after bleaching.

Absorbency and softness are mostly affected by the porosity of paper. High porosity helps to gain elevated absorbency and softness. In Fig. 14, the air permeability of the low and high brightness DIPs before and after bleaching is compared. Air permeability of high brightness DIP was by 178% higher than low brightness DIP. Air permeability of DIPs increased after bleaching by 7.8% to 26%. Air permeability of DIPs increased in the P stage by 9% more than in the Y stage. The increase of air permeability after bleaching of DIPs is in accordance with increased water absorption (Fig. 12) and bulk softness (Fig. 13).

CONCLUSIONS

The brightness of DIPs in single-stage bleaching increased significantly with hydrogen peroxide and sodium dithionite dosage up to 1.5%. The brightness gain in the P stage was higher than in Y stage. At the same bleaching chemical dosage, the brightness gain of the high brightness DIP was higher than the low brightness DIP. With increasing dosage of bleaching agents, the coordinate b* value and yellowness decreased with dosage of sodium dithionite more than with hydrogen peroxide.

In the second stage of PY and YP bleaching sequences, the brightness of DIPs increased significantly with hydrogen peroxide and sodium dithionite dosage up to 1.5%. The brightness increased more with dosage of hydrogen peroxide than with sodium dithionite. The two-stage peroxide-dithionite (PY) sequence enabled to achieve for high brightness DIP by 3.0% higher brightness and for low brightness DIP by 3.5% ISO as was achieved by peroxide-dithionite (YP) sequence. The coordinate b* value and yellowness increased with hydrogen peroxide dosage in the second stage of YP sequence, while with increasing of sodium dithionite dosage in the second stage of PY sequence decreased. The PY sequence is more advantageous than YP sequence for bleaching of DIP. The effect of the fibre composition does not play a significant role.

After single-stage (P, Y) and two-stage (PY, YP) bleaching sequences, the tensile index and the tensile energy absorption index of DIPs slightly decreased, the reduction in the P stage was greater than in the Y stage.

The fibre strength and fibre length of DIPs decreased after bleaching, while fibre bonding ability increased. Despite of, that the lower fibre strength and fibre length were partially compensated with higher fibre bonding ability, the tensile strength slightly decreased.

The functional properties of hygienic paper, water absorbency and bulk softness after bleaching of DIPs increased. Water absorption and bulk softness increased after P stage more than after Y stage. Air permeability of DIPs increased after bleaching which is in accordance with increased water absorption and bulk softness.

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