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The Effects of Paper Recycling and its Environmental Impact

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1. Introduction

It is well known the paper production (likewise the other brands of industry) has enormous effects on the environment. The using and processing of raw materials has a variety of negative effects on the environment.

At the other hand there are technologies which can moderate the negative impacts on the environment and they also have a positive economical effect. One of these processes is the recycling, which is not only the next use of the wastes. The main benefit of the recycling is a double decrease of the environment loading, known as an environmental impact reducing. From the first view point, the natural resources conserves at side of the manufacturing process inputs, from the second view point, the harmful compounds amount leaking to the environment decreases at side of the manufacturing process outputs.

The paper production from the recycled fibers consumes less energy; conserves the natural resources viz. wood and decreases the environmental pollution. The conflict between economic optimization and environmental protection has received wide attention in recent research programs for waste management system planning. This has also resulted in a set of new waste management goals in reverse logistics system planning. Pati et al. (2008) have proposed a mixed integer goal programming (MIGP) model to capture the inter-relationships among the paper recycling network system. Use of this model can bring indirectly benefit to the environment as well as improve the quality of waste paper reaching the recycling unit.

In 2005, the total production of paper in Europe was 99.3 million tonnes which generated 11 million tonnes of waste, representing about 11% in relation to the total paper production. The production of recycled paper, during the same period, was 47.3 million tonnes generating 7.7 million tonnes of solid waste (about 70% of total generated waste in papermaking) which represents 16% of the total production from this raw material (CEPI 2006).

The consumption of recovered paper has been in continuous growth during the past decades. According to the Confederation of European Paper Industries (CEPI), the use of recovered paper was almost even with the use of virgin fiber in 2005. This development has been boosted by technological progress and the good price competitiveness of recycled fiber, but also by environmental awareness – at both the producer and consumer ends – and regulation that has influenced the demand for recovered paper. The European paper industry suffered a very difficult year in 2009 during which the industry encountered more down-time and capacity closures as a result of the weakened global economy. Recovered paper utilisation in Europe decreased in 2009, but exports of recovered paper to countries outside CEPI continued to rise, especially to Asian markets (96.3%). However, recycling rate expressed as "volume of paper recycling/volume of paper consumption" resulted in a record high 72.2% recycling rate after having reached 66.7% the year before (Fig. 1) (Hujala et al. 2010; CEPI 2006; European Declaration on Paper Recycling 2010; Huhtala & Samakovlis 2002; CEPI Annual Statistic 2010).

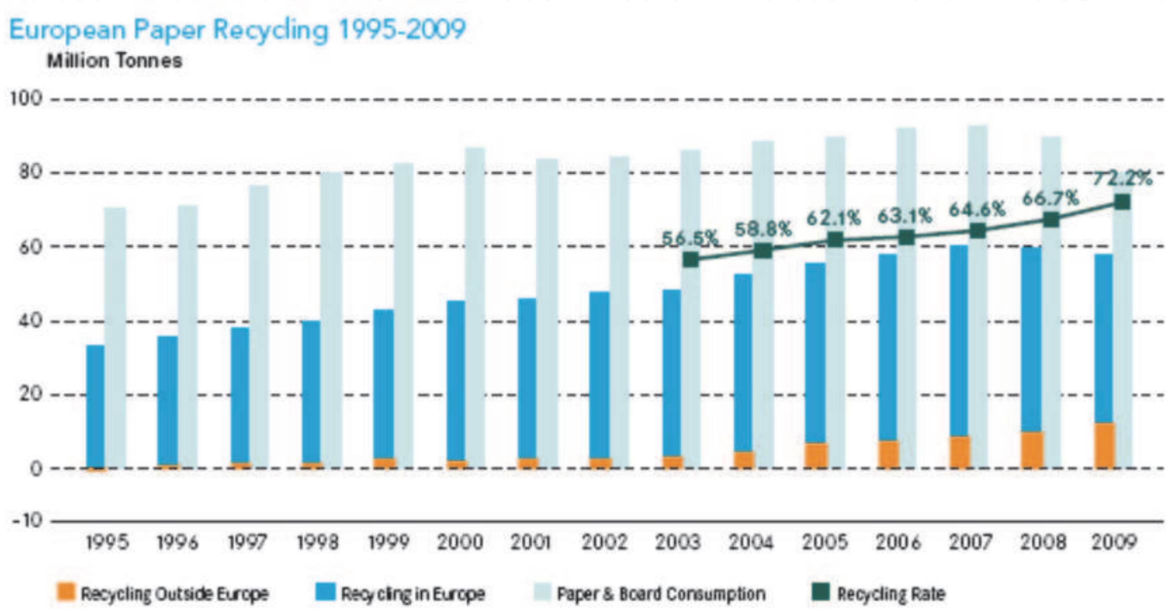

Fig. 1. European paper recycling 1995-2009 in million tonnes (European Declaration on Paper Recycling 2006 – 2010, Monitoring Report 2009 (2010) (www.erpa.info)

Recycling is not a new technology. It has become a commercial proposition since Matthias Koops established the Neckinger mill, in 1826, which produced white paper from printed waste paper. However, there were very few investigations into the effect of recycling on sheet properties until late 1960's. From then until the late 1970's, a considerable amount of work was carried out to identify the effects of recycling on pulp properties and the cause of these effects (Nazhad 2005; Nazhad & Paszner 1994). In the late 1980's and early 1990's, recycling issues have emerged stronger than before due to the higher cost of landfills in developed countries and an evolution in human awareness. The findings of the early 70's on recycling effects have since been confirmed, although attempts to trace the cause of these effects are still not resolved (Howard & Bichard 1992).

Recycling has been thought to reduce the fibre swelling capability, and thus the flexibility of fibres. The restricted swelling of recycled fibres has been ascribed to hornification, which has been introduced as a main cause of poor quality of recycled paper (Scallan & Tydeman 1992). Since 1950's, fibre flexibility among the papermakers has been recognized as a main source of paper strength. Therefore, it is not surprising to see that, for over half a century, papermakers have supported and rationalized hornification as a main source of tensile loss due to drying, even though it has never been fully understood (Sutjipto et al. 2008).

Recycled paper has been increasingly produced in various grades in the paper industry. However, there are still technical problems including reduction in mechanical strength for recycled paper. Especially, chemical pulp-origin paper, that is, fine paper requires a certain level of strength. Howard & Bichard (1992) reported that beaten bleached kraft pulp produced handsheets which were bulky and weak in tensile and burst strengths by handsheet recycling. This behaviour could be explained by the reduction in re-swelling capability or the reduction in flexibility of rewetted pulp fibers due to fiber hornification and, possibly, by fines loss during recycling processes, which decrease both total bonding area and the strength of paper (Howard 1995; Nazhad & Paszner 1994; Nazhad et al. 1995; Khantayanuwong et al. 2002; Kim et al. 2000).

Paper recycling is increasingly important for the sustainable development of the paper industry as an environmentally friendly sound. The research related to paper recycling is therefore increasingly crucial for the need of the industry. Even though there are a number of researches ascertained the effect of recycling treatment on properties of softwood pulp fibres (Cao et al. 1999; Horn 1975; Howard & Bichard 1992; Jang et al. 1995), however, it is likely that hardwood pulp fibres have rarely been used in the research operated with recycling treatment. Changes in some morphological properties of hardwood pulp fibres, such as curl, kink, and length of fibre, due to recycling effects also have not been determined considerably. This is possibly because most of the researches were conducted in the countries where softwood pulp fibres are commercial extensively (Khantayanuwong 2003). Therefore, it is the purpose of the present research to crucially determine the effect of recycling treatment on some important properties of softwood pulp fibres.

2. Alterations of pulp fibres properties at recycling

The goal of a recycled paper or board manufacturer is to make a product that meets customers' specification and requirements. At the present utilization rate, using recycled fibres in commodity grades such as newsprint and packaging paper and board has not caused noticeable deterioration in product quality and performance (Čabalová et al. 2009). The expected increase in recovery rates of used paper products will require a considerable consumption increase of recycled fibres in higher quality grades such as office paper and magazine paper. To promote expanded use of recovered paper, understanding the fundamental nature of recycled fibres and the differences from virgin fibres is necessary.

Essentially, recycled fibres are contaminated, used fibres. Recycled pulp quality is, therefore, directly affected by the history of the fibres, i.e. by the origins, processes and treatments which these fibres have experienced.

McKinney (1995) classified the history into five periods:

1. fibre furnish and pulp history
2. paper making process history
3. printing and converting history
4. consumer and collection history
5. recycling process history.

To identity changes in fibre properties, many recycling studies have occurred at laboratory. Realistically repeating all the stages of the recycling chain is difficult especially when including printing and deinking. Some insight into changes in fibre structure, cell wall properties, and bonding ability is possible from investigations using various recycling procedures, testing methods, and furnishes.

Mechanical pulp is chemically and physically different from chemical pulp then recycling effect on those furnishes is also different. When chemical fibres undergo repeated drying and rewetting, they are hornified and can significantly lose their originally high bonding potential (Somwand et al. 2002; Song & Law 2010; Kato & Cameron 1999; Bouchard & Douek 1994; Khantayanuwong et al. 2002; Zanuttini et al. 2007; da Silva et al. 2007). The degree of hornification can be measured by water retention value (WRW) (Kim et al. 2000). In contrast to the chemical pulps, originally weaker mechanical pulps do not deteriorate but somewhat even improve bonding potential during a corresponding treatment. Several studies (Maloney et al. 1998; Weise 1998; Ackerman et al. 2000) have shown good recyclability of mechanical fibres.

Adámková a Milichovský (2002) present the dependence of beating degree (°SR – Schopper-Riegler degree) and WRV from the relative length of hardwood and softwood pulps. From their results we can see the WRV increase in dependence on the pulp length alteration is more rapid at hardwood pulp, but finally this value is higher at softwood pulps. Kim et al. (2000) determined the WRV decrease at softwood pulps with the higher number of recycling (at zero recycling about cca 1.5 g/g at fifth recycling about cca 1.1 g/g). Utilisation of the secondary fibres to furnish at paper production decrease of the initial need of woody raw (less of cutting tress) but the paper quality is not significantly worse.

2.1 Paper recycling

The primary raw material for the paper production is pulps fibres obtaining by a complicated chemical process from natural materials, mainly from wood. This fibres production is very energy demanding and at the manufacturing process there are used many of the chemical matters which are very problematic from view point of the environment protection. The suitable alternative is obtaining of the pulp fibres from already made paper. This process is far less demanding on energy and chemicals utilisation. The paper recycling, simplified, means the repeated defibring, grinding and drying, when there are altered the mechanical properties of the secondary stock, the chemical properties of fibres, the polymerisation degree of pulp polysaccharidic components, mainly of cellulose, their supramolecular structure, the morphological structure of fibres, range and level of interfibres bonds e.g.. The cause of above mentioned alterations is the fibres ageing at the paper recycling and manufacturing, mainly the drying process.

At the repeat use of the secondary fibres, it need deliberate the paper properties alter due to the fiber deterioration during the recycling, when many alteration are irreversible. The alteration depth depends on the cycle's number and way to the fibres use. The main problem is the decrease of the secondary pulp mechanical properties with the continuing recycling, mainly the paper strength (Khantayanuwong et al. 2002; Jahan 2003; Hubbe & Zhang 2005; Garg & Singh 2006; Geffertová et al. 2008; Sutjipto et al. 2008). This decrease is an effect of many alterations, which can but need not arise in the secondary pulp during the recycling process. The recycling causes the hornification of the cell walls that result in the decline of some pulp properties. It is due to the irreversible alterations in the cells structure during the drying (Oksanen et al. 1997; Kim et al. 2000; Diniz et al. 2004).

The worse properties of the recycled fibres in comparison with the primary fibres can be caused by hornification but also by the decrease of the hydrophilic properties of the fibres surface during the drying due to the redistribution or migration of resin and fat acids to the surface (Nazhad & Paszner 1994; Nazhad 2005). Okayama (2002) observed the enormous increase of the contact angle with water which is related to the fiber inactivation at the recycling. This process is known as „irreversible hornification".

Paper recycling saves the natural wood raw stock, decreases the operation and capital costs to paper unit, decrease water consumption and last but not least this paper processing gives rise to the environment preservation (e.g. 1 t of waste paper can replace cca 2.5 m^3 of wood). A key issue in paper recycling is the impact of energy use in manufacturing. Processing waste paper for paper and board manufacture requires energy that is usually derived from fossil fuels, such as oil and coal. In contrast to the production of virgin fibre-based chemical pulp, waste paper processing does not yield a thermal surplus and thus thermal energy must be supplied to dry the paper web. If, however, the waste paper was recovered for energy purposes the need for fossil fuel would be reduced and this reduction would have a favourable impact on the carbon dioxide balance and the greenhouse effect. Moreover, pulp production based on virgin fibres requires consumption of round wood and causes emissions of air-polluting compounds as does the collection of waste paper. For better paper utilization, an interactive model, the Optimal Fibre Flow Model, considers both a quality (age) and an environmental measure of waste paper recycling was developed (Byström & Lönnstedt 1997).

2.1.1 Influence of beating on pulp fibres

Beating of chemical pulp is an essential step in improving the bonding ability of fibres. The knowledge complete about beating improves the present opinion of the fibres alteration at the beating. The main and extraneous influences of the beating device on pulps were defined. The main influences are these, each of them can be improve by the suitable beating mode, but only one alteration cannot be attained. Known are varieties of simultaneous changes in fibres, such as internal fibrilation, external fibrilation, fiber shortening or cutting, and fines formation (Page 1989; Kang & Paulapuro 2006a; Kang & Paulapuro 2006c).

- Freeing and disintegration of a cell wall affiliated with strong swelling expressed as an internal fibrilation and delamination. The delamination is a coaxial cleavage in the middle layer of the secondary wall. It causes the increased water penetration to the cell wall and the fibre plasticizing.
- External fibrillation and fibrils peeling from surface, which particularly or fully attacks primary wall and outside layers of secondary walls. Simultaneously from the outside layers there are cleavage fibrils, microfibrils, nanofibrils to the macromolecule of cellulose and hemicelluloses.
- Fibres shortening in any place in any angle-wise across fibre in accordance with loading, most commonly in weak places.
- Concurrently the main effects at the beating also the extraneous effects take place, e.g. fines making, compression along the fibres axis, fibres waving due to the compression. It has low bonding ability and it influences the paper porosity, stocks freeness (Sinke & Westenbroek 2004).

The beating causes the fibres shortening, the external and internal fibrillation affiliated with delamination and the fibres plasticizing. The outside primary wall of the pulp fibre leaks water little, it has usually an intact primary layer and a tendency to prevent from the swelling of the secondary layer of the cell wall. At the beating beginning there are disintegrated the fibre outside layers (P and S1), the fibrilar structure of the fibre secondary layer is uncovering, the water approach is improving, the swelling is taking place and the fibrillation process is beginning. The fibrillation process is finished by the weaking and cleavaging of the bonds between the particular fibrils and microfibrils of cell walls during the mechanical effect and the penetration into the interfibrilar spaces, it means to the amorphous region, there is the main portion of hemicelluloses.

Češek & Milichovský (2005) showed that with the increase of pulp beating degree the standard rheosettling velocity of pulp decreases more at the fibres fibrillation than at the fibres shortening.

Refining causes a variety of simultaneous changes in the fiber structure, such as internal fibrillation, external fibrillation and fines formation. Among these effects, swelling is commonly recognized as an important factor affecting the strength of recycled paper (Kang & Paulapuro 2006d).

Scallan & Tigerstrom (1991) observed the elasticity modulus of the long fibres from kraft pulp during the recycling. Flexibility decrease was evident at the beating degree decrease (°SR), and also with the increase of draining velocity of low-yield pulp.

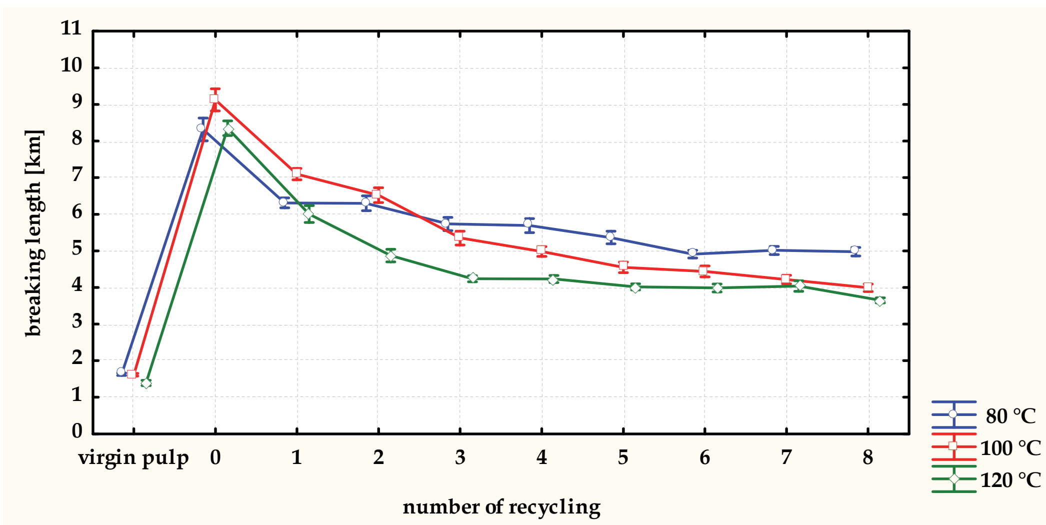

Fig. 2. Alteration of the breaking length of the paper sheet drying at the temperature of 80, 100 a 120 °C during eightfold recycling

properties of paper sheets by drying temperature 80 °C	number of recycling									
	virgin pulp	0	1	2	3	4	5	6	7	8
Breaking length [km]	1.6	8.3	6.3	6.3	5.7	5.7	5.4	4.9	5.0	5.0
Tear index [mN.m²/g]	1.6	2.1	2.5	2.7	2.8	2.8	2.5	3.1	2.7	2.7
Brightnees [%MgO]	83.8	80.0	82.2	82.8	82.5	82.4	82.0	82.4	82.5	82.6
Opacity [%]	71.4	63.9	68.8	67.8	69.5	69.1	70.0	70.1	69.1	70.3
DP by viscometry	699	666	661	663	653	642	642	608	607	611
DP by SEC	1138	1128	1126	1136	1115	1106	1094	1069	1053	1076

properties of paper sheets by drying temperature 100 °C	number of recycling									
	virgin pulp	0	1	2	3	4	5	6	7	8
Breaking length [km]	1.5	9.1	7.1	6.5	5.4	5.0	4.3	4.4	4.2	4.0
Tear index [mN.m²/g]	1.5	2.2	2.3	2.6	2.7	2.9	2.7	3.0	2.8	2.7
Brightnees [%MgO]	83.4	81.0	81.8	81.8	82.9	82.4	82.8	82.5	82.3	82.4
Opacity [%]	72.0	64.4	67.7	68.5	69.3	70.1	70.8	71.0	71.1	71.2
DP by viscometry	699	689	688	680	650	672	660	646	636	624
DP by SEC	1138	1012	1010	938	923	918	901	946	942	941

properties of paper sheets by drying temperature 120 °C	number of recycling									
	virgin pulp	0	1	2	3	4	5	6	7	8
Breaking length [km]	1.4	8.4	6.0	4.9	4.2	4.2	4.0	4.0	4.0	3.7
Tear index [mN.m²/g]	1.4	2.1	2.5	2.7	2.8	2.9	2.7	3.1	2.7	2.7
Brightnees [%MgO]	83.2	79.8	80.6	80.5	81.3	81.2	81.3	81.1	81.1	80.7
Opacity [%]	72.9	65.4	69.0	70.7	71.6	71.7	72.4	72.6	72.4	72.8
DP by viscometry	699	677	665	658	675	677	672	658	673	662
DP by SEC	1138	1030	1015	1059	1042	950	947	945	944	933

Table 1,2,3. The selected properties of the pulp fibres and the paper sheets during the process of eightfold recycling at three drying temperatures of 80 °C, 100 °C a 120 °C.

From the result on Fig. 2 we can see the increase of the pulp fibres active surface takes place during the beating process, which results in the improve of the bonding and the paper strength after the first beating. It causes also the breaking length increase of the laboratory sheets. The secondary fibres wear by repeated beating, what causes the decrease of strength values (Tab. 1,2,3).

The biggest alterations of tear index (Fig. 3) were observed after fifth recycling at the bleached softwood pulp fibres. The first beating causes the fibrillation of the outside layer of the cell wall, it results in the formation of the mechanical (felting) and the chemical bonds between the fibres. The repeated beating and drying dues, except the continuing fibrillation of the layer, the successive fibrils peeling until the peeling of the primary and outside

secondary layer of the cell wall. It discovers the next non-fibriled layer S2 (second, the biggest layer of the secondary wall) what can do the tear index decrease. The next beating causes also this layer fibrillation, which leads to the increase of the strength value (Fig. 3, Tab. 1,2,3). Paper strength properties such as tensile strength and Scott bond strength were strongly influenced by internal fibrillation; these could also be increased further by promoting mostly external fibrillation (Kang & Paulapuro 2006b).
The course of the breaking length decrease and the tearing strength increase of the paper sheet is in accordance with the results of Sutjipto et al. (2008) at the threefold recycling of the bleached (88 % ISO) softwood pulps prepared at the laboratory conditions, beated on PFI mill to 25 °SR.

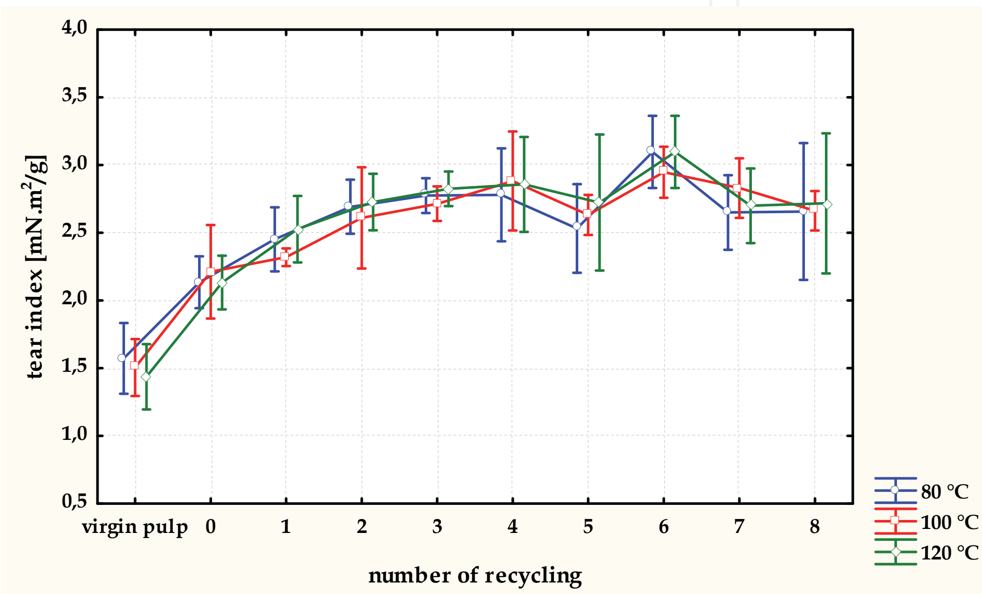

Fig. 3. Tear index alteration of the paper sheets drying at the temperature of 80, 100 a 120 °C, during eightfold recycling

Song & Law (2010) observed kraft pulp oxidation and its influence on recycling characteristics of fibres, the found up the fibre oxidation influences negatively the tear index of paper sheets. Oxidation of virgin fibre prior to recycling minimized the loss of WRV and sheet density.
The beating causes the fibres shortening and fines formation which is washed away in the large extent and it endeds in the paper sludges. This waste can be further processed and effective declined.
Within the European Union several already issued and other foreseen directives have great influence on the waste management strategy of paper producing companies. Due to the large quantities of waste generated, the high moisture content of the waste and the changing composition, some recovery methods, for example, conversion to fuel components, are simply too expensive and their environmental impact uncertain. The thermal processes, gasification and pyrolysis, seem to be interesting emerging options, although it is still necessary to improve the technologies for sludge application. Other applications, such as the hydrolysis to obtain ethanol, have several advantages (use of wet sludge and applicable technology to sludges) but these are not well developed for pulp and paper sludges.

Therefore, at this moment, the minimization of waste generation still has the highest priority (Monte et al. 2009).

2.1.2 Drying influence on the recycled fibres

Characteristic differences between recycled fibres and virgin fibres can by expected. Many of these can by attributed to drying. Drying is a process that is accompanied by partially irreversible closure of small pores in the fibre wall, as well as increased resistance to swelling during rewetting. Further differences between virgin and recycled fibres can be attributed to the effects of a wide range of contaminating substances (Hubbe et al. 2007). Drying, which has an anisotropic character, has a big influence on the properties of paper produced from the secondary fibres. During the drying the shear stress are formatted in the interfibrilar bonding area. The stresses formatted in the fibres and between them effect the mechanical properties in the drying paper. The additional effect dues the tensioning of the wet pulp stock on the paper machine.

During the drying and recycling the fibres are destructed. It is important to understand the loss of the bonding strength of the drying chemical fibres. Dang (2007) characterized the destruction like a percentage reduction of ability of the water retention value (WRV) in pulp at dewatering.

$$\text{Hornification} = [(WRV_0\text{-}WRV_1)/WRV_0\ ].\ 100 \qquad [\%],$$

WRV_0 – is value of virgin pup

WRV_1 – the value of recycled pulp after drying and reslushing.

According to the prevailing concept, hornification occurs in the cell wall matrix of chemical fibres. During drying, delaminated parts of the fiber wall, i.e., cellulose microfibrils become attached as Fig. 4 shows (Ackerman et al. 2000).

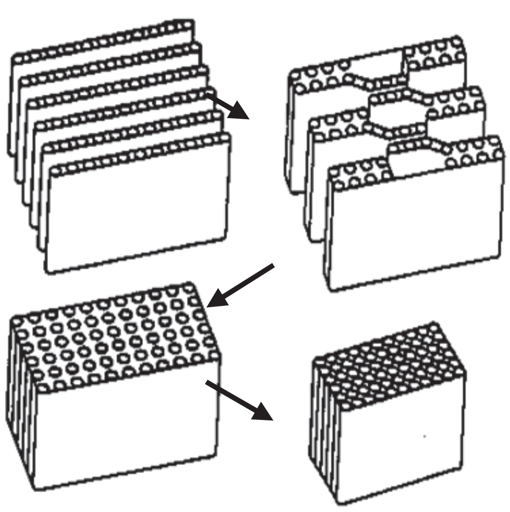

Fig. 4. Changes in fiber wall structure (Weise & Paulapuro 1996)

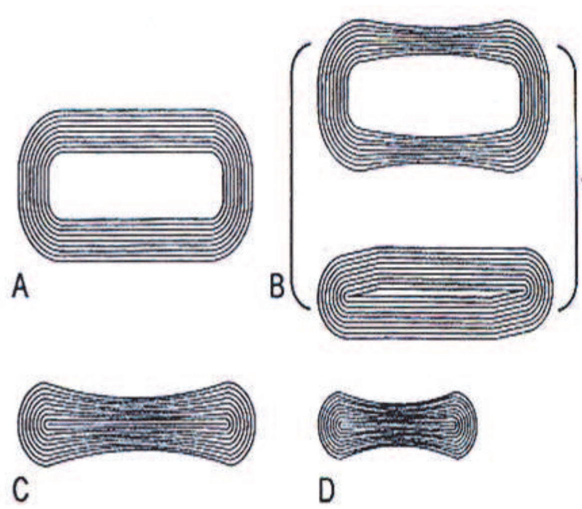

Fig. 5. Shrinkage of a fiber cross section (Ackerman et al. 2000)

Hydrogen bonds between those lamellae also form. Reorientation and better alignment of microfibrils also occur. All this causes an intensely bonded structure. In a subsequent reslushing in water, the fiber cell wall microstructure remains more resistant to delaminating forces because some hydrogen bonds do not reopen. The entire fiber is stiffer and more brittle (Howard 1991). According to some studies (Bouchard & Douek 1994; Maloney et al. 1998), hornification does not increase the crystallinity of cellulose or the degree of order in the hemicelluloses of the fiber wall.

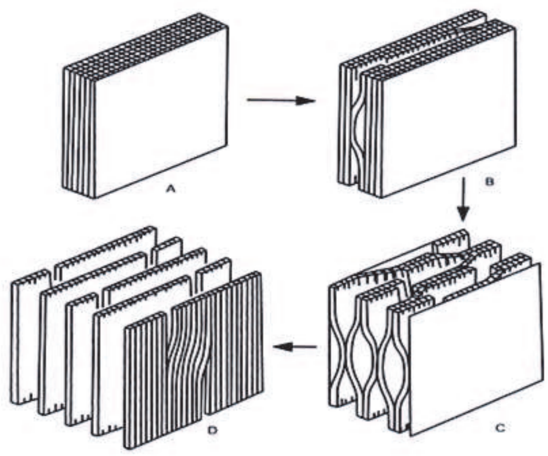

Fig. 6. The drying model of Scallan (Laivins & Scallan 1993) suggests that hornification prevents the dry structure in A from fully expanding to the wet structure in D. Instead, only partial expansion to B may be possible after initial drying creates hydrogen bonds between the microfibrils (Kato & Cameron 1999)

Weise & Paulapuro (1996) did very revealing work about the events during fiber drying. They studied fiber cross section of kraft fibers in various solids by Confocal Laser Scanning Microscope (CLSM) and simultaneously measured hornification with WRV tests. Irreversible hornification of fibers began on the degree of beating. It does not directly follow shrinkage since the greatest shrinkage of fibers occurs above 80 % solids content. In Figs. 4 and 5, stage A represented wet kraft fiber before drying. In stage B, the drainage has started to cause morphological changes in the fiber wall matrix at about 30 % solids content. The fiber wall lamellae start to approach each other because of capillary forces. During this stage, the lumen can collapse. With additional drying, spaces between lamellae continue shrinking to phase C where most free voids in the lamellar structure of the cell wall have already closed. Toward the end of drying in stage D, the water removal occurs in the fine structure of the fiber wall. Kraft fiber shrink strongly and uniformly during this final phase of drying, i.e., at solid contents above 75-80 %. The shrinkage of stage D is irreversible.
At a repeated use of the dried fibres in paper making industry, the cell walls receive the water again. Then the opposite processes take place than in the Fig. 4 and 5. It show Scallan´s model of the drying in Fig. 6.
The drying dues also macroscopic stress applied on paper and distributed in fibres system according a local structure.

2.1.3 Properties of fibres from recycled paper

The basic properties of origin wet fibres change in the drying process of pulp and they are not fully regenerated in the process of slushing and beating.
The same parameters are suitable for the description of the paper properties of secondary fibres and fibres at ageing as well as for description of primary fibres properties. The

experiences obtained at the utilisation of waste paper showed the secondary fibres have very different properties from the origin fibres. Next recycling of fibres causes the formation of extreme nonhomogeneous mixture of various old fibres. At the optimum utilisation of the secondary fibres it need take into account their altered properties at the repeated use. With the increase number of use cycles the fibres change irreversible, perish and alter their properties. Slushing and beating causes water absorption, fibres swelling and a partial regeneration of properties of origin fibres. However the repeated beating and drying at the multiple production cycles dues the gradual decrease of swelling ability, what influences a bonding ability of fibres. With the increase of cycles number the fibres are shortened. These alterations express in paper properties. The decrease of bonding ability and mechanical properties bring the improving of some utility properties. Between them there is higher velocity of dewatering and drying, air permeability and blotting properties improve of light scattering, opacity and paper dimensional stability.

The highest alterations of fibres properties are at the first and following three cycles. The size of strength properties depends on fibres type (Geffertová et al. 2008).

Drying influences fibres length, width, shape factor, kinks which are the important factors to the strength of paper made from recycled fibres. The dimensional characteristics are measured by many methods, known is FQA (Fiber Quality Analyser), which is a prototype IFA (Imaging Fiber Analyser) and also Kajaani FS-200 fibre-length analyser. They measure fibres length, different kinks and their angles. Robertson et al. (1999) show correlation between methods FQA and Kajaani FS-200. A relatively new method of fibres width measurement is also SEM (Scanning Electron Microscope) (Bennis et al. 2010). Among devices for analyse of fibres different properties and characteristics, e.g. fibres length and width, fines, various deformations of fibres and percentage composition of pulp mixture is L&W Fiber Tester (Lorentzen & Wettre, Sweden). At every measurement the minimum of 20 000 fibres in a sample is evaluated. On Fig. 7 there is expressed the alteration of fibres average length of softwood pulps during the eightfold recycling at the different drying temperature of pulp fibres.

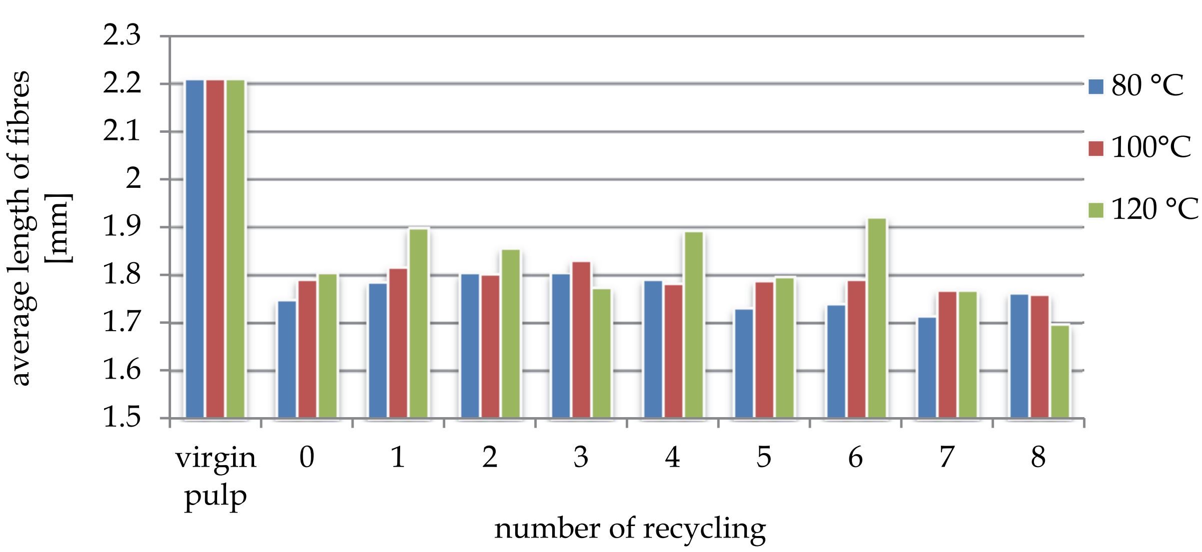

Fig. 7. Influence of recycling number and drying temperature on length of softwood pulps

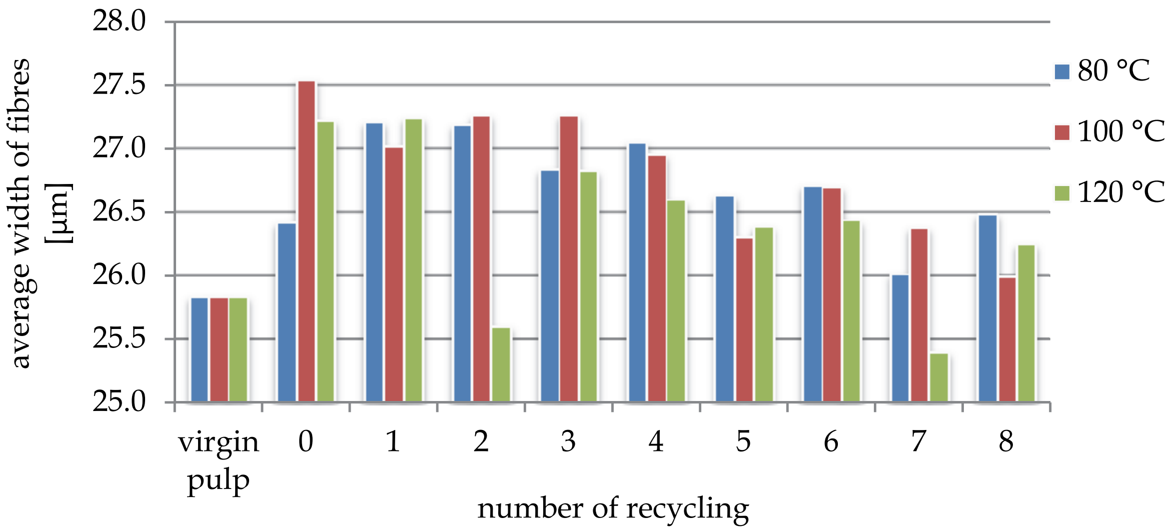

Fig. 8. Influence of recycling number and drying temperature on width of softwood pulps

The biggest alteration were observed after first beating (zero recycling), when the fibres average length decrease at the sheet drying temperature of 80 °C about 17%, at the temperature of 100 °C about 15.6% and at the temperature of 120 °C about 14.6%.

After the first beating the fibres average width was markedly increased at the all temperatures dues to the fibrillation influence. The fibres fibrillation causes the fibre surface increase. Following markedly alteration is observed after fifth recycling, when the fibres average width was decreased. We assume the separation of fibrils and microfibrils from the cell walls dues the separation of the cell walls outside layer, the inside nonfibriled wall S2 was discovered and the fibres average width decreased. After the fifth recycling the strength properties became worse, mainly tear index (Fig. 3).

The softwood fibres are longer than hardwood fibres, they are not so straight. The high value of shape factor means fibres straightness. The biggest alterations of shape factor can be observed mainly at the high drying temperatures. The water molecules occurring on fibres surface quick evaporate at the high temperatures and fibre more shrinks. It can result in the formation of weaker bonds between fibres those surfaces are not enough near. At the beginning of wet paper sheet drying the hydrogen bond creates through water layer on the fibres surface, after the drying through monomolecular layer of water, finally the hydrogen bond results after the water removal and the surfaces approach. It results in destruction of paper and fibre at the drying.

Chemical pulp fines are an important component in papermaking furnish. They can significantly affect the mechanical and optical properties of paper and the drainage properties of pulp (Retulainen et al. 1993). Characterizing the fines will therefore allow a better understanding of the role of fines and better control the papermaking process and the properties of paper. Chemical pulp fines retard dewatering of the pulp suspension due to the high water holding capacity of fines. In the conventional method for characterizing the role of fines in dewatering, a proportion of fines is added to the fiber furnish, and then only the drainage time. Fines suspension is composed of heterogeneous fines particles in water. The suspension exhibits different rheological characteristics depending on the degree of interaction between the fines particles and on their hydration (Kang & Paulapuro 2006b).

From Fig. 9 we can see the highest formation of fines were after seventh and eight recycling, when the fibres were markedly weakened by the multiple using at the processes of paper making. They are easier and faster beating (the number of revolution decreased by the higher number of the recycling).

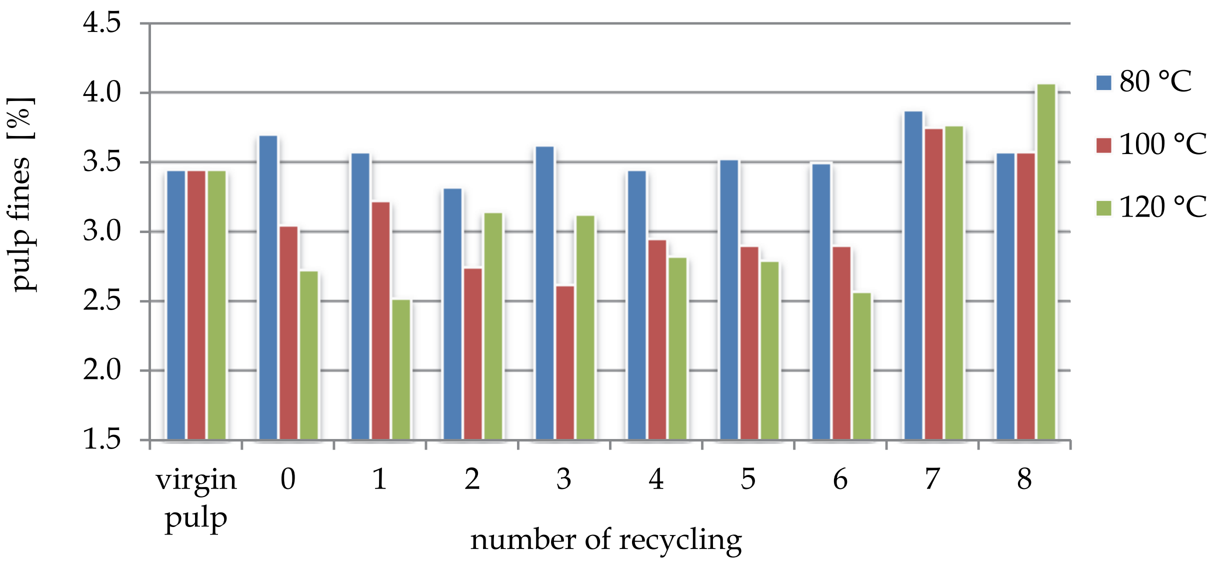

Fig. 9. Influence of recycling process and drying temperature on pulp fines changes

The macroscopic level (density, volume, porosity, paper thickness) consists from the physical properties very important for the use of paper and paperboard. They indirectly characterize the three dimensional structure of paper (Niskanen 1998). A paper is a complex structure consisting mainly of a fibre network, filler pigment particles and air. Light is reflected at fibre and pigment surfaces in the surface layer and inside the paper structure. The light also penetrates into the cellulose fibres and pigments, and changes directions. Some light is absorbed, but the remainder passes into the air and is reflected and refracted again by new fibres and pigments. After a number of reflections and refractions, a certain proportion of the light reaches the paper surface again and is then reflected at all possible angles from the surface. We do not perceive all the reflections and refractions (the multiple reflections or refractions) which take place inside the paper structure, but we perceive that the paper has a matt white surface i.e. we perceive a diffuse surface reflection. Some of the incident light exists at the back of the paper as transmitted light, and the remainder has been absorbed by the cellulose and the pigments. Besides reflection, refraction and absorption, there is a fourth effect called diffraction. In other contexts, diffraction is usually the same thing as light scattering, but within the field of paper technology, diffraction is only one aspect of the light scattering phenomenon. Diffraction occurs when the light meets particles or pores which are as large as or smaller then the wavelength of the light, i.e. particles which are smaller than one micrometer (µm). These small elements oscillate with the light oscillation and thus function as sites for new light sources. When the particles or pores are smaller than half of the light wavelength the diffraction decreases. It can be said that the light passes around the particle without being affected (Pauler 2002).

The opacity, brightness, colouring and brilliance are important optical properties of papers and paperboards. For example the high value of opacity is need at the printing papers, but opacity of translucent paper must be lower. The paper producer must understand the physical principles of the paper structure and to determine their characteristics composition. It is possible to characterize nondirect the paper structure. The opacity characterizes the paper ability to hide a text or a figure on the opposite side of the paper sheet. The paper brightness is a paper reflection at a blue light use. The blue light is used because the made fibers have yellowish colour and a human eye senses a blue tone like a white colour. The typical brightness of the printing papers is 70 – 95% and opacity is higher than 90% (Niskanen 1998).

3. Paper ageing

The recycled paper is increasingly used not only for the products of short term consumption (newspaper, sanitary paper, packaging materials e.g.), but also on the production of the higher quality papers, which can serve as a culture heritage medium. The study of the recycled papers alterations in the ageing process is therefore important, but the information in literature are missing.

The recycling is also another form of the paper ageing. It causes the paper alterations, which results in the degradation of their physical and mechanical properties. The recycling causes a chemical, thermal, biological and mechanical destruction, or their combination (Milichovský 1994; Geffertová et al. 2008). The effect of the paper ageing is the degradation of cellulose, hemicelluloses and lignin macromolecules, the decrease of low molecular fractions, the degree of polymerisation (DP) decrease, but also the decline of the mechanical and optical properties (El Ashmawy et al. 1974; Valtasaari & Saarela 1975; Lauriol et al. 1987a,b,c; Bansa 2002; Havermans 2003; Dupont & Mortha 2004; Kučerová & Halajová, 2009; Čabalová et al. 2011). Cellulose as the most abundant natural polymer on the Earth is very important as a renewable organic material. The degradation of cellulose based paper is important especially in archives and museums where ageing in various conditions reduces the mechanical properties and deteriorates optical quality of stored papers, books and other artefacts. The low rate of paper degradation results in the necessity of using accelerating ageing tests. The ageing tests consist in increasing the observed changes of paper properties, usually by using different temperature, humidity, oxygen content and acidity, respectively. Ageing tests are used in studies of degradation rate and mechanism. During the first ageing stages—natural or accelerated—there are no significant variations in mechanical properties: degradation evidence is only provided by measuring chemical processes. Oxidation induced by environmental conditions, in fact, causes carbonyl and carboxyl groups formation, with great impact on paper permanence and durability, even if mechanical characteristics are not affected in the short term (Piantanida et al. 2005). During the degradation two main reactions prevail – hydrolysis of glycosidic bonds and oxidation of glucopyranose rings. As a result of some oxidation processes keto- and aldehyde groups are formed. These groups are highly reactive; they are prone to crosslinking, which is the third chemical process of cellulose decay (Bansa 2002, Calvini & Gorassini 2006).

At the accelerated paper ageing the decrease of DP is very rapid in the first stages of the ageing, later decelerates. During the longer time of the ageing there was determined the cellulose crosslinking by the method of size exclusion chromatography (SEC) (Kačík et al. 2009). The similar dependences were obtained at the photo-induced cellulose degradation (Malesic et al. 2005).

An attention is pay to the kinetic of the cellulose degradation in several decades, this process was studied by Kuhn in 1930 and the first model of the kinetic of the cellulose chains cleavage was elaborated by Ekenstam in 1936. This model is based on the kinetic equation of first-order and it is used to this day in modifications for the watching of the cellulose degradation in different conditions. Hill et al. (1995) deduced a similar model with the

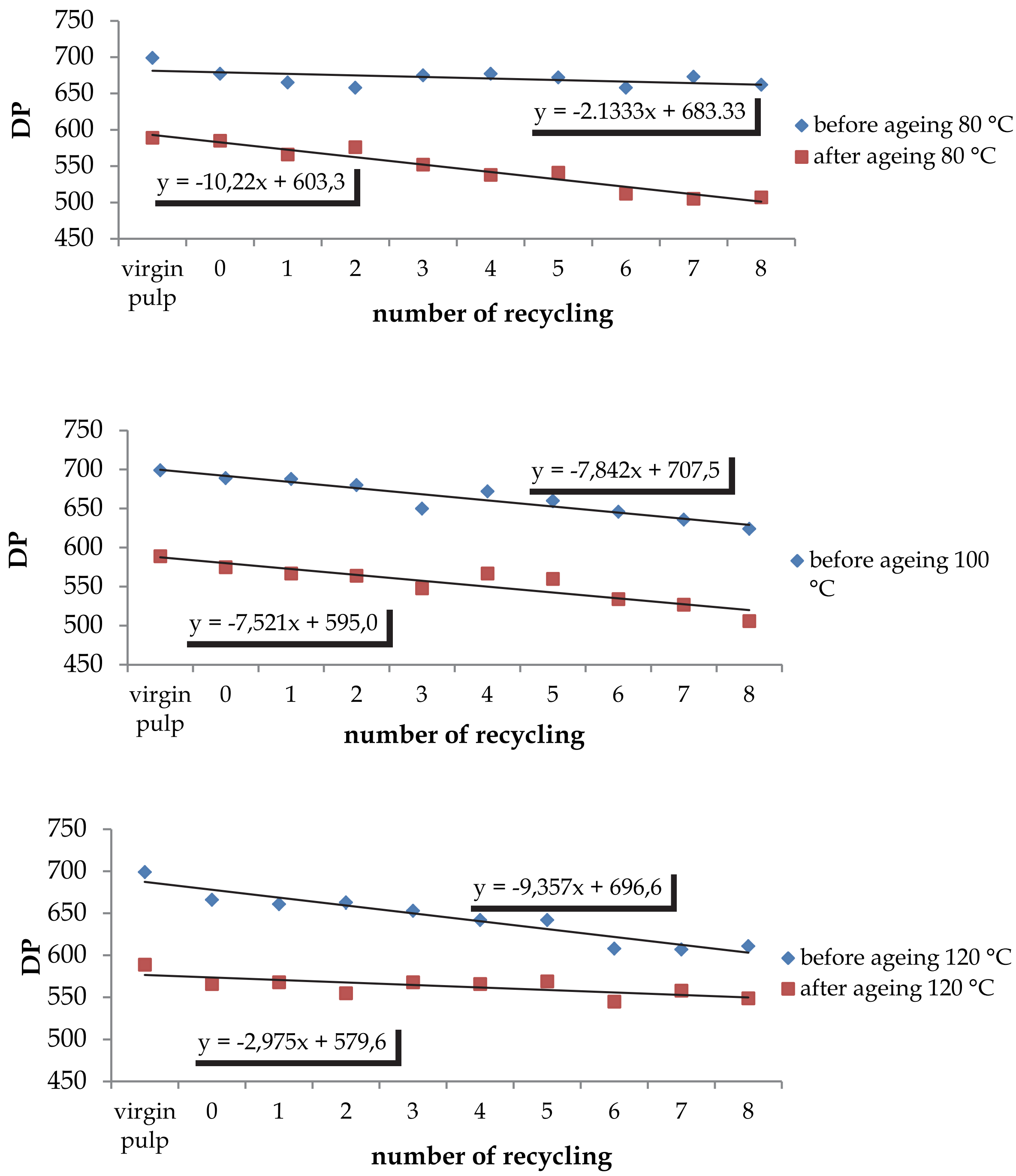

Fig. 10. Alterations of DP (degree of polymerisation) of cellulose fibres due to recycling and ageing at the pulp fibres drying temperature of 80 °C, 100 °C a 120 °C.

contribution of the zero order kinetic. Experimental results are often controversial and new kinetic model for explanation of cellulose degradation at various conditions was proposed (Calvini et al. 2008). The first-order kinetic model developed by these authors suggests that the kinetics of cellulose degradation depends upon the mode of ageing. An autoretardant path is followed during either acid hydrolysis in aqueous suspensions or oven ageing, while the production of volatile acid compounds trapped during the degradation in sealed environments primes an autocatalytic mechanism. Both these mechanisms are depleted by the consumption of the glycosidic bonds in the amorphous regions of cellulose until the levelling-off DP (LODP) is reached.

At the accelerated ageing of newspaper (Kačík et al. 2008), the cellulose degradation causes the decrease of the average degree of polymerisation (DP). The DP decrease is caused by two factors in accordance with equation

$$DP = LODP + DP01.e^{-k1.t} + DP02.e^{-k2.t},$$

where LODP is levelling-off degree of polymerisation. There is a first factor higher and quick decreasing during eight days and a second factor is lower and slow decreasing and dominant after eight days of the accelerating ageing in the equation. The number of cleavaged bonds can be well described by equation

$$DP_0/DP_t - 1 = n_0.(1-e^{-k.t}),$$

where n_0 is an initial number of bonds available for degradation. The equation of the regression function is in accordance with Calvini et al. (2007) proposal, the calculated value (4.4976) is in a good accordance with the experimentally obtained average values of DP_0 a DP_{60} (4.5057). The DP decreased to cca 38% of the initial value and the polydispersity degree to 66% of the initial value. The decrease of the rate constant with the time of ageing was obtained also by next authors (Emsley et al. 1997; Zervos & Moropoulou 2005; Ding & Wang 2007). Čabalová et al. (2011) observed the influence of the accelerated ageing on the recycled pulp fibres, they determined the lowest decrease of DP at the fibres dried at the temperature of 120 °C (Fig. 10).

The simultaneous influence of the recycling and ageing has the similar impact at the drying temperatures of 80 °C (decrease about 27,5 %) and 100 °C (decrease about 27.6%) in regard of virgin pulp, lower alterations were at the temperature of 120 °C (decrease about 21.5%). The ageing of the recycled paper causes the decrease of the pulp fiber DP, but the paper remains good properties.

4. Conclusion

The recycling is a necessity of this civilisation. The paper manufacturing is from its beginning affiliated with the recycling, because the paper was primarily manufactured from the 100 % furnish of rag. It is increasingly assented the trend of the recycled fibers use from the European and world criterion. The present European papermaking industry is based on the recycling.

The presence of the secondary fibres from the waste paper, their quality and amount is various in the time intervals, the seasons and the regional conditions. It depends on the manufacturing conditions in the paper making industry of the country.

At present the recycling is understood in larger sense than the material recycling, which has a big importance from view point of the paper recycling. Repeatedly used fibres do not fully regenerate their properties, so they cannot be recycled ad anfinitum. It allows to use the alternative possibilities of the paper utilisation in the building industry, at the soil reclamation, it the agriculture, in the power industry.

The most important aim is, however, the recycled paper utilisation for the paper manufacturing.

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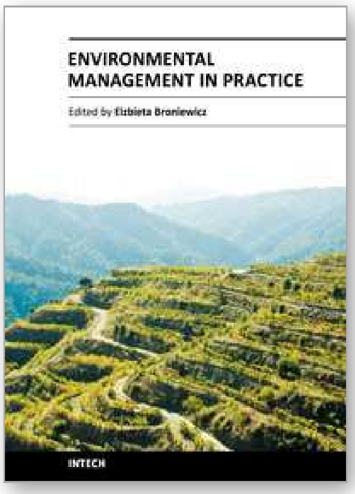

Environmental Management in Practice

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In recent years the topic of environmental management has become very common. In sustainable development conditions, central and local governments much more often notice the need of acting in ways that diminish negative impact on environment. Environmental management may take place on many different levels - starting from global level, e.g. climate changes, through national and regional level (environmental policy) and ending on micro level. This publication shows many examples of environmental management. The diversity of presented aspects within environmental management and approaching the subject from the perspective of various countries contributes greatly to the development of environmental management field of research.