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Evaluation of the Possibilities of Upgrading the Papermaking Potential for Different Recycled Pulp Grades

Abstract
The effectiveness of two regeneration methods (i.e. improvement of the papermaking potential) for five different grades of recycled fibres was investigated in present work. In the first method, only the refining operation was used, and in the second, removal of fines and subsequent refining were applied. The dewatering ability of every regenerated pulp (measured by the SR test) and basic strength properties of papers made from these pulps were tested. The results show that it was possible to increase the papermaking potential of all pulps tested; however, higher effectiveness was achieved when the removal of fines was followed by the refining operation. Further analysis of the results also indicates that recycled pulp grades based on kraft paper have sufficiently high papermaking potential, and in many cases they do not need additional regeneration. Pulp regeneration is strongly recommended in the case of pulps based on LWC, SC and Newsprint papers. Experiments have also proved that the selection of an optimal method for improved papermaking potential always has an individual character, and the method always has to be adjusted to a specific pulp grade and the paper grade made from it.

Key words: *recycled paper, fines, papermaking potential, regeneration, upgrading, recycled pulp refining, dewatering, paper strength.*

Introduction

Optimal paper production always requires a compromise between product quality and process efficiency. Today the majority of paper mills aim at obtaining the highest yield (lowest reject ratio) from processed recycled pulp. Such an attitude leads to the inevitable loss of product quality and can be continued as long as the product parameters obtained are accepted by customers.

It can be assumed that, along with the growing utilisation of recycled fibres in paper production and the increased number of reprocessing cycles, the quality of material will deteriorate so much that it will be impossible to maintain the satisfactory quality of a paper product. As a consequence, more radical and expensive methods for improving the papermaking potential of recovered fibres will be required.

In the case of recovered paper utilisation for papermaking purposes (main application), it should be noted that recovered fibres are characterised by a number of negative factors (e.g. lower papermaking potential and higher level of contaminants). Therefore, additional technological operations are needed (e.g. washing, screening and refining). Nowadays, the total level of fines material and inorganic content (ash) seem to be one of the most important factors determining the usefulness of a given recycled pulp for specific purposes as well as for an initial evaluation of its regeneration possibilities (i.e. improvement of papermaking potential).

Because of the fast growing utilisation of recovered paper, especially in developing countries, several paper mills have experienced particular difficulties with its effective management. Therefore the decision was made to carry out an extended research project on the possible regeneration of various grades of recycled fibres.

Demand for the regeneration of recycled fibres was already being mentioned in specialised literature in the 1970's and 80's. Fines and ash removal as well as subsequent refining are the most often suggested methods for the improvement of papermaking potential in the case of these fibres. The works of Szwarcsztajn and Przybysz [1- 4] were among the first publications that suggested the removal of fines from recycled pulp and subsequent fines-free pulp refining. One must remember that fines material in recycled pulp may also contain inorganic particles (fillers). Many changes in paper quality observed are highly related to filler content.

The usefulness of fines removal was confirmed by Mancebo and Krokoska [5], proving that the major loss of the papermaking potential of once hornified fines cannot be reversed by repeated refining. Therefore, from a papermaking point of view, these fines can be regarded as an unwanted filler only. Apart from that, Mancebo and Krokoska also concluded that secondary fines generated during the refining operation have a positive impact on paper properties, as confirmed by Waterhouse and Omori [6] and Abubakr [7]. Interesting results were also obtained by Hawes and Doshi [8]. They proved that secondary fines maintain their positive properties no matter if they came from earlier dried pulps (hornified) or primary sources. These facts were also confirmed by the subsequent research of Retulainen, Moss, and Nieminen [9].

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As the removal of fines itself has no impact on increasing the papermaking potential of fibres [3, 4, 10], it is necessary to use an additional technological operation. The effectiveness of refining, as a process allowing to reverse, at least partly, the negative effects of hornification, was proved by Szwarcsztajn and Przybysz [3, 4] and Lumiainen [11 - 13]. They confirm the crucial impact of refining on the general improvement of the papermaking potential of recovered fibres. The problem was also examined by Wandelt et al. [14], focusing mainly on OCC (Old Corrugated Containers) and MOW (Mixed Office Wastepaper) based pulps. The most interesting finding indicates certain improvements in pulp quality (e.g. pulp dewatering ability) when pulps were refined first and then the fines material was removed from them.

It is obvious that cellulose fibres are the most valuable components of any recycled pulp. On the other hand, depending on the grade and even the origin of recycled pulp, the fines material may differ in terms of quantity, quality and, hence, usefulness in the production process. Moreover, most recycled paper based fibrous raw materials usually contain a high amount of fines, which usually negatively affects both the dewatering ability of the paper web and paper strength properties. A tendency to increase the contribution of recycled raw materials in papermaking calls for better quality management of these pulps.

The main objective of the present work was to determine the possibility of the improvement of selected recycled paper grades. This was determined based on comparison of the properties of pulps with and without fines, as well as comparison of the properties of paper samples produced from these pulps. The pulp dewatering ability (measured by SR test) and strength properties of paper: breaking length and tear resistance were tested.

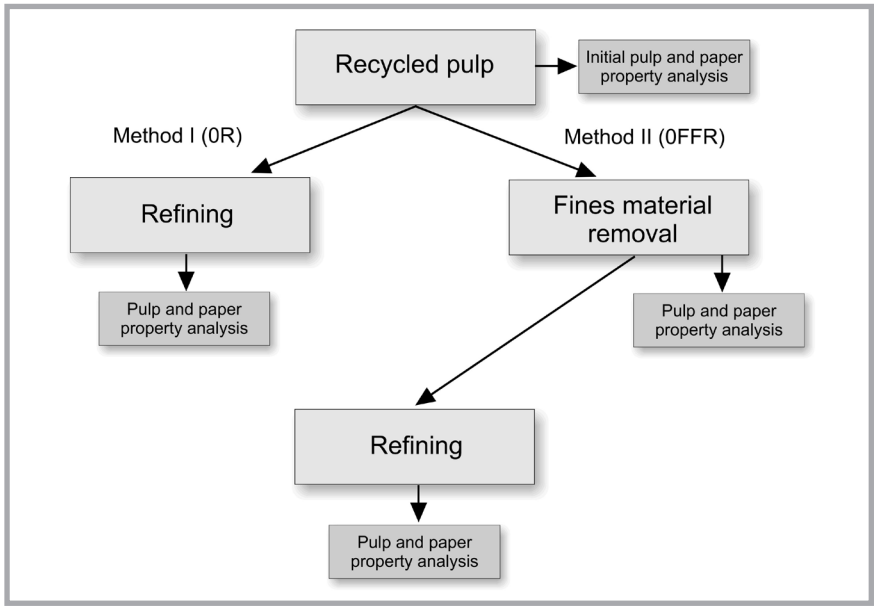

Figure 1. *Diagram of tests performed.*

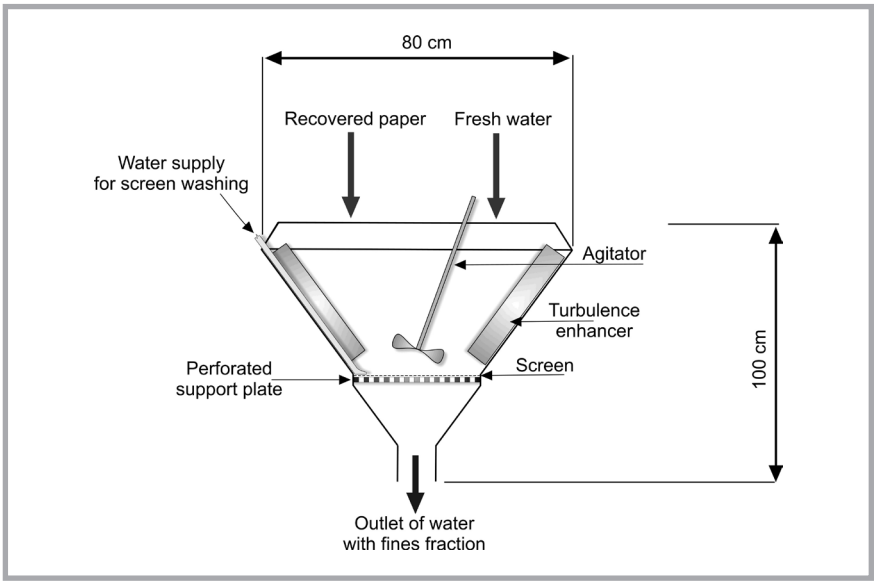

Figure 2. *Diagram of equipment designed for removing fines from recycled pulp.*

Materials and methods

Five secondary pulp grades based on the following recycled papers were tested:

- Kraft Sack paper (EN 643 4 05 00 acc. to CEPI),
- OCC (EN 643 1 05 00 acc. to CEPI),
- LWC (EN 643 3 16 00 acc. to CEPI),
- SC (EN 643 3 14 00 acc. to CEPI),
- Newsprint (EN 643 2 02 00 acc. to CEPI).

Papers for secondary pulp preparation were obtained directly from different paper mills and printing works. All papers obtained were not older than 3-4 weeks. During the investigation, two parallel regeneration methods were used (***Figure 1***). The first method (marked as '0R') was based only on refining, whereas the other one (marked as '0FRR') involved removal of fines and subsequent refining. The results obtained after regeneration were compared with corresponding initial properties of the pulps and papers tested.

Fines material was removed by a washing operation. As suggested by the research of Steenberg, Sandgren and Wahren [15 - 17], a 150 mesh screen (a hole size of 0.1 mm) was used for this purpose. Moreover new equipment was designed allowing the removal of fines from larger amounts of pulp (***Figure 2***).

The tank of 120 dm^3 is cone shaped. 200 g of OD pulp was used in every single experiment, and 2 m^3 of fresh water was used for the removal of fines material. The efficiency was examined each time through histogram analysis of the fibre length distribution of cleaned stock. The fibre length of samples was measured using a Kajaani FS200. After the washing operation, less than 1% of pulp

particles of a size below 0.2 mm was detected.

Every pulp sample was washed with 2 m^3 of fresh water. The entire amount of the fines fraction removed was determined by the gravimetric method, comparing the furnish weight before and after the washing operation.

During the experiments, three samples precisely weighted out and re-pulped first were prepared from each pulp grade. For one of the samples (initial sample of reference), measurements of pulp properties were made immediately, and then laboratory paper sheets were formed and tested. The second sample was refined and then treated in the same way as the first one. For the third sample, the fines were removed and then the sample was divided into two portions, for one of which tests of pulp properties were done immediately, and laboratory paper sheets were formed while the other one was refined and then tested. All refinings were done in a PFI mill according to TAPPI T 248 standard method. The same conditions of refining (3000 revolutions / 2.5 minutes of refining) were used for all test pulps in order to compare the results.

The refined pulp was examined, and laboratory sheets of a basic weight of 75 g/m^2 were formed in Rapid-Köthen apparatus according to Standard ISO 5259-2:2001. Paper samples were conditioned according to the ISO 187:1990 standard. All the properties were tested in accordance with adequate ISO standards. The following properties are included in present publication:

- Fines and ash content (ash: ISO 2144:1997),
- SR value (ISO 5267-1:1999),
- Breaking length (ISO 1924-2:2008),
- Elmendorf tear resistance (ISO 1974:1990).

Table 1. *Initial properties of recycled pulps tested (Student-Fischer method, confidence level = 95%).*

Property / Pulp Grade	Recycled kraft sack paper	Recycled OCC	Recycled LWC	Recycled SC	Recycled newsprint	Mean square error	Standard deviation
Fines content, %	22	29	49	44	44	0.4	1.12
Ash content, %	0,9	5,9	31,0	27,5	11,0	0.7	1.4
Initial SR value, °SR	17	19	45	63	47	0.24	0.76
Breaking length, m	7000	3800	2100	3700	4100	50.0	105.1
Tear resistance, mN	520	420	200	240	260	6.65	18.4

Results

In present research, the quality of the regeneration method was determined by comparison of the properties of papers made from raw pulp (not regenerated) and those made from the same pulp but after the application of the regeneration procedure chosen. Initial values of all the properties tested for all the recycled pulps and information about the typical accuracy of all measurements are listed in ***Table 1***.

The largest amount of fines, representing over 40% of the initial weight, were determined for the LWC, SC and Newsprint grades. All these pulps contained fillers, as is reflected by the ash content (over 30% for LWC based pulp, over 27% for SC based pulp, and slightly less – approx. 11% for Newsprint pulp). A significantly lower amount of fines - up to 22% for sack paper based grades and 29% for OCC - was found in the pulps based on Kraft grades. These pulps also contained much less inorganic substances (up to 1% for sack paper and up to 6% for OCC).

Fines content is one of the main factors determining the dewatering ability of manufactured paper web, which subsequently affects the runnability and efficiency of a paper machine. On the basis of the results obtained , the recycled pulps made of LWC, SC and Newsprint based papers were expected to have a lower drainage property (characterised by the SR value). For this reason, it was concluded that the regeneration method based only on refining could not be effective because of the large amount of fines material. Negative effects related to the further growth of the fines fraction could eliminate expected benefits (higher paper strength properties). On the other hand, it was expected that fines removal would improve significantly the regeneration effectiveness (e.g. better pulp dewatering ability and higher paper strength properties). It should be mentioned that after this operation, the overall effect of regeneration (including the low yield of the pulp caused by the removal of over 30-40% thereof) would be very unsatisfactory. The question whether it is worth using this method can be answered only by the assessment of the changes in paper properties obtained.

Figure 3.a shows the changes in dewatering ability (expressed by SR value) as a result of the application of regeneration methods for recycled pulp based on LWC. The results obtained show that a single refining operation results in an increase in the SR value to a level unacceptable from an industrial point of view (approx. 75 °SR). Initial removal of fines from unrefined pulp reduced the SR value from 45 °SR to one typical for unrefined virgin pulps (below 20 °SR). Subsequent refining caused the growth

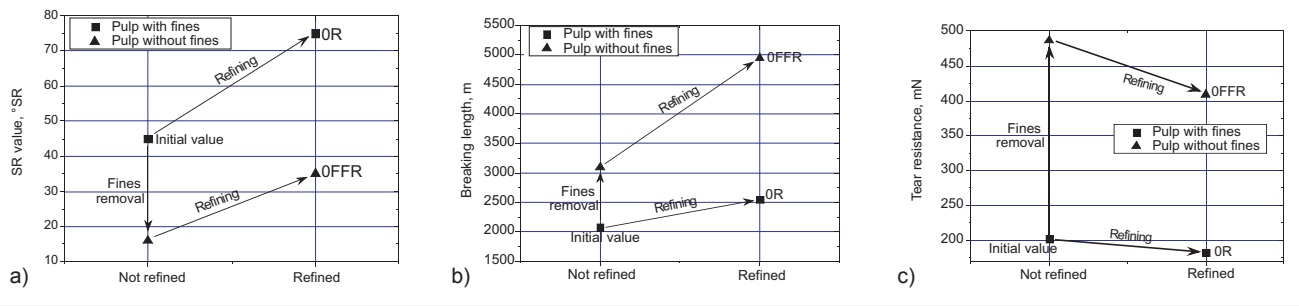

Figure 3. *Changes in: SR values - pulp dewatering ability (a), breaking length (b), and tear resistance (c) as a result of regeneration methods used for LWC based recycled pulp.*

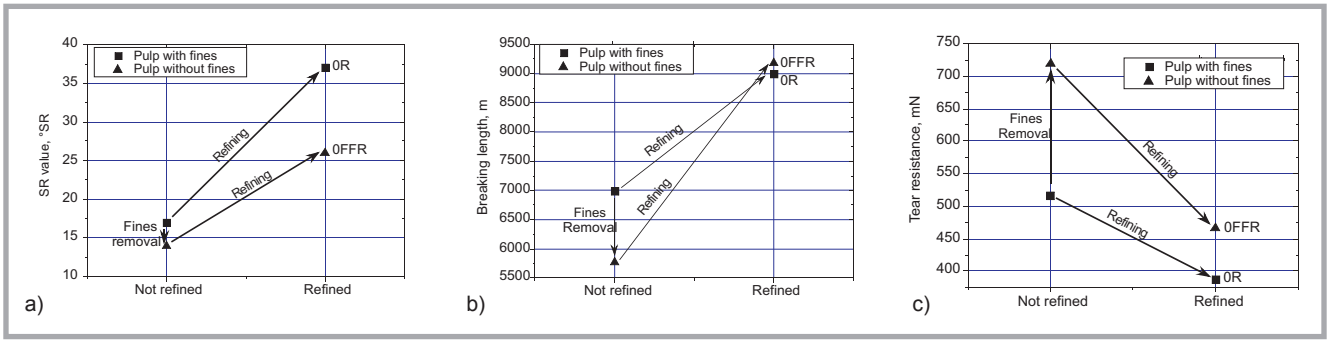

Figure 4. *Changes in: SR values - pulp dewatering ability (a), breaking length (b), and tear resistance (c) as a result of regeneration methods used for Kraft recycled pulp.*

of this parameter to the acceptable value of 35 °SR. For the purpose of further analysis of the regeneration methods applied, basic strength properties of paper made from the pulps tested were measured. ***Figure 4.b*** shows the initial value of the breaking length and changes in this parameter for paper made from the recycled pulp analysed. The initial value of the parameter was low, as refining improved it slightly (change from 2000 to 2500 m). Better results were obtained using the 0FFR method. Fines removal itself greatly improved the breaking length (an increase to over 3000 m). Additionally, further refining helped to obtain a value of around 5000 m. Breaking length changes prove the importance of the removal of fines which have no papermaking properties. A large level of such fines usually appear in recycled pulps based on filled papers.

Tear resistance was the next strength parameter tested (***Figure 3.c***). This parameter is most closely connected with the fibre length. Therefore the tear resistance was not expected to be improved during refining. In this case, the best results were achieved by fines removal only. As a result of this operation, tear resistance increased from around 200 mN to nearly 500 mN, whereas the refining process reduced the value of tear resistance each time.

A significantly higher final value was recorded for paper made from refined pulp without the fines fraction. In this case, tear resistance was more than doubled when compared to the initial pulp.

Taking into account all the parameters tested, it can be concluded that even the recycled pulp based on LWC paper has a certain papermaking potential which can be developed by applying proper treatment methods. However, under industrial conditions, additional unit operations are required to remove the part of raw material which is useless from a papermaking point of view.

A slightly different situation occurs in the case of kraft paper based recycled pulps. These grades have relatively good initial papermaking potential and are widely used without being additionally regenerated. ***Figure 4.a*** shows that the initial SR value of the pulp tested was relatively low (17 °SR), therefore it can be assumed that the dewatering ability of a manufactured paper web during formation on a paper machine will not have a negative impact on the machine's performance. Fines removal during the experiment helped to reduce this parameter to approx. 14 °SR. Larger differences in the SR value were observed after refining the initial pulp with and without the fines fraction. Final values of this parameter differed by 11 units °SR. The SR value for the pulp refined without fines amounted to 26 °SR, whereas the SR value for the pulp refined with fines was 37 °SR. These changes are quite significant, but separately they cannot be regarded as a factor deciding the advantages of one of the regeneration methods used.

Figure 4.b shows changes in the breaking length as a result of the regeneration methods used for the pulp analysed. Results show that the removal of fines itself reduced the initial breaking length by over 1000 m, which indicates the relatively high quality of primary fines in this pulp. This fact can be also confirmed by results obtained after refining. Regardless of the regeneration method used, final values of the breaking length are almost the same. It should be noted, however, that secondary fines separated during refining almost always have a better impact on paper properties than primary ones, as reflected by the increase in breaking length obtained: 2010 m for the pulp refined with fines and 3417 m for that refined without fines. Additionally, a slightly higher breaking length was exhibited by the pulp with fines removed before refining (a difference of around 3% in relation to the pulp refined with the fines fraction).

The situation looks slightly different when analysing tear resistance (***Figure 4.c***). In this case, owing to the removal of fines, a significant property improvement was achieved (around 39%) when compared to the value of this parameter for the initial pulp. The subsequent refining process decreased the tear resistance below the initial value for the initial pulp. Therefore, if the tensile strength or burst strength are crucial factors during the manufacture of a given product, the removal of fines is the best solution.

Table 3. *Comparison of percentage changes (in relation to initial value of given parameter) in test parameters after refining (0R) and after removal of fines and refining (0FFR). Better values are marked with grey colour.*

Property	Change, %									
	Recycled kraft sack paper		Recycled OCC		Recycled LWC		Recycled SC		Recycled newsprint	
	0R	0FRR	0R	0FRR	0R	0FRR	0R	0FRR	0R	0FRR
SR value	+118	+53	+247	+195	+67	-22	+24	-4	+60	-34
Breaking length	+29	+31	+80	+95	+23	+138	+61	+75	+15	+45
Tear resistance	-25	-10	-24	-15	-10	+103	-31	+10	-14	+17

The number of figures is limited to the results for two pulp grades – Kraft sack and LWC - the first one without a filler and the second one – with an inorganic filler. Results for all pulps, presented as a percentage change, are given in ***Table 3***.

Summary

The results obtained proved that the quality and quantity of the fines fraction in recycled pulps strongly depend on the origin of a given pulp. It can be also concluded that, regardless of the grade of recycled pulp tested, the fines material strongly affects the dewatering ability of pulp and the strength properties of paper. For pulps based on papers containing a considerable amount of fillers (e.g. LWC, SC, Newsprint), the fines material does not have any positive effect on strength properties or water removal properties during papermaking. It was found that after having removed the fines, even recycled pulps of relatively poor initial quality have certain papermaking potential. It was also found that after application of the proper regeneration method (dependent on the initial pulp quality and its purpose), some of these pulps could be used even as an addition to virgin pulps intended for the production of higher quality papers.

Experiments proved that a regeneration method based on the refining process only does not always enable to obtain a satisfactory effect. Therefore, in the case of recycled pulps based on paper grades with a high level of fines (e.g. Newsprint, LWC and SC), for optimal regeneration purposes, it would be beneficial to remove the fines material before refining. For sack paper and OCC grades, refining can be carried out on pulp with fines.

One must remember that on an industrial scale, the regeneration operation involves investment in additional equipment and higher energy consumption. It seems that if the removal of fines and/or refining in a recovered paper preparation plant are not economically justified, the lowest grades of recovered paper may be considered as suitable more for non-papermaking purposes.

It was also confirmed that recycled pulps obtained from Kraft papers should be treated in a completely different way. These grades contain less primary fines and are of better quality. For many applications there is no need to remove them, and there is often no need to use any regeneration methods. These pulp grades have relatively high papermaking potential and may be used for many purposes except for products with excellent strength properties.

However, the studies performed proved that the application of a suitable regeneration method (0FRR for the tested pulp) makes it possible to improve the papermaking potential of Kraft pulps to such a level that even their limited addition to virgin pulps intended for the production of sack papers could be considered.

Generally it is expected that in the future papermakers will have to face the problem of a lower yield of pulps, resulting from the fact that the components having no papermaking potential should be removed. An inevitable growth in costs will be a consequence of this trend.

There is no one universal solution for upgrading the papermaking potential of manufactured pulp and for fines management. It depends on the grade of recovered paper processed and the final purpose of secondary pulp manufactured. Nowadays, the model of a general recovered paper preparation plant should be transformed into specialised units processing specific grades of recovered paper. It should be emphasised that the higher costs involved in upgrading the quality of recycled pulp can be compensated by relieving further production stages of difficult-to-deal-with solid and dissolved contaminants, the benefits of which may result from a simplified production line, reduced consumption of chemical aids, a longer life cycle of materials and improved capacities of paper machines.

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