Resource efficiency in deinked pulp production – a review

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ABSTRACT: The use of recovered paper as a raw material for paper production is by far the most economical and ecological strategy for the disposal of waste paper. However, paper production from recovered paper furnish generates a great amount of residues, and the higher the demand requirements for the end product, the higher the amount of rejected material. The reason for this is that the selectivity of the deinking process is limited; therefore, some valuable components are also lost in reject streams. The rejection of usable components affects the economics of recycled paper production. As the cost of waste disposal continues to increase, this issue is becoming more and more severe. This paper summarizes the current state of the resource efficiency in recycled pulp production and provides information on the volumes of rejected streams and the usable material within them. Various means to use these reject streams are also discussed, including the main findings of a recent thesis by the main author. This review summarizes current internal and external use of reject streams generated in the deinking operations.

Application: This article describes ways to improve the resource efficiency of deinked pulp mills that can be used in designing rational and environmentally sustainable strategies for improving the resource efficiency and sustainability of deinked pulp mills.

The use of recovered paper as a raw material in the pulp and paper industry has increased in importance. It is now the most important source of raw material for the production of paper and board [1]. This is a desirable trend, because paper recycling is by far the most economical and ecological strategy for using waste paper, being superior to alternatives such as thermal production, incineration, or landfilling [2,3]. The economics of deinked pulp (DIP) production from recovered papers is also better than virgin fiber pulp manufacturing, even though more residues are produced during DIP manufacturing because of contaminants such as trash, printing inks, and stickies within the recovered paper. These contaminants need to be removed because they can cause problems in DIP processing and papermaking and affect the quality of the final product. The disposal of these residues has become more and more important because of increasingly stringent waste legislation and increasing waste disposal costs.

Increased collection rates of recovered paper have had a major impact on the quality of the recovered paper, which has declined within the last few years [4-6]. According to Hudson [4], the amount of unusable material (trash) within recovered paper in some U.S. mills has increased from 3% to 15%. In Europe, the reported amount is approximately 9% [5]. The drawback of unusable material within recovered paper is a double penalty – first, the DIP producer pays for it as a raw material, and once more as a waste for disposal. It is apparent that this has a major effect on deinked pulp profitability. Trash should be removed from the process as soon as possible, thus most of it is removed at the end of the pulping stage as a pulping reject. The amount of pulping reject (i.e., trash) can be reduced by improving paper recycling practices and public awareness of paper recycling.

For any given raw material, the practical means for a DIP producer to improve the resource efficiency of the deinking process is by avoiding the loss of valuable raw material into reject streams. The rejected streams not only contain contaminants, but because of the limited selectivity of the deinking processes, also contain some valuable components (e.g., fibers, fines, and fillers). The loss of valuable material in the rejects is environmentally and economically unacceptable. This paper summarizes the current state of resource efficiency in recycled pulp production, including volumes of rejected streams and the usable material within them. Various means to use these reject streams are also discussed. Material recovery and internal or external use of this valuable material can ensure the economic and environmental feasibility of DIP production. These means include fiber recovery from fine screening rejects, and the recovery of fiber fines and mineral fillers from flotation froth, which are considered internal uses. In addition, we review external uses, such as thermal use or use of the rejects in land applications or building materials. This paper summarizes the current state of the art of internal and external use of reject streams and includes the main findings of a recent Ph.D. thesis by the main author [7].

AMOUNT AND COMPOSITION OF DEINKING RESIDUES

The European pulp and paper industry produces about 11 million metric tons of waste (rejects, sludge, and ash) each year, 70% of which is generated from recycled paper production [8]. Several processing stages are used to remove contaminants from recovered paper to produce clean deinked pulp for the production of new paper products. Generally, large, non-paper elements are removed during pulping, staples and flakes are removed by coarse screening, sand is removed by cleaning, ink and microstickies (<100-150 μm) are removed by flotation or washing, and macrostickies (>150 μm) and dirt specks are removed by fine screening.

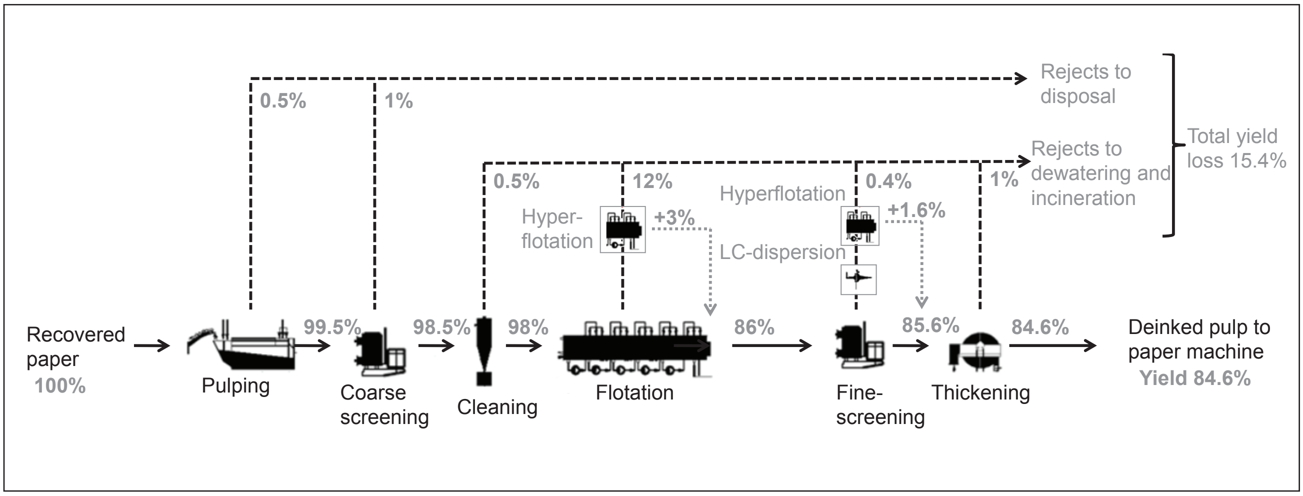
As mentioned, unusable material is removed at the beginning of the process during pulping. This usually amounts to about 0.5%-1% of the raw material fed into the process [9], but, as a result of increased recycling rates and different collection systems, it can be as high as 8%-15% [4, 5]. The pulping rejects mainly consist of materials such as plastic foils, metal string, and wet-strength paper [5,10], and normally, only very low amounts of reject material are usable for papermaking. Besides unusable material, depending on the waste paper grade and required quality of the end product, a total of 15%-25% of the raw material entering a deinked pulp mill might be rejected as a result of poor process efficiencies [11]. This high material loss during DIP production is excessive. For example, the average ink application during the printing process is about 1%-2% of the total mass [12,13], whereas the yield loss during the flotation stage can be as high as 16% [11]. The selectivity of the ink flotation process is indeed poor. In addition, the aim is to remove contaminants by coarse screening, fine prescreening, and fine screening as well as the cleaning stages, each of which delivers a material loss of about 0.5%-2% [9,11,14]. Substantial material losses (1%-8%) can also take place during pulp thickening and process water treatment with dissolved air flotation (DAF) [11,15].

Analyses of deinking reject composition have shown the potential for use of some reject streams [15-20]. Deinking processes are intended to separate contaminants from fibers, which are the main component in the papermaking process. However, DIP processes do not selectively remove only contaminants, and some fibers are lost. Some good quality, long fibers also can be found in the fine screening and cleaning rejects [6,17-19]. Fibers in fine screening rejects have been shown to have high brightness, with low residual ink [19,21,22]; thus, they can be appealing material to recover in DIP mills.

Although fibers can be found in cleaning and screening rejects, not so many fibers pass into the flotation froth reject, and the main losses during flotation are because of mineral fillers. The filler content of a flotation froth reject can vary from about 58% to 70% [16-20]. Solids losses via flotation froth reject could be most easily reduced if mineral fillers were to be recovered. However, Carré et al. [16] have stated that the fines and fillers in froth contained more ink than unfloated fillers and fines. On the other hand, flotation froth reject is the largest waste stream produced during deinking, meaning that recovery of only a small fraction of the froth reject would notably decrease the total amount of rejects. Lastly, DAF rejects are rich in fines [15] that might still be suitable, for example, as a natural filler for low-grade graphic paper [23]. Consequently, fibers could be recovered from fine screening and cleaning rejects, while flotation froth rejects and DAF rejects are more suitable for fillers and fines recovery. **Table I** lists various rejects generated during deinking processes and potential uses [4,5,9-11,14-22,24-32].

Process Stage	Intended to Remove	Amount (%) by Dry Weight [4,5,9,11,14]	Valuable Material also within Reject	Composition Analysis Studied by	Recovery Possibilities Studied by
Pulping	Unusable material (e.g., wet strength paper, metals, and plastic)	0.5–15	None (when pulping working properly)	[10,24]	
Coarse screening	Staples and flakes	0.5–2			
Fine pre-screening	Macrostickies, dirt specks	0.5–2	Fibers	[18,19]	[21,22]
Flotation	Ink, microstickies	8–16	Filler	[16,17,19]	[25-28,31]
Fine screening	Macrostickies, dirt specks	0.5–2	Fibers	[18,19]	[21,22]
Cleaning	Sand	0.5–1	Fibers	[18,20]	[29]
Thickening/DAF	Ink, extractives	1–5	Fines	[15]	[30-32]

I. Volumes of rejected streams during deinking processes, usable material within them, and research done for recovering this material.



1. A deinked pulp line after the insertion of material recovery from the reject streams.

MATERIAL RECOVERY FOR INTERNAL USE

DIP mills have sought options for improving resource efficiency by finding alternative ways of using or disposing of reject streams, and by attempting to recover as much usable material from their raw furnish as possible to minimize the amount of waste to be disposed. At the moment, waste minimization through internal use, for instance, has the highest priority as a waste management solution. Abou-Elela et al. [33] have stated that the implementation of pollution prevention measures such as fiber recovery proved to be highly cost-effective compared with end-of-pipe treatments in a board paper mill. Focusing on minimization of waste at the source invariably will be the most cost-effective approach for rejects treatment, and therefore, the emphasis in future will be more on improved efficiency.

Fibers in the screening and cleaning rejects represent more than half of the total rejected fibers [6,18,19]. With that in mind, Perrin and Julien-Saint-Amand [20] and Korpela [18] have recommended an additional reject stage or optimization of the existing reject stages for fiber recovery from the screening and cleaning steps. In practice, however, the number of stages is limited to two or three. A new approach for fiber recovery was examined by Mäkinen et al. [21,22] in a proof-of-concept study. The results indicated that the recovery of long fibers from fine screening rejects was possible by removing contaminants by flotation after the removal of contaminants was enhanced by high-intensity dispersion at low consistency. The researchers determined that 80% of the most valuable fibers from fine screening rejects could be recovered by the method introduced. A similar approach was used for recovering fillers and fiber fines from process waters and flotation froth rejects by Noda et al. [28] when they dispersed large contaminants with fluid-jet cavitation treatment. Flotation, and more recently column flotation, has also been studied as a method for removing contaminants from rejects for fiber recovery. Heise et al. [34] and Engert and Haveri [35] have reported removal of residual stickies from tailing screen accepts, De Jong et al. [29] used flotation to remove stickies from the forward cleaner rejects, and Ben et al. [30] used column flotation to recover fines from deinking DAF rejects. They found that 65%-70% of the solids in DAF were recoverable. Similarly, Matzke et al. [31] examined the recovery of fines and fillers from wash filtrate and froth reject by a joint filtrate flotation treatment method. Fjallstrom et al. [34] also studied material recovery from wash filtrates.

Recently, Ämmälä et al. [25] found that approximately 15% of fine materials and fillers possessing adequate brightness for use in newsprint production could be recovered by refloating the flotation froth reject in a tertiary stage. Additionally, increased recovery was possible by using carboxymethyl cellulose (CMC) as a flotation depressant in a tertiary stage. New approaches to improve flotation efficiency have been studied recently. Some of the most interesting options are the use of depressants [25] or enzyme treatment [20] to improve the selectivity of flotation, froth washing [36,37], and column flotation [27,30,38-40].

Material recovery might be easier from some reject streams than from others. Therefore, material recovery should be aimed at the purest reject streams, near production, not from the sludge in which the rejects and sludges have already been mixed together. However, fibers and other raw materials have also been recovered from primary sludge [41,42], from wastewater [43], and even from dried sludge [44,45].

Altogether, there are many interesting options for recovering material from reject streams. **Figure 1** presents a simple example of a recovery process. The process includes recovery of fine materials from the flotation froth reject stream by tertiary flotation, and that of fibers from the fine screening reject stream, similarly by a separate flotation after the dispersion of hydrophobic contaminants [7]. Although the reject streams are treated here in isolation, optimization of the reject treatment parameters would minimize other parameters, such as process investment costs, energy consumption, and land area requirements. In this example, material recovery amounts to 5%.

EXTERNAL USE OF RESIDUES

If internal use of the rejects is not feasible, an external means of using rejects and sludges should be considered; landfilling is no longer a recommended disposal method. In the past, land spreading was a common practice for using sludge, as was the use of deinking residues in land applications (e.g., fertilizers, soil amendment, and earthworks), and those practices have been widely studied [46-52]. Presently, one of the most commonly applied disposal methods is incineration [8]. Thermal processes, including incineration, pyrolysis, steam reforming, wet oxidation, and supercritical water oxidation, can be used for energy recovery [8,49,53-60]. The disposal of incineration ash in landfills is still very expensive; thus, the recovery of the

Method for Using Pulp and Paper Reject or Sludge	Reported by	Advantages	Disadvantages
External uses		**Excellent option if user can be found near the mill**	**Risk of over-dependence on external users who can determine prices among themselves**
Land applications	[46-52]	Use of pulp and paper sludges increases organic matter, the water-holding capacity, and porosity of the soil, and decreases soil acidification [47,48]	Low nitrogen content of pulp and paper mill sludges, possible contamination of soils by heavy metals or organic micro-pollutants [8]
Thermal use	[8,49,53-60]	Reduction of the volume of residue to be landfilled [8]	Energy balance of the incineration process might be energy deficient because of the high ash and water content of the sludge [8]
Recovery of mineral part from ash	[49,61-63]	Decreases the need for virgin filler in pulp and paper production	Brightness and abrasiveness of filler can change during incineration of the sludge [77]
Asphalt, bricks, cement	[64-67]	Energy and material content of the sludge can be recovered [8]	Brick manufacture is limited to the warmer months of the year, thus sludges need to be stored until further processing [66]
Building materials	[66,68-70]	Decreases the need for virgin cellulose material in fiber-cement production [70]	Transportation costs might be too high if the fiber-cement factory is not near
Absorbent manufacturing	[49,71-73]	Pulp and paper mill sludges have good chemical, hydrodynamic, and geotechnical properties, which can be used to make impermeable layers for landfill construction [78]	Demand for the absorbent (e.g., in closing of old landfill sites) is limited, and thus absorbent manufacturing alone cannot be a final disposal method, but other disposal alternatives are required as well
Glass aggregate	[49,74]	Organic content of sludge produces energy for the process; trace metals are permanently stabilized in the product [74]	Air emissions from the process [49]
Internal uses			
Fiber recovery	[21,22,29,34,35]	Improved process efficiency through increased yield	Fiber recovery alone weakens combined sludge dewatering [79]
Filler and fines material recovery	[25-28,30-32]	Improved process efficiency through increased yield	Filler recovery alone increases pulp ash content

II. Summary of the internal and external methods for using pulp and paper mill sludges and rejects.

mineral part from the ash has been suggested by Dahlblom et al. [61], Engel and Moore [49], Kunesh et al. [62], Higgs et al. [63], and others. The mineral part recovered from incineration ash has been studied regarding its use as an ingredient of asphalt, bricks, or cement [64-67]. Use of sludges and residues also has been studied in the production of building materials, including panels, tiles, blocks, and briquettes [66,68-70]; in absorbent manufacturing [49,71-73]; or in glass aggregate production [49,74].

The external uses for deinking sludges and residues are an excellent option if a user can be found near the mill [75]. In many cases, however, this is not the situation, and deinking residues are commonly incinerated at the mill site [8]. On the other hand, energy recovery by incineration might be difficult due to the high moisture and ash content of the sludge, which can cause the overall energy balance of the incineration process to be energy deficient [8]. As a result, incineration is largely conducted to reduce the volume of the disposed waste and to convert the waste into an inorganic form for landfilling purposes [76] rather than for energy recovery.

SUMMARY

For a more economically and environmentally sustainable production of recycled pulp, the resource efficiency of DIP mills should be improved. A way to do that is through material recovery from the reject streams. The resource efficiency of deinked pulp production is currently poor (yield = 15%-25%), and gradually becoming even worse. The amount of unusable material (i.e., trash) within recovered paper has risen to 8%-16% through increased collection rates of papers. This has resulted in a situation where the economic viability of deinked pulp production has become threatened.

On the other hand, deinking reject composition analyses have shown great potential for material recovery from reject streams. Because of the limited selectivity of the deinking processes, the reject streams contain valuable raw materials (fibers, fine materials and fillers) along with contaminants. The loss of these valuable materials in the rejects is environmentally and economically unacceptable, and the recovery of these materials and their internal or external use would be highly desirable. Studies have shown potential for fiber recovery from fines screening and cleaning rejects, and for fillers and fine materials recovery from flotation froth rejects and DAF rejects. **Table II** summarizes internal and external methods for using deinking rejects and sludge [8,21,22,25-32,34,35,46-75,77-79]. **TJ**

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We chose this topic because reducing and reusing deinking rejects from recycled paper production is very important. Current resource efficiency in recycled paper production is poor. Improvements are needed to ensure that deinked pulp production remains economically and environmentally feasible. This study complements earlier studies by summarizing the current state of resource efficiency in recycled pulp production.

The most difficult aspect of this study was to find the most relevant studies and try to give a short, simple, and straightforward summarization about the work done in the field of deinking rejects and their use. It was surprising to observe that so much valuable and usable material is lost in the rejects during deinking, and there are hardly any recovery possibilities for this material.

Mills can benefit from this study by using this information in designing totally new, environmentally sustainable, and economical deinking strategies.

In the next phase, we want to put the results into practice and implement new material recovery systems (e.g., ZRI concept) into the deinking mills. Naturally, the aim is to further improve the resource efficiency in recycled paper production.

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