CHARACTERIZATION AND POTENTIAL UTILIZATION OF RECYCLED PAPER MILL SLUDGE

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Introduction

Conservation, reuse, recycling, and composting are the solid waste management philosophies of the 21st century. The largest recyclable component of the solid waste generated in Canada is paper products [1]. In 2003, 3,346,000 tonnes of paper was recovered from Canadian domestic paper production, a recovery rate of 45.1% and the highest in our country's history [2]. The growth of the paper recycling industry has been ecologically beneficial leading to an extension of our fiber base, conservation of our forest resources and reduction in landfill requirement. Ultimately this will reduce the intensity of forest management required to meet the demand for paper which may help to preserve sensitive habitats, and direct limited resources to solid wood products rather than fiber.

The evolution of solid waste management practices has lead to the development of increasingly comprehensive and sophisticated collections systems in many large North American municipalities. The end result being a reliable and economical supply of waste paper available for recycling processes. Paper mills situated in large urban areas are eagerly exploiting waste paper as an economical fibre source. However the deinking operations, which turn the raw waste paper into usable fibre, generate substantially greater quantities of sludge than do virgin fibre operations [3]. On a wet weight basis the sludge output may approximate the total paper production capacity of a mill. Residue generated from tissue mills utilizing only recovered paper is reported to be 40.6% [4], while residue generated from a newsprint mill utilizing 70% ONP and 30% OMG is reported to be 20% [5].

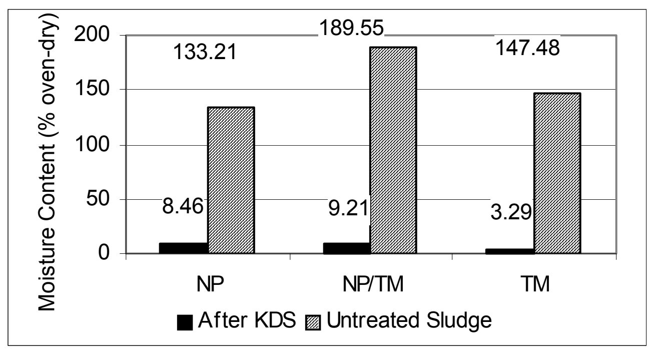
Sludge from a typical recycled pulp and paper effluent treatment facility undergoes dewatering operations, which reduces the moisture content of the liquid sludge from 3-5% to about 50% (wet weight basis). Chemical flocculation coupled with mechanical force is used to remove water from the mixture. The resultant material is a tightly held wet mass of wood fibre, inorganic clays and filler, and contaminants. The current practices of sludge disposal such as land spreading, land filling and incineration are becoming increasingly unfavorable due to ecological arguments or economic considerations. New residue management approaches must be sought that utilize this material in a value-added manner. This initiative has been considered by many but has proved unrealistic due to large quantities, high moisture content, unpleasant odours, substantial variability and difficulty in handling [5,6,7]. To ensure the sustainability of the recycled paper industry, economically viable and ecologically sound alternatives must be found for the re-use of the waste residue.

The focus of this work was to use AGES/KDS technology to prepare recycled papermill sludge for further processing. The AGES/KDS sludge drier can be easily located at the end of the traditional sludge dewatering process. It renders wet sludge into a dry, non-odourous, easy to handle material. The specific aim of this investigation is qualify the available fibre in the dried sludge material for re-use in the papermaking process.

Material & Methods

Raw sludge (approximately 50% dry material) was collected from three recycled paper mills. The mills selected represent a range of recycling operations in North America. They included a recycled newsprint mill (NP), a combination recycled newsprint and tissue mill (NP/TM) and a recycled tissue mill. The materials were successfully treated in the KDS Micronex to dryness as shown in Figure 1.

Figure 1. Moisture content (dry weight) of sludge from three mills before and after KDS treatment.



Fractionation of the KDS dried material was carried out by subjecting the material to a very brief treatment in a Laboratory Wiley mill equipped with a 2 mm holed-screen. The short treatment time released entangled, smaller particles leaving the long fibre fraction retained on the screen. The portion, which passed through the 2.0 mm holed-screen, was screened on a 40 mesh Endecotte test sieve, yielding 40 mesh (+) and 40 mesh (-) fractions. A comparison of the characteristics for the NP/TM sludge materials is given in Table 1.

Ash testing was done using a modified Tappi procedure T211-om93 [8]. The sample was charred at 250^0C for 2 hours to prevent flaming, and then heated at 525^0C for 4 hours, samples were desiccated and weighted and then re-heated to 900^0C for 1 hour to enable determination of calcium carbonate content. Fibre characteristics were determined using an Optest Fibre Quality Analyzer – Code LDA93.

Table 1. Characteristics of air-dried untreated sludge and

KDS sludge.

Sample	% Ash (525^{0}C)	Mean Fibre Length- Weight weighted(mm)	% Fines-length weighted	Curl Index	Kink Index	Coarse (mg/m)
Untreated sludge	48.04	1.45	31.04	0.092	1.18	0.56
KDS composite	44.80	1.46	25.70	0.106	1.44	0.69
Long fibre	22.36	2.24	2.26	0.146	1.85	0.34
Fines 40+		0.98	11.25	0.088	1.32	0.34
Fines 40-		0.62	64.39	0.067	0.72	1.02
TMP	1.19	2.09	14.14	0.096	1.05	0.39

The recycled NP/TM sludge was selected for the initial investigation. Handsheets were prepared using mixtures of the long fibre fraction of the KDS dried sludge and commercially produced northern softwood TMP fibre. Considerations were made to account for loss of fines from both materials. For the TMP, the loss of fines during handsheet preparation was measured to be 11% of the original dry weight. The amount of fines in the TMP was 14% as measured by the FQA. The amount of fines in the long fibre fraction was 2.26% as measure on the FQA. An adjustment of 10% was made for potential loss of material from the TMP and 4% for the long fibre fraction when determining the mass proportions for the handsheets.

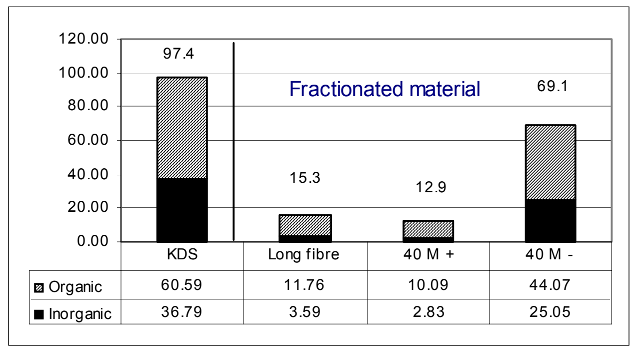
Handsheets were made according to Tappi standard T205 sp95, using British pulp evaluation apparatus, to a target weigh of 1.26 grams moisture free. After formation the handsheets were conditioned for 24-36 hours according to T402 om-93, omitting preconditioning step. Fourteen handsheets were made for each of the mass combinations. The handsheet properties were determined using standard Tappi method T220 sp-96 for bulk, tear index and tensile index. Brightness and yellowness were measured on an Elrephro brightness meter.

Results and Discussion

In this investigation the quality of the fibre for re-use in the paper making process is of ultimate interest. The KDS drying process did not appear to cause a major change in the characteristics of the sludge, Table 1. Characteristics of air-dried untreated sludge and KDS sludge.1. The ash content and the fines content were slightly lower after the KDS dryer treatment. This may be due to loss of small size particles during venting or delivery of the dried sludge. The average fibre length remained constant through the drying process, which was surprising considering the intense mechanical action in the KDS chamber. The curl and kink indices did increased after drying. A curl index of 0-0.05 represents a nearly straight fibre, while a measure of 0.5 would represent a very curly fibre [9]. The increased average curl is possibly a result of the mechanical action or heat to which the fibres are exposed during the drying process. It is common to see fibre develop curl when subjected to incidental mechanical action.

The fractionation process, yielded three fractions; a long fibre fraction, a 40 mesh (+) fraction and a 40 mesh (-) fraction. The long fibre fraction had lower ash content and fines content and a higher average fibre length (2.24 mm) than the original sludge. The smaller particles contain a higher concentration of the inorganic materials. The overall yield of the various fractions in terms of inorganic versus organic content is illustrated in Figure 2. The long fibre fraction, which was isolated for this investigation, represents approximately 15% by weight of the dried sample.

Figure 2. Wiley mill fractionation of Newsprint/Tissue mill sludge by weight.



The long fibre fraction was selected for the handsheet testing because of its superior properties. It had low ash (22.36%) and fines (2.26%) contents, and high average fibre length. Normally high ash content translated to high fines content however, this is not the case. The inorganics in the long fibre fraction may be smaller in size than the detection limit of the FQA analyzer (0.07 mm) and may therefore not be counted as a fine. Alternatively, the inorganics might be physically bonded to the fibre, and not liberated when dissolved in water. Future work will confirm the nature of the relationship between the inorganic component and the fibre. The long fibre fraction has coarseness similar to TMP. A high coarseness suggests thicker cell walls and less fibre flexibility. On the other hand, higher curl and kink indices suggest that this fibre is more flexible than the TMP fibre and will promote superior bondability.

A SEM of the long fibre compared to a TMP fibre can be seen in Figure 3. The TMP fibre shows typical fibrillation of the fibre, with well-developed microfibrils attached to the fibre. The long fibre however, has a relatively clean surface, with small (1-5m) platy shaped particles attached. These fibres also show a high degree of damage as can be seen at 4000 X magnification, where various lamellae of the secondary wall can be seen. Microscopic evaluation of the fibre show that they maintain their length but are severely fractured along the cell axis. There are also transverse cuts and numerous kinks and twists in the fibre. This suggests that the inherent fibre strength may be reduced. The lack of fibrillation suggests lower bond area and consequently diminishes bondability. The higher flexibility of the fibre may offset this affect.

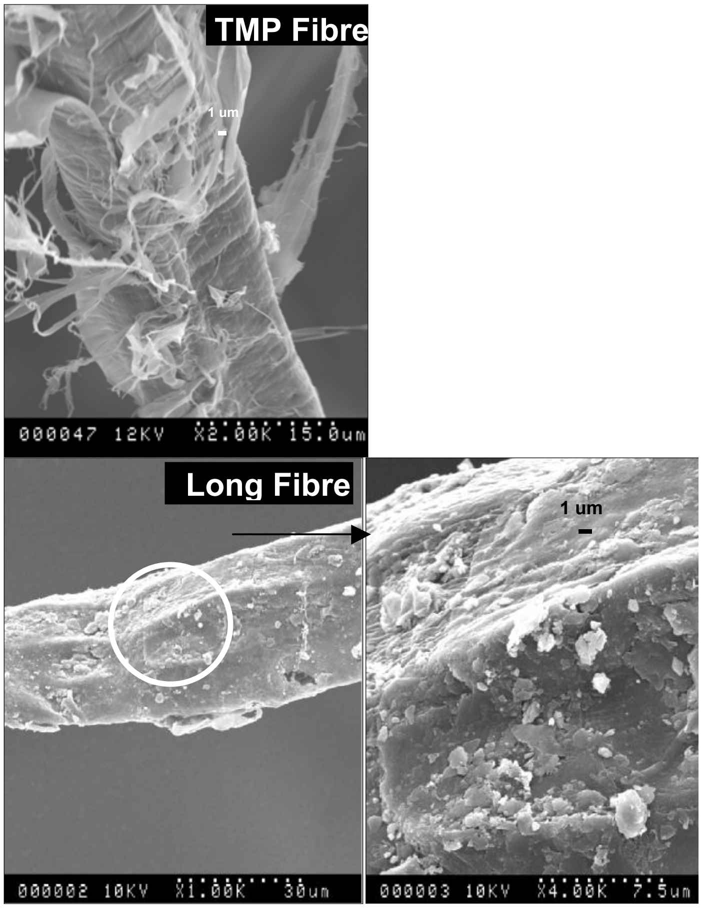
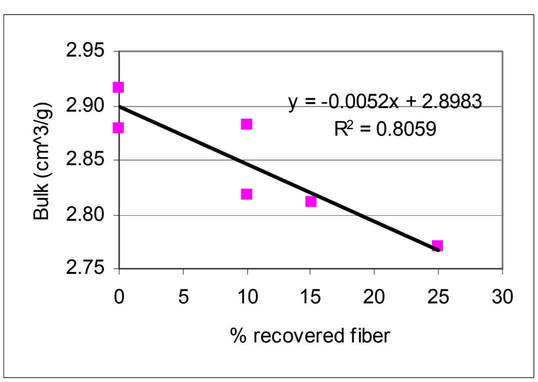


Figure 3. SEM micrograph of commercially produced northern softwood TMP and long fibre fraction.

__Influence of recovered fibre on strength properties__

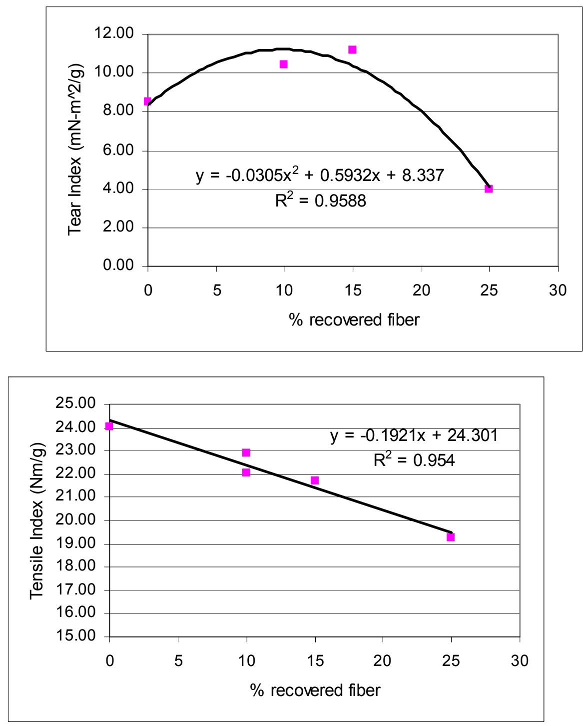
The bulk of the paper decreased with increasing recovered fibre content (Figure 4). The longer fibre fraction which exhibits higher flexibility and collapsed than the TMP portion, contributed to compaction of the sheet. High fibre curl is known to increase bulk, however this effect was overshadowed by the influence of the collapsed fibre.

Figure 4. Decreasing bulk of handsheets with increasing recovered fibre content.



A higher strength sheet is normally achieved at lower bulk because of the greater bond area between fibres in closer contact with one another. Accordingly, one would expect that increasing recovered fibre content would result in a stronger paper. However, it is also well known that lower intrinsic fibre strength will lead to a decrease in paper strength. The damage to the fibres may well generate this result. The tensile and tear indices are depicted in Figure 5. Tensile strength is negatively affected by the addition of recovered fibre however tear strength is positively affected to a maximum level.

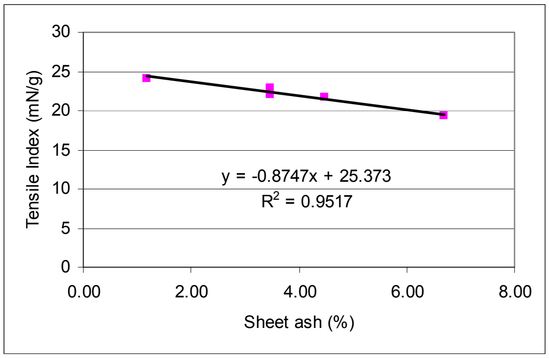
Figure 5. Influence of increasing recovered fibre content on Tensile Index and Tear Index.

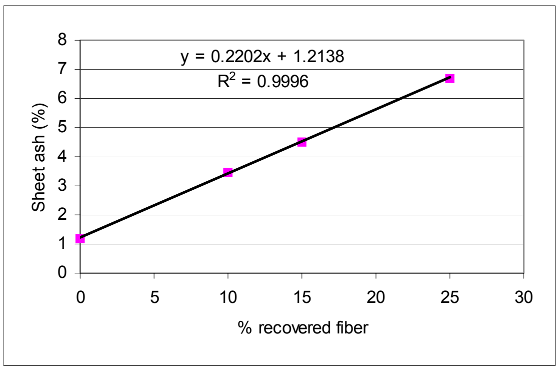


Compactness or density of the sheet is strongly influenced by the amount of recovered fibre. Due to its compressed or collapsed nature one would think that the higher the recovered fibre content the lower the bulk and the stronger the paper. This investigation demonstrates that increasing density (decreasing bulk) actually leads to a lower strength paper. Several factors may be responsible for this observation. There was found to be a strong positive relationship between the sheet ash and the compactness of the sheet. In addition, the tensile strength showed a strong negative relationship to increasing ash content. Ultimately the ash may be interfering with the fibre-to-fibre bonding effectively diminishing the strength of the sheet.

The high curl of the fibre can decrease tensile strength because the fibres essentially curl out of the plane in which the tensile test is taking place. This reduces the effective fibre length resulting in more stresses on the inter-fibre bonds as opposed to the fibre. Curl has been shown to have a positive affect of tear strength [9].

Figure 6. Sheet ash and its influence on Tensile strength.





Tear strength, as is well documented, is strongly influenced by fibre length and fibre strength. The recovered fibre offers the benefit of longer average fibre length then the TMP fibre as it contains strong chemical fibre from the initial raw material resource. As can be seen in Figure 5 there was an increase in the tear index up to a substitution level of approximately 10%. After this point there is a decline in the tear strength. The reduction in tear strength is believed to be from interference of the ash in the fibre-to-fibre bonding.

Conclusion

In a paper recycling mill materials rejected from the screening, cleaning and floatation processes become the waste stream treated at the mill's wastewater treatment plant. Operational efforts concentrate on minimizing rejected material to reduce the requirement for fresh water make up and decrease effluent flows. In addition, holding more fiber and filler in the accepted stream helps to conserve waste paper and decrease shrinkage. However, even with the high priority given to the activity of preserving incoming fibre, ample usable fibre escapes the process. The recovery of this lost fibre from recycled paper mill sludge may now be feasible with the KDS Micronex technology. The dry, odourless material can be successfully fractionated to enhance desired characteristics.

Substitution of recovered fibre into TMP pulp, to a maximum of 9.7%, improves the tear strength. Tensile strength is negatively affected, with each percent substitution causing a 1% decline in the tensile index. The important fibre characteristics, which affect the tensile strength of paper, are the bond area, which is affected by fibre flexibility and degree of fibrillation, the intrinsic fibre strength, which is affected by the original source of the fibre and degree of damage, and the strength of the fibre-fibre bond. Recovered fibre has some advantages over TMP fibre with respect to fibre flexibility and possibly in fibre strength. These advantages may be overshadowed by the degree of fibre damage, the lack of surface fibrils, or the interference of ash with fibre-to-fibre bonding. In order to elucidate the true value of this fibre the intrinsic strength of the fibre needs to be determined. Thorough removal of ash and/or mild refining may also prove to enhance the tensile strength of this fibre paper.

Acknowledgements

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