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Production of corrugating medium paper with secondary fibers from digested deinking sludge

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ABSTRACT

This work focused on developing an approach to reusing digested deinking sludge for corrugating medium paper manufacture by recycling secondary fibers. The fiber content in the digested deinking sludge (DDS) was around 41.87%, and the main proportion of fibers (87.6%) was subject to secondary fines with lengths less than 0.2 mm. The qualified corrugating medium paper was obtained when the secondary fiber load from DDS was equal or less than 30%. Corrugating medium paper manufactured by adding DDS could maximize reuse and recycling of deinking sludge via methane and papermaking material production, and reduce the environmental pollution as well.

Introduction

The pulp and paper industry, which is in rapid development nowadays, has become one of the main industries in China. Simultaneously, waste water and sludge are produced in large quantities in the pulping and papermaking processes. Deinking sludge (DS), which is formed in the process of wastepaper pulping by means of flotation deinking, dominates over 50% of the total sludge yield in the pulp and paper industry and it will reach 70% in the following years because more and more wastepaper is reused as a papermaking raw material [1]. Generally, 80–150 kg dry deinking sludge or 160–500 kg wet deinking sludge is generated when one ton dry pulp is produced [2]. How to appropriately treat the huge amounts of deinking sludge has become a vital issue to be addressed for pulping and papermaking plants.

In China, randomly discarding sludge is banned owing to the serious secondary pollution. The representatives of traditional conversion technologies for pulp & paper mill sludge (including deinking sludge and sewage sludge) are incineration and composting, even though some researchers have been trying to look for some different ways for pulp & paper mill sludge reusage, such as cement and brick manufacture, specific sorbent production and agriculture land application [3–6]. Nevertheless, evident shortcomings of applying both above main technologies have been found. Regarding incineration, the difficulty to dehydrate, the low efficiency of energy generation, the trouble to cleanse the toxic exhausted gas and the overall high investment hinder its application [7]. As regards to composting, it is a widely used bio-conversion technology for sludge. Currently, some plants have been set up and they focused on the pulp & paper mill sludge reutilization by composting in China [8]. However, low nitrogen contents, long time for lignocellulose decomposing, lower contents of humic acid in compost and a high risk of heavy metal pollution existing in compost land application have become the main problems to stagnate the development of sludge composting [9–11]. Thus, investigating new technologies to reuse pulp & paper mill sludge, especially the deinking sludge which yield is growing with the increasing recycle of wastepaper, is significantly important.

As mentioned by many authors, the deinking sludge is rich in polysaccharides, cellulose, hemicellulose, lignin and other inorganic components [12]. On the other hand, anaerobic digestion has been highly concerned in the world as a renewable energy production technology for solid waste from various sources, like agricultural residues, municipal solid waste, green trimmings and sludge. Anaerobic digestion of pulp & paper mill sludge (including deinking sludge and sewage sludge) for methane production was also reported currently. Lin et al. [13,14] studied the possibility of

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anaerobic co-digestion of pulp & paper sewage sludge and monosodium glutamate waste liquor and found the accumulative methane yield could reach 88.82 mL g^{-1} VS (volatile solid). Some other authors found that by controlling pH, hydraulic retention time and temperature, it was possible to optimize the acidogenic and acetogenic phases in the sludge anaerobic digestion process and took good advantages of the soluble organics produced in the hydrolysis stage [15,16]. Besides, Ratnieks and Gaylarde [17] investigated the effect of systemic pH on anaerobic digestion of paper mill sludge, and found that when the systemic pH was 7, the sludge degradation efficiency could be increased to 60%. Domestic and foreign research results indicate that it is feasible to use pulp & paper mill sludge to generate methane for heat or electricity recovery. In addition, papermaking is subject to the process with high consumption of energy. The overall consumption is around 0.98 ton standard coal for 1 ton dry paper production. Anaerobic digestion of pulp & paper mill sludge could develop an approach to reducing coal consumption in papermaking plants by methane generation, so as to meet the requirement of market globalization competition.

On the other hand, a large amount of anaerobic digestate is produced after anaerobic digestion of sludge, and solid–liquid separation is generally operated to the digestate. Regularly, the liquid part can be recycled to fields as NPK fertilizer [18], and the solid residue of digestate is disposed by landfill or composting. Otherwise, papermaking is an industry leader from the standpoint of recycling and sustainability, the main reason being that virgin and recycled fibers can be used together, sometimes contributing with complementary characteristics. Since the solid phase of digested deinking sludge (DDS) contains most of the secondary fibers/fines which reached 41.87% based on the total solid (TS) (see Table 1), and less tannins, resins and other pigments compared to the original deinking sludge, it might be another potential material to manufacture specific papers. What's more, abundant active hydroxyls are contained in the tiny fibers/fines which are the principal organic components of the digested deinking sludge. The possible reason for the digested sludge playing an important role in the series of esterification, etherification, graft copolymerization, cross-linking and other derivative reactions are related to the hydroxyls [19].

Besides, non-woods are used extensively in pulp and paper production in several countries due to its abundance and cost-effectiveness, and the scarcity of forest resources especially in Asian countries. Many studies have been carried out on non-wood pulping for pulp and paper production [19–21]. Since China is severely short of woods for pulp and paper making, over 80% of woody papermaking materials in China depend on importation. Looking for new sources of raw materials for papermaking in domestic is challenging. Meanwhile it has become an urgent task for relevant researchers. Nowadays, China is the biggest non-wood producer in the world. Straw has become the largest source of non-woods for the paper industry. Like the traditional non-woods of straws, reeds, bamboo and so on, deinking sludge has already been tested as a specific papermaking raw material [22]. Furthermore, it is a recommended wastewater reduction method by recycling of wastewater with simultaneous recovery of fibers [23]. The most common technique for reclaiming fiber is to recycle primary sludge back into the fiber – processing system. Some recycled paperboard mills and some manufacturers of unbleached and bleached pulp and paper have reduced sludge volume by reclaiming the fiber, fillers, or both in sludge to be reused within their pulping and papermaking processes [24,25]. Fiber recycling has played an important role in the sustainable development of pulp and paper industry with the benefits of environmental pollution decrease, leading to an extension of fiber life cycle, forest conservation and landfill requirement reduction. Otherwise, to the authors' knowledge, the recycle of fibers from digested deinking sludge to manufacture paper has not been reported.

In this study, digested deinking sludge was investigated as a raw material to manufacture corrugating medium paper, mixed with wastepaper pulp and softwood pulp. Deinking sludge was also studied for corrugating medium paper manufacture as a comparison. The ratios of feedstocks were determined based on the sheet properties. This study aimed to reclaim a valuable approach to reusing the secondary fibers in deinking sludge, which not only reduced the environmental pollution, but also developed a highly efficient reutilization of waste fibers, including methane production and corrugating medium paper manufacture.

Table 1
Secondary fiber sources and loads for the corrugating medium paper manufacture.

Treatment no.	Softwood pulp (%, TS)[a]	Wastepaper pulp (%, TS)	DS or DDS[b] (%, TS)
Ctrl.	20	80	0
1	20	70	10
2	20	60	20
3	20	50	30
4	20	40	40
5	20	30	50
6	20	20	60

[a] Based on dry weight.
[b] DS and DDS were added as secondary fiber sources, respectively.

Materials and methods

Experimental material preparation

The DS was collected from Guangzhou Pulp & Paper Plant (Guangdong, China). The plant uses waste newspaper as a main raw material to manufacture newsprint. The DS was generated in the process of wastepaper pulping by means of flotation deinking and dewatering (see Fig. 1). The DDS samples were collected from the dewatered digestate of deinking sludge after anaerobic digestion with nitrogen supplement of monosodium glutamate waste liquor. Raw softwood unbleached pulp with a beating degree of 20° SR was imported from the United States, which was obtained from the Kraft pulping process. Raw wastepaper pulp originated from the waste corrugating medium paper and cardboard, of which the beating degree was 20° SR, was provided by a papermaking plant in Dongguan (Guangdong, China). The raw softwood pulp and wastepaper pulp was pretreaed by the following process before used for the downstream handsheet formation. Washing and screening by a Messmer Somerville screen (71-20-00-0002, the Netherlands) were carried out to the raw softwood pulp and wastepaper pulp, respectively, and then disintegrating for each pulp (3 L, 2.5 wt%) at 3000 rpm for 200 s by using a disintegrator (PTI 95568, Australia). After that, beating the softwood pulp and wastepaper pulp by using a PFI mill (Mark V1 PFI, Hamjern Maskin 621, Norway) till the degree of 40° SR and 35° SR was observed, respectively. And then centrifugal dewatering at 1000 rpm, 5 min was implemented to the pulps. Each material was prepared prior to the experiment, and put into nylon ziplock bags storing in a refrigerator (0–4 °C). The main characteristics of the DS and DDS, such as pH values, moisture contents, organics contents and ash contents were analyzed.

The chemicals including French chalk (papermaking grade, 800 meshes), cationic polyacrylamide solution (industrial grade, 0.1% (w/v)), aluminum sulfate solution (analytical pure, 10% (w/v)) and liquid rosin solution (industrial grade, 50% (w/v)) were applied for handsheet formation [26,27], and all of them were purchased from Tai'an Qineng Chemical Sci-Tech Co., Ltd (Tai'an, China).