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Conditions for cost-efficient reuse of biological sludge for paper and board manufacturing

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ABSTRACT

Integrated water treatment plants in recycled paper and board mills produce significant amounts of excess biological sludge. Disposing of it is becoming increasingly expensive, as land filling is no longer an option. One possible solution is to reuse it internally for manufacturing paper. Recycling it in the process would reduce both the cost associated with sludge treatment and the amount of recovered paper to be purchased. However, this strategy deteriorates the mechanical properties of the paper to some extent. This detrimental effect can be compensated for by surface sizing. This paper examines the conditions in which it may be profitable for a mill to replace a proportion of recovered paper with biological sludge, depending on the cost of sludge disposal, surface sizing and the recovered paper itself. The effect of biological sludge reuse on the drainability of the papermaking suspension is studied as well. The consequences in terms of microbiological contamination of the paper and board are also reported. In the present situation, bio-sludge reuse is not cost-efficient. However that may change in the near future, as the cost of sludge disposal and the price of starch increase.

1. Introduction

Recycled paper manufacturing offers potential savings in terms of cellulosic fibres, water and energy (Finnveden and Ekvall, 1998). However, removing contaminants from the raw material throughout the recycling process generates losses in the form of various types of sludge. Recycled board mills are equipped with integrated wastewater treatment plants, which typically comprise primary clarification, followed by anaerobic digestion and aerobic treatment with activated sludge (Pokhrel and Viraraghavan, 2004). A significant amount of secondary sludge is generated by the activated sludge treatment, although considerable efforts have been made recently to reduce this (Mahmood and Elliott, 2006). The generated sludge requires special handling, and the associated costs are increasing. Traditionally, paper mill sludge has been disposed of by means of land filling or land spreading (Ribeiro et al., 2010; Ochoa de Alda, 2008). However, land filling is no longer an option for final disposal of sludge in Europe, due to legislation, increased taxes, competition for land and environmental concerns (Jung et al., 2011; Monte et al., 2009). This leaves the papermaker with other disposal routes, which are more and more expensive (on-site burning for energy recovery is becoming the most popular option; others are incorporation in cement, concrete, tiles or brick manufacturing). As the cost of sludge disposal is soaring, a few paper mills are investigating the advantages of internal recycling. One possibility is to recycle bio-treated sludge directly in paper manufacturing (as a filler), and to compensate for the loss of mechanical properties by appropriate surface sizing.

Although the strategy of bio-sludge reuse for recycled board manufacturing is currently being investigated at several recycling mills in Europe, there is no documented study on this topic, to our knowledge. The closest application to papermaking that is reported in the literature is the incorporation of paper mill sludge in medium density fibreboards (MDF) (Zerhouni et al., 2012; Migneault et al., 2010; Geng et al., 2007b). Some studies describe the typical composition of papermaking sludge (Ochoa de Alda, 2008). In recycling processes, primary sludge contains a significant amount of fibres, which may be collected in various ways. These fibre-rich fractions may then be recycled in the papermaking process (Žarković et al., 2011; Maxham, 1992). This strategy may contribute to fibre resource conservation, but will usually impair the mechanical properties of the sheet as the recovered fibres are hornified and lack bonding ability (Krigstin and Sain, 2005). However, bio-treated sludge from a recycled board mill contains virtually no fibre, so there is no incentive for collecting it. On the other hand,

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bio-sludge typically has a large mineral fraction (from 35% to more than 70% in some recycling mills with low fresh water consumption, (Huber et al., 2012; Lerner et al., 2007; Vogelaar et al., 2002)). The high mineral fraction of bio-sludge is expected to have a detrimental impact on the mechanical properties of the sheet, as small mineral particles have low affinity for cellulose and hinder inter-fibre bondings (Van de Ven et al., 2004; Middleton et al., 2003; Li et al., 2002; Kinoshita et al., 2000). On the other hand, activated sludge produces extracellular polymeric substances (EPS), consisting mainly of proteinic substances, polysaccharides and extracellular DNA (Garnier et al., 2005; Dignac et al., 1998). The composition of EPS can vary considerably depending on wastewater quality (Bura et al., 1998). In EPS from pulp and paper activated sludge, equivalent fractions of proteins and carbohydrates were found, with lower DNA fractions (Sponza, 2003). EPS can be either bonded to the flocs or in soluble form (Laspidou and Rittmann, 2002). The bondability of organic substances from bio-sludge is one of the rationales for incorporation in MDF boards (Zerhouni et al., 2012; Migneault et al., 2011; Geng et al., 2007a). The protein fraction of EPS has been proposed as an adhesive for plywood (Pervaiz and Sain, 2011). One may wonder whether the EPS of bio-sludge may help to enhance sheet properties (or at least limit the detrimental impact of mineral particles). The light brownish colour of bio-sludge makes it appropriate for reuse in brown board grades.

Typically, the maximum amount of excess biological sludge represents a few percent of paper production. Following the strategy of bio-sludge recycling in the paper machine, part of the recovered paper to be recycled is replaced by bio-sludge. Therefore there is an economic balance between the cost of recovered paper used as raw material and the cost of disposing of sludge. Furthermore, the detrimental impact of sludge on the mechanical properties of the sheet may be compensated for by surface sizing with starch, so that there is an economic compromise between the amount of sludge added and the cost-efficiency of surface sizing. It can be seen that optimum manufacturing conditions depend on the relative costs of (i) recovered paper raw material, (ii) surface starch and (iii) sludge disposal. As their prices are subject to market fluctuations, there is a need for a general answer, which can help determine the best option in the current market situation.

(i) Analysis of statistics for the period 2000–2011 shows that the buying price for board grade raw material (1.02 Mixed papers and boards (sorted), EN 643 “European List of Standard Grades of Recovered Paper and Board”) varied from −20 (!) to 100 EUR/t on the French market (source: Pap’Argus, http://www.pap-argus.com). The latest available price was around 50 EUR/t.

(ii) The price for native corn starch as of 2010 on the European market was 350 EUR/t not including enzymation (Todd, 2011). Considerable variations have, however, been observed over the last decade. The latest prices range from around 500 to 550 EUR/t in France.

(iii) A variable cost is associated with sludge disposal, depending on the options (agricultural spreading: 20–50 EUR/t, land filling: 50 EUR/t, energy production: 50–100 EUR/t, brickworks: 20–40 EUR/t; all costs are given for wet sludge, assuming a 50% dry content, as typically observed at the outlet of a sludge press (source: ADEME, Agence de l’Environnement et de la Maîtrise de l’Energie, France, 2009).

The objective of this work is to assess whether it is profitable for a recycled paper and board mill to reuse part of the biological sludge for its production.

The parameters studied to assess this profitability are the cost and the mechanical properties of the produced paper (mainly the SCT (Short span Compression Test) index). Laboratory sheets are manufactured using various amounts of bio-sludge and additives, and then submitted to size-press treatment. Models for the mechanical properties of the sized sheets are built using the Design of Experiment methodology. The optimum bio-sludge reuse ratio, for minimum cost after sizing, at given mechanical properties, is found by global optimisation. Sensitivity to the cost of surface starch, raw material and sludge disposal is determined. The impact of bio-sludge reuse on the drainability of the papermaking suspension is also studied and the consequences on microbiological contamination of the sheet are reported.

2. Methods

Three different recycling mills were sampled for raw materials (mills A, B and C, all producing linerboard from 100% recycled board). Mill A is the test case for the model (Fig. 1). The circuits comprise a pulp preparation loop and a paper machine separated by a thickening stage. The mill has a low specific fresh water consumption of around 5 m^3 per tonne of produced paper. Effluent is treated in an integrated wastewater treatment plant (WWTP) consisting of primary clarifier, then an anaerobic stage followed by an aerobic stage. The mill reuses most of its excess biological sludge in the paper machine mixing chest. The paper produced is sized with starch (5 g/m^2 total). In order to assess the effect of bio-sludge reuse in the laboratory tests, a testliner was sampled from a mill that does not recycle biological sludge (mill B). A third recycling site (mill C) was sampled for raw material as well in a series of preliminary tests, in order to assess the effect of bio-sludge reuse on pulp drainability and microbiological contamination of handsheets (see below in Section 2.8).

2.1. Raw materials

Biological sludge was sampled from the aerobic treatment stage of mill A. Process water was sampled from disk-filter clear filtrate from the same mill. Fresh bio-sludge and process water were sampled every week in mill A, and further used in the laboratory over a few days. Each sampling week corresponds to 1 block in the design of experiment (see Section 2.5). The testliner was sampled at

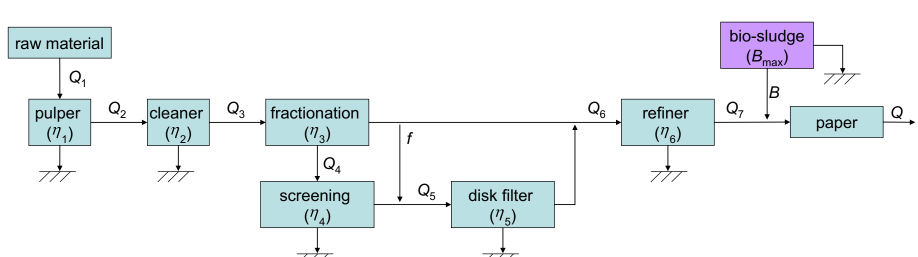

Fig. 1. Flow sheet of the modelled process (only the main pulp and sludge flows are considered, water flows not shown).