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A comparative study of biopolymers and alum in the separation and recovery of pulp fibres from paper mill effluent by flocculation

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ABSTRACT

Recovery of cellulose fibres from paper mill effluent has been studied using common polysaccharides or biopolymers such as Guar gum, Xanthan gum and Locust bean gum as flocculent. Guar gum is commonly used in sizing paper and routinely used in paper making. The results have been compared with the performance of alum, which is a common coagulant and a key ingredient of the paper industry. Guar gum recovered about 3.86 mg/L of fibre and was most effective among the biopolymers. Settling velocity distribution curves demonstrated that Guar gum was able to settle the fibres faster than the other biopolymers; however, alum displayed the highest particle removal rate than all the biopolymers at any of the settling velocities. Alum, Guar gum, Xanthan gum and Locust bean gum removed 97.46%, 94.68%, 92.39% and 92.46% turbidity of raw effluent at a settling velocity of 0.5 cm/min, respectively. The conditions for obtaining the lowest sludge volume index such as pH, dose and mixing speed were optimised for guar gum which was the most effective among the biopolymers. Response surface methodology was used to design all experiments, and an optimum operational setting was proposed. The test results indicate similar performance of alum and Guar gum in terms of floc settling velocities and sludge volume index. Since Guar gum is a plant derived natural substance, it is environmentally benign and offers a green treatment option to the paper mills for pulp recycling.

Introduction

Converting wood into paper is a complicated process in addition to being energy and resource intensive (Byström and Lönnstedt, 1997). A very high volume of water is required in the various processing steps, resulting in high volume of effluent. The principal polluting steps in the entire process are pulping, pulp washing, screening, washing, bleaching, paper making and coating (Ince et al., 2011). Treatment and disposal of the large quantity of generated sludge is a big challenge for the paper mill industry. The sludge consists of a significant quantity of fibres, sizing chemicals and fillers (Hashim and Sen Gupta, 1998). A significant volume of fine fibres is lost at different stages of the wet end of the paper production. Through existing facilities, much of the fibre is recovered in the different process; however, the total amount of fibre lost is substantial. Therefore, reclaiming the fibre

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content of the sludge would significantly reduce the sludge volume (Scott and Smith, 1995).

Conventional equipment like screens, cleaners or wet air oxidation have been used to separate fibre from the sludge (Wiegand, 1993). The most common technique for reclaiming fibre from sludge is to recycle primary sludge back into the fibre processing system of the mill which is commonly used by recycled paper-board mills and manufactures of bleached and unbleached pulp and paper (Ochoa de Alda, 2008). Some systems utilize sludge from the primary clarification of the effluent that contains higher amounts of fibre. However, recovered fibre sometimes loses its characteristics and becomes shorter in length and brittle; thus reducing the strength of the paper and other commercial attributes (Ochoa de Alda, 2006). Therefore, care must be taken so that recycled fibre does not affect the overall quality of the finished paper and reduce its market price.

Flocculation is a separation process which is widely used in paper mills for both paper making and effluent treatment. Flocculation can also be used for recovery of fibres from paper mill effluent. Traditionally, chemical coagulants such as ferric chloride, aluminium chloride, potassium alum and other polyelectrolytes are used for coagulation and flocculation process. However studies have shown that alum and other chemical coagulants reduce the bonding capability of the fibres when they are recycled (Guest and Voss, 1983). Wastewater treatment by natural polymers is being increasingly advocated in recent years. The biopolymers which are being currently studied for industrial wastewater treatment are chitosan (Guibal and Roussy, 2007), vegetable tannin (Özacar and Şengil, 2003), *Cassia javahikai* seed gum (Sanghi et al., 2006b), okra gum (Agarwal et al., 2003) and *Ipomea dasysperma* seed gum (Sanghi et al., 2006a). Guar gum is known to be used in potable water treatment and in food processing industry (Sen Gupta and Ako, 2005). These biopolymers are renewable resources, biodegradable and non-toxic for the aquatic organisms. Also secondary pollution due to accidental excess of biopolymer can be avoided.

In the present study, three polysaccharides (biopolymers) have been used as flocculents for separation of pulp fibres. Their efficiency has been compared to alum, which is a known chemical flocculent. The selected biopolymers *viz.* Guar gum, Locust bean gum and Xanthan gum are non-toxic, biodegradable and widely available (Levy et al., 1995). Guar gum is also a sizing additive commonly used in paper industry (Whistler Roy, 1954).

Sludge volume index (SVI) is a common parameter used for studying the settling characteristics of flocs. SVI establishes a functional relationship between settling velocity and suspended solids concentration (Koopman and Cadee, 1983) which is an important requirement for designing the capacity of a secondary clarifier's capacity. Dose, pH and mixing speed are the design parameters that were optimised to obtain the lowest SVI for the most effective flocculent. The floc settling rate at different pH values and for different flocculents was studied and the data from experimental runs were used to generate the settling velocity distribution curves (SDVC).

1. Methodology

1.1. Coagulants

The effluent was treated with one chemical coagulant and three biopolymers *viz.* plant origin Guar gum and Locust bean gum, and bacterial origin Xanthan gum. Guar gum is produced by grinding the endosperm of Guar beans and is a straight chain galactomannan that has galactose on every other mannose unit. Locust bean gum is the extract from seeds of carob tree. Locust bean gum is also a galactomannan with galactose and mannose units linked by glycosidic linkages. Xanthan gum is polysaccharide secreted by bacterium *Xanthomonas campestris*. The structure of all the three biopolymers is shown in Fig. 1. The polymers used for the experiments were of food grade. The inorganic chemical coagulant used is analytical grade hydrated potassium aluminium sulphate (alum) with chemical formula $KAl(SO_4)_2 \cdot 12H_2O$. A stock solution of concentration 1 g/L was prepared for all the biopolymers. In the case of the biopolymers, the powdered polymer was slowly added to distilled water and the beaker containing the water was slowly shaken. This ensured an evenly wetted solution. For the biopolymers, fresh solutions were prepared after every 12 hr to avoid growth of moulds.

1.2. Effluent and its characterisation

Synthetic paper mill effluent stock solution was prepared in the laboratory by mixing 2 g of ordinary tissue paper in 1 L distilled water following the method reported by Hashim and Sen Gupta (1998). The stock solution was diluted 10 times to perform further experiments. No chemicals were added to the diluted slurry and it was prepared fresh for each set of experiment to avoid bacterial degradation. The effluent was analysed for various physico-chemical parameters, namely, total dissolved solids (TDS), total alkalinity (TA), total organic carbon (TOC), hardness, total nitrogen and phosphorus using standard methods (APHA, 1998). The COD was analysed using a standard dichromate closed reflux method. The concentration of heavy metals, such as sodium, potassium, iron and calcium were measured using inductively coupled plasma optical emission spectrometry (Optima 7000 with Autosampler S10, PerkinElmer, USA). The experiments were carried out in duplicate under identical conditions. Functional groups present in Guar gum, effluent and flocs were characterised by Fourier transform infra red (FT-IR) spectra (Bruker Vertex 70/70 V spectrophotometer).

1.3. Comparison of different biopolymers

A jar test apparatus (Phipps and Bird PB-900 Programmable Jar Tester) was used for the flocculation studies with Guar gum, Xanthan gum and Locust bean gum and alum. These were tested for the separation efficiency of fibres from the effluent. The tests were conducted in 500 mL glass beakers; the pH was adjusted using HCl or NaOH. The mixing was carried out in jar test apparatus in three phases. In the first phase the stirring paddles were operated at maximum speed (flash mixing) for 5 min. Dosing of the flocculents was done as close to the hub of the propeller as possible, 2 min after beginning of flash mixing and the flash mixing was continued for another 3 min. The speed of the propeller was reduced in two phases of 10 min each. There were two set mixing designs used in the study. In one set the flash mixing speed was kept at 185 r/min and the speed was subsequently reduced to 60 r/min followed by 40 r/min. In the second mixing design the flash mixing speed was set at 200 r/min and the speed being further reduced to 70 r/min followed by a slow mixing speed of 40 r/min. The supernatant obtained after 30 min of settling was subjected to turbidity analysis in HACH 2100 N Turbidimeter.