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Adsorption of sugarcane vinasse effluent on bagasse fly ash: A parametric and kinetic study

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ABSTRACT

Sugarcane and bioethanol production produces large amounts of bagasse fly ash and vinasse, which are solid and viscous liquid wastes, respectively. However, these wastes are often disposed into the environment without treatment, thus posing an environmental and public health risk. This study investigated the treatment of vinasse effluent in terms of reduction of chemical oxygen demand (COD) and acidity removal using sugarcane bagasse fly ash. A maximum COD removal efficiency of 72% was obtained using an effluent volume of 100 mL, contact time of 180 min, and shaking speed of 240 rpm. The adsorbent dose and particle sizes were 4.5 g and 90–125 μm, respectively. Furthermore, the potential application of bagasse fly ash as an adsorbent in a sand filtration bed was assessed using a column test. A maximum recovery of 68% was obtained at the 25-min interval. The adsorption data was found to fit the Freundlich model best (K_f = 2.16 mg g^{-1}; R^2 = 0.96), and the kinetics fit the pseudo-second order model (R^2 = 0.98).

1. Introduction

Bioethanol production from sugarcane is often commended as a sustainable source of fuel. However, it produces large amounts of vinasse and bagasse, which are liquid and solid wastes, respectively (Colin et al., 2016). Vinasse is a complex acidic effluent formed during the distillation stage in the production of bioethanol. It often has high chemical oxygen demand (COD) and biochemical oxygen demand (BOD) that can be as high as 90000–210000 mg L^{-1} and 45000–100000 mg L^{-1}, respectively (Fagier et al., 2016). Vinasse is widely used for fertigation since it has high amounts of nutrients such as nitrogen, phosphorus, and sulfate (Christofoletti et al., 2013). However, vinasse effluent has been shown to have mutagenic and genotoxic potential in aquatic and terrestrial organisms such as fish (Correia et al., 2017a, 2017b), onion (*Allium cepa*) (Garcia et al., 2017), and *Rhinocricus padbergi* (Diplopoda) (Coelho et al., 2017). Therefore, discharging untreated vinasse into the aquatic and terrestrial environment may pose an environmental risk.

Sugarcane bagasse is often burned in the production of bioethanol as a source of energy and this result in the formation of bagasse fly ash (Bhatnagar et al., 2016). The bagasse fly ash has been successfully used as a filler material in the production of concrete in the construction industry (Ríos-Parada et al., 2017). Despite the increase in use in the construction industry, the amount of fly ash produced per year continues to grow (Janoš et al., 2003). Hence, in the past decade additional green applications of fly ash have been explored (Wong et al., 2018). Sugarcane bagasse fly ash contains about 15–35 wt% unburned carbon that could be easily separated and activated to low-cost sorbents for removal and recovery of small molecules (Gonçalves et al., 2016). For example, several studies successfully employed fly ash for the removal of dyes (Caqueret et al., 2012; Wang et al., 2010), organic compounds (Subramanian et al., 2013), and heavy metals (Yadav et al., 2014) in industrial waste. Unlike fly ash from incinerators, bagasse fly ash is more suitable for water treatment because it does not contain high concentrations of toxic metals (Janoš et al., 2003). Recently, 78% of melanoidins were successfully recovered from distillery wastewater using activated carbon derived from bagasse fly ash (Kaushik et al., 2017). Thus, using sugarcane bagasse fly ash as a sorbent is not only important for waste removal but volarization of agro-waste as well.

Bioethanol plants in Zimbabwe produce about 60 million liters of anhydrous ethanol each season, with approximately 470 million liters of vinasse effluent (Maqhuzu et al., 2017). In Zimbabwe, vinasse effluent is often discharged into the environment untreated. Furthermore, sugarcane bagasse fly ash is sometimes used for landfilling. Thus, although bioethanol production is essential for Zimbabwe to meet its sustainable development goals, the generation and subsequent

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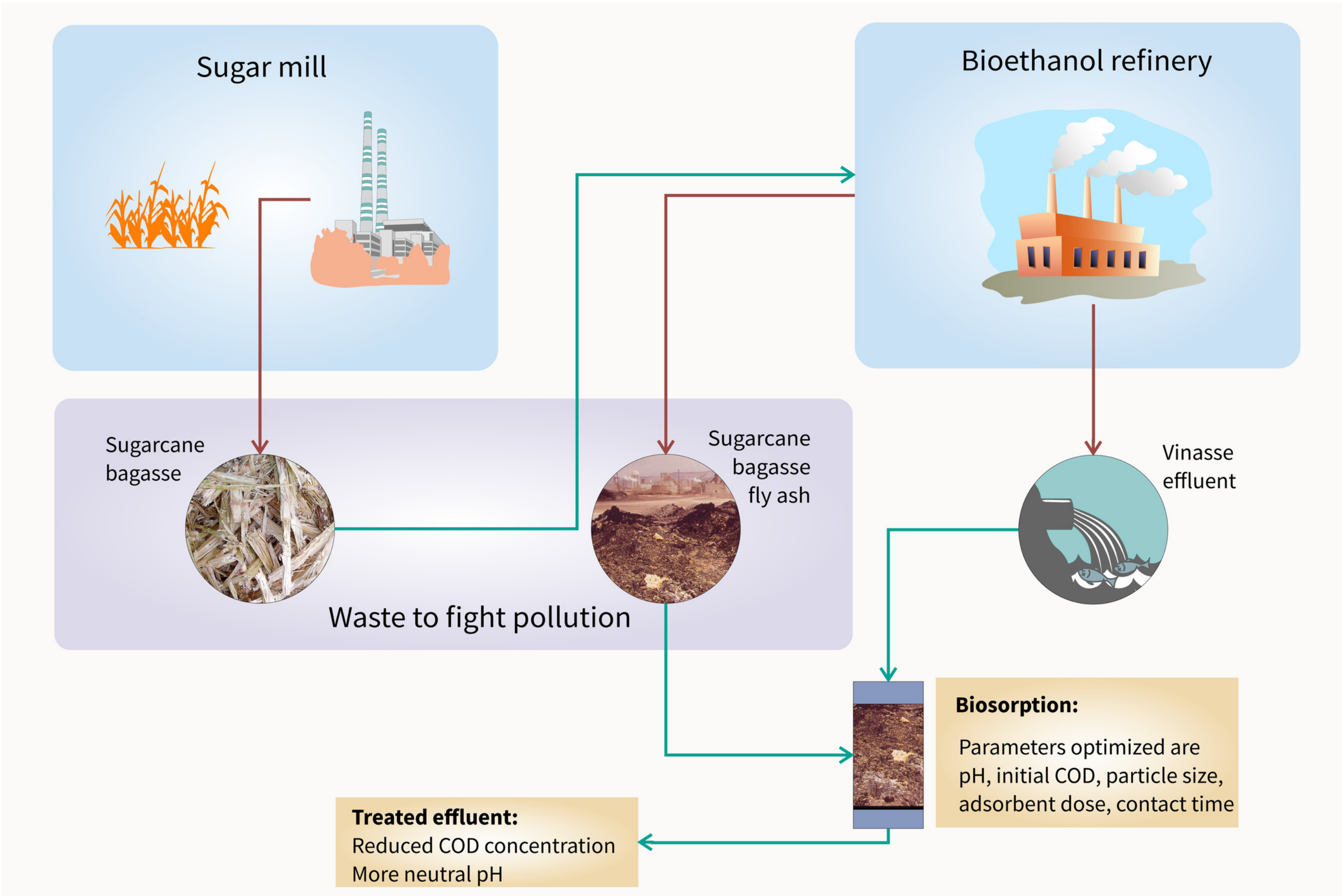

Fig. 1. An overview of the application of bagasse fly ash for treatment of vinasse effluent.

discharge of untreated vinasse and bagasse fly ash into the environment is an issue of major concern (Duvenage et al., 2013; Sanganyado and Nkomo, 2018). In other countries such as Brazil and India, vinasse effluent is often treated using physicochemical, electrochemical, and biological processes such as ultrasonic membrane anaerobic, membrane anaerobic, aluminum electrocoagulation reactor, electrochemical reactor, and ozonation systems (Bordonal et al., 2018; Christofoletti et al., 2013). These processes are often complex and sometimes cost-intensive. However, a previous study used bagasse fly ash as a low-cost adsorbent for treatment of dairy wastewater, and an adsorptive COD removal efficiency of 65% was observed (Kushwaha et al., 2010). Bagasse fly ash was also used to treat molasses spent wash in Ethiopia, and a COD removal efficiency of about 61% was obtained (Nure et al., 2017). The purpose of this study was to establish the applicability of a biorefinery waste product – sugarcane bagasse fly ash as a low-cost adsorbent in the treatment of COD and pH in vinasse effluents before releasing to the environment (Fig. 1). The optimum parameters for the adsorption process were investigated by varying the experimental conditions (e.g., contact time, adsorbent dose, initial COD concentration, and initial pH) and the experimental data were modeled using kinetic and adsorption isotherm models.

2. Materials and methods

2.1. Vinasse effluent

Vinasse effluent samples were collected from a bioethanol production site (Green Fuel, Chisumbanje, Zimbabwe). To minimize contamination by organics, glass sampling containers that had been thoroughly washed with detergent and rinsed with 20% H_2SO_4 were used. They were analyzed as soon as possible or preserved for up to 28 days after acidification to pH < 2 using H_2SO_4 and kept at 4 °C.

2.2. Bagasse fly ash and their characterization

Bagasse fly ash obtained from a boiler at the Green Fuel Bioethanol Plant (Chisumbanje, Zimbabwe) was soaked in distilled water, dried at 105 °C for 24 h, and sieved using IS sieves (IS 437-1979) on a Macsalab ES 200 Mark IV electronic sieve shaker (Caerphilly, United Kingdom). Five fractions were obtained, and the 90–125 μm particle size was chosen for use in the treatment of vinasse effluent because it represented 43% of the bagasse fly ash by mass. Furthermore, the 90–125 μm fraction was recommended in previous studies (Mane et al., 2007; Taha, 2006). Previous studies have comprehensively established the physicochemical properties of the bagasse fly ash (Srivastava et al., 2005; Wasewar et al., 2009). Bagasse fly ash was characterized using standard methods. Proximate analysis was conducted using IS: 1350-1984. Elemental analysis was carried out using a RIX 3000 X-ray fluorescence spectrometer (Rigaku Co. Tokyo, Japan).

2.3. Optimization using batch experiments

The COD concentration was determined using standard procedures on a Jenway 7300 UV-VIS Spectrophotometer (Staffordshire, UK). A known amount of bagasse fly ash adsorbent was used for 100 mL of vinasse effluent with an initial concentration of 1000 mg L^{-1} COD (C_0).