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Research article

Reduction of adsorbed dyes content in the discharged sludge coming from an industrial textile wastewater treatment plant using aerobic activated sludge process

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ABSTRACT

Dye mass balance study at full-scale industrial textile wastewater (ITW) treatment plant showed that 1.5 ton of excess waste sludge, containing 304.5 Kg of dyes, are daily produced and discharged in landfills. Therefore, this by-product of activated sludge process (ASP) presents a serious environmental problem. In this work, a laboratory and pilot scale investigations were carried out to optimize aerobic biodegradation efficiency to reduce the amount of residual adsorbed dye that will be found in the waste sludge. The resistance of acclimated biomass to the toxicity of ITW was studied in 2.5 L batch reactors using different dye to biomass (D/B) ratios of 0.102, 0.25 and 0.72 g COD_S/g VSS. Results of respirometric analyses showed that acclimated activated sludge (AS) biomass is able to treat ITW at high D/B ratio of 0.72 g COD_S/g VSS. Moreover, biodegradation kinetic study using Monod law showed that COD and color removal were better for the highest D/B ratio. The half saturation coefficient of heterotrophs for indigo dye (K_{Sind}) of 20.01 g/m^3 showed high affinity between biomass and dye molecules. Optimization of the process at pilot-scale with different hydraulic retention time (HRT) of 2–5 days, and different sludge recycling rates (SRR) of 220–680 m^3/d, showed that high HRT of 5 days and a SRR of 0.22 allowed the best dye biodegradation efficiency (95%). Application of the best conditions at full-scale reduced significantly (89%) the amount of the discharged dyes from 304.5 Kg/d to 33 Kg/d. Results were numerically validated using a mathematical model based on the activated sludge model 1 (ASM1).

1. Introduction

Textile wastewaters have been rated as the most polluting amongst all other industrial effluents due to their complex composition (Alinsafi et al., 2006; Verma et al., 2012). According to the World Bank reports, it seems that textile industry contributes to 20% of fresh water pollution. It contains weakly biodegradable substances such as detergents and dyes. Several treatment methods have been used for dye degradation which requires chemical, physical and biological processes or a combination of them, (Patel and Vashi, 2015; Dasgupta et al., 2015; Banerjee et al., 2015).

Biological methods are considered as the eco-friendliest processes for textile effluent treatment which are essentially based on biosorption and biodegradation efficiency (Mullai et al., 2017). Aerobic biodegradation of dyes by ASP is known as an efficient and cost-effective technology. However, it has got a serious environmental impact especially as they produce large volumes of sludge containing residual biodegradation resistant compounds (Guo et al., 2013; Manai et al., 2016). According to Huang et al. (2011), 25 m^3 of sludge is generated for every million tons of treated textile wastewaters. Moreover, Deraniyagala (2017) showed that ITW treatment by ASP produced 2000 tons of mechanically pressed hazardous sludge per year for a daily flow rate of 4000 m^3 of ITW.

In fact, the generated sludge is rich in potassium, nitrogen, metal ions and dyes (Roy Choudhury, 2017). However, dye molecules are designed to be resistant to spontaneous degradation in nature (Casas et al., 2013). Therefore, the discharge of excess waste sludge containing huge amounts of adsorbed dyes, coming from ITW treatment, into receiving medium will cause severe damages to the environment due to its toxic effect (Wang et al., 2009; Sohaimi et al., 2017).

To minimize the environmental impact of the textile wastewater treatment by-products using ASP, solutions would be essentially based on the acclimation and the selection of performant biomass. Authors suggested that microorganisms are able to create a highly adapted consortium capable of degrading toxic dye molecules (Lade et al., 2015; Meerbergen et al., 2017). Therefore, ITW treatment by acclimated

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Nomenclature

a	initial adsorption rate (mg/(g.min))
b	Elovich constant (g/mg)
b_H	decay rate for heterotrophs (1/day)
C_o	Initial dye concentration (mg/L)
C_e	Dye concentration at equilibrium (mg/L)
f_p	fraction of biomass yielding decay products
K	rate constant of sorption (g/mg.min)
K_1	first-order rate constant of adsorption (1/min)
K_F	Freundlich isotherm constant (mg/g) $(dm^3/g)^n$
k_h	Hydrolysis constant ((g slowly biodegradable. COD)/(g cell COD. day))
K_{OH}	Oxygen half-saturation coefficient for heterotrophs (g O_2/m^3)
K_S	half-saturation coefficient for heterotrophs (g COD/m^3)
K_{Sind}	half-saturation coefficient for heterotrophs for indigo degradation (g COD_S/m^3)
K_X	Half saturation coefficient for hydrolysis of slowly biodegradable substrate (g slowly biodegradable. COD/(g cell COD))
n_f	Freundlich constant
OUR	Oxygen Uptake Rate (mg/L.h)
q_e	Amount of dye in the sludge at equilibrium (mg/g)
q_{in}	Influent flowrate (m^3)
q_{max}	maximum monolayer coverage capacities (mg/g)
q_{out}	Effluent flowrate (m^3)
q_r	Recycling flowrate (m^3
R_L	Separation factor
S	Substrate concentration (mg/L)
S_d	Soluble dye concentration (mg/L)
S_o	Dissolved oxygen concentration (mg/L)
S_S	Readily biodegradable substrate (mg/L)
VSS	Volatile Suspended Solids (mg/L)
X_{BH}	Active heterotrophic biomass (mg/L)
X_I	particulate inert organic matter (mg/L)
X_p	particulate products (mg/L)
X_S	Slowly biodegradable substrate (mg/L)
Y_H	Heterotrophic yield (g cell COD formed/(g COD oxidized))
Y_{Hind}	Heterotrophic yield of indigo degradation (g cell COD formed/(g COD_S oxidized))
μ_H	maximum heterotrophic specific growth rate (1/day)
μ_{Hind}	maximum heterotrophic specific growth rate (1/day)
η_h	correction factor for anoxic hydrolysis

activated sludge should be more stimulated and optimized. The effect of hydrodynamic, physical and chemical conditions should be also studied for enhancing dyes biodegradation efficiency and to reduce the amount of residual adsorbed dye that will be found in the waste sludge.

This study aims to minimize dye content in the discharged sludge at the outlet of ITWTPs. The full-scale plant performance was examined in which dye mass balance was established according to its content in the excess waste sludge. A scale-down study was carried out by studying activated sludge acclimation level using respirometry analyses followed by biodegradation batch-cultures at laboratory scale. The best-operating conditions were determined at semi-industrial scale plants which were further applied at full-scale. On the basis of the obtained results, a mathematical model was established to describe and validate the optimal operating conditions. Therefore, this work offers an optimized process for reducing dyes toxic impact on the environment.

2. Materials and methods

2.1. Full-scale textile wastewater treatment plant description

This study was based on a full-scale wastewater treatment plant located in Ksar Hellal Tunisia treating ITW coming from dying and washing processes of a textile processing company (SITEX). The produced wastewater was collected in a homogenization tank to be treated later through a grit chamber to remove all the large solids (Fig. 1(A)). The pH of the influent was neutralized by liquid CO_2 to reach a value between 7.5 and 8.5, which is convenient for biological treatment. Two oxidation ditches, with a capacity of 2500 m^3 each, were used for biodegradation of pollutants. The aeration rate was about 250 m^3 air/h corresponding to a concentration of 2–3 mg O_2/L in the oxidation ditch. The treated influent was clarified in two secondary settlers with a volume of 224 m^3 each. The produced sludge was partially recycled. The treated ITW was discharged into the sewerage system. The excess waste sludge was treated through a thickener and a press filter for a complete dehydration. The plant was designed to deal with a daily flow rate of ITW of 1800 m^3. All performance assessment data were used for mass balance establishment, model calibration and validation.

2.2. Mass balance elaboration and total COD fractioning

Physical-chemical analyses were conducted for ITW characterization. pH, total suspended solids (TSS), volatile suspended solids (VSS), electric conductivity (EC), total COD (COD_t) and soluble COD (COD_S) were determined according to standard methods (APHA, 1995). The maximum absorbance of colorants was determined at 620 nm using UV-spectrophotometer. The obtained optical density values were converted into dye concentration in mg/L using an indigo calibration curve. Results showed that COD_S presented 84% of the COD_t, which proves that most of the organic pollution is soluble (Table 1). The value of TSS is about 450 mg/L which is relatively high compared to values of other studies conducted on SITEX plant (Manai et al., 2016). This difference is related to changes in textile industry activities.

ITW characterization was followed by a mass balance which was basically established for dyes (Eq. (1)). This equation was used by Liu et al. (2017) for biocides mass balance calculations.

$$\text{Minfluent} = \text{Meffluent} + \text{Msludge} + \text{Mloss} \quad (1)$$

Where, Minfluent, Meffluent and Msludge (Kg/d) are the mass loads of dye in the influent, effluent and excess waste sludge at the outlet of the filter press.

2.2.1. Desorption

The object of this test is to determine the amount of the final residual adsorbed dye on AS at the outlet of the plant. This was determined according to the method used by Sonai et al. (2016). For this purpose, 0.5 g of concentrated sludge collected from the outlet of filter press of SITEX plant, was placed in 250 mL conical flask with 100 mL of alkaline distilled water. Experiments were conducted for 15 days and aliquots were daily analyzed to determine the released dye concentration. All of the mentioned analyses were conducted in triplicate.

2.2.2. Total COD fractioning by respirometry tests

The respirometric tool was used for COD_t fractioning following the method of Spérandio and Etienne (2000). They worked with low and high food to microorganisms (F/M) ratios, which allowed the determination of the readily biodegradable substrate (S_S) and slowly biodegradable substrate (X_S) concentrations.

2.3. Sludge physical chemical analysis

Sludge physical chemical analyses were carried out following