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Research article

Enhanced dewaterability of textile dyeing sludge using micro-electrolysis pretreatment

Xun-an Ning*, [1], Weibin Wen [1], Yaping Zhang, Ruijing Li, Jian Sun, Yujie Wang, Zuoyi Yang, Jingyong Liu

School of Environmental Science and Engineering, Guangdong University of Technology, Guangzhou 510006, China

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ABSTRACT

The effects of micro-electrolysis treatment on textile dyeing sludge dewatering and its mechanisms were investigated in this study. Capillary suction time (CST) and settling velocity (SV) were used to evaluate sludge dewaterability. Extracellular polymeric substances (EPS) concentration and sludge disintegration degree (DD_{SCOD}) were determined to explain the observed changes in sludge dewaterability. The results demonstrated that the micro-electrolysis could significantly improve sludge dewaterability by disrupting the sludge floc structure. The optimal conditions of sludge dewatering were the reaction time of 20 min, initial pH of 2.5, Fe/C mass ratio of 1/1, and the iron powder dosage of 2.50 g/L, which achieved good CST (from 34.1 to 27.8 s) and SV (from 75 to 60%) reduction efficiency. In addition, the scanning electron microscope (SEM) images revealed that the treated sludge floc clusters are broken up and that the dispersion degree is better than that of a raw sludge sample. The optimal EPS concentration and DD_{SCOD} to obtain maximum sludge dewaterability was 43–46 mg/L and 4.2–4.9%, respectively. The destruction of EPS was one of the primary reasons for the improvement of sludge dewaterability during micro-electrolysis treatment.

1. Introduction

With the expansion of the textile industry in China, textile dyeing sludge production is increasing steadily in the processes of treating wastewater (Dos Santos et al., 2007; Nguyen and Juang, 2013). Currently, the disposal of textile dyeing sludge is a great challenge for the wastewater treatment plant because transportation and disposal of sludge may account for up to 60% of the total operation expenses (Qi et al., 2011). Sludge dewatering is of major importance during wastewater treatment because it lowers the cost of sludge transportation and disposal by separating the water from the sludge flocs and reducing the sludge volume (Guan et al., 2012). It is generally accepted that the formation of sludge flocs is based on interactions among microbial polymers, organic particles, inorganic particles, and filamentous bacterial strains, which are glued together by extracellular polymeric substances (EPS) (Neyens et al., 2004; Bala et al., 2010). Polysaccharides and proteins have been recognized as the major components of EPS, which are identified as the key to the improve dewaterability of sludge because of its strong affinity for water (Frølund et al., 1996). Hence, it is believed that sludge dewatering efficiency can be promoted by means of the quick attack on the EPS and the bacterial cells trapped in sludge flocs.

Various methods, including thermal (Neyens et al., 2003), AOP (Tony et al., 2008; Liu et al., 2013), ultrasonication (Appels et al., 2008; Dewil et al., 2006; Feng et al., 2009), biological treatment (More et al., 2010), microwave conditioning (Yu et al., 2009), have been developed to improve sludge dewaterability have been developed to improve sludge dewaterability. However, the application of these methods has been limited by factors including the complexity of implementation, the toxicity of the chemicals and high-energy consumption for the operation, and the increase in sludge volume. Therefore, it is urgent to explore a new method with low capital investment and environmental risk.

The micro-electrolysis technology was first used in the pretreatment of dyeing wastewaters in the 1970s (Yang et al., 2009). Currently, this technology has been widely applied in industrial wastewaters such as antibiotic (Liu et al., 2005), olive mill (Kallel et al., 2009), and coking wastewater (Liu et al., 2012a,b). In recent

* Corresponding author.
E-mail addresses: ningxunan666@126.com (X.-a. Ning), wenweibin0@sina.com (W. Wen).
[1] These authors contributed to the work equally.

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years, the micro-electrolysis technology has shown an enormous potential for disposing organic wastes. Organic pollutants, such as phenol (Guan et al., 2012), p-nitrophenol (Tang et al., 2012), propionitrile (Lai et al., 2013), nitrobenzene (Li et al., 2011) and organic dyestuff (Huang et al., 2013; Zhang et al., 2014), can be oxidized by oxidants and radicals produced during the micro-electrolysis process. The advantages of the micro-electrolysis technology include: (1) high process efficiency, (2) simple reactor construction (3) moderate operating costs, and (4) the availability of moderate cost, plentiful raw materials (Ju, 2011). Raw materials, activated carbon and iron chips are employed to be the electrolytic materials of micro-electrolysis. When the mixture of activated carbon and iron chips contacts acid wastewater (electrolyte solution), there are numerous macroscopic galvanic cells formed between the particles of carbon and iron. The electrode reactions can be represented as follows (Yang et al., 2009; Ruan et al., 2010; Cheng et al., 2007):

Iron anode (oxidation):

$$Fe(s) - 2e^- \rightarrow Fe^{2+}(aq),\ E^{\theta}\ (Fe^{2+}/Fe) = -0.44\ V$$

$$Fe^{2+}(aq) - e^- \rightarrow Fe^{3+}(aq),\ E^{\theta}\ (Fe^{3+}/Fe^{2+}) = +0.77\ V$$

Carbon cathode (reduction):

$$2H^+(aq) + 2e^- \rightarrow 2H \rightarrow H_2(g),\ E^{\theta}\ (H^+/H_2) = 0\ V$$

In the presence of oxygen:

$$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O,\ E^{\theta}\ (O_2/\ H_2O) = +1.23\ V$$

$$O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O_2,\ E^{\theta}\ (O_2/\ H_2O_2) = +0.68\ V$$

$$O_2(g) + 2H_2O + 4e^- \rightarrow 4OH^-(aq),\ E^{\theta}\ (O_2/OH^-) = +0.40\ V$$

Ferrous ions (Fe^{2+}) are rapidly released into the solution because of the dissolution of iron scraps. Subsequently, H_2O_2 is generated and combined with Fe^{2+} to form Fenton's reagents, which, theoretically, can generate •OH with powerful oxidizing abilities, resulting in the degradation of EPS and the improvement of the sludge dewatering property (Ju et al., 2011; Neyens et al., 2003; Ning et al., 2014).

Based on the advantage and analysis mentioned above, micro-electrolysis is likely an effective, moderate cost and novel technology for dewatering textile dyeing sludge. To the best of our knowledge, there has been no detailed report that uses micro-electrolysis to improve the sludge dewaterability.

This paper aims to investigate the effect of micro-electrolysis treatment on the physicochemical features of textile dyeing sludge. Sludge samples were treated with different electrolysis parameters (reaction time, initial pH mass ratio of iron powder to carbon and the dosage of iron powder). Capillary suction time (CST) and settling velocity (SV) were measured to define the optimal parameters for enhancing sludge dewaterability. The EPS concentration and sludge disintegration degree (DD_{SCOD}) of the sludge sample supernatant were measured to analyze the relationship between sludge dewaterability and disintegration. The mechanism behind the changes observed in sludge disintegration and dewaterability was also discussed.

2. Materials and methods

2.1. Sludge samples

The sludge samples collected from a textile dyeing wastewater treatment plant (Dongguan City, Guangdong province, China) were subsequently settled for 24 h to acquire thickened sludge samples. The thickened samples were stored in plastic containers and were placed in a refrigerator at 4 °C prior to use. The fundamental properties of the sludge samples are listed in Table 1.

2.2. Apparatus

A bench-scale experiment was performed in the self-made micro-electrolysis reactor, which is depicted schematically in Fig. 1. The reactor was made of a transparent synthetic glass column (Φ9 cm × 14 cm), and the electromagnetic vibrating air pump (YT-304, air pressure 0.013 MPa, air delivery rate 4.5 L/min) was used to generate oxygen and mix the granular activated carbon (GAC) and iron powder together. In addition, 400-mL textile dyeing wastewater sludge was employed to investigate the sludge dewaterability.

The mean particle size of the commercial GAC (Tianjin Fucheng Chemical Reagent Factory) was approximately 4 mm. Prior to use, GAC was immersed in the sludge for 48 h to avoid the interference of adsorption. The commercial iron powder was obtained from Chengdu Kelong Chemical Reagent Factory, particle size was approximately 0.08–0.10 mm and the iron content was 98%.

2.3. Experimental procedure

A 400-mL sludge sample was transferred to the micro-electrolytic reactor, and the pH was adjusted with sulfuric acid (H_2SO_4) and measured with a pH meter (pHS-3C, LEICI, China). The micro-electrolysis treatment conditions were optimized by the single-factor experiments, and the main influence factors including reaction time (0 min, 5 min, 10 min, 15 min, 20 min, 25 min and 30 min), initial pH (2.0, 2.5, 3.0, 3.5, 4.0, 4.5, and 5.0), mass ratio of iron powder to GAC (1/2, 2/3, 1/1, 4/3, 2/1, and 4/1) and the dosage of iron powder (1.25 g/L, 2.50 g/L, 3.75 g/L, 5.00 g/L, 6.25 g/L, and 7.50 g/L) were investigated. The sludge dewaterability was evaluated in terms of CST, SV and the viscosity of sludge. To further understand the mechanism behind the observed changes in sludge dewaterability, the EPS concentration and DD_{SCOD} of the supernatant sample were also measured. All experiments were conducted at room temperature, each experiment was performed in triplicate, and the average values and the standard deviations were obtained.

2.4. Analytical methods

Sludge dewaterability was determined by the CST, which was obtained using a standard apparatus (304 M, Triton, UK). The SV of the sludge sample was obtained by measuring the sludge volume change in a 100-ml cylinder (100 mL, ARROW) after a 30-min settlement. The viscosity of sludge was measured by a viscosity analyzer (NDJ-8S, Changji, China).

Proteins and polysaccharides were selected to characterize the EPS concentration of the sludge supernatant, which were determined spectrophotometrically using a T6 UV/visible

Table 1
Characteristics of the raw sludge sample.

Parameters	Unit	Average value
pH		6.70
Moisture content	%	98.68
Settling velocity	%	99
Soluble chemical oxygen demand	mg/L	77.53
Protein	mg/L	1.37
Polysaccharide	mg/L	11.94
Capillary suction time	S	59.60