Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Combination of electrocoagulation with advanced oxidation processes for the treatment of distillery industrial effluent

*Abdul Raman Abdul Aziz**, *P. Asaithambi**, *Wan Mohd Ashri Bin Wan Daud*

Department of Chemical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 26 August 2015
Received in revised form 13 November 2015
Accepted 26 November 2015
Available online 10 December 2015

Keywords:
Electrocoagulation
Distillery effluent
Ozonation
Photo
Color and COD removal
Power consumption

ABSTRACT

The treatment of distillery industrial effluent by means various combinations of electrocoagulation with Advanced Oxidation Processes (AOPs) such as ozonation, electrocoagulation, peroxi–electrocoagulation, photo–electrocoagulation, ozone–electrocoagulation and peroxi–photo–electrocoagulation process on the removal of percentage color, COD and energy consumption. The effects of various operating parameters such as ozone flow rate (5 to 15 LPM), initial effluent pH (2 to 10), current density (0.10 to 0.50 A/dm^2) and H_2O_2 concentration (50 to 500 mg/L) on the removal of pollutant were studied in this study. Moreover comparison of all the processes in terms of color removal, COD removal and energy consumption was also carried out. The experimental results showed that100% of color and COD removal could be achieved by ozone–electrocoagulation process with an energy consumption of 5.7 kW h/m^3 within four hours of reaction time. The extent of color and COD removal was analyzed using a UV/vis spectrophotometer and closed reflux method.

1. Introduction

Contamination of fresh water supplies and growing demand of clean drinking water are threatening human kind and environment. Currently, there are more than a billion people who do not have access to clean drinking water and more than two million people, mostly children under the age of five, who die due to lack of clean drinking water (United Nations Educational et al., 2003). The demand for clean water is on a rising trend. However, due to rapid industrialization, a large quantity of polluted water is generated every year by different industries such as textile (Zheng et al., 2012), tannery (Houshyar et al., 2012), landfill (Wu et al., 2011), pharmaceutical (Farhadi et al., 2012; Boroski et al., 2009), heavy metal (Aji et al., 2012), baker's yeast (Gengec et al., 2012), food-processing (Pablo Pocostales et al., 2012), distilleries, pulp and paper, petrochemical, leather and etc. The above mentioned industries produce wastewater that contain polluting substances such as complex pollutants, nitrogen, phosphorous, sulphur, food scraps, recalcitrant or toxic organic compounds, phenolic compounds, soap, oil, pathogens and other harmful substances (Kerc et al., 2003; Gómez et al., 2011). All these substances affect the human health and aquatic living organisms. Therefore, wastewater must be treated prior to discharge to natural water bodies. There are several methods available for treatment of industrial effluent such as physical (Chowdhury et al., 2013; Liu et al., 2012a), chemical (Liu et al., 2012b; Lucas et al., 2010) and biological treatment. (Chandra et al., 2008, 2012; Chaturvedi et al., 2006; Prasad, 2009; Liang et al., 2009). However, from the reported results in the literature, it is concluded that a single process is not effective for the treatment of industrial wastewater. Thus, research is focused on the combination of two or more techniques for effective removal of pollutant. Our research group then introduced

* Corresponding authors. Tel.: +60 3 7967 7687; fax: +60 3 79675319.
E-mail addresses: aziraman@um.edu.my (A.R.A. Aziz), drasaithambi2014@gmail.com (P. Asaithambi).
http://dx.doi.org/10.1016/j.psep.2015.11.010
0957-5820/

Electrochemical Advanced Oxidation Processes (EAOPs) for the treatment of industrial effluent. Electron plays the main role in EAOPs. The other advantages of EAOPs include: (i) it can be operated at room temperature and pressure, (ii) high oxidation ability, (iii) fast reaction rate, (iv) total pollutant removal in the organic and inorganic pollutants with minimal cost and (v) it can be combined with other treatment processes.

A variety of advanced oxidation processes (Basturk and Karatas, 2014; Babuponnusami and Muthukumar, 2011; Monteagudo et al., 2014) have been applied to the removal of pollutants from wastewater. AOPs such as chemical (Fe^{2+}/H_2O_2), photo-chemical ($UV/Fe^{2+}/H_2O_2$), and sonochemical (US/Fenton, US/photocatalytic) methods, these method are promising efficient process, environment-friendly methods, do not require addition of more amount of reagent and have the capability for in-situ production of more hydroxyl radical, and also have proved to be efficient methods to remove the pollutant (Pontes et al., 2010; Primo et al., 2008; Karcia et al., 2012; Li et al., 2013; Monteagudo et al., 2014). The main aim of EAOPs is to generate $^{\bullet}OH$, which is the second strongest oxidizing agent after fluorine. It has a high standard reduction potential ($E^{\circ}(^{\bullet}OH/H_2O) = 2.8$ vs SHE) and is able to non-selectively react with most organics and inorganics via hydroxylation or dehydrogenation. Several reviews have extensively described the use of O_3 (Turhanet al., 2012), chemical AOPs (O_3/H_2O_2), Fenton's reagent (Fe^{2+}/H_2O_2) (Chandrasekara Pillai et al., 2009), ultrasound and wet oxidation (Sangave and Pandit, 2004; Sangave and Pandit, 2006), photochemical AOPs (O_3/UV, H_2O_2/UV, $O_3/UV/H_2O_2$) (Brillas et al., 2004; Yuan et al., 2012; Im et al., 2012; Schrank et al., 2005), photo Fenton (Fe^{2+}/H_2O_2/UV), UV/Solar (Chang et al., 2006) and TiO_2 Photocatalyst (Catalkaya and Kargi, 2007) processes for the removal of pollutant.

Recent research has focused on the development of hybrid process based on the electrochemical and advanced oxidation processes (AOPs), which are widely applied for disinfection of reclaimed water, treating wastewater residues and wastewater (Brillas et al., 2004). The electrochemical systems are coupled with photo (Farhadi et al., 2012), ozone (Bernal-Martínez et al., 2013; García-García et al., 2014; Hernández-Ortega et al., 2010) or hydrogen peroxide (Yuksel et al., 2009) and advanced oxidation processes (Durante et al., 2011) which can remove a wide range of organic and inorganic pollutants and ensure good-quality effluent. Song et al. (2007) reported the combination of ozonation and electrocoagulation process for the removal of azo dye and C.I. Reactive Blue 19. This process results shows that the enhancement of the removal percentage of the color and COD. Bernal-Martínez et al. (2010) reported that the effectiveness of electrochemical, ozone and integrated electrochemical–ozone processes of industrial wastewater and they are found the integration of electrochemical–ozone processes significantly improved the removal of COD, BOD_5, color, turbidity and total coliforms was 99%, 84%, 79%, 95%, 96% and 99%, respectively. Yuksel et al. (2009) developed the peroxi–electrocoagulation process for the removal of sodium dodecyl sulfate (SDS) surfactant. The results revealed that the overall SDS removal efficiency reached 81.60% with energy consumption of 1.63 kW h $(kgSDS)^{-1}$. Farhadi et al. (2012) investigated the comparison between electrocoagulation, photo–electrocoagulation, peroxi–electrocoagulation and peroxi–photo–electrocoagulation processes to removal of COD from pharmaceutical wastewater. They were observed that the COD removal efficiency was in order of peroxi–electrocoagulation > peroxi–photo–electrocoagulation > photo–electrocoagulation > electrocoagulation process.

A correct combination of the system should be selected by considering several technical (plant simplicity, treatment efficiency, flexibility, operating parameters etc.) and economical aspects (capital and operating cost including reagent and energy consumption, sludge and gas disposal, maintenance etc.). Integrating electrochemical process with AOPs is conceptually beneficial as it results in increased overall efficiencies compared to the efficiency of a single process, and is also an active research for developing the hybrid process.

However, to the best of our knowledge, the application of hybrid process based on the electrochemical and AOPs for this kind of industrial effluent has not been reported. The aim of this work is therefore to study the novel technology based on the integration of electrocoagulation with ozonation, hydrogen peroxide and photo process. This study also presented a comparison efficiency of six wastewater treatment methods, i.e. ozonation, electrocoagulation, ozone–electrocoagulation, peroxi–electrocoagulation, photo–electrocoagulation, peroxi–photo–electrocoagulation process for removing color and COD from distillery industrial effluents with minimum energy consumption. To perform the techniques, studied various operating parameters such as ozone flow rate (5 to 15 LPM), initial effluent pH (2 to 10), current density (0.10 to 0.50 A/dm^2) and H_2O_2 concentration (50 to 500 mg/L) on the percentage color, COD removal and power consumption. The color and COD removal has been analyzed using UV/vis spectrophotometer and closed reflux method.

2. Material and methods

2.1. *Wastewater samples and characteristics*

The industrial effluent was collected from nearby cane molasses based distillery industries, Kuala lumpur, Malaysia. The effluent was analyzed for various parameters such as pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), color and Odor as per as per standard method of analysis (APHA et al., 1998). The COD was measured by closed reflux method using potassium dichromate, the BOD was measured using Winkler method and color was determined by UV–vis spectrophotometer (Jasco, V-570) and the main characteristic are given in Table 1. The chemicals used in the experiments were H_2O_2 (50% w/w) as an oxidant reagent,

Table 1 – Characteristics of distillery effluent (ten times dilution).

Characteristics	Before treatment	After treatment at optimized condition[a]
pH	5.20	7.1
COD (mg/L)	8500	550
BOD (mg/L)	3000	250
TSS (g/L)	14	4.50
TDS (g/L)	5.60	0.80
Color	Dark brown	Color less
Odor	Burnt sugar	Nil

[a] Initial pH = 6; current density = 3 A/dm^2, ozone concentration = 2 g/h, in-between electrode desistance: 2 cm and electrode combination = Fe/Fe.