

Removal of phosphate from surface and wastewater via electrocoagulation

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ABSTRACT

Water with excessive nutrients are continuously released into water bodies, the resulting eutrophication causes public health, environmental, and economic problems. Phosphorus (P) impairment of fresh surface waters is a major concern in the USA and worldwide. The aim of this study is to use a bench scale P removal system that utilizes electrocoagulation (EC) to address this water quality problem. This study examined the effects of treatment parameters (initial pH, initial conductivity, power input, and initial P concentration) on the ability of the EC process to remove P in solutions with initial P concentrations less than 2 mg/L. It also investigated the ability of EC to reduce concentrations of P in surface water and treated wastewater. P concentrations in phosphate solutions, surface water, and wastewater effluent were reduced by 99% in under 60 min. The removal efficiency was demonstrated to be directly proportional to the conductivity and power supplied.

1. Introduction

Phosphorous (P) plays a critical role in the survival of living organisms. This nutrient is mainly found as phosphate in animals and plants, where it is essential for the formation of Adenosine Triphosphate and the creation of nucleotides. Nevertheless, phosphate is a widely-used fertilizer in agriculture and animal supplements. Excess P in farming areas is directly discharged to water bodies where P concentrations increase dramatically (Vasudevan et al., 2008a). High P loads into surface water leads to eutrophication of the water. Eutrophication of water bodies has harmful ecological effects such as toxic algal blooms and the development of oxygen depleted or hypoxic zones (Carpenter et al., 1998). Both toxic algal blooms and hypoxic zones harm aquatic organisms and can lead to fish kills (Bennett et al., 2001). Eutrophication of water bodies can also lead to a change in plant and animal species composition, loss of biodiversity, and disruption of food webs (Carpenter et al., 1998).

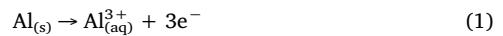
The total amount of P allowed to be discharged into water bodies varies greatly from state to state. Numerous states have established numeric nutrient criteria to determine the maximum amount of P and nitrogen a water body can receive without impairing water quality. These nutrient criteria were then used to establish National Pollutant Discharge Elimination System (NPDES) discharge permits and for the development of total maximum daily loads (TMDL) to limit the release of nutrients into impaired water bodies (USEPA, 2016).

To reduce the amount of P being released into water bodies from point source discharges several treatment methods have been

developed. Some methods utilize physio-chemical processes such as adsorption, ion-exchange, and chemical precipitation. Enhanced biological phosphorus removal processes, which utilize microorganisms to extract P from solutions, have also been employed (Lacasa et al., 2011). Nevertheless, disadvantages such as high residence time and cost, and low removal efficiencies are persistent throughout most of these treatment methods (Mahvi et al., 2011).

Investigations into electrocoagulation (EC) treatment processes have gained interest among researcher's due to its ability to remove a variety of contaminates, such as heavy metals, organic matter, oils, suspended particles, dissolved particles, and various chemical compounds (Mollah et al., 2004; Holt et al., 2005). EC permits the removal of dissolved P in a solution by having a current applied to submerged electrodes. The electrodes are usually made of iron or aluminum. The electric current applied to the electrodes causes the release of metal cations in the contaminated water. These metal cations can form polymeric metal hydroxide species which neutralize negatively charged contaminates, such as PO_4^{3-} . These particles aggregate together to form floc and settle out of the solution. The metal cations can also directly bind to the suspended P contaminant and precipitate out of the solution (Mollah et al., 2001). During EC, removal of P by amorphous metal hydroxides and formation of metal phosphate occurs simultaneously (Lacasa et al., 2011). Equations 1–4 illustrate the chemical reactions that take place at the anode, cathode, and in the solution.

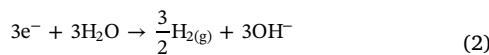
Chemical Reaction at Anode:



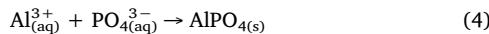
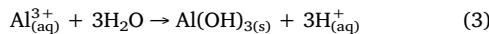
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Chemical Reaction at Cathode:



Chemical Reaction in Solution:



Numerous publications have analyzed the effects of several operating parameters such as the initial pH, initial conductivity, current density, and initial concentration of P, on the efficiency of the EC process (Attour et al., 2014; Irdemez et al., 2006a,b,c; Lacasa et al., 2011; Vasudevan et al., 2008a).

1.1. Objectives

1. Determine the capabilities of EC to remove P in solutions with initial P concentrations less than 2 mg/L under various operating parameters (initial pH, initial conductivity, and applied power).
2. Determine the extent to which EC can reduce the P concentration in surface water and wastewater without negatively impacting pH, conductivity, turbidity, and alkalinity.

2. Materials and methods

2.1. Phosphate solutions, surface water, and wastewater samples

Synthetic phosphate solutions were prepared from KH₂PO₄ using distilled water. To prepare a completely mixed solution a magnetic stirrer plate was used. The solution's initial pH was adjusted to pH ranging from 3 to 9 using 0.5 M HCl and 0.5 M NaOH. Initial conductivity was adjusted to 150–880 µS/cm by dissolving 0.01 M KCl into the solution. Wastewater effluent from the Three Oaks Waste Water Treatment (WWTP) plant clarifiers, as well as surface water samples from Billy Creek were collected and tested. The Three Oaks WWTP is in Estero, Florida, and Billy Creek, a tributary of the Caloosahatchee River, is in North Fort Myers. The numeric nutrient criteria for total phosphorous in rivers and streams in peninsular Florida of 0.12 mg/L applies to Billy Creek and the Caloosahatchee River (USEPA, 2016).

2.2. Experiment configuration and testing

The EC reactors consisted of a square Plexiglas container capable of holding 1 L of liquid. Two pre-weighed aluminum electrodes, 50 mm × 82 mm each, were used for the anode and cathode in each reactor. The electrodes were held 2.5 cm apart. A portion of the electrode surface area, 13.32 cm², was submerged in the solution held in the 1 L Plexiglas container. A 30 V/5A Single-Output DC Power Supply 110 V/220 V Switchable, with alligator clips, was used to apply a predetermined current and voltage to the electrodes. The container was placed on a magnetic stir plate to allow the solution to be continuously mixed, at the lowest speed, as power was applied to the electrodes. All tests were conducted for 50 or 60 min at room temperature.

20 mL samples were extracted at specific time intervals (0, 2, 6, 10, 15, 20, 30, 40, 50, and 60 min). The pH and conductivity of the samples were measured using a pH meter (Oakton) and conductivity meter (Oakton). 10 mL from each 20 mL sample was filtered through a syringe membrane 25 mm filter with the pore diameter of 0.45 µm and then analyzed for the P concentration. All tests were conducted at room temperature. Turbidity of the surface water and wastewater were analyzed before and after each EC test using a turbidity meter (Clarkson 600100). Alkalinity testing was carried out on 50 mL samples of surface water and wastewater collected prior to and immediately after EC testing. Alkalinity testing was carried out per standard methods for examination of water (Clesceri et al., 1999). Dissolve reactive P or

orthophosphate concentration was measured using PhosVer® 3 Phosphate Reagent Powder Pillows (HACH DOC316.53.01119) and a spectrophotometer (Thermoscientific). Soluble reactive P concentrations were measured because it provides a good estimation of the P that can be easily utilized algae and other aquatic organisms (Busman et al., 2009).

Prior to the surface and wastewater EC tests, a series of preliminary EC experiments on phosphate solutions were conducted to determine the capabilities of EC to remove P in solutions with initial P concentrations less than 2 mg/L under various operating parameters such as initial pH, initial conductivity, and power applied. Tests were conducted for low initial P concentrations of 0.07–0.15 mg/L (Low P) and high initial P concentrations of 1.5 mg/L ± 0.25 mg/L (High P). The study of differing initial P concentrations was done with the purpose of emulating the typical concentrations of P in wastewater and surface water.

3. Results and discussion

3.1. Effects of initial pH

The initial pH has been reported to have a significant effect on the performance of the EC treatment process (Attour et al., 2014; Behbahani, 2011; Kobya et al., 2009; Vasudevan et al., 2008a). As seen in Fig. 1, the P removal efficiency varied significantly depending on the initial pH of the batch. For both High P tests, the solutions with initial pH of about 7.5 were observed to have fastest P removal rate, with 99% reduction achieved by 15 min of reaction time. For both High P tests, solutions with initial pH around 5.5–7 had the second fastest P removal rate and tests with initial pH 8.12–8.83 had the third fastest P removal. 99% reduction of P concentration by 60 min of reaction time for High P tests was achieved for the solutions with pH 5–8.83. Similar removal efficiencies were obtained by other studies with initial pH 5–10 (Attour et al., 2014; Behbahani, 2011; Bektas et al., 2004; Chen et al., 2014; Kobya et al., 2009; Kuokkanen et al., 2014; Mahvi et al., 2011; Vasudevan et al., 2008a).

For Low P concentration, the results were found to be similar. However, the reactor with a pH of about 8.83 displayed the fastest removal efficiency, removing 99% of P in less than 10 min of reaction time. Solutions in the Low P and High P tests with an initial pH of 3 did not remove any P. These results conflicted with many studies that reported 60–100% reduction in P concentration with an initial pH of 3 (Attour et al., 2014; Behbahani, 2011; Irdemez et al., 2006a; Kobya et al., 2009). The lack of P removal at this initial pH compared to other studies may be attributed to differences in electrode materials used, power levels applied, initial conductivity, and submerged electrode area, all of which are important parameters for P reduction using EC (Chen, 2004). Thus, it was determined that the use of EC for the reduction of P was feasible over a wide range of initial pH.

3.2. Effects of initial conductivity

Deionized water has been known to be ineffective at conducting electricity due to the lack of ions in the solution. The conductivity of surface and wastewater is usually dependent on the amount of total dissolved solids. Therefore, KCl was added to the Low P and High P solutions to create mixtures with approximate conductivity of 146–225 µS/cm, 314–345 µS/cm, and 681–880 µS/cm as shown in Fig. 2. These values were selected with the purpose of covering typical conductivities of surface and wastewater. Lake Trafford, a surface water body near Immokalee, FL, has a conductivity of approximately 280 µS/cm (Cabezas and Tomasko, 2009), which falls within the range tested. Similarly, as presented later in this report, surface water channels near the Fort Myers area such as Billy Creek, have a conductivity of 500 µS/cm. Regarding wastewater, the conductivity measured varied from 700 to 800 µS/cm.

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