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Bismuth oxychloride-mediated and laser-induced efficient reduction of Cr(VI) in aqueous suspensions

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ABSTRACT

The reduction of Cr(VI) was investigated in aqueous suspensions of BiOCl and Degussa P25 using a 355 nm laser radiation and conventional lamp. BiOCl showed better photocatalytic activity than Degussa P25 and ~95% Cr(VI) was reduced within short time (30 min) of laser exposure in presence of BiOCl without the use of any additive. Effects of critical parameters, such as laser energy, catalyst amount and chromium concentration on the photocatalytic reduction process were investigated. The photocatalytic removal of metal was fitted to first-order kinetic and reaction rate was estimated. Structural and compositional stability of BiOCl before and after photocatalytic reaction were determined by XRD, Raman, FT-IR, TGA/DSC analyses.

1. Introduction

A wide variety of organic pollutants are introduced into the water system from various sources such as industrial effluents, agricultural runoff and chemical spills. Their toxicity, stability to natural decomposition and persistence in the environment has been the cause of much concern to the societies and regulation authorities around the world [1]. The increased level of hexavalent chromium, which is carcinogenic, in water can damage all major organs and functions of the body such as liver, kidney circulatory, nerve tissues etc. Chromium has been used extensively in several industries, such as alloys and steel manufacturing, metal plating, military purposes, and tanning of leather, as well as in the pigment and refractory industries [2,3]. The toxicity and carcinogenic properties of chromium(VI) have been known for a long time [4] and it is included in the list of priority pollutants in many countries of the world [5]. Conventionally, industrial waste treatments for heavy metal reduction include techniques such as biological treatment, ion exchange, liquid–liquid extraction, precipitation, reverse osmosis, and activated carbon adsorption [6]. However, these techniques often utilize potentially hazardous or polluting materials and can only transform the pollutants from one phase to another [7]. Moreover, they may require pretreatment, their by-products are often considered hazardous, and their disposal is costly. Among many processes proposed and/or being developed for the removal of the organic contaminants, considerable attention has been focused on the use of semiconductor as a means to oxidize and reduce toxic chemicals both in aqueous [8–11] and gaseous phase [12–14] using solar or artificial light. The fundamentals of heterogeneous photocatalytic oxidation processes have been well documented in the literature [15,16]. The photo-reduction process involves metal ions being reduced to form metal deposits on the surface of the semiconductor catalyst. The deposited metal can subsequently be recovered by mechanical and/or chemical methods. Attempts have been made to study the reduction of metals using semiconductor-mediated photocatalytic process. It is noteworthy that the efficiency of the photocatalytic process utilizing semiconductors for metal reduction has been found to be low in absence of any additive. For instance, investigated the solar photocatalytic reduction of Cu(II), Ni(II), Zn(II) and Pd(II) and observed that the photocatalytic reduction of the these metals was significantly accelerated by citric acid and, however, the reduction was negligible in the absence of citric acid [17]. Numerous examples could be presented here demonstrating that most of the studies have been carried out in the presence of some organic additives such as salicylic acid, oxalate, phenols, dye, and humic acid [18–21], as well as some electron donors such as methanol, formate ions etc. [6,22].

Recently, bismuth oxyhalides (BiOX, X = Cl, Br, I) have been studied as a new catalyst for photocatalytic applications [23–27]. Different morphologies such as 2D and hierarchical structure of BiOCl have been fabricated and their photocatalytic activity was studied [25]. In most of the cases, dyes and priority organic pollutants such as phenol have been selected as model pollutants to

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