Chemosphere 81 (2010) 1069–1074

Contents lists available at ScienceDirect

Chemosphere

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

Phytoremediation of ethylene glycol and its derivatives by the burhead plant (*Echinodorus cordifolius* (L.)): Effect of molecular size

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ARTICLE INFO

Article history:
Received 11 May 2010
Received in revised form 16 September 2010
Accepted 16 September 2010
Available online 12 October 2010

Keywords:
Phytoremediation
Monoethylene glycol
Diethylene glycol
Triethylene glycol
Echinodorus cordifolius (L.)

ABSTRACT

Ethylene glycol (EG) is a group of dihydroxy alcohol that has been utilised in a variety of industrial and residential settings. EG contaminated wastewater has a high chemical oxygen demand (COD), which causes environmental problems. The aim of this research was to investigate the efficiency of the burhead plant (*Echinodorus cordifolius* (L.)) in the removal of mono-, di- and triethylene glycol (MEG, DEG and TEG), the first three members of the dihydroxy alcohol group, from synthetic wastewaters, to examine the toxic effect of EG on the plant and to identify differences among MEG, DEG, and TEG removal. It was found that the COD of synthetic wastewaters decreased to levels below the standard effluent (COD = 120 mg L^{-1}) on day 18, 21 and 33 for MEG, DEG and TEG, respectively. On day 18 of the experiment, the burhead plant removed approximately 2000, 1950 and 730 mg L^{-1} of MEG, DEG and TEG, respectively. The removal rate of MEG was faster than that of DEG and TEG, suggesting that the molecular size of the EG had affected its rate of removal. The concentrations of MEG, DEG, and TEG in plant tissue were measured to show that burhead can take up EG, and the major site of EG accumulation is the leaf. The molar of MEG that was taken up into the plant leaf was higher than that of DEG and TEG. This suggested that EG of smaller molecular sizes can be taken up more rapidly by the plant than EG of larger molecular sizes. EG concentrations in the leaf increased to a peak concentration and then slowly decreased. GC–MS analysis of DEG-treated plant tissue found MEG, 1,4-dioxan-2-one, neophytadiene, and 2-propenamide, that may be DEG-degradation products and/or compounds that are induced when plants are exposed to DEG. The result indicates that burhead can potentially be used for EG removal.

1. Introduction

Ethylene glycol (EG) is a group of organic chemicals having two separate hydroxyl groups. The first three dihydroxy alcohols are mono-, di- and triethylene glycol (MEG, DEG and TEG). They are colourless, odourless, and highly soluble in water and some organic solvents (Dye, 2001). The three glycols have similar chemical properties and are used in different applications mainly due to their physical properties such as viscosity, hygroscopicity and boiling point. They are used in antifreeze formulations, de-icing of airplanes, hydraulic fluids, surface coatings, surfactants, emulsifiers, as solvents, and as chemical intermediates in the production of polyethylene terephthalate, polyester and films (Staples et al., 2001; Upadhyay et al., 2008). Their toxicity is relatively low, but ingestion of relatively high doses of MEG and DEG may affect the central nervous system, and cause metabolic acidosis and renal toxicity (Upadhyay et al., 2008).

The use of EG in many industries resulted in its contamination of the wastewater from these industries. EG is highly soluble in water. In Thailand, EG is often found as a contaminant in wastewater effluent from the pigment and printing industries. Even after treatment by chemical precipitation, the COD in this wastewater still remains approximately 2000 mg L^{-1}, which is higher than the standard wastewater effluent. Therefore, this research aims to reduce the remaining COD in wastewater below the Thailand standard effluent (COD $\leqslant$ 120 mg L^{-1}).

The use of plants to remove a toxicant, also called "phytoremediation", is appropriate for low concentrations of a contaminant. In many remediation projects, phytoremediation is used as a final step following the initial treatment of the high-level contamination. However, when the concentration of a contaminant is low, phytoremediation alone may be the economical and effective treatment option (Susarla et al., 2002). Selecting this treatment to remediate wastewater after chemical precipitation or activated carbon adsorption may be a suitable method for reducing the EG and COD that remain in the wastewater to below the standard effluent.

Selecting the plant for use in a phytoremediation project is an important step. The plant should grow well, have tolerance to the pollutant and to the climate, and take up large amounts of the target pollutants (Karenlampi et al., 2000). The major source

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0045-6535/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2010.09.049

of EG contamination is in wastewater so the target plant should be an aquatic plant. *Echinodorus cordifolius* (L.) is an aquatic plant in Alismataceae family. It is found predominantly in shallow ponds and swamps (Buznego and Perez-Saad, 2006; Pansarin, 2008). It has a dense root system and grows rapidly, so it may be appropriate for use in EG remediation.

The objective of this research is to test the ability of *E. cordifolius* to remove EG from synthetic wastewater by focusing on MEG, DEG, and TEG, the first three members of the dihydroxy alcohol group which have similar chemical properties but which differ in some physical properties. This research demonstrates the response of plant to EG of different molecular weights (MEG, DEG, and TEG), the efficiency of *E. cordifolius* in removing MEG, DEG and TEG, their toxicity to the plant and EG degradation within the plant using DEG as an example.

2. Material and methods

2.1. Plant culture conditions

Burhead (*E. cordifolius* (L.)) was purchased from local plant shop in Thailand. Plant was grown (by vegetative propagation) under soil condition in a greenhouse of the Remediation Laboratory at King Mongkut's University of Technology Thonburi, Bangkhuntien. Plants were selected at the same stage of growth (300–500 g in weight with 7–8 leaves) and cleaned with tap and distilled water to disperse soil particles, algae and insect larvae that had adhered to the plant stem and root. Burhead plants were pre-cultured in 50% Hoagland solution for at least 2 weeks before the experiment.

2.2. Efficiency of the plant for COD removal

E. cordifolius plants were cultured in 2000 mg L^{-1} EG synthetic wastewater, at a volume of 3000 mL per pot at an initial pH between 7 and 8 under soilless conditions. The purity of MEG, DEG, and TEG are 99.5%, 95%, and 99%, respectively. Although the plants grow well in soil, this research used soilless conditions because wanted to determine the efficiency and potential of the plant to remove EG without interference from the microorganisms found in the soil and rhizosphere. *E. cordifolius* plants were grown in a greenhouse at a temperature of 30.5 ± 3.0 °C, a relative humidity of 70 ± 12%, an average photosynthetically active radiation of about 650 lx and a 12 h light/dark cycle. Data were collected every 3 d by measuring the COD of the synthetic wastewater following the standard method (APHA, 1998). COD can be used as an indirect way to measure EG in synthetic wastewater and the test is easier and less expensive than direct measurement of EG by GC.

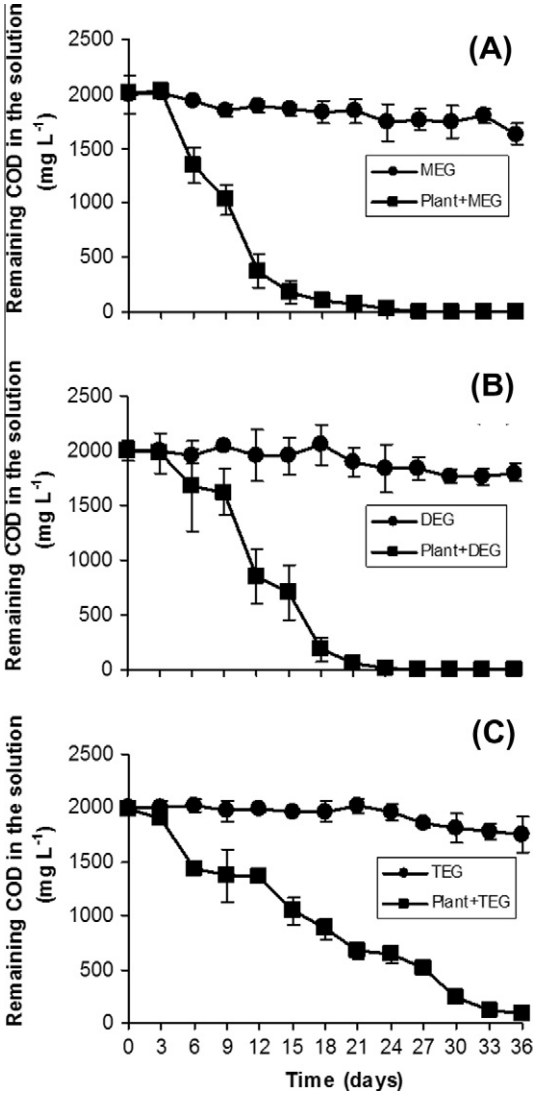

Fig. 2. The remaining COD concentration in synthetic MEG (A), DEG (B) and TEG (C) wastewater.

2.3. Efficiency of the plant in EG removal

The EG concentration in the wastewater was measured by GC using 1 μL of wastewater. The system is comprised of the Shimadzu model GC 17A GC with an Rtx-200 capillary column

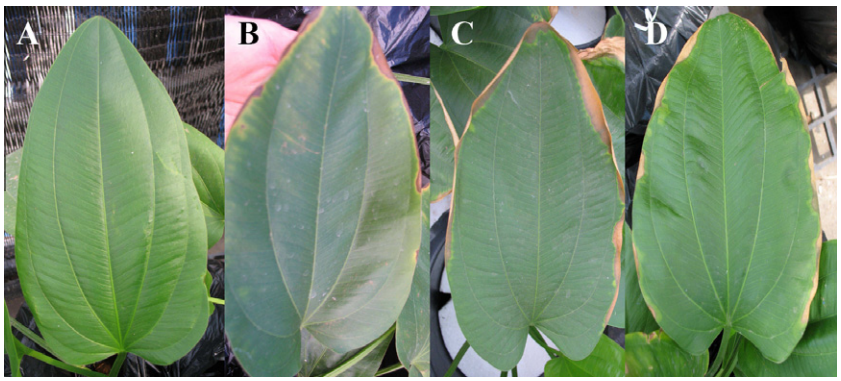

Fig. 1. Appearance of symptoms on *E. cordifolius* leaves on day 7 after exposure to MEG (B), DEG (C), TEG (D) at 2000 mg L^{-1} and an untreated control plant (A).