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Stoichiometry and kinetic of the aerobic oxidation of phenolic compounds by activated sludge

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HIGHLIGHTS

- Study of the aerobic degradation of several phenolic compounds by activated sludge.
- Biodegradation rate: catechol > phenol >> pyrogallol ≅ resorcinol > hydroquinone.
- Toxicity: pyrogallol >> catechol ≅ resorcinol >> phenol > hydroquinone.
- Oxidation coefficients are reported.
- The role of some enzymes involved in the degradation pathways is discussed.

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ABSTRACT

The aerobic degradation of phenol (PH), catechol (CA), resorcinol (RE), pyrogallol (PY), and hydroquinone (HY) by phenol-acclimated activated sludge was investigated. A Haldane-type dependence of the respiration rate on PH, RE, and HY was observed; CA and PY exhibited a biphasic respiration pattern. According to the initial biodegradation rate, tested compounds were ordered as follows: CA > PH >> PY RE > HY. Also, they exhibited the following degree of toxicity to their own degradation: PY >> CA RE >> PH > HY. Oxidation coefficients for PH, PY, RE, and HY were constant as a function of the consecutive additions of the compound. Conversely, an increase of $Y_{O/S}$ from 1 to 1.5 $molO_2$ $molCA^{-1}$ was observed during repeated additions of CA. The role of some enzymes involved in the aerobic degradation pathways of the tested compounds is discussed and related to the obtained results.

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1. Introduction

Phenolic compounds are considered as priority pollutants by US Environment Protection Agency (US-EPA). Due to the large use of phenol and its derivatives in many industries, phenolic compounds are widespread in the environment. Several industries, such as petroleum processing plants, oil refineries, coke oven, and pharmaceutical generate large amounts of phenolic wastewaters (Lepik and Tenno, 2011; Pramparo et al., 2012). Phenol is used as an intermediate in the production of phenolic resins, which are used in the plywood, adhesive, construction, automotive, and appliance industries, in the production of synthetic fibers, and for epoxy resin precursors (US-EPA, 2000). Hydroxy-derivatives of phenol, such as catechol, resorcinol, hydroquinone, and pyrogallol, are also broadly used in several industrial processes. Catechol and hydroquinone are used as photographic and fur dyes developers, as intermediates for antioxidants in rubber, and lubricating oils, as polymerization inhibitors, and in pharmaceuticals. Resorcinol is an essential component used in the manufacture fiber reinforced rubber mechanical goods. Several adhesives for wood bonding applications are formulated from resorcinol–formaldehyde resins. Resorcinol is a chemical intermediate in the manufacture of UV-light screening agents for the protection of plastics, dye-stuffs, pharmaceuticals, flame retardants, explosive primers, and antioxidants (INDSPEC, 2004). The current main commercial application of pyrogallol is the production of pharmaceuticals, pesticides, and hair dyes. In analytical chemistry, pyrogallol is used as a complexing agent, reducing agent, and, in alkaline solution, as an indicator of gaseous oxygen (NIH, 2012).

The presence of phenols and its derivatives in the environment poses a significant risk to water reservoirs and soils. Phenolic wastewaters may not be conducted into open water without treatment because of the toxicity of phenols. Several physicochemical methods such as ozonation, Fenton's reagent, UV, hydrogen peroxide, or a combination of them can be used to re-

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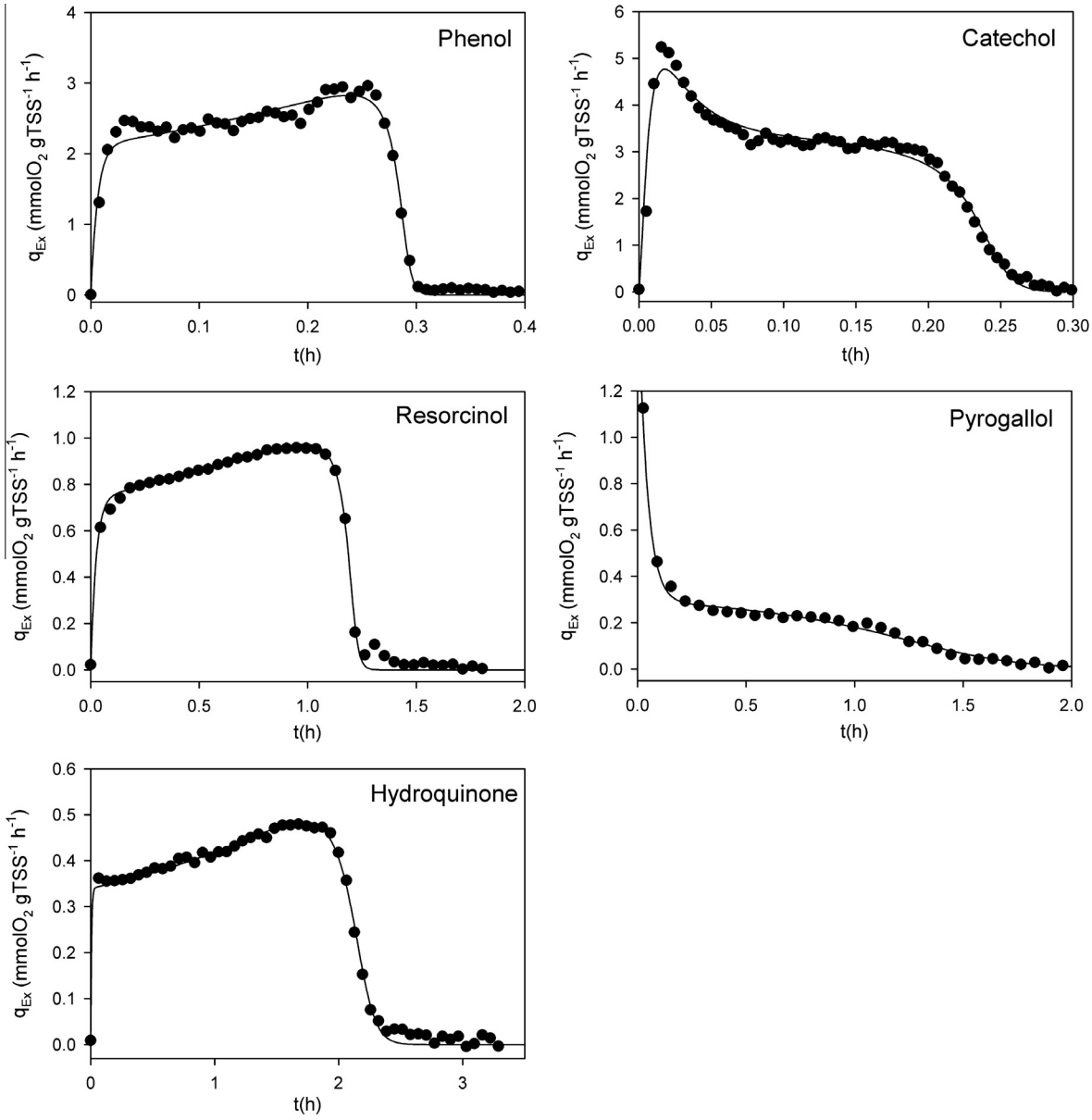

Fig. 1. Examples of the specific exogenous respiration rate (q_{Ex}) as a function of time during the aerobic biodegradation of different phenolic compounds by phenol-acclimated activated sludge.

move phenolic compounds from industrial wastewater. Because these treatments are usually complex and expensive, biological methods are preferred (Busca et al., 2008). A great number of studies on biodegradation of phenolic compounds by pure cultures as well as mixed bacterial consortia have been conducted over the last decades. Several studies have focused attention on the aerobic biodegradation of single and mixtures of phenolic compounds by activated sludge (Orupold et al., 2001; Antizar-Ladislao and Galil, 2004; Bajaj et al., 2008; Lepik and Tenno, 2011; Pramparo et al., 2012). Moreover, control strategies in the removal phenolic compounds by activated sludge have been developed also (Yoong et al., 2000; Buitron et al., 2005). However, detail information concerning the stoichiometry and the stability of the biodegradation ability of activated sludge to remove phenolic compounds has been less studied. Considering that these issues are essential for the understanding of the behavior of the biodegradation process of phenolic compounds, the objective of the present work was to study the stoichiometry and the stability of the biodegradation ability of the aerobic degradation of phenol (PH), catechol (CA), resorcinol (RE), pyrogallol (PY), and hydroquinone (HY) by phenol-acclimated activated sludge.

2. Methods

2.1. Chemicals and reagents

Phenol (PH) (loose crystals, >99%) and resorcinol (RE) (ACS reagent, >99%) were obtained from Sigma (St. Louis, MO, USA). Catechol (CA), pyrogallol (PY), and hydroquinone (HY) were analytical grade from Biomed Inc., (Aurora, Ohio). Dehydrated cheese whey was from Food S.A. (Villa Maipú, Argentina). All inorganic salts were commercial products of reagent grade from Anedra (San Fernando, Argentina).

2.2. Activated sludge and culture conditions

Activated sludge used in this study were cultured in a laboratory scale (2.5 L) cylindrical semicontinuous fill and draw reactor.

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