



Review

Efficient biodegradation of quinolone – Factors determining the process



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ABSTRACT

Quinolone and its derivatives are N-heterocyclic compounds that are widely distributed in the environment. Many of these compounds are toxic and therefore pose a significant concern as recalcitrant pollutants. This review describes the possibilities for the removal of quinoline and its derivatives. Emphasis has been placed on the microbial degradation of these compounds. Transformation of quinoline compounds by microorganisms occurs under both aerobic and anaerobic conditions. A number of bacteria have the ability to eliminate quinoline, but only a portion of them are capable of its mineralization. A common strategy in quinoline degradation is the formation of 1H-2-oxoquinoline. Throughout this article, we have briefly reviewed different quinoline degradation pathways and characterized biotic and abiotic factors determining the bioconversion process.

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1. Introduction

N-heterocyclic compounds are a class of compounds in which one or more carbon atoms in the molecule backbone have been replaced by nitrogen. Quinolone, pyridine and nicotinic acid are

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representatives of this class. The specific structure, especially the substitution of carbon with a heteroatom, determines their physical and chemical properties. Due to their persistence and high mobility, N-heterocyclic compounds are common contaminants of the environment, and their presence in soil and water is a world-wide concern. Some N-heterocyclic compounds occur naturally in the environment, while others have been introduced into ecosystems by man as a result of industrial activity. Naturally occurring heterocyclic compounds perform multiple biological functions. They are constituents of such molecules as ATP, GTP, NADP/NADPH or FAD/FADH. Quinoline derivatives are commonly isolated from higher plants, fungi and bacteria (Orjala and Gerwick, 1997; Michael, 2008; Teichert et al., 2008). N-heterocycles are also constituents of coal tar and creosote. During the processing of the raw material, high amounts of N-heterocyclic compounds, such as carbazole, quinoline, indole, acridine and pyridine, are released (Pereira et al., 1983; Fetzner, 1998). Additionally, N-heterocyclic compounds have been used in many industries, e.g., in the manufacture of dyes, in the production of pesticides, and as food additives and substrates for the synthesis of medicines (Sims and O'Loughlin, 1989).

2. Sources, application and toxicity of quinoline and its derivatives

Quinoline, with the formula C_9H_7N , is a colorless liquid with a pungent odor and weakly soluble in water. Basic parameters describing the physical and chemical properties are summarized in Table 1.

Quinoline derivatives naturally appear in structures of biological active compounds including quinine alkaloids (Fetzner, 1998). A significant anthropogenic source of environment pollution by quinoline and their derivatives is coal processing (Pereira et al., 1983; Fetzner, 1998). Fossil fuels coking, gasification and carbonization processes results in the production of a large amount of tars. The global manufacturing of coal tar in cooking plants reaches a value 15×10^6 tons per year, wherein the content of quinoline is 0.2–0.3% (Fetzner, 1998). Moreover, quinoline can be found in creosote, which is obtained during coal processing. Creosote is a complex mixture containing 75–85% polyaromatic hydrocarbons, 5–15% monoaromatic hydrocarbons and 3–13% heterocyclic aromatic compounds, including N-heterocycles. It should be noted that heterocyclic compounds are mainly responsible for the contamination of groundwater because they are dominant constituents of the water-soluble fraction of creosote (Dyreborg et al., 1997; Padma et al., 1998; Hartnik et al., 2007; Reineke et al., 2007; Blum et al., 2011). Concentration of quinoline in wastewater generated during shale oil production reaches 2–50 mg/L (Fetzner, 1998).

Quinoline and its derivatives have a number of uses in many industries. In chemical manufacturing, they serve as solvents and dyes. They are used as substrates in the production of pesticides and medicines such as fluoroquinolone antibiotics (Fetzner, 1998; Fetzner et al., 1998). It is worth mentioning that fluoro-

substituted quinolones are active against Gram-positive and Gram-negative bacteria, anaerobic strains and *Mycobacterium*. Moreover, fluoroquinolone antibiotics are characterized by excellent oral bioavailability, good tissue penetration and a long half-life (Jones and Mandell, 2002; Kümmerer, 2009). Fig. 1 presents the main sources of quinoline contamination.

Additionally, quinoline and its derivatives are toxic and harmful to organisms representing different trophic levels. The fraction of creosote consisting of alkylated quinolones is the most toxic and accounts for 26% of the total measured toxicity (Hartnik et al., 2007). Published data indicate that the mentioned compounds show an ecotoxic potential toward soil invertebrates, daphnids, algae and bacteria (Eisentraeger et al., 2008; Kobeticová et al., 2008; Neuwoehner et al., 2009). Mutagenic activity was confirmed for quinoline and 6-methylquinoline (Eisentraeger et al., 2008). Recent studies have also shown that fluoroquinolone pharmaceuticals are ecotoxic and genotoxic and can cause disturbances in the functioning of both aquatic and soil ecosystems (Hu et al., 2007). For this reason, the presence of quinoline compounds in surface waters attracts particular attention from researchers and should be constantly monitored. The selected toxicological data are presented in Table 2.

Widespread use of quinoline and its derivatives, including antimicrobial agents, results in environmental contamination and increases the risk of antibiotic-resistant pathogenic bacteria formation. Despite measures taken to limit the release of quinoline compounds, such compounds are still detected in many ecosystems. Their presence has been confirmed in soil, water, sediments and air (Fetzner, 1998; Lopes and Furlong, 2001). High amounts of quinoline have been detected especially in the vicinity of coal tar processing and creosote wood preservation facilities (Brumly et al., 1991; Godsy et al., 1992).

3. Elimination of quinoline and its derivatives

Currently, the release of quinoline derivatives into the environment is limited by a two-stage procedure. Control at the first stage is based on the reduction of pollution by the substitution of raw material or the recovery of some compounds for re-use. The secondary control includes wastewater treatment using appropriate methods with physical, chemical or biological agents (Padoley et al., 2008). The physical methods include adsorption on materials, ultrafiltration, soil percolation and catalytic incineration (Padoley et al., 2008). The chemical methods are based on advanced oxidation processes (Huang and Wang, 2007). In the case of quinoline, the most common removal methods include the technique of wet air oxidation, ozonation and the UV method combined with ozonation (Andreozzi et al., 1992; Thomsen and Kilen, 1998; Oliviero et al., 2003; X. Wang et al., 2004).

The traditional physico-chemical methods of removing toxic compounds can be ineffective or uneconomical when contaminant concentration is low. An attractive alternative to physical and chemical methods is the use of biological techniques based on the ability of microorganisms to degrade certain compounds, including quinoline. Biodegradation involves aerobic or anaerobic decomposition of compounds, such as quinoline, with the participation of living organisms, usually microorganisms. Not all quinoline-degrading microorganisms are capable of the pollutant's mineralization. This capability is connected with adequate enzymatic pathways and mechanisms responsible for survival in the presence of high concentrations of xenobiotics. The efficiency of quinoline elimination depends on many factors, which can be divided into biotic and abiotic factors. The purpose of this paper is to describe the complexity of the biodegradation process and to characterize the key factors determining it.

Table 1
Physico-chemical properties of quinoline.

Property	Value	Reference
Melting point (°C)	–15.0	Mackay et al., 1999
Boiling point (°C)	237.7	
Density at 20 °C (g/cm ³)	1.1	
log K _{ow} (dimensionless)	2.10	
Water solubility at 20 °C (mg/L)	6110	

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