

Microbial PAH-Degradation in Soil: Degradation Pathways and Contributing Factors*¹

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ABSTRACT

Adverse effects on the environment and high persistence in the microbial degradation and environmental fate of polycyclic aromatic hydrocarbons (PAHs) are motivating interest. Many soil microorganisms can degrade PAHs and use various metabolic pathways to do so. However, both the physio-chemical characteristics of compounds as well as the physical, chemical, and biological properties of soils can drastically influence the degradation capacity of naturally occurring microorganisms for field bioremediation. Modern biological techniques have been widely used to promote the efficiency of microbial PAH-degradation and make the biodegradation metabolic pathways more clear. In this review microbial degradation of PAHs in soil is discussed, with emphasis placed on the main degradation pathways and the environmental factors affecting biodegradation.

Key Words: bioremediation, microbial degradation, PAHs, soil

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs), as a result of the incomplete combustion of organic matter, emission sources, automobile exhaust, coal-fired electricity generating power plants, domestic matter, and area source matter, are ubiquitous in the environment (Finlayson-Pitts and Pitts, 1997; Norse, 2005). PAHs in the air and water can also be brought into the soil and sediment through precipitation effects (Johnsen *et al.*, 2005). Therefore, soil becomes the main environmental receptor of PAHs. Because of their carcinogenic, teratogenic, mutagenic, and other toxic properties, PAHs have been of great environmental interest (Bispo *et al.*, 1999). Consequently, the US Environmental Protection Agency (EPA) has listed 17 PAHs (Table I) as priority pollutants for remediation (Liu, K. *et al.*, 2001), among which 15 PAHs have carcinogenic risk to humans reported by the International Agency for Research on Cancer (IARC).

PAHs are composed of fused, aromatic rings (Fig. 1) whose biochemical persistence arises from dense clouds of π -electrons on both sides of the ring structures making them resistant to nucleophilic attack (Johnsen *et al.*, 2005). Besides this, they possess physical properties, such as low aqueous solubility and high solid-water distribution ratios (Table I). These properties stand against their ready microbial utilization and promote their accumulation in the solid phases of the terrestrial environment. Generally, the aqueous solubility and, as a consequence, the biodegradability of PAHs decreases almost logarithmically with an increase in molecular mass. However, there are reports of a variety of microorganisms, ranging from low molecular weight (naphthalene) to high molecular weight (coronene) that degrade various PAHs. More and more environmental concerns are turning to the biodegradation of PAHs. Therefore, this review will discuss microbial degradation of PAHs in soil with an emphasis on metabolic pathways and factors affecting biodegradation rates.

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TABLE I

Main physico-chemical and carcinogenic characteristics of US Environmental Protection Agency (EPA) priority polycyclic aromatic hydrocarbons (PAHs) for control

PAHs	No. of rings	Solubility at 25 °C	Octanol/water partition coefficient ^{a)}	Carcinogenicity groups ^{b)}
		mg L ⁻¹		
Naphthalene	2	3.2	2.3×10^3	2B
Naphthylamine	2	4.6	1.4×10^3	1
Acenaphthene	3	3.4	2.1×10^4	NR ^{c)}
Acenaphthylene	3	3.93	1.2×10^4	NR ^{c)}
Fluorene	3	1.9	1.5×10^4	3
Anthracene	3	0.05–0.07	2.8×10^4	3
Phenanthrene	3	1.0–1.3	2.9×10^4	3
Fluoranthene	4	0.26	3.4×10^5	3
Chrysene	4	0.002	4.0×10^5	3
Pyrene	4	0.14	2.0×10^5	3
Benz[a]anthracene	4	0.01	4.0×10^5	2A
Benzo[b]fluoranthene	5	NR ^{c)}	4.0×10^6	2B
Benzo[k]fluoranthene	5	NR ^{c)}	7.0×10^6	2B
Benzo[a]pyrene	5	0.0038	1.0×10^6	2A
Dibenz[a,h]anthracene	5	0.0005	1.0×10^6	2A
Benzo[g,h,i]perylene	6	0.0003	1.0×10^7	3
Indeno[1,2,3-c,d]pyrene	6	0.062	5.0×10^7	2B

^{a)}Octanol/water partition coefficient is defined as the ratio of concentration of a compound in all its forms between an aqueous phase (with buffer) and an oil phase, and the coefficient is used to represent the lipophilic character of a compound, which is a very useful physico-chemical parameter reflecting the transfer properties of a compound across biological membranes.

^{b)}Pollutants are classified by the International Agency for Research on Cancer (IARC) as to their carcinogenic risk to humans. Group 1: carcinogenic; Group 2A: probably carcinogenic; Group 2B: possibly carcinogenic; and Group 3: carcinogenicity not classifiable.

^{c)}Not reported.

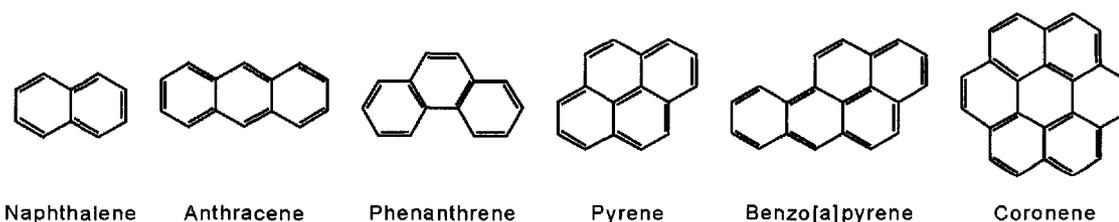


Fig. 1 Molecular structure of some typical polycyclic aromatic hydrocarbons (PAHs) in soil.

On account of the importance of PAHs as soil contaminants, there has been strong interest in their microbial degradation (Johnsen *et al.*, 2005; Meckenstock *et al.*, 2004). Both prokaryote (including various bacteria listed in Table II) and eucaryote (including some fungi listed in Table III) isolated from soils have a prominent function in PAH-degradation. Nevertheless, microorganisms vary considerably in their capacity to degrade ranges of PAHs. Some (not all) organisms, owing to the comparatively high bioavailability of the compounds of two or three cycles, degrade only the more readily degradable naphthalene and phenanthrene. Meanwhile, only a very limited number of bacteria have been isolated that can grow in pure cultures on PAHs with five or more aromatic rings (high molecular weight (HMW) PAHs). A possible reason is the high retention of these compounds by the solid soil phase resulting in mass-transfer rates of HMW-PAHs to the bacterial cells, which are too low to match the cells' basic metabolic requirements. The low bioavailability of PAHs may have prevented the evolution of suitable enzymatic pathways in soil bacteria.

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