Egyptian Journal of Petroleum (2016) 25, 107–123

HOSTED BY ELSEVIER

Egyptian Petroleum Research Institute

Egyptian Journal of Petroleum

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REVIEW

A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation

Hussein I. Abdel-Shafy [a,*], **Mona S.M. Mansour** [b]

[a] *Water Research & Pollution Control Department, National Research Center, Tahreer Street (El-Behous St.), Dokki, Cairo, Egypt*
[b] *Analysis & Evaluation Department, Egyptian Petroleum Research Institute, 1 Ahmed El-Zomor Street, Nasr City, Cairo, Egypt*

Received 4 November 2014; revised 11 March 2015; accepted 16 March 2015
Available online 18 December 2015

KEYWORDS

Polycyclic aromatic hydrocarbons (PAHs);
Sources of PAHs;
Effect on human health;
Environmental risk;
Removal of PAHs

Abstract Polycyclic aromatic hydrocarbons (PAHs) are ubiquitous environmental pollutants generated primarily during the incomplete combustion of organic materials (e.g. coal, oil, petrol, and wood). Emissions from anthropogenic activities predominate; nevertheless, some PAHs in the environment originate from natural sources such as open burning, natural losses or seepage of petroleum or coal deposits, and volcanic activities. Major anthropogenic sources of PAHs include residential heating, coal gasification and liquefying plants, carbon black, coal-tar pitch and asphalt production, coke and aluminum production, catalytic cracking towers and related activities in petroleum refineries as well as and motor vehicle exhaust. PAHs are found in the ambient air in gas-phase and as sorbet to aerosols. Atmospheric partitioning of PAH compounds between the particulate and the gaseous phases strongly influences their fate and transport in the atmosphere and the way they enter into the human body. The removal of PAHs from the atmosphere by dry and wet deposition processes are strongly influenced by their gas/particle partitioning. Atmospheric deposition is a major source for PAHs in soil.

Many PAHs have toxic, mutagenic and/or carcinogenic properties. PAHs are highly lipid soluble and thus readily absorbed from the gastrointestinal tract of mammals. They are rapidly distributed in a wide variety of tissues with a marked tendency for localization in body fat. Metabolism of PAHs occurs via the cytochrome P450-mediated mixed function oxidase system with oxidation or hydroxylation as the first step.

Several different remediation technologies have been tested in efforts to remove these environmental contaminants. Among them, bioremediation is showing particular promise as a safe and cost-effective option. In spite of their xenobiotic properties, a variety of genera of gram-positive and -negative bacteria, fungi and algae have been isolated and characterized for their ability to utilize PAHs.

* Corresponding author. Tel.: +20 1224018017; fax: +20 223095589.
E-mail addresses: hshafywater@yahoo.com, waterbiotech@yahoo.com (H.I. Abdel-Shafy).

Peer review under responsibility of Egyptian Petroleum Research Institute.

http://dx.doi.org/10.1016/j.ejpe.2015.03.011

The aim of this review is to discuss PAHs impact on the environmental and the magnitude of the human health risks posed by such substances. They also contain important information on concentrations, burdens and fate of polycyclic aromatic hydrocarbons (PAHs) in the atmosphere. The main anthropogenic sources of PAHs and their effect on the concentrations of these compounds in air are discussed. The fate of PAHs in the air, their persistence and the main mechanisms of their losses are presented. Health hazards associated with PAH air pollution are stressed.

1. Introduction

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that are mostly colorless, white, or pale yellow solids. They are a ubiquitous group of several hundred chemically related compounds, environmentally persistent with various structures and varied toxicity. They have toxic effects on organisms through various actions. Generally, PAHs enter the environment through various routes and are usually found as a mixture containing two or more of these compounds, e.g. soot. Some PAHs are manufactured in the industry. The mechanism of toxicity is considered to be interference with the function of cellular membranes as well as with enzyme systems which are associated with the membrane. It has been proved that PAHs can cause carcinogenic and mutagenic effects and are potent immune-suppressants. Effects have been documented on immune system development, humoral immunity and on host resistance [1,2]. PAHs can be formed both during biological processes and as products of incomplete combustion from either natural combustion sources (forest and brush fires) or man-made combustion sources (automobile emissions and cigarette smoke). Thus, PAHs are commonly detected in air, soil, and water. Therefore, PAHs are considered ubiquitous in the environment [3,4]. The ubiquitous nature of PAHs in the environment has been well summarized by Menzie et al. [5].

The term "PAH" refers to compounds consisting of only carbon and hydrogen atoms. Chemically the PAHs are comprised of two or more benzene rings bonded in linear, cluster, or angular arrangements [6,7]. Such molecular arrangements are illustrated in (Fig. 1). Although there are many PAHs, most regulations, analyses, and data reporting focus on only a limited number of PAHs, typically between 14 and 20 individual PAH compounds.

Polycyclic aromatic hydrocarbons have two or more single or fused aromatic rings with a pair of carbon atoms shared between rings in their molecules. PAHs containing up to six fused aromatic rings are often known as "small" PAHs, and those containing more than six aromatic rings are called "large" PAHs. The majority of research on PAHs has been conducted on small PAHs due to the availability of samples of various small PAHs. The simplest PAHs, as defined by the International Agency for Research on Cancer [8], are phenanthrene and anthracene, which both contain three fused aromatic rings. On the other hand, smaller molecules, such as benzene, are not PAHs. Naphthalene, which consists of two coplanar six-membered rings sharing an edge, is another aromatic hydrocarbon. Therefore, it is not a true PAH, though is referred to as a bicyclic aromatic hydrocarbon. The most extensively studied PAHs are 7, 12-dimethylbenzo anthracene (DMBA) and benzo(a)pyrene (BaP) [2]. The most commonly analyzed PAHs are given in (Fig. 2).

The general characteristics of PAHs are high melting and boiling points (therefore they are solid), low vapor pressure, and very low aqueous solubility [10]. The latter two characteristics tend to decrease with increasing molecular weight, on the contrary, resistance to oxidation and reduction increases [10]. Aqueous solubility of PAHs decreases for each additional ring [11]. Meanwhile, PAHs are very soluble in organic solvents because they are highly lipophilic. PAHs also manifest various functions such as light sensitivity, heat resistance, conductivity; emit ability, corrosion resistance, and physiological action [12].

PAHs possess very characteristic UV absorbance spectra. Each ring structure has a unique UV spectrum, thus each isomer has a different UV absorbance spectrum. This is especially useful in the identification of PAHs. Most PAHs are also fluorescent, emitting characteristic wavelengths of light when they are excited (when the molecules absorb light).

The major source of PAHs is the incomplete combustion of organic material such as coal, oil and wood. PAHs are not synthesized chemically for industrial purposes. Nevertheless, there are a few commercial uses for many PAHs. They are mostly used as intermediaries in pharmaceuticals, agricultural products, photographic products, thermosetting plastics, lubricating materials, and other chemical industries [13]. However, the general uses of some PAHs are:

- *Acenaphthene:* manufacture of pigments, dyes, plastics, pesticides and pharmaceuticals.
- *Anthracene:* diluent for wood preservatives and manufacture of dyes and pigments.
- *Fluoranthene:* manufacture of agrochemicals, dyes and pharmaceuticals.
- *Fluorene:* manufacture of pharmaceuticals, pigments, dyes, pesticides and thermoset plastic.
- *Phenanthrene:* manufacture of resins and pesticides.
- *Pyrene:* manufacture of pigments.

Other PAHs may be contained in asphalt used for the construction of roads, in addition to roofing tar. Furthermore, specific refined products, of precise PAHs, are used also in the field of electronics, functional plastics, and liquid crystals.

2. Source of polycyclic aromatic hydrocarbons (PAHs)

The following three types: *pyrogenic*, *petrogenic*, and *biological* are the major PAH sources to the environment. In a