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Review

A short review on polycyclic aromatic hydrocarbon contamination

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Polycyclic aromatic hydrocarbons (PAHs) are prevalent environmental pollutants produced by incomplete combustion of biomass including fossil fuels, wood, and coal. The majority of PAHs in the environment emits from anthropogenic activities, while some are released from naturally occurring phenomena, such as volcanic activities. Consequently, PAHs concentration is significantly higher in industrialized and urban areas than in rural areas. Human exposure to PAHs results in many health problems, depending on the PAH concentration type, time and method of exposure, and individual health status. The PAHs readily transport between soil, water, and the atmosphere. Four main processes involved in PAH transportation are volatilization, absorption, leaching, and erosion. However, many factors affect PAHs' transportation, including PAHs' molecular weight, vapor pressure, soil matrix, climate condition, and topography. Various remediation techniques have experimented in order to PAHs remove from the natural environment. Bioremediation, in particular, is an optimistic way that can be done by bacteria, fungi, and alga.

Keywords: PAH source, transportation, biodegradation, pollution, environmental risk

1 Introduction

Aromatic hydrocarbons containing more than one condensed ring in diverse structural configurations are known as polycyclic aromatic hydrocarbons (PAHs) (Sharma, 2014). They are synthesized using incomplete combustion of C and H-containing compounds, as well as diagenesis. The "small" PAHs was defined as a PAHs with up to six fused aromatic rings, whereas "large" PAHs are referred to as those with more than 6 aromatic rings (Abdel-Shafy & Mansour, 2016). Small PAHs are less toxic and less stable than large PAHs in ecosystem (Kuppusamy et al., 2016). The PAHs have high melting and boiling temperatures, low vapor pressure, and very low aqueous solubility (Masih et al., 2012). The resistance to oxidation and reduction cause to increase with enhancing weight of molecular, whereas the vapor pressure and aqueous solubility tend to decline (Masih et al., 2012). However, PAHs are particularly soluble in organic solvents because of their high lipophilicity. these complexes are extremely mobile in the environment due to their physicochemical qualities, allowing them to spread through the air, soil, and water (Baklanov et al., 2007).

The 16 PAHs have been identified as precedence contaminants by the US Environmental Protection Agency (EPA) (Sereshk & Bakhtiari, 2014), and their chemical structure is shown in Fig. 1. Small PAHs have been more studied because of the sample's accessibility and the number of small PAHs that exist. This review aimed to discuss the most important aspects of PAHs pollution, transportation, remediation, and effects of PAHs on human health and well-being. This particular study is useful for those who needed to acquire essential information regarding PAHs.

2 Source of PAHs

The three main PAH sources in the environment are pyrogenic, petrogenic, and biological production.

2.1 Pyrogenic production

The PAHs are generated when organic molecules are subjected to high temperatures under low oxygen or anaerobic, a process known as pyrolysis. The temperatures at which pyrogenic reactions occur range from roughly 350 to 1,200 °C. Pyrogenic PAHs are often observed in higher quantities in metropolitan areas

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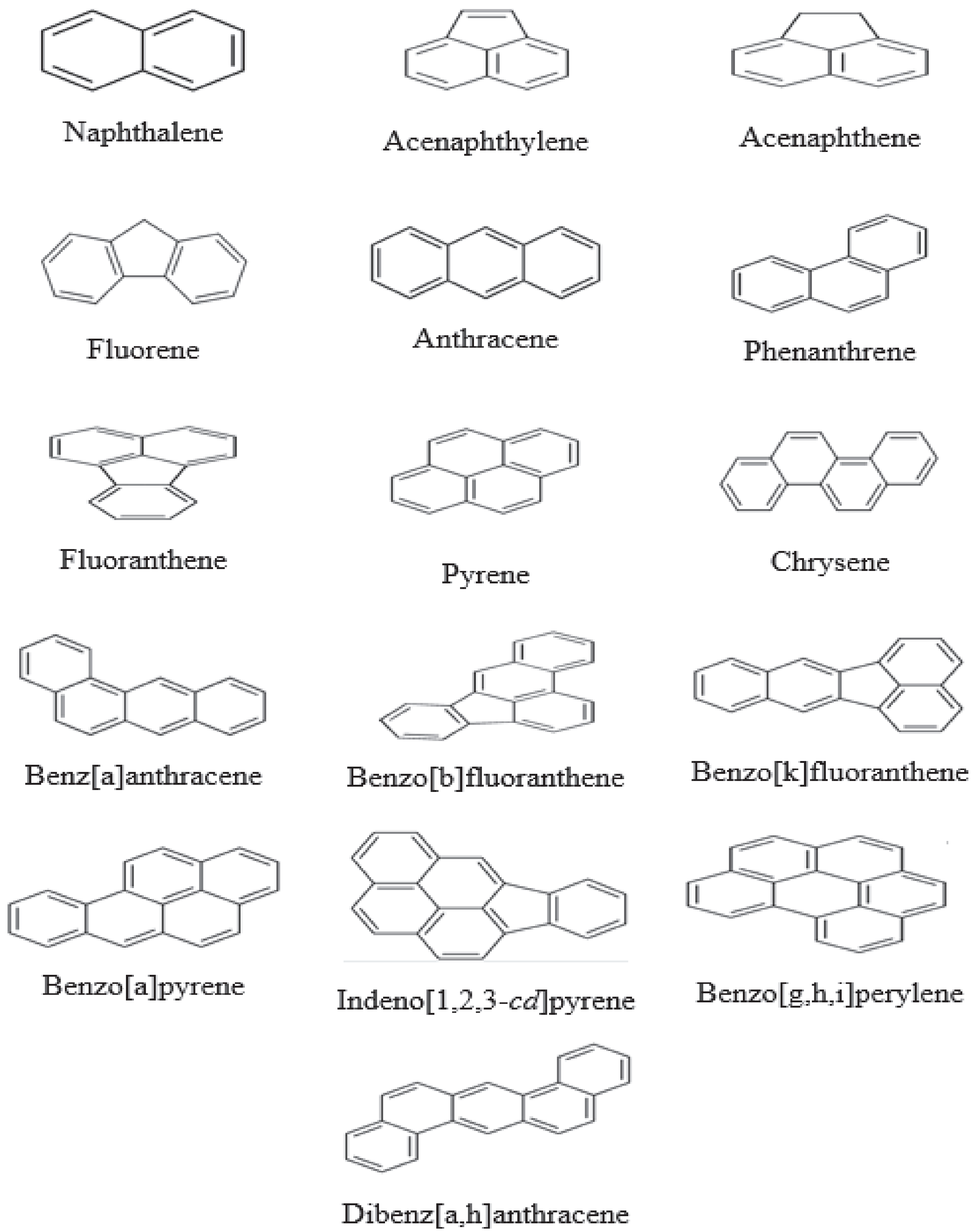

Figure 1 Chemical structure of priority polycyclic aromatic hydrocarbons (PAHs) identified by US Environmental Protection Agency
Source: US EPA

and regions near significant PAH sources (Behera et al., 2018; Du & Jing, 2018).

2.2 Petrogenic production

PAHs are produced during the maturation of crude oil and other related processes in crude oil production and derivatives that are widely transported, stored, and used in different industries. Oil spills in ocean and freshwater, subterranean and aboveground storage tank leaks, and the accumulation of many minor releases of gasoline, motor oil, and similar compounds connected with transportation are all key sources of petrogenic PAHs (Du & Jing, 2018; Stout et al., 2015).

2.3 Biological production

The source of PAHs production is unknown. Some plants and microorganisms can make PAHs, or they might arise during the decomposition of vegetative matter (Seo et al., 2007; Tolosa, Bayona & Albaigés, 1996).

Nowadays, the main source of PAHs inputs to the environment is the burning of fossil fuels, such as coal and oil (Baek et al., 1991). They are diffused through the atmosphere and deposited on terrestrial, lacustrine, and marine surfaces after being released from different sources. It is estimated that at least 90% of the environmental PAHs is stored in soil (Wild & Jones, 1995). The high molecular weight PAHs are more toxic than low molecular due to their mutagenic and carcinogenic qualities. The PAHs are long-lasting contaminants in the environment because of their hydrophobicity, poor water solubility, and high infiltration potential. These features lead to limited PAH bioavailability and, as a result, a slow rate of biodegradation (Koshlaf et al., 2019).

3 Transportation of PAHs

As shown in Fig. 2, PAHs disperse through the air and circulate across terrestrial and aquatic ecosystems as a result of numerous mechanisms. Fig. 2 depicts some of these processes in general terms, demonstrating how PAHs are produced, distributed, and destroyed in the ecosystem, and human exposure to PAHs is also shown.

The PAHs are easily transported from one system to another, including water, air, soil, and biological systems. The volatilization, absorption, leaching, and erosion processes are involved in transporting PAHs. Volatilization occurs both in soil and water systems via diffusion, according to Henry's law, molecules movement from a high concentration region to a lower concentration region. Physiological properties of soil and PAH and environmental factors can influence the volatilization rate. The PAHs with high molecular weight have high vapor pressure and lower half-life, resulting in a high volatilization rate (Liu et al., 2022). Also, PAH volatilization in soil depends on soil moisture and clay, and organic matter contents and air temperature, wind

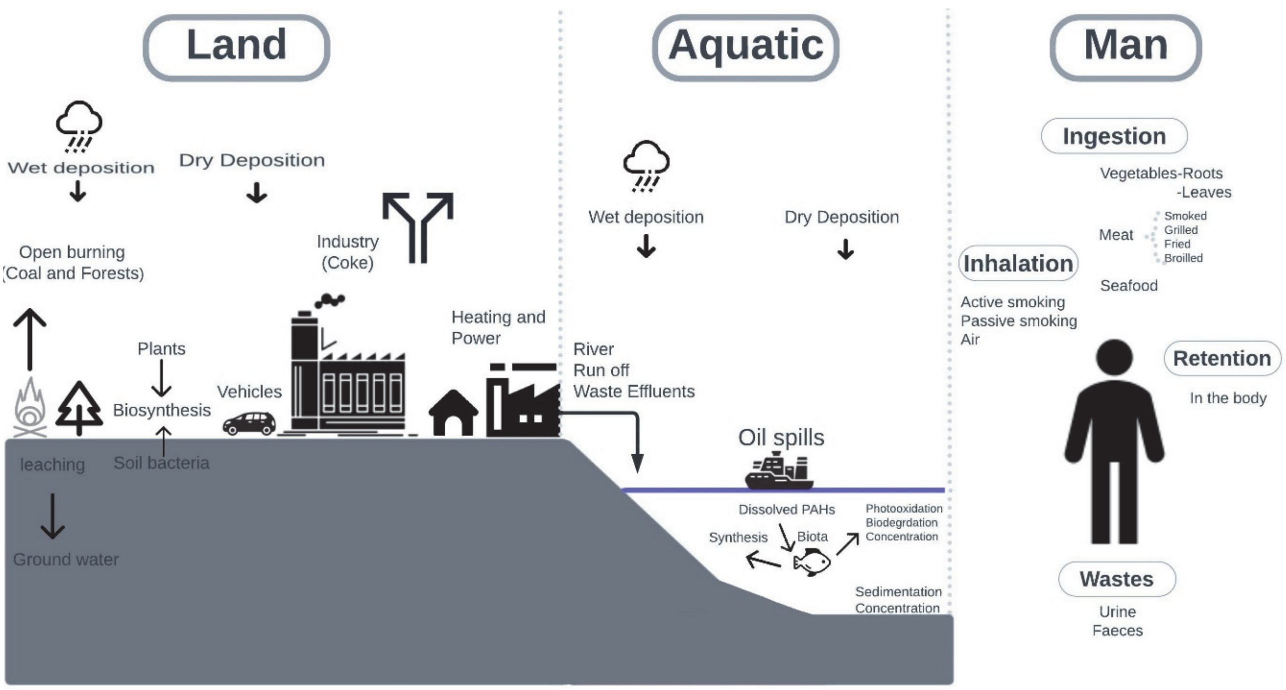

Figure 2 PAHs cycle in the environment
Source: Suess, 1976

speed, and humidity (Zhang et al., 2019). The uptake of PAH by plants can be affected by plant species, cell membrane, susceptibility, and contact time (Abdel-Shafy & Mansour, 2016; Huang et al., 2018). Plants can uptake and accumulate PAHs in their shoot parts. Plants can also uptake PAH from soil through their roots, but PAH cannot be translocated to leaves and fruits in xylem (Yin et al., 2011). The PAHs concentration in plant tissue in rural areas ranges between 50 to 80 $\mu g.kg^{-1}$, and it varies depending on plant species, PAH type, and environmental conditions (Salanitro et al., 1997). However, plants in industrial areas can have more than 10 times PAH in their tissue (Juhasz & Naidu, 2000). Water dissolvable PAHs can be transferred vertically or in soil horizons. Leaching mainly depends on soil water content, soil texture, soil organic matter, and precipitation rate. When soil pores are large and connected, accompanied by high soil moisture, leaching is higher than a soil with small pores (Cai et al., 2019). The PAH can be transported by erosion, depending on climate (precipitation rate, wind speed), landscape, and soil type (texture, aggregation, vegetation status, and organic matter content) (Qiu, Gong & Ni, 2019).

4 Concentration of PAHs in the environment

Soils are the primary sink for PAHs (Chunhui et al., 2017). Soil is contaminated with PAHs mainly from direct industrial activities, or the long-distance distant air deposition (Wang et al., 2017; Xing et al., 2016). In distant places, wildfire and airborne pollution deposition are the principal ways of soil PAHs contamination. It has been shown that soil's natural amount of PAHs is between 1 to 10 $\mu g.kg^{-1}$ (Edwards, 1983). It has been indicated that PAHs concentration in industrial areas' soil can be up to 10 times higher than in rural areas' soil (Wild & Jones, 1995), and the PAHs concentration has increased in the past century because of the increased industrialized areas (Wick et al., 2011).

Different studies set a permissible volume of PAHs in aquatic environments. The National Primary Drinking Water established a legally allowed maximum of 0.002 $mg.l^{-1}$ for benzo[a]pyrene in drinking water (Cotruvo & Regelski, 2017). The Agency for Toxic Substances and Disease Registry (ATSDR) has set an allowable range of 0.004 to 0.024 $mg.l^{-1}$ for PAHs detected in surface water samples (Reyes et al., 2017).

5 Concentration of PAHs in the human body and health

Human exposure to environmental pollutants, including PAHs, can occur through food consumption (Xia et al., 2010). Crops and fish that are grown in contaminated fields and waters can contain PAH in their texture. Also, PAHs can be deposited from the atmosphere on plants' leaves. Moreover, food preparation and processing procedures, such as drying and smoking and high-temperature cooking (grilling, roasting, and frying) can add PAHs to the food. In this regard, several factors such as duration, fuel type, fat drainage, and cooking technique can affect the generation of PAHs in the food (Abdel-Shafy & Mansour, 2016).

The 16 PAHs have been recognized as the most alarming ones in terms of possible human exposure and harmful health consequences and are so grouped. Some PAHs have been identified as carcinogens, mutagens, and teratogens, posing a major hazard to human health and well-being. The most serious health impact associated with PAH inhalation exposure is an increased chance of lung cancer. The primary ways of PAHs exposure are breathing ambient indoor air, eating PAHs-containing food, smoking cigarettes, exposure to industrial emissions, motor exhausts, and hazardous waste sites (Zhang et al., 2015). In addition, various jobs that expose humans to a mixture of severe PAHs levels lead to many diseases (Unwin et al., 2006).

The PAHs influence on human health is determined chiefly by the time and method of exposure, the level of PAHs encountered, and the PAHs' relative toxicity (Dahlstrom & Bloomhuff, 2014). The short-term PAHS effects on human health include eye irritation, qualm, vomiting, diarrhea, disorientation, and skin irritation and inflammation (Unwin et al., 2006). The long-term effect of exposure to PAHs is reduced immune system function, cataracts, kidney and liver damage, breathing issues, asthma, and lung miss function (Bach et al., 2003; Olsson et al., 2010).

6 Remediation of PAHs-contaminated soils

There is a need to remediate contaminated areas due to the toxicity associated with PAHs contamination. These remediation procedures are generally divided into *in situ* and *ex situ* remediation procedures. Conventionally, physical techniques for treating contaminated soils were used, where these soils were disposed to landfills or isolated *in situ* to prevent contaminants from moving off-site or contacting humans. Disposal to landfills is the most widespread method worldwide, but the regulation for waste disposal is moderately changing, and the increments in the costs make this an infeasible technique (Scullion, 2006). Therefore, it is necessary to find alternative environmentally friendly and sustainable ways. Bioremediation is a promising method that overcomes the above-mentioned problems.

6.1 Bioremediation

The PAHs can be eliminated in the environment through biotic and abiotic processes, with microbial degradation being the most important step for the natural removal of PAHs from polluted environments. PAHs are known to be metabolized by a wide range of species. Bacteria, fungi, and algae capable of degrading PAHs are often found in contaminated settings, and they all have diverse metabolic processes and substrate ranges (Regonne et al., 2013).

Bioremediation is the application of microorganisms to decompose contaminants in the environment and remove harmful compounds by biological processes. Many organic pollutants are susceptible to bioremediation since the organic molecules transform into inorganic compounds by many bioremediation processes through enzymes. Moreover, in contrast to conventional methods, bioremediation can be done on-site, which removes the expenses and risk of transportation. Bioremediation results in the permanent elimination of contaminants by converting them to innocuous molecules such as carbon dioxide (CO_2), water, and ethane, making bioremediation environmentally secure and widely accepted (Hussain et al., 2018).

Bioremediation of PAH depends on many factors, including the number of condensed rings; PAHs with a low number of condensed rings are more prone to biodegradation (Muckian et al., 2009). Also, PAHs biodegradation is affected by soil pH, temperature, porosity, soil depth, soil characteristics, type of PAH, soil organic matter, nutrients, PAH molecular weight, and soil microorganisms (Muckian et al., 2009; Wick et al., 2011).

6.2 Abiotic degradation

There are some mechanisms that can occur that do not need a microbial breakdown to diminish the PAHs content in the environment. In the transfer process, when the molecular weight of the substance is low, PAHs can be relocated through erosion, volatilization, absorption, or leaching (Shahsavari et al., 2019). Furthermore, chemical degradation changes the form of the PAHs to typically less hazardous substances by oxidation-reduction and photochemical exposure that naturally occurs (Wick et al., 2011). In most environmental conditions, chemical oxidation accounts for a negligible amount of PAHs degradation (Abdel-Shafy & Mansour, 2013). The results are influenced by the compound's molecular weight, structure, as well as physical form and temperature, and activity of the oxidant (Moursy & Abdel-Shafy, 1983).

6.3 Biotic degradation

Various microorganisms such as bacteria and fungi have been identified that have the ability to degrade PAHs using various metabolic pathways under aerobic and anaerobic conditions. However, PAHs degradation occurs more in aerobic conditions that are somehow faster than in anaerobic conditions (Grossman et al., 2000; Silva et al., 2009; Toledo et al., 2006). But the pace of anaerobic degradation increases in severe levels of contamination (Gan, Lau & Ng, 2009).

7 Conclusion

Polycyclic aromatic hydrocarbons are compounds that contain only carbon and hydrogen comprising multiple aromatic rings. The PAHs are ubiquitous contaminants that can be generated naturally and by human activities, while the latter is more responsible for the high concentration in the ecosystem. Excessive exposure to PAHs pollution can have detrimental effects on human health. thus, it is necessary to explore methods to combat this dilemma. Many different methods studied for remediation potential, but bioremediation is accepted as a beneficial way due to its cost-effectiveness, less risk, and the availability to perform *in situ*.

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