POLYCYCLIC AROMATIC HYDROCARBONS (PAHS): CLASSIFICATION, OCCURRENCE, AND EFFECT AND TREATMENT ON HUMAN BEINGS

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Abstract

The credo "cancer is a disease of genes" has evolved over the past decades. The epidemiological studies and other studies reveal that environmental factors contribute a lot the carcinogenicity and it is here the role of chemical carcinogens comes into play. The association of cancer with exposure to polyaromatic hydrocarbons has been a matter of concern for a long time. The present review outlines major concerns associated with polyaromatic hydrocarbons in the environment, their effect on human health, their toxicity, and their removal. We have discussed the effect of polycyclic aromatic hydrocarbons on the environment along with their important sources of production. The classification of these polycyclic aromatic hydrocarbons is provided based on their natural occurrence and anthropogenic sources. The effect of PAHs on the human body is further discussed in detail. At the last, we have discussed the different methodologies which are being employed for the removal of PAHs.

Keywords: PAHs, Cancer, Toxicity, Environment, Aromaticity.

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1. INTRODUCTION

The role of Polycyclic Aromatic Hydrocarbons (PAHs) in different types of human cancers is known for many years through epidemiological observations [1]. These PAHs act as the major source of environmental pollutants which are potentially hazardous for human life as well as other animals including marine species. Primarily polycyclic aromatic hydrocarbons represent the class of organic compounds comprising of carbon and hydrogen having at least two fused benzene rings. These benzene rings may be fused in linear or angular configuration. Recently, the definition of PAHs has been extended to comprise some hetero atoms such as nitrogen, oxygen, and sulphur as an integral part of the molecular core structure. Further, PAHs may comprise of nonaromatic substructures in the form of side chains, bridges, or even part of a cyclic molecular core ring [2-3]. In this way, PAHs consist of thousands of organic compounds, out of which United States Environmental Protection Agency has identified 16 PAHs as significant pollutants for animals [4]. Some important PAHs are provided in figure 1.

The melting and boiling points of PAHs are very high due to which they exist in the form of solid particles in nature. On increasing the molecular weight of PAHs, vapour pressure and water solubility further decrease. Generally, PAHs are colourless solids that are lipophilic (very low water solubility) and chemically inert in nature [5-6]. It is observed that on addition of each aromatic ring, water solubility of PAHs decreases. Besides these properties, PAHs show heat resistance, corrosion resistance, light sensitivity, conductivity, and enzyme sensitivity in animals.

As PAHs are mostly comprised of aromatic rings in their molecular structure, they possess unique UV-Visible absorption spectra. It is helpful in the identification of isomeric forms of PAHs as each isomer show a different UV-Visible absorption spectrum [7]. Most of these PAHs are fluorescent in nature and show emitting spectra on excitation with a suitable wavelength of light.

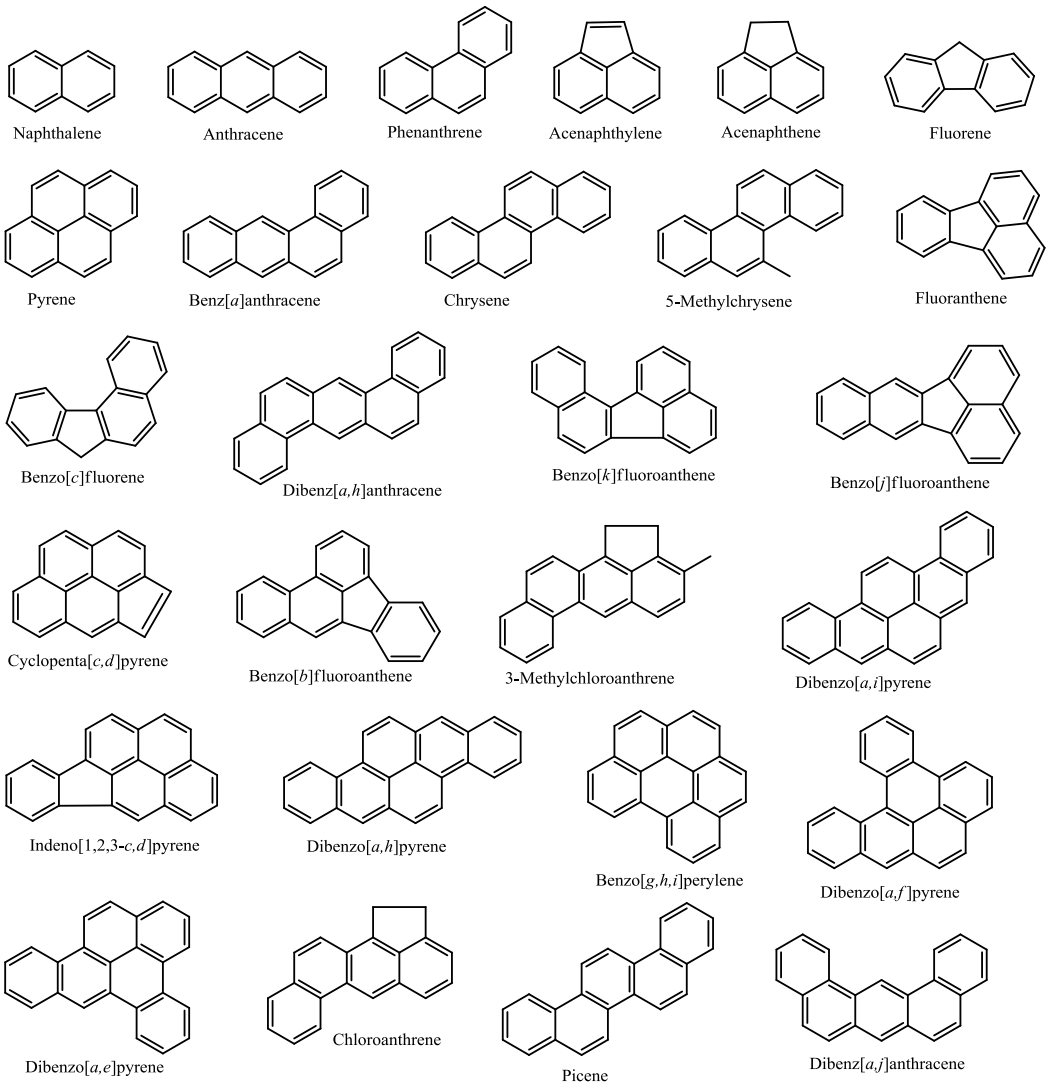

Figure 1: Most common polycyclic aromatic hydrocarbons (PAHs).

The toxic effects of PAHs are observed by the various mechanistic actions of animal enzymes on these PAHs. It involves the interference of cellular membrane functionality as well as enzymes of cellular membranes. It is well established that PAHs majorly cause carcinogenic and mutagenic effects in human beings and behave as immune suppressants [8]. Therefore, it becomes extremely important to know the occurrence of PAHs in nature, its effect on human beings, and the method to minimize its adverse effects.

Environmental occurrence and sources of polycyclic hydrocarbons

Both, biological processes, and incomplete combustion, are the major source of PAHs in the environment. The incomplete combustion may be either natural comprising forest, volcanic eruptions, and brush fires or man-made incomplete combustion comprising automobile emission, industrial emission, food processing, and cigarette smoke [9-10]. Therefore, PAHs can be detected in soil, air, and water through analytical techniques. However, PAHs are important components of industrial growth and development as they play an important role as intermediaries in different industries such as photographic products, lubricating materials, pharmaceuticals, thermosetting plastics, agricultural products, construction of roads, and other chemical industries (figure 2).

SOURCES OF PAHs	Natural sources	Natural petroleum
		Plant or bacterial synthesis
		Rare Minerals
		Vegetative decay
	Anthropogenic sources	Industrial comprising incomplete combustion ▪ Iron and steel production ▪ Cement manufacturing ▪ Waste incineration ▪ Rubber tire manufacturing ▪ Dye manufacturing ▪ Coal-tar pitch production ▪ Power production
		Mobile comprising exhaust from automobiles ▪ Aircrafts ▪ Ships ▪ Trains ▪ Off-road heavy-weight and light-weight vehicles
		Domestic emission sources ▪ Garbage burning ▪ Coal coking ▪ Wood burning ▪ Cooking on oil/gas burners and kerosene/wood stoves ▪ Other residential heating
		Agricultural emission sources ▪ Open biomass burning ▪ Agricultural waste burning

Figure 2: Different sources of PAHs

Sources of PAHs to the environment can be divided into three categories: pyrogenic, petrogenic, and biological. The pyrogenic source of PAHs includes the pyrolysis of organic substances at very high temperatures (~350°C-1250°C) in the absence of oxygen or very low oxygen conditions. The common examples of pyrogenic processes are the destructive distillation of coal into coke and coal tar, and the thermal cracking of petroleum crude products into low molecular weight hydrocarbons. It further includes the unintentional process that may be manmade or even natural process. The manmade unintentional process includes incomplete combustion of motor fuels in automobiles such as cars, bikes, trucks, or even airplanes. Natural unintentional processes are natural forest fire, volcanic eruptions, and moorland fire caused by lightning flashes, but these processes contribute very little to the total PAHs present in the environment. In urban areas, the pyrogenic sources are present in higher concentrations than in rural areas [11-12].

The petrogenic sources of PAHs include the generation of PAHs during crude oil maturation. Petrogenic PAHs are very common due to the high dependency of human life on crude oil and its products. These PAHs are generated during the transportation and storage of crude oils. Common examples of petrogenic PAHs include leakage of storage tanks of underground and above the ground, oceanic and freshwater oil spills, and the increase of huge numbers of minor releases of motor oil, gasoline, and other related materials involved during transportation [13].

The biological sources of PAHs are not well studied. However, it is assumed PAHs can be produced by some plants and bacteria during their biological process or produced during the degradation of vegetative substances. The processes of PAHs generation can be either natural or anthropogenic [14].

The dry/wet deposition methods of PAHs are important processes for atmospheric PAHs disposition in water, soil, and plants. PAHs possessing more than three aromatic rings in their molecular structure possess low vapor pressure and high hydrophobicity and show strong adsorption to the dust particles. This accumulation of PAHs in the soil further helps in the transport of pollution to the plants, groundwater, and food [15]. From groundwater, plants absorb PAHs through their root and further distributes it in all plant parts. The animals/human who consumes these plants are further contaminated with PAHs.

Humans are exposed to PAHs via three routes: inhalation, ingestion, and dermal contact. It must be remembered that in one human, PAHs can be exposed via more than one route simultaneously [16]. Commonly, the workplace is the primary source of exposure to humans. For example, workers of food processing industries, coke manufacturing factories, and different chemical industries inhale PAHs. The other most common sources are consumption of polluted water and foods, cigarette smoke, inhalation through dust particles, and unhygienic conditions. In rural areas, PAHs are formed during the incomplete combustion of woods during the cooking of foods. Even the tea and coffee are also contaminated with PAHs through deposition of PAHs from the atmosphere on raw plants, industrial drying/roasting process, and other heating steps involved in manufacturing [17].

Polycyclic hydrocarbons in humans

During the eighteenth century, people exposed to soot complained of the problem of a high rate of skin cancer [18]. In 1947, workers of the coal tar gas industry reported a high rate of lung cancer. Thereafter, it was established that coal tar has a high percentage of PAHs that which was associated with causing skin and lung cancer [19]. Later, 17 PAHs were detected as being of the highest concern regarding their capability for damaging human health (figure 3) [20]. After entering in the human body, PAHs behave differently and causes severe problems. PAHs interact with proteins, amino acids, lipids, etc of the body and get modified.

PAHs affect human health in two forms: molecular PAHs and reactive metabolites of PAHs such as epoxides and dihydrodiols (figure 4). The reactive metabolite forms of PAHs bind with cellular protein and cause damage to DNA. It leads to a change of biochemical pathways and damages cells. In this way, reactive metabolites of PAHs produce mutations, tumors, cancer, and other developmental malformations. Some studies suggest that PAHs supress the immune system of humans. There are several factors that promote the growth of reactive metabolites such photo-induced generation, enzymatic activity, thermal generation, etc [21-22].

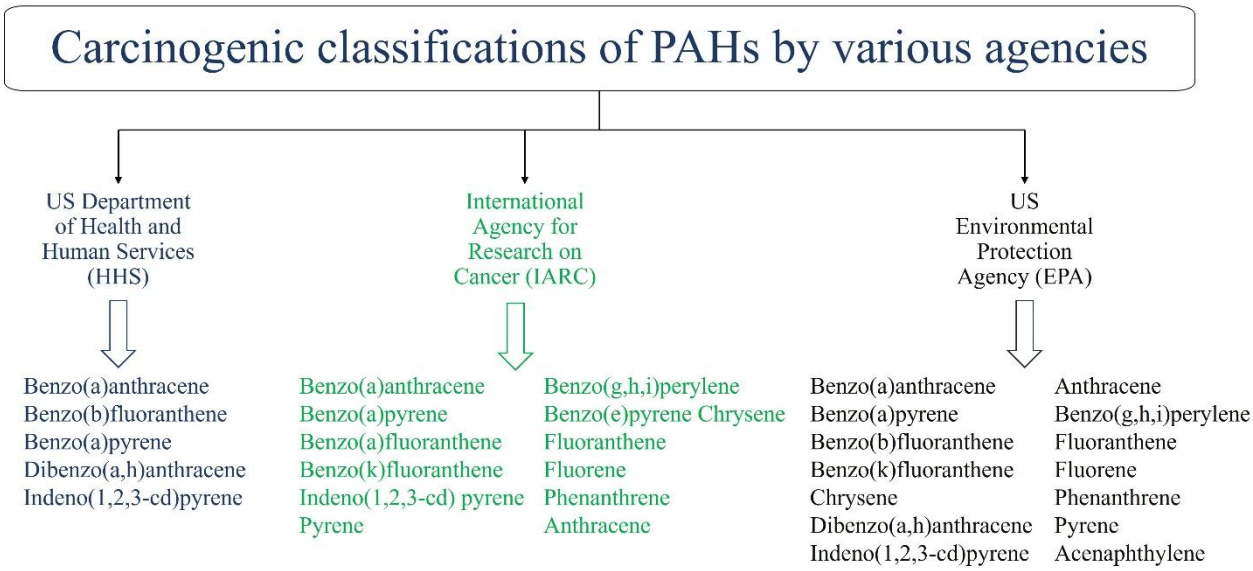

Figure 3: Classification of different PAHs by various agencies

It has been observed that the majority of the PAHs are not genotoxic by themselves, and it is its metabolic forms such as diols and epoxides which interacts with DNA and generates genotoxic effects. In the human body, PAHs undergo numerous metabolic changes and forms different types of electrophilic derivatives such as quinones, conjugated hydroxyalkyl derivatives, diols, epoxides, etc. These electrophilic derivatives have a strong affinity to covalently bind with the nucleophilic center of macromolecules of the human body [23].

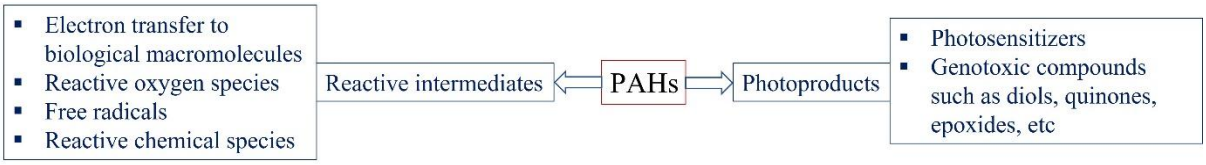

Figure 4: Phototoxic effects of PAHs

Removal of PAHs from the environment

PAHs can be removed through two methods from the environment i.e., biodegradation and photochemical degradation through light. Recently other methods for removal of PAHs have been developed such as leaching, chemical oxidation adsorption to soil particles, bioaccumulation, etc [24-25]. Biodegradation of PAHs is basically based on aerobic degradation under denitrifying conditions. PAH must be made available to the bacteria for their degradation and they become bioavailable when they are in a dissolved or vapor phase. PAHs that sorbet onto soil particles cannot be degraded by bacteria. The microorganism that reduces PAH includes algae, bacteria, and mold. It involves the dissociation of PAHs through biotransformation into a small metabolite, and the minerals are converted to inorganic minerals, H_2O, CO_2 (aerobic) or CH_4 (anaerobic) [26].

The photolysis reactions involving PAHs are quite similar to biodegradation reactions in terms of the phase in which they exist. Only a little photo-degradation occurs when PAHs sorbet to particles in the atmosphere or soil [27]. Such reactions occur more effectively with increasing particle surface area. The chemical treatment and/or physical treatment can remove PAHs efficiently from the surface water. The synergistic effect of UV irradiation and TiO_2 or ZnO catalysis is also an efficient way for the degradation of PAHs in contaminated soil [28-29].

Dry deposition occurs when the PAHs that sorbet to atmospheric particles settle down to the earth in the absence of any precipitation. The rates of dry deposition vary depending on the specific properties of the PAHs, sorbent particles, and atmospheric conditions. The temperature also affects the rate at which PAHs are deposited from the atmosphere. A higher temperature causes a greater fraction of the total PAHs to be in the vapor phase making the degradation process easier while lower temperatures will increase sorption of PAHs making degradation difficult [30].

Wet deposition is referred to the scrubbing off the contaminants sorbed onto particulates out of the

atmosphere by precipitation, as well as the dissolution of vapor phase contaminants into precipitation. The amounts of PAHs removed from the atmosphere by wet deposition vary Review on polycyclic aromatic hydrocarbons depending on the phase. Generally, absorbed PAHs are more easily removed from the atmosphere than vapor phase PAHs [31].

Therefore, the use of substances producing PAHs in industry and automobile sectors must be avoided or reduced and awareness programs about the toxic effects of PAHs must be improved.

2. CONCLUSION

Polycyclic aromatic hydrocarbons are generated in the form of gas and/or solid particles. In molecular form, PAHs are less toxic as compared with their reactive metabolite forms. The reason for the carcinogenicity is the interaction of reactive metabolic species with cells and DNA. The interaction of reactive metabolites and their effect have been discussed in detail. PAHs can be produced from different sources and transported from one animal to another or plant to animal. PAHs are degraded through volatilization, photolysis, adsorption, and chemical degradation whereas microbial degradation is considered as the major degradation process. The hydrophobic nature of PAHs is responsible for their absorption into sludge. The continuous discharge of waste containing PAHs from automobiles and industries in small quantities may pose a hazard to the environment.

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