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Wastewater technology attenuates the toxicity of shisha smoking

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Shisha smoking is rapidly gaining popularity, especially among the youths, yet knowledge on its toxic effects is limited. While the waterpipe device through which the smoke is bubbling should remove particles and toxic compounds, shisha smoking is still inducing cancers and several acute and chronic diseases. A possible solution to decrease smoke toxicity would be to trap most toxic smoke compounds in the water phase by adding adsorbents, solubilizers and complexing agents such as activated charcoal, cyclodextrins, biomicelles, liposomes and bionanocomposites (Fig. 1). Here we discuss flavored tobacco, smoke toxicity, the Low Tox Nargileh, and materials that can be added to the water bowl to decrease toxicity. Further research on the trapping of shisha smoke may also lead to application in various industrial sectors involving smoke emissions.

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Natural flavors

Are natural substances systematically good? Waterpipe, also known as nargileh, shisha, hubble–bubble or hookah, is gaining popularity worldwide. High rates of water pipe smoking have been recently reported among high school and university students during the last few years (Majeed et al. 2017; Galimov et al. 2019; Naicker et al. 2020; Khodadost et al. 2020). Many products are smoked through shisha devices, such as tobacco, flavored tobacco (known as mu'assel), tobacco-free herbal mu'assel, cannabis and opium. The rapid rise of shisha smoking is explained by the recent addition of flavors in tobacco mixtures (Maziak et al. 2014; Zaatari and Bazzi 2019). However, the effects of flavors on neurobiology are not yet fully understood, and both the European Parliament and the USA Food and Drug Administration have recently banned menthol, a natural flavor used in combustible cigarettes and electronic nicotine delivery systems (EU 2014; Avelar et al. 2019; Cadham et al. 2020). Farnesol, the main natural compound responsible for the flavor of the green apple, is still under toxicity evaluation (Avelar et al. 2019). Overall, contrary to the popular belief that 'all natural is good', the greening of smoking using natural flavors may not be safe.

Addiction and cancer

Waterpipe smoking is the second most common method of non-medical intake of cannabis by young people (Baggio et al. 2014; Paleiron et al. 2016). Compared to cannabis oral ingestion, the pulmonary absorption of cannabis smoke is faster and induces the higher intense effects that are actively sought by smokers. A recent survey shows that cannabis smoking with waterpipes is associated with higher risks of engaging in more addictive behaviors (Tsai et al. 2021). Besides, waterpipe smoke has genotoxic effects and is associated with cancers such as head, neck, esophageal and lung cancers (El-Zaatari et al. 2015; Alsaad et al. 2019; Montazeri et al. 2017; Mamtani et al. 2017). Waterpipe

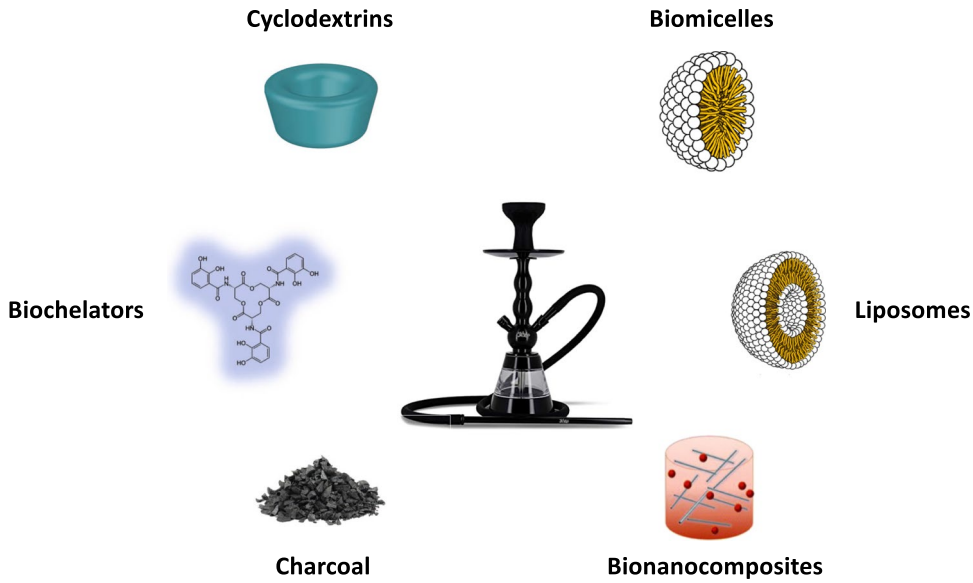

Fig. 1 Shisha smoking refers to inhaling smoke that has bubbled through a water bowl to simultaneously cool the smoke and remove some toxic smoke chemicals; however, shisha smoking is still inducing many diseases such as cancer. Inspired by wastewater technology, several materials such as cyclodextrins, biochelators, activated charcoal, biomicelles, liposomes and bionanocomposites can be added to the water bowl to trap toxic chemicals by adsorption, solubilization and complexation

smoke also induces adverse effects on the oral cavity, the respiratory system, the cardiovascular system and the brain functions (Meo et al. 2017; Pratiti and Mukherjee 2019). Addiction and alteration of cognitive functions are caused by the nicotine present in waterpipe products (Meo et al. 2017). Lastly, waterpipe smoking increases the risk of infection and is associated with the spread of many infectious diseases (Altindis et al. 2020).

Fine and numerous

Smoke aerosols contains two phases: the particle phase and the gas phase. The mean particle size ranges between 0.04 µm and 0.24 µm (Monn et al. 2007; Becquemin et al. 2008; Markowicz et al. 2014). As a consequence, the risk of deleterious effects is high because pharmacokinetic studies show that ultrafine particles can penetrate the alveolar sacs of the lungs (Monn et al. 2007; Becquemin et al. 2008; Markowicz et al. 2014). The composition of smoke aerosols has been studied using a smoking machine (Shihadeh 2003; Shihadeh and Saleh 2005; Schubert et al. 2012; Sepetdjian et al. 2013). 206 organic and inorganic compounds belonging to various chemical classes have been identified in tobacco smoke, including alcohols, ketones, aldehydes, acids, esters, acetals, lactones, hydrocarbons, monoterpenes, oxygenated monoterpenes, sesquiterpene hydrocarbons, phenylpropenes, derivatives of phenol, derivatives of cresol, alkaloids, furanic compounds, humectants, polycyclic aromatic hydrocarbons (PAH), volatile organic compounds (VOC), carbon monoxide, resorcinol and hydroquinone, and heavy metals (Aljadani et al. 2020). Among these, 16 compounds belong to the group A of carcinogenic substances, two compounds belong to the group 2A of probably carcinogenic substances, and 25 compounds belong to the group 2B of possibly carcinogenic substances, according to the International Agency for Research on Cancer (IARC, 2022). Other compounds are biologically active and cause harmful effects at high doses. Lastly, the waterpipe, in particular the mouthpiece, has been shown to be contaminated by antibiotic-resistant bacteria, thus contributing to the spreading of diseases (Masadeh et al. 2015; Martinasek et al. 2018). There are most probably many other yet unidentified toxic compounds in tobacco smoke and thus there is an urgent need to assess their impact on health.

Low tox nargileh

High amounts of smoke toxicants can be stopped by adsorption and solubilization in the water bowl of the hookah waterpipe, thus decreasing the toxicity of the inhaled smoke. Smoke toxicity can be further decreased by changing the water volume and the shisha features (Hauser et al. 2020). Toxicity can also be diminished by adding polymers and chelating agents into water to better trap toxicants. Indeed, a first patent reveals that adding cellulose- or pectine-based products and chelating agents such as Trilon B or Unitiol reduces the amounts of toxicants inhaled by the smokers (Rozenfeld and Dyachenko 2011). Nonetheless, surprisingly, Trilon B is a powder that may cause damage to the respiratory system after prolonged inhalation (BASF, 2021). Recently, Low Tox Nargileh, a new product aiming to reduce the toxicity of shisha smoking by adding a liquid formulation to the water phase, has reached the market (www.mnpnet.com). Since the mechanisms involved in smoke trapping are similar to those occurring in environmental remediation, e.g. in water and wastewater treatment, we propose several

alternative materials that could decrease smoke toxicity in the following sections.

Activated charcoal

Activated carbon has been used for the adsorption of polycyclic aromatic hydrocarbons from water (Eeshwarasinghe et al. 2018). Charcoal cartridges are largely used in solid phase extraction to concentrate polycyclic aromatic hydrocarbons and nitrosamines from contaminating water samples (Yoon et al. 2012). Incorporation of activated charcoal in cigarette filters is also effective in the filtration of mainstream smoke constituents (Polzin et al. 2008; Goel et al. 2018). The specific adsorption of nitrosamines was further done using other sorbents such as zeolites and mesoporous silica (Wang et al. 2004; Li et al. 2014, 2017; Shi et al. 2019; Wei et al. 2009).

Biochelators

Microbial metal chelators were recently introduced for the management of water pollution. For example, siderophores, iron chelators produced by bacteria, can be used. Siderophores can trap several types of metals and can be grafted on solids for easier metal removal from water (Hofmann et al. 2020; Moscatello et al. 2018).

Cyclodextrins

Cyclodextrins are cage-like molecules made of cyclic oligosaccharides that possess a hydrophobic cavity and can thus form inclusion complexes with guests (Fig. 2; Szejtli 1998; Crini et al. 2018; Morin-Crini et al. 2021). This entrapping property confers cyclodextrins the ability to increase the apparent solubility of hydrophobic compounds such as polycyclic aromatic hydrocarbons, essential oils and nitroaromatic compounds (Landy et al. 2012). The formation of cyclodextrin/guest inclusion complexes in aqueous media leads to a higher solubilization of hydrophobic compounds (Kfoury et al. 2019). The complexation of cyclodextrins with many flavors is also largely documented (Decock et al. 2008; Kfoury et al. 2014, 2018). Therefore, cyclodextrins could be used to solubilize toxic compounds of smoke in water. For instance, acetaldehyde, a compound of shisha smoke, forms inclusion complexes with the three native cyclodextrins (Almenar et al. 2007). Similarly, β-cyclodextrin forms an inclusion complex with benzaldehyde (da Silva et al. 1995).

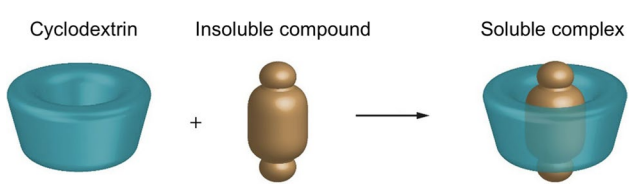

Fig. 2 Cyclodextrins can trap water-insoluble compounds to form a water-soluble complex. This principle can be applied to retain toxic compounds in the shisha water bowl

Cyclodextrins were evaluated as adsorbents for trapping nitrosamines from tobacco smoke (Wang et al. 2004). The complexation of cyclodextrins with polycyclic aromatic hydrocarbons was also suggested for remediation of soil pollution (Bardi et al. 2007). In addition, cyclodextrin-functional materials were proposed for removing water micropollutants such as polycyclic aromatic hydrocarbon derivatives (Alsbaiee et al. 2016; Topuz and Uyar 2017; Morin-Crini et al. 2019).

Concerning metallic contaminants, β-cyclodextrin and its carboxylmethylated derivative are able to extract arsenic, copper and iron from soil by solubilization (Chatain et al. 2004). The removal of lead and cadmium ions from contaminated water can be done by adsorption on β-cyclodextrin graphted on minerals, zeolite and vermiculite, using epichlorohydrin as a crosslinking agent (Zheng et al. 2019). Cyclodextrin-based nanofibers and nanofibrous poly-cyclodextrin membrane are able to adsorb both polycyclic aromatic hydrocarbon compounds and heavy metals, e.g. Pb^{2+}, Cd^{2+}, Zn^{2+}, and Ni^{2+} in aqueous solutions (Celebioglu et al. 2019).

Biomicelles

In an aqueous solution and at a concentration higher than its critical micelle concentration, an amphiphilic surfactant self-assembles into micelles composed of a hydrophobic core–hydrophilic shell architecture, which can be used for the solubilization of poorly water-soluble contaminants (Fig. 3). Biosurfactants usually refer to surfactants of microbial origin generating bio-micelles through self-assembling. Biosurfactants are popular due to their high biodegradability, low toxicity, and effectiveness in removing heavy metals and hydrophobic organic compounds from soil and water (da Rocha Junior et al. 2019). Microbial surfactants such as rhamnolipids and biosurfactin, and plant surfactants such as saponins have demonstrated an ability for the adsorption of polycyclic aromatic hydrocarbons and heavy metals in water (Mulligan 2005; Aryanti et al. 2020).

Liposomes

Liposomes are small spherical artificial lipid vesicles that are composed of phospholipids and may contain cholesterol (Azzi et al. 2018; Hammoud et al. 2019). Liposomes are usually biocompatible, biodegradable, non-immunogenic and non-toxic (Sheoran et al. 2019; Shah et al. 2020). They

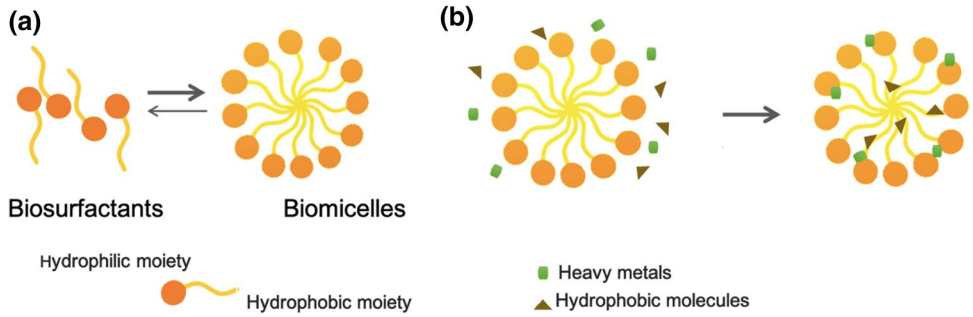

Fig. 3 (**a**) Self-assembling of biosurfactants into biomicelles in aqueous media at concentrations higher than the critical micellar concentrations; (**b**) biomicelles remove heavy metals and poorly water-soluble compounds from wastewater samples

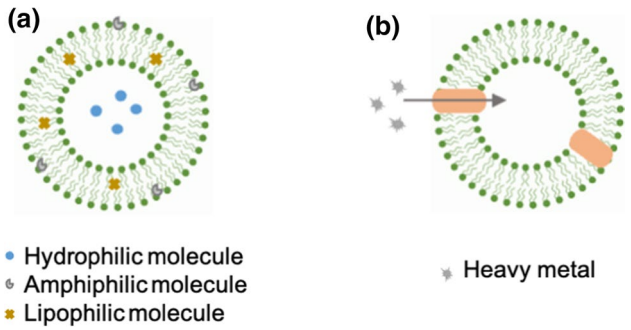

Fig. 4 a) Liposomes entrap hydrophilic molecules into their interior cavity, amphiphilic molecules at the water-membrane interface, and hydrophobic molecules into the lipophilic membrane; b) proteoliposome transporters carry heavy metals into the interior cavity of liposomes

can encapsulate hydrophilic, hydrophobic and amphiphilic molecules (Fig. 4). Liposomes have found applications in pharmacology for drug delivery, and in food for the delivery of flavors and nutrients. They are also used as models to study the interaction of chemicals with biological cells (Habib et al. 2015). Concerning the encapsulation of contaminants, 1-aminopyrene and 1-hydroxymethylpyrene bind strongly on neutral liposomes composed of 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine (Macii et al. 2019). The partition of a contaminant between the extra vesicular medium and the liposomal membrane is controlled by the liposome surface charge. Recently a proteoliposome transporter was designed to remove radioactive cesium, ^{137}Cs, from contaminated water (Hakim Elahi et al. 2020).

Bionanocomposites

Bionanocomposites are composites containing a biopolymer and nanomaterials made of minerals, metals or carbon. Bionanocomposites have been recently applied for wastewater decontamination (Chkirida et al. 2021). The biopolymer could be a polysaccharide such as starch, cellulose, chitin, chitosan, alginate, carrageenan, xanthan gum, lignin, carrageenan, humic acid; a protein such as gelatin and collagen; or polymers (Ahmad et al. 2017; Cao et al. 2020; Chkirida et al. 2021). The removal of heavy metals by bionanocomposites may occur through adsorption, electrostatic interaction, surface complexation and ion exchange (Chkirida et al. 2021). In addition, some bionanocomposites were proven to possess antimicrobial effects and demonstrated high ability to decrease the total organic carbon content in contaminated water (Chkirida et al. 2021).

Overall, the toxicity of smoke in waterpipes could be decreased by adsorption and solubilization using processes and materials that are known in wastewater technology. Further research on the trapping of shisha smoke may also lead to application in various industrial sectors involving smoke emissions.

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