CIGARETTE BUTTS AS WATER EMERGING CONTAMINANTS: POSSIBLE METHOD FOR THEIR REMEDIATION

A CIGARETTACSIKK, MINT VÍZSZENNYEZŐ: A MENTESÍTÉS LEHETSÉGES MÓDSZERE

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Abstract

Nano-sized particles derived from cigarette butts (CBs) are extremely small particles, typically less than 100 nanometers in size, generated by the degradation or breakdown of CB materials. While limited research exists on this topic, the presence of toxic compounds in CBs, including nicotine, heavy metals, and polycyclic aromatic hydrocarbons raises concerns about water contamination and soil impact. Nano-sized particles can travel through water systems and may reach irrigation channels and sources through various pathways, and if CB nano-litter is present in nearby surface water bodies or infiltrates into groundwater, it can introduce these particles and associated contaminants into water sources and the agricultural environment. To ensure the safety and limited entry into water sources used for irrigation it is crucial to implement effective water treatment processes capable of removing or reducing nano-sized particles, as well as the associated chemicals, from the water supply. To mitigate potential risks, magnetic biochar, enriched with magnetic materials, can be used as a potential solution. Magnetic biochar exhibits unique properties such as adsorptive ability and solar responsiveness, making it an attractive option for removing CB-derived nano-litter and associated contaminants from water. The study will assess the effectiveness of magnetic biochar in adsorbing these particles, its impact on water quality, soil health, and crop growth, and the feasibility of its implementation.
Keywords: *cigarette butts, irrigation water, heavy metals, polycyclic aromatic hydrocarbons, nicotine, magnetic biochar, soil*
JEL Code: *Q25, Q50*

Összefoglalás

A cigarettacsikkekből származó nanoméretű részecskék rendkívül kicsi, jellemzően 100 nanométernél kisebb méretűek, amelyek a cigerattecsikkek lebomlásából származnak. Noha erre a témára vonatkozóan korlátozott mennyiségű kutatás létezik, a cigarettacsikkekben található mérgező vegyületek, mint pl. a nikotin, a nehézfémek és a policiklusos aromás szénhidrogének aggályokat vetnek fel a víz- és talaj szennyezés miatt. A nanoméretű részecskék áthaladhatnak a vízrendszereken, és különféle utakon juthatnak el az öntözőcsatornákhoz és forrásokhoz, és ha a cigarettacsikkek nano-szennyeződés jelen van a közeli felszíni víztestekben, vagy beszivárog a talajvízbe, akkor ezeket a részecskéket és a kapcsolódó szennyeződéseket a vízforrásokba, valamint a mezőgazdasági területekre juttathatja. A biztonság és az öntözésre

használt vízforrásokba való korlátozott bejutás érdekében kulcsfontosságú olyan hatékony vízkezelési eljárások megvalósítása, amelyek képesek eltávolítani vagy csökkenteni a nanoméretű részecskéket, valamint a kapcsolódó vegyszereket a vízellátásból. A potenciális kockázatok mérséklésére megoldásként alkalmazható a mágneses anyagokkal dúsított mágneses bioszén. A mágneses bioszén egyedülálló tulajdonságokkal rendelkezik, mint például adszorpciós képessége és napsugárzásra való reagáló képessége, így vonzó lehetőség a cigarettacsikkekből származó nanoméretű szennyeződések, valamint egyéb kapcsolódó szennyeződések vízből való eltávolítására. A tanulmány felméri a mágneses bioszén hatékonyságát ezen részecskék adszorbeálásában, a vízminőségre, a talaj egészségére és a termésnövekedésre gyakorolt hatását, valamint a megvalósítás megvalósíthatóságát.
Kulcsszavak: *cigarettacsikk, öntözővíz, nehézfémek, policiklusos aromás szénhidrogének, nikotin, mágneses bioszén, talaj*
JEL Kód: *Q25, Q50*

Introduction

Technology advancement and the nefarious activities of man have increased the pollution of the environment (NASROLLAHI et al., 2020; NNADOZIE - AJIBADE, 2020). In 2001 the United Nations Environment Programme (UNEP) at the Stockholm convention; identified and labelled 12 chemicals as persistent organic pollutants (POPs) (FANG et al., 2020; RASUL et al., 2020). The flagged chemicals popularly also referred to as “dirty dozen” and found in several household products were banned because of their toxic and carcinogenic side effects. Closely, related to the dirty dozen is the “nasty nine” (OLISAH et al., 2020). These are groups of chemicals commonly used as pesticides, insecticides, and flame-retardant that were restricted or banned because of their toxicity to the human system. Recently, there have been heightened concerns about the rising risk of emerging contaminants in the environment (GEISSEN et al., 2015; NAIDU et al., 2016; KHAN et al., 2020; MORSI et al., 2020). Emerging contaminants are synthetic or biochemical, not commonly monitored but are present in the environment and have the inherent ability to impact the ecosystem negatively (GEISSEN et al., 2015). Cigarette butts (CBs) are waste resulting from the consumption of cigarettes; they are dispersed indiscreetly into the environment. It is estimated that 1.2 million tonnes of CBs are released into the environment every year (KADIR - SARANI, 2015). Based on the data collected from coastal clean-ups in over one hundred countries, CBs have been identified as the most frequently littered items on beaches (CONSERVANCY, 2019). Ghana emerged as the major contributor with 3,561,310 cis CBs followed by Canada with 167,811 CBs and Chile with 73,405 CBs. In Australia alone, an estimated 24 to 32 billion CBs are discarded annually, with approximately 10% ending up in water ecosystems (BARNES, R.L., 2011; HEALTON et al., 2011). Globally, this amounts to over 5.6 trillion CBs, equivalent to an annual mass of 845,000 tons (CARLOZO, 2008).

Cigarette butts (CBs) pose a significant problem primarily due to their composition of cellulose acetate, a synthetic plastic formed by treating cellulose obtained from cotton and wood pulp with acetic anhydride and acetic acid (FISCHER et al., 2008). The dense structure of the fibers and the inclusion of plasticizers such as polyethylene glycol impede the natural degradation of CBs in the environment (VANAPALLI et al., 2023), leading to the continuous release of hazardous microplastics (MPs) or nanoplastic fibers (VAN SCHALKWYK et al., 2019). Furthermore, it is noteworthy that MPs generated through the breakdown of CB filters, facilitated by biodegradation and photodegradation processes, can persist in the environment for approximately 10 to 15 years (MARAH - NOVOTNY, 2011; DIENG et al., 2013). In addition to their long-lasting presence in the environment, CBs contain a vast array of chemical compounds found in cigarette smoke, totaling over 7000 (RODGMAN - PERFETTI, 2013). According to the U.S. Department of Health and Human Services (2014), among these chemicals, at least 250 have been identified as harmful, including carbon monoxide, ammonia, and hydrogen cyanide. Furthermore, among the 250 toxic chemicals, at least 69 are recognized as carcinogenic, such as tobacco-specific nitrosamines and polycyclic aromatic hydrocarbons (PAHs). Additional hazardous substances present in CBs include polonium-210, benzene, acetaldehyde, arsenic (As), nickel (Ni), chromium (Cr), cadmium (Cd), beryllium (Be), aromatic amines, ethylene oxide, and 1,3-butadiene, among others. The presence of these bioaccumulative elements, including lead (Pb), alongside tar and nicotine, can lead to significant harm to water sources (LOZANO-RIVAS et al., 2020). Furthermore, it should be noted that the filter discarded with the CB is not biodegradable (SMITH - NOVOTNY, 2011). As a result, the chemical contaminants and other toxic substances easily leach out, posing a threat to the environment and ecosystems (MICEVSKA et al., 2006; SLAUGHTER et al., 2011). For instance, SLAUGHTER et al. (2011) reported that the leachate from a single CB in one liter of water contained enough toxins to cause a 50% fatality rate among freshwater or saltwater fish exposed to it. Moreover, as CBs age and are exposed to environmental factors, more contaminants can leach out, and through biomagnification, these organic contaminants can enter the food chain, leading to further bioaccumulation (HOH et al., 2019). Considering that agriculture is a major consumer of water, with irrigated farming accounting for 70% of freshwater usage (FAO, 2010), high concentrations of non-essential heavy metals/metalloids (such as arsenic, cadmium, and lead) and organic contaminants in soils and irrigation water pose a significant threat to the environment, food safety, and human and animal health (GONZALEZ HENAO - GHNEIM-HERRERA, 2021). For example, PÉREZ-REVERÓN et al. (2022) conducted a study in Spain investigating the presence of microplastics (MPs) in irrigation recycled water (IRW) and desalinated brackish water (DBW), as well as in sandy loam and clay loamy soil irrigated with IRW and DBW. The study found three times more MPs in the top layer (0-5 cm) of soil treated with IRW compared to DBW (i.e., 159 ± 338 vs. 46 ± 92 items·kg^{-1}). The most prevalent MPs in the irrigation water were cellulosic and polyester microfibers (between 84.4 and 100%), with an average length of 786.9 ± 812.1 μm and a transparent and blue color. It is important to highlight that promoting the reuse of wastewater for irrigation within the framework of a circular economy should be encouraged, provided that wastewater treatment processes are redesigned to prevent environmental contamination (KENDROVICS-BODA et al., 2018).

Numerous conventional technologies have been devised for the removal of contaminants; however, a significant hurdle lies in developing a technology that can effectively eliminate contaminants and reduce their concentration in the environment (TAKA et al., 2017). Conventional adsorbents like activated carbon, clays, silica beads, and biosorbents have limitations related to their permeability, selectivity, temperature and pH dependence, as well as the generation of secondary waste (ORHA et al., 2017; LIS et al., 2009; SADEEK et al., 2019). Other methods for contaminant removal include reverse osmosis, chemical precipitation, catalytic reduction, ion exchange, electrodialysis, and membrane filtration. However, many of these methods are costly, result in wastage, exhibit low efficiency, are highly specific, and are prone to membrane fouling issues (SAMRAT et al., 2013; AL-HARAHSHEH et al., 2017; MEADOW et al., 2017; GONZALEZ et al., 2017; CHANG et al., 2017). The existing technologies are expensive, not easily scalable, and can produce disinfection by-products, posing risks to human and environmental health (QU et al., 2013). In contrast, magnetic biochar is a desirable solution for contaminant removal due to its relatively low cost, widespread availability, and compatibility with biological and environmental systems.

Fates of cigarette butts in the environment and their potential impact on water and soil pollution

Cigarette butts (CBs) are the most commonly littered item worldwide, found in various areas including urban and protected regions (KURMUs et al., 2020). The quantity of CBs discarded in cities has increased alongside population growth. Several studies have examined the toxic effects of CBs and their contamination in urban areas (GREEN et al., 2014; LOZANO-RIVAS et al., 2020; DOBARADARAN et al., 2019; FARZADKIA et al., 2022). For instance, Green et al. (2014) investigated the presence and impact of discarded CBs on urban water systems, revealing that CBs are a significant source of nicotine pollution, exceeding levels harmful to aquatic life. In the study conducted by LOZANO-RIVAS et al., (2020), in Bogota D.C, Indonesia, the authors stated that, littered CBs are a common problem in nightlife areas, posing risks to water ecosystems, with 94.9 million butts discarded annually in these areas, and washed away by rain. In the same study, leaching tests revealed that within an hour, a hundred CBs can introduce significant levels of contaminants such as chemical oxygen demand (COD), cadmium, arsenic, turbidity, and color into one liter of water, and concluded the annual littered CBs in Bogota can contribute substantial amounts of contaminants to the city's river, impacting water quality, sewage treatment, and increasing operational costs. DOBARADARAN et al., (2019), compared PAHs concentrations in freshly smoked CBs and CBs from urban streets and river areas with varying exposure times, and found significantly higher levels of four PAHs (naphthalene, acenaphthylene, acenaphthene, and fluorene) in freshly smoked CBs compared to street samples, and concluded that large number of CBs littered annually, are a potential threat to water resources from the release of PAHs. Therefore, these contaminants, including heavy metals can leach out into the environment from CBs with age and exposure to environmental factors which in turn can pollute the soil, surface, and ground waters (BEUTEL et al., 2021). Hence, water pollution and water source depletion are causes for concern due to population growth, urbanization, climate changes, and industrialization.

Figure 1. Fates of cigarette butts into the environment / 1. ábra: A cigarettacsikk sorsa a környezetbe

Source: Own construction / Forrás: Saját szerkesztés

Effect of cigarette butts on plant growth and soil health

The disposal and leaching of CBs into the environment can have detrimental effects on plant growth (SELMAR et al., 2018; MONTALVÃO et al., 2019; GREEN et al., 2019) and soil bacterial diversity (KOROLEVA et al., 2021). Supporting this notion, SELMAR et al. (2018) demonstrated nicotine uptake from soil by peppermint plants (*Mentha × piperita*), suggesting that nicotine-contaminated soils resulting from discarded CBs can lead to nicotine uptake by plants. MONTALVÃO et al. (2019) found that leachate from smoked CBs had cytotoxic, genotoxic, and mutagenic effects on onion (Allium cepa) roots at environmentally relevant concentrations (1.9 μg L^{-1} of nicotine). GREEN et al. (2019) observed reduced germination success and shoot length in perennial ryegrass (Lolium perenne) and white clover (Trifolium repens) exposed to discarded CBs after 21 days, indicating the potential of littered CBs to hinder the net primary productivity of terrestrial plants. Soil microbiological parameters, such as microbial community structure, microbial biomass, and enzyme activity, are considered indicators of soil quality (LU et al., 2013; XIAN et al., 2015). Soil microorganisms have been shown to respond quickly to soil contamination, exhibiting greater sensitivity compared to animals and plants within the same soil (LU et al., 2013; ZHU et al., 2018). The impact of CBs on soil bacterial communities was investigated by KOROLEVA et al. (2021). Using Automated Ribosomal Intergenic Spacer Analysis (ARISA) to assess DNA fingerprints of bacterial communities, the authors examined the effects of CB leachate on soil bacteria before and after treatment. Elemental composition of biodegradable and non-biodegradable butts was also analyzed using ICP-MS. The results indicated that biodegradable butts had a significant influence on bacterial community composition, likely due to higher concentrations of metals and metalloids in their leachate. The most abundant elements found in the butts were Al, Fe, and Zn, with concentrations of 1.31 and 2.35 g kg^{-1} for Al, 2.03 and 1.11 g kg^{-1} for Fe, and 3.18 and 15.70 mg kg^{-1} for Zn in the biodegradable and non-biodegradable butts, respectively. In terms of bacterial activity, the study concluded that both biodegradable and non-biodegradable CBs can significantly impact the soil bacterial community due to the leaching of certain elements into the soil.

The potential of magnetic biochar for cigarette butt remediation

In the area of material science, scientists and engineers have become more and more interested in making and using magnetic nanoparticles made from iron oxide (SHARMA et al., 2015; KARGIN et al., 2020). Their curiosity stemmed from many characteristics such as a constant external magnetic field, unique physical and chemical properties, and quantum scale traits (SHARMA et al., 2015). Having the ability to control and modify their characteristics including dimensions, porosity, structure, and forms is beneficial to contribute to a cleaner and more environmentally friendly approach for removing contaminants (SHARMA et al., 2015). Magnetic materials derived from iron oxides have been increasingly employed to treat water contaminated with various substances (LIOSIS et al., 2021; SHI et al., 2022). Therefore, by incorporating magnetic biochar in water treatment systems, it may be possible to effectively remove nano-sized particles derived from CBs, along with other pollutants and contaminants, from water. For example, metal ions can be adsorbed via ligand exchange and complexation, while nicotine and PAHs are primarily via π-π interaction, hydrogen bonding, and electrostatic interactions (Figure 2).

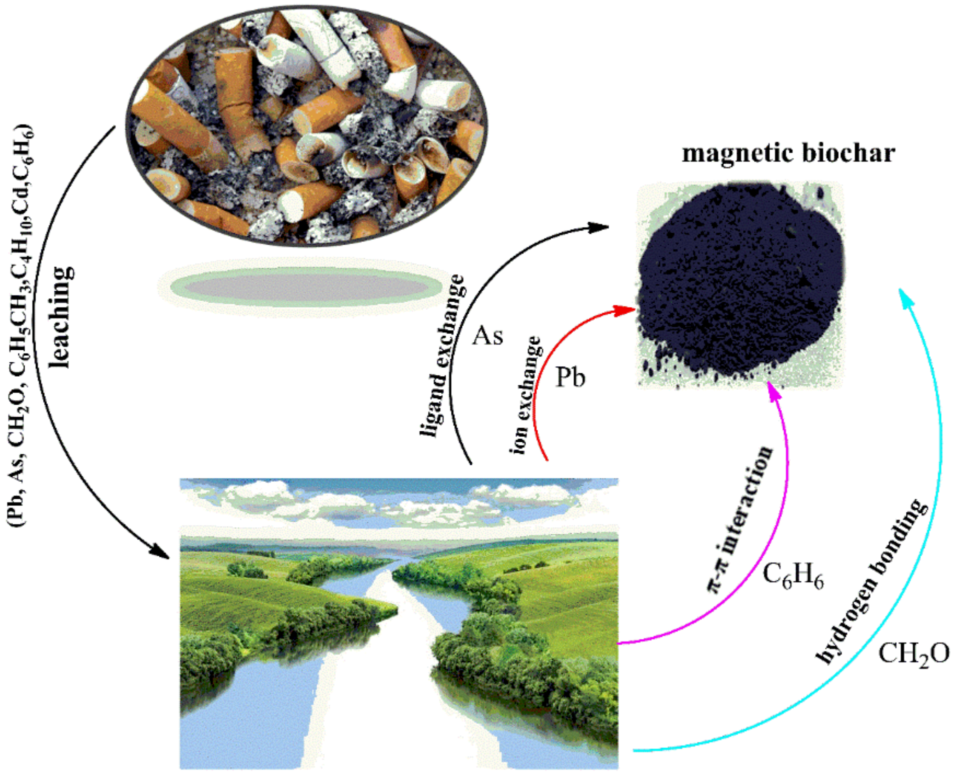

Figure 2. Mechanisms through which magnetic biochar aids in the remediation of contaminants leached into the aquatic environment by cigarette butts / 2. ábra: Mechanizmusok, amelyeken keresztül a mágneses bioszén segíti a cigarettacsikk által a vízi környezetbe kimosódott szennyeződések helyreállítását

Source: Own construction / Forrás: Saját szerkesztés

The literature has documented the use of magnetic biochar nanocomposites for remediating water contaminated with both inorganic and organic contaminants. Table 1 provides an overview of the adsorptive characteristics of specific magnetic oxide nanocomposites utilized in wastewater treatment. For example, in the study of BADRUDDOZA et al., (2013), the magnetic nanocomposite synthesized using phosphonium silane as capping agent was effective in the removal of As^{5+} and Cr^{6+}; the adsorption capacity of the heavy metals on the materials were 50.5 and 35.2 mg L^{-1}, respectively. In another study, magnetite decorated with polyacrylamide adsorbed Cu^{2+}, Ni^{2+}, Co^{2+}, and Cd^{2+} to the tune of 194, 144.3, 128 and 161 mg L^{-1} from aqueous solution (HABILA et al., 2017). Lead (Pb^{2+}), and Cu^{2+} cations were successfully adsorbed on a magnetic nanocomposite that was coated and complexed using amino enriched silicon (IV) oxide (ESSANDOH et al., 2018). The uptake of mercury (Hg^{2+}) was facilitated using a magnetic nanocomposite that was capped with humic granules (LIU et al., 2008). The magnetic nanomaterial in their study was 10 nm in size and recorded a magnetization saturation value of 79.6 $emug^{-1}$. Ethylbenzene, xylene, and toluene were effectively adsorbed on multi-walled carbon nanotube that was anchored on magnetite (YU et al., 2016). The adsorption capacities recorded were with the range 63.34 to 105.59 mg L^{-1}. Therefore, due to successful experiments on the adsorption of inorganic and organic contaminants by magnetic biochar , the remediation of contaminants from CBs MPs or nano plastics by magnetic biochar needs to be investigated, since the absorbed contaminats in MPs' biofilm surface layer can be degradated by magnetic biochar. Based on TONG et al. (2020), the Fe_3O_4 modified biochar is expected to increase plastic particle adsorption. It is an addition to porous media that might further increase the retention of plastic particles.

Table 1. Adsorptive properties of selected magnetic biochar / 1. táblázat: A kiválasztott mágneses bioszén adszorpciós tulajdonságai

Adsorbent	*Mass ($g\ L^{-1}$)	Surface Area ($m^2\ g^{-1}$)	Adsorbates	Adsorption Capacity (mg/g)	Ref.
Fe_3O_4	12	105.7	As^{5+} Cr^{6+}	50.5 35.2	(Badruddoza et al., 2013)
Fe_3O_4@C/PAA	0.3	8.2	Cu^{2+} Ni^{2+} Co^{2+} Cd^{2+}	194 144.3 128 161	(Habila et al., 2017)
Fe_3O_4-haemoglobin	2	12.43	Eriochrome black T Indigo carmine Naphthol blue black Tartrazine Erythrosine Bromophenol blue	178.6 104.2 114.9 80 178.6 101	(Essandoh and Garcia et al., 2018)
Fe_3O_4@SiO_2/NH_2	0.4	216.2	Cu^{2+} Pb^{2+} Cd^{2+}	43.8 111.9 37	(Wang et al., 2010)
Fe_3O_4@APS/AA-co-AA	1	-	Methylene blue Crystal violet Alkali blue	124 180.5 17.8	(Ge et al., 2012)
Fe_3O_4@humic	0.1	64	Cu^{2+} Cd^{2+} Pb^{2+} Hg^{2+}	46.3 50.4 92.4 97.7	(Liu et al., 2008)
Fe_3O_4@SiO_2/GO-PEA	1	133	Chlorpyrifos Malathion Parathion	87 74 86	(Wanjeri et al., 2016)
Fe_3O_4@MWCNT-KOH	0.4	662.1	Toluene Ethylbenzene Xylene (meta) Xylene (otho) Xylene (para)	63.34 249.44 227.05 138.04 105.59	(Yu et al., 2016)

Source: NNADOZIE - AJIBADE (2020) / Forrás: NNADOZIE - AJIBADE (2020)

Conclusions

This review paper sheds light on the critical concern of cigarette butts (CBs) as emerging contaminants in water sources and explores potential methods for their effective remediation. Despite their small size, CBs present substantial environmental and health hazards, releasing toxic compounds like nicotine, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) into water bodies. These contaminants can infiltrate groundwater and surface water. As the river water is not filtered to satisfy the same standards as drinking water, the use of CB contaminated river water may pose a risk to agricultural production and food safety. The effect on agricultural production is explained by the reported impact of CBs on plant growth, and soil bacterial diversity. These findings underscore the urgent need for responsible CB disposal and remediation measures to protect both terrestrial ecosystems and soil quality. Whether irrigation water is drawn from the surface or riverbed and then filtered to remove particle remains, leached contaminants, microplastics, and nano plastics from CBs may contaminate the water sources. Magnetic biochar, enriched with magnetic materials, emerges as a promising remediation strategy due to its exceptional adsorption capacity, solar responsiveness, and reusability. The integration of magnetic biochar into water treatment systems offers a feasible approach to remove nano-sized particles and associated contaminants derived from CBs, thereby mitigating potential risks. While further research is needed to fully explore the potential and practicality of magnetic biochar and other emerging remediation techniques, this review provides a foundational knowledge base for ongoing efforts to combat CB contamination in water resources. Therefore, more research on the effect of CB contaminants, MPs or nano plastics on plant and soil quality requires extensive attention due to the potential contamination of river water, which is mostly used for irrigation purposes in agriculture. The paper highlights the need for increased awareness about the environmental consequences of CB littering and emphasizes the promotion of magnetic oxide nanocomposites due to its desirable characteristics for the purification of water, and soil.

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