7 Biological Treatment of Pharmaceuticals and Personal Care Products (PPCPs)

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Abstract

In the global era, the use of pharmaceuticals and personal care products (PPCPs) has increased rapidly worldwide. In general, the PPCPs after being utilized/consumed are emitted into the sewage system and thereby into municipal waste material. With improper treatment of these wastes through conventional wastewater treatment, PPCPs easily seep into nearby soil and water and in turn contaminate our ecosystem. With regular addition of these compounds, there has been a significant increase in the amount of PPCPs material in the environment rendering them hazardous for aquatic as well as terrestrial animals and humans. Studies have also shown that PPCP compounds have percolated even into groundwater. Therefore, a proper mechanism is required for the removal of these PPCPs from drinking water, sewage, and environment. This chapter discusses conventional methods such as nanofiltration, reverse osmosis, and ozone with advanced oxidation along with focusing on mechanism and future perspective of the biological treatments that can be used for removal of PPCPs from contaminated sites.

Keywords

Pharmaceuticals and personal care products · Biological treatment · Wastewater · Physicochemical techniques

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7.1 Introduction

Pharmaceuticals and personal care products (PPCPs) are classified as chemically active ingredients also known as "emerging contaminants (ECs)," while pharmaceuticals are products that are majorly used in treating or preventing diseases and can be categorized into antibiotics, analgesics, blood lipid regulators, natural and synthetic hormones, β-blockers, antidiabetics, antihypertensive, non-steroidal anti-inflammatory drugs (NSAIDS), and many more (Liu and Wong 2013; Daughton and Ternes 1999; Yang et al. 2017). Products used every day for uplifting standard of living of humans such as cosmetics, shampoos and conditioners, soaps and detergents, and various other household products come under (PPCPs) (Ebele et al. 2017). Occurrence of these ECs in the environment has become a major concern because of their physiochemical properties and metabolically active compounds present in pharmaceuticals; they tend to have a hydrophobic nature, which easily enables them to bioaccumulate in the environment.

There are many ways by which PPCPs can enter into the environment. Discharge of waste materials from industries, hospitals, households, and wastewater treatment plants straight into surface water makes them contaminated with PPCPs. And leaching of these PPCPs into the groundwater makes them also contaminated. These PPCPs then finally enter into the food chain via irrigation and agricultural practices (Sui et al. 2015).

Conventional wastewater treatment plants are not effective in removing these ECs, and hence they persist in the environment.

Various studies have shown that PPCPs persist in our environment much longer than previously thought ranging from few months to even many years (Kumar et al. 2010; Monteiro and Boxall 2009). Because of their polar nature, PPCPs persist in surface water and then percolate to ground level during groundwater recharge, and in this process, few PPCPs do get removed, but compounds such as carbamazepine can easily percolate and reach groundwater with a travel time of up to 8 years (Chen et al. 2016a, b). To minimize the effects of these contaminants on the environment, the scientific community has raised questions about the presence, outcome, and consequences these PPCPs pose on our environment.

7.2 Issues Related to the Presence of PPCPs in Wastewater Streams

PPCPs when get release into the environment due to their physiochemical properties become persistent and start getting bioaccumulated. Individual PPCPs may not become persistence, but because these PPCPs get continuously deposited in the environment, they become "pseudo-persistent." These pseudo-persistent compounds have much more persistence capability in the environment than the original pharmaceutical compounds since their source of origin continuously gets refilled although these compounds repeatedly get biodegraded and photodegraded by the environment (Houtman et al. 2004; Kar et al. 2020).

Because of the biologically active compounds present in PPCPs, when these chemicals are released into freshwater, they become harmful to many aquatic animals, even when present in very low concentration. The majority of these PPCPs being manufactured for humans and animals have a severe impact on non-target aquatic animals (Chen et al. 2016a, b).

Recent studies have shown that PPCPs have hazardous effects on fishes, they being the non-target organism. For example, a study showed that when gemfibrozil was exposed to goldfish (*Carassius auratus*) for 14 days, it got bioaccumulated in its plasma at a concentration factor of 113 (Mimeault et al. 2005). Another experiment conducted by Vernouillet et al. (2010) showed that carbamazepine (CBZ) which is an antiepileptic drug gets bioaccumulated by algae *Pseudokirchneriella subcapitata* at a bioaccumulation factor of 2.2, whereas the same compound gets bioaccumulated in crustacean *Thamnocephalus platyurus* at a concentration factor of 12.6. Yet another concerning factor that comes to light with PPCPs being accumulated in the environment due to overuse of these ECs in human medicine and animal husbandry is the generation of antibiotic-resistant strains inside a pool of natural population of bacteria, and this in turn has led to ineffective treatment of certain diseases that are caused by antibiotic-resistant bacteria (World Health Organization 2015).

One of the significant threats posed by PPCPs being present in water bodies is their potential to hinder the pathways of endocrine systems thereby producing undesirable effects or disturbance in homeostasis. Endocrine disrupters (ED) are compounds of exogenous nature that have the potential to change the working ability of the endocrine system and thereby affect the health of an organism and its progeny adversely (Wielogórska et al. 2015). Toxicity of certain PPCP compounds increases when they act synergistically, which implies that while singly these PPCPs may be present in low concentrations and not imply much toxic effects, when a cocktail of PPCP compounds work together, they impose significant toxic effects leading to severe ecotoxicity. This was shown by a study conducted by Cleuvers (2003) where carbamazepine and clofibric acid—two different drugs belonging to two different therapeutic classes—elicited more severe effects on *Daphnia magna* than when acting singly on the organism at the same concentration (Thorpe et al. 2001).

Studies of recent times have depicted that the toxicity due to exposure to PPCPs depends on the organism that has been exposed to it, the time duration to which it has been exposed, and the developmental stage at which it was exposed and at what concentration. More abnormalities are observed at crucial stages of development in non-targeted organisms even when PPCPs are present in trace amount (Wilkinson et al. 2016).

7.3 Existing Physicochemical Techniques

As already mentioned earlier, PPCPs are present in nature in very small amount, but the concern as well as the necessity to remove these compounds arises due to the reason that these are being introduced in the nature continuously. Methods to remove

PPCPs are broadly divided into physiochemical methods and biological methods. In this section we will focus on physiochemical methods.

7.3.1 Physical Adsorption Processes to Remove PPCPs

7.3.1.1 Adsorption

Adsorption is one of the most commonly used physical techniques to remove organic PPCP compounds from the environment especially from polluted water. Various research has been done to increase the removing efficiency of PPCPs from aqueous environment using discrete adsorbents. The below section focuses only on the carbon-containing materials used for adsorption of PPCPs because they are cheap, are easily available, and are also effective in removing PPCPs.

Activated Carbon

Activated carbon has long been used in the treatment of water, and its performance in removal of endocrine disruptors has been reported by Liu et al. (2009). The result of the study was positive; however, over time, two problems occurred. First, the adsorption capacity decreased and, second, the quality of the activated carbon got deteriorated. The main types of activated carbon are powdered activated carbon (PAC) and granular activated carbon (GAC), and the efficiency of these activated carbons to capture PPCPs depends on the hydrophobicity and charge of the PPCPs. Apart from these, even the water matrix has an effect on the adsorption capability of the activated carbon (Mailler et al. 2015; Rodriguez et al. 2016).

Graphene and Graphene Oxide

Recent studies have shown that both graphene and its oxide can be used to extract PPCPs, and their efficiency to remove them depends on physiochemical properties of PPCPs. Apart from this, the pH and the time of contact also influence the efficiency rate of PPCPs removal (Kyzas et al. 2015; Yang and Tang 2016). Because graphene and its oxide comparatively have more surface area than activated carbon, they have become one of the preferred adsorbents to remove PPCPs. More research needs to be carried out on graphene and graphene oxide, to study real wastewater and its effect on the adsorption capacity of PPCPs by these compounds.

Carbon Nanotubes

Carbon nanotubes (CNTs) are composed of graphene sheets, and they can be arranged as single-walled carbon nanotubes (SWCNTs) or multi-walled carbon nanotubes (MWCNTs) (Czech and Buda 2016). Because CNTs have an extraordinary capacity of sorption, they also have a very high specific surface area-to-mass ratio which ranges between 75 and 1020 m^2/g (Jung et al. 2015). CNTs form three types of chemical bonds—hydrophobic interactions, van der Waals forces, and π-π stacking—which allow them to create four distinct sites of adsorption such as inner cavities, interstitial channels, external grooves, and outermost surfaces (Ye et al. 2019; Wei et al. 2013).

$BiVO_4$ is a semiconductor which is used for degrading pollutants of organic nature. In a study using MWCNT/$BiVO_4$ composites, photocatalytic degradation of oxytetracyclines using high-performance liquid chromatography (HPLC) was measured, and the value reached 88.7% in a duration of 60 min. Because of the synergistic effect that happened between MWCNT and $BiVO_4$ composites, such an enhanced rate of photocatalytic degradation was achieved (Marques et al. 2013).

7.3.1.2 Coagulative Precipitation

Coagulative precipitation is one of the first methods that are applied to remove PPCPs. It works on the principle of colloidal coalescence, bonding, and precipitation due to gravity (Yuan et al. 2016). Coagulants help in the process of adsorption and flocculation of the wastewater and also increase the biodegradability of organic and inorganic wastes. Coagulants that are frequently used are broadly categorized into two main groups: (1) coagulants made up of inorganic salts such as aluminum and iron salts and (2) coagulants made up of polymers, both organic such as polyacrylamide and inorganic such as polyaluminum chloride (PAC) and polyferric sulfate (PFS). However, there are few disadvantages of this method such as slow removal rate of dissolved wastes, production of huge amount of chemical sludge, and incomplete treatment of pathogens.

7.3.1.3 Flotation

Flotation can be applied to both solid-liquid and liquid-liquid interface and is an easy method which is applied to remove micropollutant particles. Processes such as electroflotation, induced air flotation, and dissolved air flotation allow these micropollutant particles to have a density lower than that of the water, thereby allowing these micropollutants to rise and float on the surface of water and henceforth be removed (Suarez et al. 2009). This method being simple has an added advantage of being economical, consumes less power, and is easy to maintain.

7.3.1.4 Membrane Separation

Membrane separation is an adequate traditional process which uses membranes of varying sizes and materials for diffusion dialysis, electrodialysis, reverse osmosis, and ultrafiltration (Martínez et al. 2013). This process is cheap and easy to handle with low production of sewage output making them convenient for primary treatment of wastewater. But there are a few disadvantages also, such as all these processes included in membrane separation require external energy input to remove the pollutants from wastewater. And apart from them, the membranes utilized in these processes are costly and are not reusable.

7.3.2 Advanced Chemical Oxidation

Conventional treatment techniques to remove PPCPs from wastewater are not that effective, so advanced chemical methods are required to handle these types of pollutants. Few of the advanced chemical methods are discussed in the following section.

7.3.2.1 Ozonation

Ozonation has a good potential to remove PPCPs from wastewater, and it is one of the most frequently studied oxidation processes. The method on which ozonation works is formation of hydroxyl radicals, and it strongly depends on the oxidizing capability of the hydroxyl radicals to remove PPCPs (Bai et al. 2016a, b), and therefore the amount of hydroxyl radicals generated becomes directly proportional to the rate at which the PPCPs get ozonized. This process is generally used in post-treatment of wastewater to remove PPCPs. More research is required to study the effect of various sources of wastewater on the formation of hydroxyl radicals, and also the release of toxic by-products of ozonation should be monitored.

7.3.2.2 Fenton Oxidation

Fenton oxidation is one of the oxidation methods to remove industrial wastewater pollutants with the use of iron salts and hydrogen peroxide at acidic pH. This method also heavily depends on oxidizing capabilities of the hydroxyl ions. Few studies have shown the effectiveness of this method to remove PPCPs. The fundamental process of Fenton oxidation is to use various metal catalysts to breakdown H_2O_2 to produce hydroxyl radicals (Xu and Wang 2012). More research is required to study the effect of various sources of wastewater on the formation of hydroxyl radicals, and also the release of toxic by-products of Fenton oxidation process.

7.3.2.3 UV Treatment

Recent studies have used UV treatment to remove PPCPs from wastewater (Kim et al. 2009). The principle behind the process of photolysis is to break the chemical bonds of the pollutants in the wastewater by applying direct UV light. But a study conducted by Vogna et al. (2004) had shown that photolysis by direct UV light is not that efficient for some of the pollutants such as carbamazepine. Yuan et al. (2016) has shown the effectiveness of UV treatment removal process, the UV light can be combined with hydrogen peroxide. This process is also based on generation of hydrogen radicals caused by the breakdown of hydrogen peroxide by UV light. More research should be done to study the efficiency of this process to remove different pollutants from wastewater with a mixture of complex pollutants.

7.3.2.4 Ionizing Radiation

A study conducted by Kim et al. (2014a, b) showed that radiation of gamma rays has a higher potential to degrade lincomycin, sulfamethoxazole, and tetracycline when present in aqueous environment. Another study conducted by Sági et al. (2016) showed that the BOD/COD value of sulfamethoxazole after treatment with gamma radiation at 2.5 kGy was improved. Kimura et al. (2012) used 2.0 kGy of gamma irradiation on wastewater to completely biodegrade stern PPCPs such as carbamazepine, ketoprofen, mefenamic acid, clofibric acid, and diclofenac. In the study conducted by Liu and Wong (2013), it was reported that when H_2O_2 was combined with gamma radiations, the removal efficiency of TOC was heavily increased from 5% to 48%.

7.4 Biological Treatment: Introduction

Recently, biological treatment of PPCPs has become one of the most researched areas for degrading persistent organic pollutants. This technique has several advantages over the existing physiochemical techniques such as easy operating parameters, recovery of additional by-products, and cost-effectiveness. In biological treatment process of PPCPs, the focus is mainly on factors which can increase the robustness of the process such as type of microbial culture to be used, material of the sorption process, and calculating the potential of degradation and also production and disposal of secondary pollutants with sludge. Various biological treatments have been described in the following section.

7.4.1 Aerobic Biological Treatment

7.4.1.1 Activated Sludge Process (ASP)

Activated sludge process (ASP) is one of the most frequently used techniques to treat PPCPs in wastewater treatment processes (WWTPs). This technique follows the principle of using synergistic microbial population to degrade PPCPS. Several studies have conducted experiment to increase the efficiency of biodegradation by allowing cultures of mixed microbes to grow in activated sludge (Zhou et al. 2014). While some of the population of these mixed microbial cultures feed on the PPCPs, others use certain biochemical pathways to degrade them, thereby making this treatment method one of the potential candidates to treat PPCPs in wastewater efficiently (He et al. 2020). Suarez et al. (2010) studied compounds such as trimethoprim, sulfamethoxazole, carbamazepine, and diazepam and showed that these compounds are highly resistant towards biological transformation. Verlicchi and Zambello (2014) studied the removal process of 29 antibiotics by using conventional activated sludge (CAS) system. This study reported biological transformation of most of the compounds, but spiramycin had an insignificant removal rate, while cefaclor showed a removal rate of around 98%.

7.4.1.2 Membrane Bioreactor (MBR)

Membrane bioreactor (MBR) is an alternate method for PPCPs removal, and it works with a combinational approach where membranes and ASP work together. This method uses ultrafiltration membrane rather than secondary sedimentation tank (Yang et al. 2019). A study conducted by Sahar et al. (2011) compared antibiotics such as macrolide and sulfonamide removal process between CAS and MBR techniques, and the data showed that 15–42% of the antibiotics were removed by MBR technique compared to CAS process. Compounds such as carbamazepine and EDTA which are effectively removed in CAS however get poorly removed in MBR, but other persistent compounds such as diclofenac and sulfophenyl carboxylates get easily removed through MBR technique (Hai et al. 2011). In a different study, it was showed that MBRs were efficient in removing 90% of the 23 PPCPs out of 26 PPCPs used. ECs such as atorvastatin, metformin, 2-hydroxyibuprofen, and naproxen were most effectively removed, whereas compounds such as meprobamate, clarithromycin, trimethoprim, and thiabendazole were not so significantly removed through this process (Kim et al. 2014a, b).

7.4.1.3 Sequencing Batch Reactor (SBR)

This technique requires choosing certain suitable organisms that have the capability to degrade and remove PPCPs from wastewater systems. The study conducted by Muz et al. (2014) used both oxic and anoxic conditions in lab-scale SBR units to remove PPCPs such as endocrine-disrupting compounds. The data showed that 80% of the PPCPs were removed without involvement of any nitrifying microbes, when the experiment was conducted at (solid retention time) SRT of 5 days. The result of this study also showed that the process of removing carbamazepine followed aggregation onto sludge, while the leftover PPCPs were removed through biodegradation.

PPCPs can also be degraded through aerobic granular sludge sequencing bioreactor (AGSBR). The technique makes use of extracellular polymeric substances (EPS) which are present on the outer surface of the bacterial cell. EPS are made up of proteins and polysaccharides which help in aggregation and formation of aerobic granular sludge. In a study when PPCPs such as prednisolone, ibuprofen, naproxen, sulfamethoxazole, and norfloxacin in synthetic wastewater were added to AGSBR, initially the amount of EPS increased, because to protect themselves from the toxic effect of these compounds, the microbes synthesized and exported out more EPS. But with duration of time, the content of EPS in AGSBR decreased because the EPS secreted by the microbes started combing with the PPCP compounds and this made free PPCP molecules less available in the wastewater which in turn reduced the toxicity these compounds pose to the microbes. Therefore, this technique is an excellent method to remove PPCPs from wastewater, but more studies involving research with real wastewater are required to estimate the full potential of this technique (Shi et al. 2013).

7.4.2 Natural Aerobic Treatment

7.4.2.1 Waste Stabilization Ponds (WSPs)

This method is also a budding candidate for PPCPs removal from wastewater. A study conducted by Li et al. (2013) had shown that WSPs have the capability to remove 88–100% of PPCPs at (hydraulic retention time) HRT of 20–30 days. Because this technique involves processes such as biodegradation, photodegradation, and sorption onto solids, they are highly effective to remove PPCPs from wastewater.

7.4.2.2 Constructed Wetlands (CW)

Recently CWs have become an attention for extraction of PPCPs from wastewater (Li et al. 2014). But parameters such as carbon load (CL) and hydraulic rate (HR) affect the efficiency of PPCPs removal (Sharif et al. 2014). A study done by Chen et al. (2015) showed that by utilizing integrated CWs, antibiotics can be removed from domestic wastewater. The rate of removal of the antibiotics was found to be 78–100%. More than 70% of the antibiotic compounds such as cotinine, nadolol, ciprofloxacin HCl, and enrofloxacin were efficiently removed; however, only 20–50% of the compounds were removed when it comes to persistent PPCPs such as salinomycin, monensin, and narasin. Further research should be conducted to evaluate the potential of these CWs to treat PPCPs in secondary wastewater treatment plants.

7.4.2.3 Microbial Cultures

Recent researches have shown that microbial cultures of pure strains collected from sediments and activated sludge after secondary treatment of wastewater can be effectively used for removing PPCPs such as sulfamethoxazole (Reis et al. 2014; Jiang et al. 2013), iopromide (Liu et al. 2013), ibuprofen (Almeida et al. 2013), paracetamol (De Gusseme et al. 2011), diclofenac (Hata et al. 2010), triclosan (Zhou et al. 2014), and carbamazepine (Santos et al. 2012). Reis et al. (2014) had shown that activated sludge harbors *Achromobacter denitrificans*, and when pure culture of this strain was used, it was able to effectively remove PPCPs such as sulfamethoxazole and other sulfonamides. Other studies have shown that cultures of *Delftia tsuruhatensis*, *Pseudomonas aeruginosa*, and *Stenotrophomonas* can effectively remove paracetamol. These microorganisms were not only capable of degrading the PPCPs, but they also used them as a carbon source for growth and survival (Almeida et al. 2013; De Gusseme et al. 2011). Currently extensive researches are being conducted on the usage of mixed microbial culture for removal and treatment of PPCPs from wastewater in WWTPs (Khunjar et al. 2011).

7.4.3 Anaerobic Removal Technologies

7.4.3.1 Bench-Scale Upflow Anaerobic Sludge Blanket (UASB)

A study conducted by Sponza and Demirden (2007) using UASB reactor in combination with continuous stirred tank reactor (CSTR) showed that PPCP such as sulfonamide (sulfamerazine) was removed effectively with 97% removal rate. Another study performed by Carballa et al. (2006) in mesophilic anaerobic conditions effectively removed ibuprofen and naproxen with a removal rate of 40% and 87%, respectively. For chemically alike compounds, removal rate of even more than 90% has also been achieved (Samaras et al. 2013). This technique is a bit superior when compared with aerobic processes when factors such as power input, generation of biogas, small area of installation, and cost-effectiveness are considered. But certain studies have also showed that this technique is not that efficient for removal of persistent PPCPs because of their diverse and complicated chemical composition (Deegan et al. 2011).

7.4.3.2 Upflow Anaerobic Stage Reactors (UASRs)

Chelliapan et al. (2006) conducted a research to study the extraction process of PPCPs from industrial wastewater utilizing UASRs and showed that the process is effective in removing high amount of PPCPs. In a different study conducted by Oktem et al. (2008) by combining both UASR and anaerobic filter technology, significant amount of COD was removed from wastewater containing high organic load. When thermophilic temperature was maintained in a study conducted by Sreekanth et al. (2009), it was reported that both COD and BOD were removed from organic load of 9 kg at a removal rate of 65–75% and 80–94%, respectively. But the study also revealed that PPCPs such as carbamazepine were not effectively removed by using UASR. In another work conducted by Carballa et al. (2006), anaerobic microbes from sewage sludge were used to remove PPCPs. While many of the compounds were effectively removed, iopromide and carbamazepine were found to be persistent.

7.5 Future Prospects and Conclusion

Currently since there are no legal restrictions on maximum permissible limits for the disposal of PPCPs in the environment, the amount of these compounds is rapidly building up in the environment. Although conventional treatment methods such as physical and chemical techniques are regularly used to degrade and remove PPCPs, it comes with some drawbacks such as they are not so eco-friendly and their cost of maintenance is very high. As many of these PPCPs are new emergent, knowledge about their fate, behavior, impact on the environment, and methods to treat them are very limited. So, future research should focus on improving the biological treatment methods by improving their degradation ability, lowering their power consumption, and reducing the release of secondary pollution.

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