A BRIEF REVIEW OF TREATMENT METHODS FOR CERTAIN EMERGING CONTAMINANTS IN DOMESTIC AND INDUSTRIAL EFFLUENTS

Abstract

Over the past few decades, there has been a significant surge in industrial activity driven by the ever-increasing demands of a growing global population. This exponential growth has resulted in the synthesis and subsequent discharge of a wide range of novel and complex emerging contaminants into the environment. These contaminants pose a significant threat due to their persistent and recalcitrant nature, making them resistant to degradation and removal by traditional wastewater treatment methods. The presence of these emerging contaminants in receiving waters serves as a clear indication of their ability to escape the confines of conventional treatment plants. This escape can be attributed to their unique and complex chemical compositions, which challenge the efficacy of existing treatment processes. Consequently, these contaminants have the potential to accumulate in the environment, disrupting ecosystems and posing risks to human health. Addressing this complex challenge requires the development of advanced treatment technologies capable of effectively removing these emerging contaminants from wastewater streams. Extensive research and innovation have led to the emergence of various promising approaches, including advanced oxidation processes, membrane filtration, and activated carbon adsorption, among others. These technologies aim to target and degrade the recalcitrant pollutants, ensuring their removal from wastewater before it is discharged into the environment. Understanding the nature and behavior of these emerging contaminants is crucial in designing tailored treatment strategies.

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Researchers and scientists have made significant efforts to identify and analyze specific emerging contaminants, such as pharmaceuticals, personal care products, endocrine disruptors, and microplastics, among others. By studying their properties, sources, and fate in the environment, it becomes possible to develop treatment methods that effectively mitigate their adverse effects. This article provides an overview of selected emerging contaminants and explores the various advanced wastewater treatment technologies that have been developed for their removal. By addressing this critical issue, we can safeguard human and environmental health, protect our water resources, and pave the way for a more sustainable and resilient future.

Keywords: Wastewater; treatment technologies; emerging contaminants; health; environment

I. INTRODUCTION

Rising population and concomitant industrialization resultin the generation of huge quantities of wastewater especially from industrial sectors such as sugar, paper and pulp, food processing, distilleries, dairies, tanneries, slaughterhouses, poultries, and other agricultural activities. The endless rise in the demands of the growing population has stimulated the development of increasingly innovative consumer products. Excessive consumer-oriented research and development activities are producing goods of comfort but at the same time are resulting in widespread contamination of the finite natural resources. The race for the development of innovative products has led to the emergence of new kinds of contaminants, the so-called contaminants of emerging concern (CEC) that include pharmaceuticals, hormones, personal care products, surfactants, microplastics, plasticizers, flame retardants, and nanoparticles. These CEC have been found to have adverse impacts on humans as well as their environment. For instance, pharmaceuticals are typically designed to be bioactive to treat human and animal ailments. However, when they escape treatment plants and are released into the environment, they have the potential to cause risks to non-target organisms. Conventional wastewater treatment plants are inadequate to treat some of these challenging contaminants and therefore, advanced wastewater treatment strategies are necessary. Advanced wastewater purification is becoming increasingly necessary as society mitigates the impacts of increased population, urbanization, industrialization, and the depletion of potable water [1].Advanced technologies can improve wastewater quality to a much greater extent than is possible through conventional treatment thereby fulfilling the goal of resource recovery/conservation [1].

Wastewater can be defined as the transport of used water that is typically discharged from residential areas, institutions, commercial activities, or factories and is directed to treatment plants by a scientifically designed and engineered network of pipes. The key objectives of wastewater treatment are the removal of pollutants and the destruction of pathogens for the protection and preservation of our environment and human health. According to the American Institute of Chemical Engineers (AIChE), advanced wastewater treatment is any process that can reduce impurities in wastewater below what is attainable through conventional secondary or biological treatment [2]. Advanced wastewater treatment solutions have attracted global attention as individuals, communities, and industries identify ways to reduce CECs and keep essential natural resources available and suitable for use. In general, advanced wastewater treatment can be classified into biological process, physicochemical process, or a combination of both. The biological-based treatment removes nutrient pollutants such as nitrogen and phosphorus that otherwise result in widespread eutrophication. Some other types of advanced WWT technologies include sand filtration, ozone treatment, ultraviolet (UV) for disinfection of pathogenic microorganisms, membrane bioreactor (MBR), advanced oxidation processes (AOP), UV in combination with advanced oxidation, nanotechnology, and automatic variable filtration [3].

A typical wastewater treatment plant (WWTP) consists of different treatment methods that can be classified into physical, mechanical, biological, and chemical. Physical methods generally contain and control the flow of wastewater and promote contaminant removal. Mechanical methods include simple and complex machines. As the name suggests, the biological methods comprise of microorganisms that act on organic pollutants. Finally, to increase the efficiency of the process operations at various stages of the wastewater treatment the chemical treatment methods are applied. Conventional WWTPs are effective at removing many contaminants including nutrients, biodegradable organics, and pathogens from wastewater. However, such WWTPs are not designed to remove many of the emerging contaminants, persistent organic pollutants (POPs) such as PBDEs [4].To address this important issue, the conventional WWTPs are modified to integrate one or more advanced WWT technologies depending on the nature of emerging contaminant(s) that needs to be removed. In this paper, we discuss the advantages and disadvantages of some of the new and emerging advanced wastewater treatment technologies for the removal of CECs. The Central Pollution Control Board (CPCB) of India sets allowable limits of various parameters on effluents discharged from a wastewater treatment plant to ensure the quality of our natural water resources. There are various considerations while establishing the thresholds depending on for example the size and nature of the receiving water body. Traditionally, these limits are set on typical parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), pH, total phosphorus (TP), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), E. coli, and so on. Whereas there are established standards for these parameters there are none whatsoever for the emerging contaminants except for pharmaceuticals in some jurisdictions such as US FDA and EU that have set guidelines for their environmental concentrations at 1 and 0.01 μg/L, respectively. Some of the CECs tend to be present in very low concentrations and as a result, these CECs tend to remain unregulated and frequently get discharged unassessed into natural water bodies causing unnecessary exposure to flora, fauna, and human beings. Many of these CECs have potential adverse effects on humans and the environment. In a densely populated country such as India, the key focus should be wastewater management otherwise it will tend to have a negative impact on the health of its population. Regardless of the support from the government and private sector the scale of the problem of untreated wastewater polluting natural resources remains enormous. For instance, it is estimated that less than 20% of domestic and 60% of industrial wastewater is treated [5]. Whereas the large metropolitan cities are reported to treat approximately30% of their wastewater the smaller cities can treat only about4% [5]. Given the potential adverse impacts of untreated effluents, the focus over the past decades has been on modernizing the existing wastewater treatment processes with advanced technologies. Such advanced treatment technologiestend to reduce pollutants in effluents in addition tofacilitating water recycling initiatives thereby minimizing the unavoidable loss of usable water. Water pollution has further aggravated the already precarious situation of water scarcity in several parts of the world. Inadequate management of water resources and unsustainable environmental practices are pushing countries including India into a drinking water crisis; this may subsequently lead toa lack of access to potable water for its majority population.

II. BACKGROUND

We have reviewed open literature and scientific reports from different sources to extract information on some of the emerging contaminants and the different wastewater treatment technologies for their removal. Advanced techniques for the removal of pharmaceuticals and pharmaceutical products from ground and surface waters have been extensively studied [6,7].It has been reported that many organic micropollutants e.g. pharmaceuticals and pesticides that are present in wastewater are poorly removed in conventional wastewater treatment plants and as a result, these escape to reach natural waters where consumers receive unintended exposure to their non-therapeutic concentrations [8].

Several studies on the removal of pharmaceuticals from water and wastewater have been reported [9-12]. Hosseinnia et al.(2006) analyzedthe ability of rice husk as a low-cost adsorbent for the removal of ionic and non ionic surfactants from waste waters [9]. Ternes et al. (2002)reported that ozonation and filtration with granular activated carbon (GAC) were very effective in removing polar pharmaceuticals [11].One study reported that since it is challenging for a lone technology to completely remove pharmaceuticals from wastewaters hence, it suggested using conventional treatment methods along with membrane reactors and advanced post treatment methods as a hybrid wastewater treatment technology [12].Commonly used plasticizers e.g.bis (2-ethylhexyl) phthalate (DEHP), bis (2-ethylhexyl) terephthalate (DEHTP), and bis (2-ethylhexyl) adipate (DEHA) are reported to be present in significant quantities in influents, process streams, treated effluent and solid residues ina sewage treatment plant of a metropolitan city [13]. The results reported by these authors indicated the inability of the treatment plant to eliminate plasticizers from the aqueous phase because a significant portion was ending up in solid residues. Shanmugana than et al. (2018) investigated the presence of halogenated (both chlorinated and brominated) flame retardants e.g., (poly) brominated diphenyl ethers (PBDEs)at the North American wastewater treatment plants [14].In a WWTP in Albany, NY, Kim etal. (2017) examined the presence and fate of organophosphate flame retardants (OPFRs) and plasticizers [15]. Investigations on the presence of various personal care products (PCPs) such as moisturizers, hair colors, deodorants, toothpaste [16], sunscreen [17], disinfectants, fragrances, and perfumes [18] in wastewaters has been reported in the literature. Removal of nanoparticles has been reported [19-21]. In their publication, Liu et al.(2021),reviewed the characteristics and removal of microplastics in nearly forty wastewater treatment plants covering more than ten countries [22]. The most effective microplastics removal was achieved using filter-based treatment technologies. Another review highlighted that microplastics are mainly removed through adhesion, sedimentation, and filtration with average removal efficiency < 90% and how it is affected by the choice of the wastewater treatment process and their properties e.g., size, density, and morphology [23].

III. CONTAMINANTS OF EMERGING CONCERN

Following are some of the key contaminants of emerging concern that we have taken as an example to illustrate and briefly discuss some of the new and advanced wastewater treatment technologies for their removal. In addition, we have also mentioned the adverse effects caused due to undue exposure of the environment and humans to these types of contaminants.

1. **Pharmaceuticals:** Pharmaceuticals including veterinary drugs are emerging as one of the major sources of pollution in the environment. Typically known to save lives and treat diseases their presence in drinking water is now linked to potential adverse effects on aquatic fauna and humans [24]. Although most drugs tend to degrade in the environment their continual addition to natural waters in small but significant amounts leads to chronic exposure to flora and fauna. Effluent discharge from hospitals,for example, contains enough antibiotics, disinfectants, and other treatment drugs. Over five hundred pharmaceutical compounds have been found globally in influent, effluent, and sludge from wastewater treatment plants [25].The sensitivity of analytical instruments has increased multi-fold in recent times leading to the determination of thousands of pharmaceutical drugs present at micro and nanogram levels in natural waters.

Conventional wastewater treatment plants have very low removal efficiencies for drugs as these are generally designed for organic loads in the milligram levels. It is well-known that chemicals such as pharmaceutical drugs exert endocrine disruption effects on aquatic organisms and humans upon exposure at very low (non-therapeutic) concentrations.One of the ways to remove organic chemicals from the aqueous phase is by adsorption using activated carbon. Compared to ozone the advanced oxidation treatment methodologies provide only an incremental improvement in removal efficiency. According to Patel et al. (2019), low-pressure microfiltration (MF) and ultrafiltration (UF) membranes have pore sizes that are not well suited for the retention of pharmaceuticals and MF or UF did not exhibit any additional removal of pharmaceuticalswhen used in the membrane bioreactor (MBR) process [24]. However, they found high-pressure membranes more effective in the separation of many pharmaceuticals from water when used in reverse osmosis (RO) and nanofiltration (NF).They also suggested that natural processes, including soil-aquifer treatment (SAT) and riverbank filtration (RBF) that perform like a slow-sand filter with extended retention times,could be used as additional treatment steps for either wastewater reclamation or as a drinking water pre-treatment. The authors found these processesto be very effective at reducing a wide range of trace organic chemicals including pharmaceuticals by adsorption and biotransformation. When methods such as reverse osmosis (RO)and micro-, nano-, and ultrafiltration were tested for the elimination of pharmaceutical drugs from water and wastewater, RO and nanofiltration methods were found to successfully remove>85% of many non-steroidal anti-inflammatory drugs (NSAID) from groundwater [26].Some drugs were removed with greater than 99% efficiency using electrodialysis [27]. These physical separations can be amplified by using electrochemical advanced oxidation in combination to effectively eliminate pharmaceuticals [28].In relative terms, nanofiltration and reverse osmosis were able to achieve higher levels of removal of pharmaceuticals compared to micro and ultrafiltration techniques [29].For instance, nanofiltration was reported to achieve greater than 90% removal levels from water and wastewaters, and reverse osmosis was able to remove more than 90% of pharmaceuticals that had specific physicochemical properties that made those chemicals amenable to that technique [10,30]. Photochemical AOPs, ozone-based AOPs (O_3/H_2O_2, O_3/UV), and photo-Fenton processes were typically found to be more effective than ozonation alone.Akhil et al. (2021) discussed a variety of remediation methods for the removal of antibiotics and found that about 95 to 98% removal efficiency was achieved using treatment methods such as nanofilters, reverse osmosis, sono-/photo-catalysis and ozonation [31]. A recent study reported about 94% removal of emerging pharmaceuticals such as metronidazole, chloramphenicol and sulfonamide using a treatment method based on electrochemical and adsorption [32].

2. **Hormones:** Estrogen and progestin are some of the natural hormones that play a key role in the proper functioning of the female reproductive system, whereas androgens regulate the male sex organs [33]. Many types of contraceptives, hormone therapies, and veterinary drugscontain natural and synthetic hormones that are designed to interfere with the natural hormonal system of the body. However, their release into the environment especially aquatic poses a threat to organisms and their reproduction systems causing adverse effects. When humans get exposed to such hormones e.g. estrogens, through food/drinking water they suffer unintended adverse effects such as the increased risk of breast cancer in females [34] and prostate cancer in men [35]. Continuous exposure to endocrine-disrupting chemicals even at low concentrations brings risk to pregnant

women, fetuses, and infants. For instance, exposure to endocrine-disrupting chemicals has been associated with various disorders including reproductive and endocrine (e.g. breast or prostate cancer, infertility, diabetes, early puberty), immune/autoimmune, cardiopulmonary (e.g. diseases of heart, asthma), and nervous systems (e.g. Alzheimer, Parkinson and ADHD (attention deficit hyperactivity disorder)) [33]. Ultrasound is efficient in reducing the estrogen (E1) and 17 beta-estradiol (E2) from municipal wastewater [36]. They studied the effects of power, frequency, exposure time, and pH on hormonal reduction efficiency. Using electrochemiluminescence to measure the residual concentration of E1 and E2 hormones in reactor effluent they reported the efficiency of ultrasound in reducing their concentration in the range of 85–96%. In addition to low energy consumption, the ultrasound method also prevented the formation of harmful by-products.

3. **Personal care products (PCPs):** People use a variety of personal care products for different purposes ranging from cleaning (toothpaste, shampoos), protection (sunscreens), and healthcare products to keep oneself in good condition (skin creams, moisturizers). After their use, a significant amount of these products go down the drain and enter the environment via the ‘‘wastewater– sewage plant—receiving water’’ route thereby polluting the aquatic environment. A significant amount of these PCPscome off the body during say bathing and get added to the domestic wastewater. Thus, a sizeable number of PCPs are consumed daily and washed off into domestic wastes therefore, their presence in different environmental compartments (water, air, soil) is no surprise. For example, in Germany alone, approximately 790,000 tons of PCPs are produced annually [37]. PCPs include numerous chemicals such as fatty alcohols, glycerol esters, paraffins, and waxes that encompass a wide range of physicochemical properties. Their environmental fate depends largely on their physicochemical properties (water solubility, adsorption, volatility, biodegradability). Biodegradability in turn depends on the nature of microorganisms present in sewage treatment plants, surface waters, and soils. Dhodapkar and Gandhi (2019) extensively discussed the classification and possible environmental sources of personal care products, their fate, pathways, persistence, and ecotoxicological profile focusing on the aquatic environment [38]. They also described the efficiency and limitations of the existing conventional/advanced water/wastewater treatment systems in the removal of these compounds. PCPs enter the environment through various routes like absorption by the body during therapeutic use followed by excretion and discharge into sewage systems [39]. PCP manufacturing facilities tend to discharge polluted effluents directly into natural waters [39]. Fick et al. (2019) reported that adsorption generally facilitates the transportation of PCPs through water or sludge [40]. For efficient mineralization of recalcitrant and refractory species advanced oxidation processes (AOPs) have shown great promise. The combination of ionizing irradiation with other methods such as H_2O_2, ozonation, and TiO_2 nanoparticles has been indicated not only to be economical but alsoto improve the degradation efficacy of PCPs in an aqueous solution.

4. **Surfactants:** One of the emerging contaminants belongs to the class of chemicals known as surfactants. These are generally found in cleaning products (detergents) and cosmetic rinse-off products,hence, are present in domestic wastewaters. Surfactants function by detaching soils from solid surfaces like textiles and human hair/skin. Since these cleaning products are in use regularly,they are found in the natural waters and have been reported to cause adverse effects on human health and the environment [41]. Generally, it has been

observed that a large majority of surfactants used in PCPs are readily biodegradable when released into the environment. However, chronic exposure even at low concentrations to aquatic fauna may have potentially toxic effects on them leading to adverse effects on their growth and reproduction [39].Numerous negative effects that surfactants have on wildlife and, in high concentrations, on humans have been presented [42,43]. For instance, Linear alkylbenzene sulfonate (LAS) causes irritation ofthe skin and problems to the respiratory system [44]. Moreover, in 2017, another surfactant i.e. Perfluorooctanoic Acid (PFOA), used in industrial processing, has been included by the IARC in the list of possible carcinogenic compounds - class 2B and considered potentially toxic for human reproduction [45]. The removal efficiency especially of non-ionic surfactants (TAS) and anionic surfactants (MBAS) from real laundry wastewater using a thermophilic aerobic membrane reactor (TAMR), nanofiltration (NF) and adsorption on activated carbon (AC) has been investigated [46]. It was reported that the optimal combination of processes for the removal of TAS and MBAS for instance, TAMR + NF + AC sequence allowed almost complete removal of TAS (> 95%) and high removal of MBAS (> 76%) although at a higher cost [47]. Another study reported the pH-dependent ability of rice husk adsorbent to remove up to 97% of ionic and non-ionic surfactants in wastewater [9].

5. **Microplastics:** Plastic fragments that are ≤5 mm in size fall under the category of microplastics(MP) [48]. It has been reported that the annual global production of plastics tops 300 mega tons [49]. Consequently, microplastics are found ubiquitously in our environment exposing flora, fauna, and humans to it and the study of their potential adverse effectshas become essential [50,51]. MPs enter the environmental compartments via food packaging, textiles, tires, and other plastic materials. Plasticizer additives have long been associated with endocrine-disrupting properties hence, there is a growing concern over the potential adverse effects of MPs on the environment and human health [52]. Over 114 aquatic species have been reported to contain traces ofmicroplastics. As such, the MPs are recalcitrantand are a source of air pollution, occurring in dust and airborne fibrous particles. Boucher and Friot (2017) identified and evaluated seven major sources of primary microplastics such astires, synthetic textiles, marine coatings, road markings, personal care products, plastic pellets, and city dust [50]. Some of the key causes of MPs are bottled drinks, seafood, and food packaging. A recent review highlighted the evidence for the trophic transfer of microplastics and contaminants within marine food webs [53]. A variety of toxic responses in the form of oxidative stress, inflammatory lesions, and increased uptake or translocation are associated with exposure to MPs and some of them reported effects such as metabolic disturbances, neurotoxicity, and increased cancer risk. Exposure of MPs via oral and inhalation routes has been reported to cause adverse effects e.g. particle toxicity that leads to oxidative stress, secretion of cytokines, cellular damage, inflammatory and immune reactions.MPs tend to travel through waterways finally ending up in the ecosystems that shelter a range of marine life (algae, planktons, turtles, fish).Studies investigating technologies for the removal of MPs from effluents found that filter-based treatment technologies were among the best [22]. The authors reported that fibers and MPs particle size ranging from 0.5–5 mm were easily separated by primary settling whereas those such aspolyethylene and small-particle size MPs (<0.5 mm) were easily trapped by bacteria in the activated sludge of the bioreactor system. They also described how the advanced oxidation process affected the physicochemical properties by breaking and making new bonds in the MPs

molecular structure and how interactions between MPs and the membrane pores and surface using membrane filtration technology-facilitated easy adsorption of MPs onto the membrane surface. In a large study encompassing 21 sites, microplastic removal rates were reported to be around 88-94% employing secondary and tertiary wastewater treatment and about 72% by preliminary and primary treatment [54].

6. **Plasticizers:** Plasticizers are colorless and odorless esterse.g. phthalates, that increase the elasticity of a material such as polyvinylchloride (PVC). The key role of plasticizersis to make the PVC soft, flexible and bendable. Plasticizers confer durability to PVC increasing its usable,high-performance life close to 50 years. More than 90% of the global plasticizer production is dominated by phthalate esterse.g. Di-2-ethylhexyl phthalate (DEHP) alone accounts for about 50% of the production [55,56]. These esters are ubiquitous in the sense that they are used in a wide range of consumer products e.g.children'stoys, cosmetics, food packaging materials, medical equipment can linings, etc.It is,therefore, no surprise that DEHP is amongst the most abundant organic contaminants in urban wastewaters and sewage and has been classified as a priority organic pollutant [57]. Biodegradation of plasticizers e.g. DEHP and di-ethylhexyl adipate (DEHA) were reported to generate toxic metabolites such as 2-ethyl hexanoic acid, 2-ethyl hexanol, and 2-ethyl hexanolthathave the potential to cause adverse environmental and human health impacts upon exposure [58]. Phthalates are known endocrine disruptors and are associated with decreased fecundity, pregnancy loss, and adverse obstetrical outcomes [59]. An ozonation-based study reported how varying the pH from 3 to 10 resulted in the removal of bisphenols in the range of 6-100% [60].One of the effective treatment technologies for the removal of plasticizers isozone microbubble oxidation. Another study reported bisphenol removal efficiencies greater than 99% from aquatic environments by application of a novel UV/SPS/H_2O_2/Cu system [61].

7. **Flame retardants:** Flame retardants (FRs) are chemicals that are added to household and consumer products to prevent fire hazards. These chemicals have very low water solubility and tend to be hydrophobic. Owing to their low mobility in the environment the FRs tend to accumulate in wastewater, sewage sludge, soils, and in riverbeds [62]. These authors evaluated sewage treatment methods and their results indicated that using the biological N and P elimination treatment method can contribute to the decrease of flame-retardant concentrations in sludge. Due to the potential for the bioaccumulation of this class of chemicals from sludge-treated soils in food chains, thereby contributing to wildlife and human exposure to these chemicals.Lee and Kim (2017) investigated the occurrence and fate of 19 congeners of polybrominated diphenyl ethers (PBDEs) in two WWTPs in Korea [63]. The authors reported that PBDEs were found to exist mostly in the particulate phase of wastewater, which rendered sedimentation efficient for the removal of PBDEs that ended up in the sludge and only 2% found their way into final discharge.New methods of bioremediation such as the use of spent mushroom compost that shows high TBBPA removal efficiency should be considered.Another type of FRs is the organophosphate esters (OPEs) which are currently used in a wide range of consumer products as flame retardants [64]. OPEs are also used as antifoaming stabilizers in industrial processes and as additives in paints, glues, lubricants, lacquers, floor polishes, and hydraulic fluids. The presence of OPFRs has been reported in indoor air, house dust, and surface waters [65]. Studies conducted byZeng et al. (2015)revealed that wastewater treatment plants were efficient in the removal of non-chlorinated OPs but not the

chlorinated ones due to their resistance to current WW treatment technologies [66]. Pang et al. (2016) compared wastewater treatment processes e.g. anoxic–oxic (AO) and University of Cape Town (UCT) processes to investigate the removal efficiency of OPs and their results revealed better removal efficiency by UCT process compared to that of the AO process [67].

8. **Nanoparticles:** The nanotechnology industry has seen rapid growth in recent years. This has led to increased production and consumption of nanomaterials and engineered nanoparticles (NP) in common household products e.g. cosmetics, clothing, sun-creams, and food packaging. These NP tend to enhance their existing properties and/or add new benefits such as an improved texture or a longer shelf-life. For instance, silver nanoparticles are relatively economical and possess strong anti-microbial properties. Like every other product, these nanoparticles also find their way into the environment via domestic sewage. NPs tend to penetrate the food chain by way of accumulating in flora and fauna that get exposed to it.Some important emerging nanomaterials and their character are described here in brief. Carbon-based nanomaterials such asFullerenes (Carbon 60) Buckyballs (Carbon 20, Carbon 70), carbon nanotubes; nanodiamonds, and nanowiresare stable and less reactive and find applications in biomedicals, super-capacitors, sensors, and photovoltaics [68,69].Metal Oxides nanomaterialslike Titanium dioxide (TiO_2), zinc oxide (ZnO), cerium oxide (CeO_2)have photocatalytic properties, and ultraviolet (UV) absorbing ability and are therefore widely used insunscreens. Nano-TiO_2 and nanoZnOare also used in photocatalysis, pigments, drug release, medical diagnostics, UV absorber in sunscreen, diesel fuel additive, and remediation. Similarly, nano silver (10 to 200 nm)ismade up of many atoms of silver in the form of silver ions [69,70]. Due to their high surface reactivity and strong antimicrobial properties, they are used in a wide variety of commercial products, medical applications, water purification, andantimicrobials. Composite NMs made with two different NMs or NMs combined with nanosized clay and with synthetic polymers or resins are found in novel electrical, magnetic, mechanical, thermal, or imaging features [68,71]. Some studies have revealed that due to their small size the NMs tend to have the potential to pass through both the blood-brain barrier (BBB) and the placenta. For example, a recent study showed that nano anatase TiO_2 may pass the BBB of mice when injected with high doses [72].NMs e.g. TiO_2 and ZnO present in sunscreens may cause dermal exposure depending on the properties of the sunscreen and the condition of the skin. For instance, as opposed to a healthy skin where the epidermis is likely to prevent NM migration to the dermis a damaged skin,on the other hand, may allow NMs to penetrate the dermis and reach regional lymph nodes as suggested by quantum dots [73,74].Some NMs contain metals that have the potential to cause toxicity to cells by releasing harmful trace elements or chemical ions. For instance, silver NMs may release silver ions that can interact with proteins and inactivate vital enzymes. Heavy metals, for example, cadmium, and lead that are used in quantum dots are known to be reproductive and developmental toxicants [75].Nevertheless, owing to factors such as the concentration of metal in the source, the estimates of releases of metals from NMs are rather crude [69,70].Due to their ability to eliminate bad bacteria the silver nanoparticles (AgNP) are frequently used in consumer products and as a result find their way into domestic sewage, WWTP,s and subsequently get discharged into the natural waters [76,77]. However, their toxic nature also ends up killing the good bacterial species present in the WWTP [78]. The AgNPseems to stop the reproduction of the good bacterial species by generating distinctive chemicals such as the

reactive oxygen species (ROS) [79]. This necessitates another treatment for the removal ofAgNPs.Syafiuddin and coworkers (2019) investigated the performance of activated carbon derived from agricultural waste for the removal of AgNPs from water. They were able to tap the electrostatic forces e.g. van der Waals and London dispersion forces present in activated carbon to successfully adsorb and remove AgNPfrom waters [80].

For the above-referred set of eight CECs, we found that there are various advanced treatment technologies available for their effective removal. Figure 1 illustrates the nature of advanced purification technologies that are applied to each of contaminants of emerging concern and their removal efficiency.

IV. CONCLUSION

The ever-growing population and their endless demands have been exerting tremendous pressure on industries to continuously innovate consumer products. This has resulted in the release of new kinds of pollutants better known as contaminants of emerging concern (CEC) e.g. pharmaceuticals, hormones, personal care products, surfactants, microplastics, plasticizers, flame retardants, and nanoparticles. The presence of the CECs in natural waters and the environment unnecessarily exposes flora, fauna, and human beings to them causing adverse effects. Since conventional treatment methods fail to remove these CECs the key challenge was to develop newer advanced treatment technologies to efficiently prevent their escape into the environment. In this chapter, we have briefly described some of the key CECs and the different types of advanced wastewater treatment techniques and their removal efficiencies (Figure 1).

Activated carbon adsorption (ACA) seems to be the common method of choice when it comes to the removal of different CECs both from the point of view of ease of application as well as the low costs associated with its implementation. Nanoparticles and some of the pharmaceuticals have been the most challenging CECs and the existing treatment methods are not yet able to remove them completely. As seen in Figure 1, the lowest removal rates (lower end numbers) are observed for the pharmaceuticals and PCPs which are also one of those contaminants that cause endocrine disruption effects to humans exposed to them. The maximum removal efficiency of up to 99.9% was reported for microplastics by using FBTT and MBR techniques. In real life situation, a wastewater stream would tend to contain most of these emerging pollutants together as a mixture. Therefore, the selection of a specific WWT technology or a proper combination of one or more advanced WWT would be crucial to remove the CECs.

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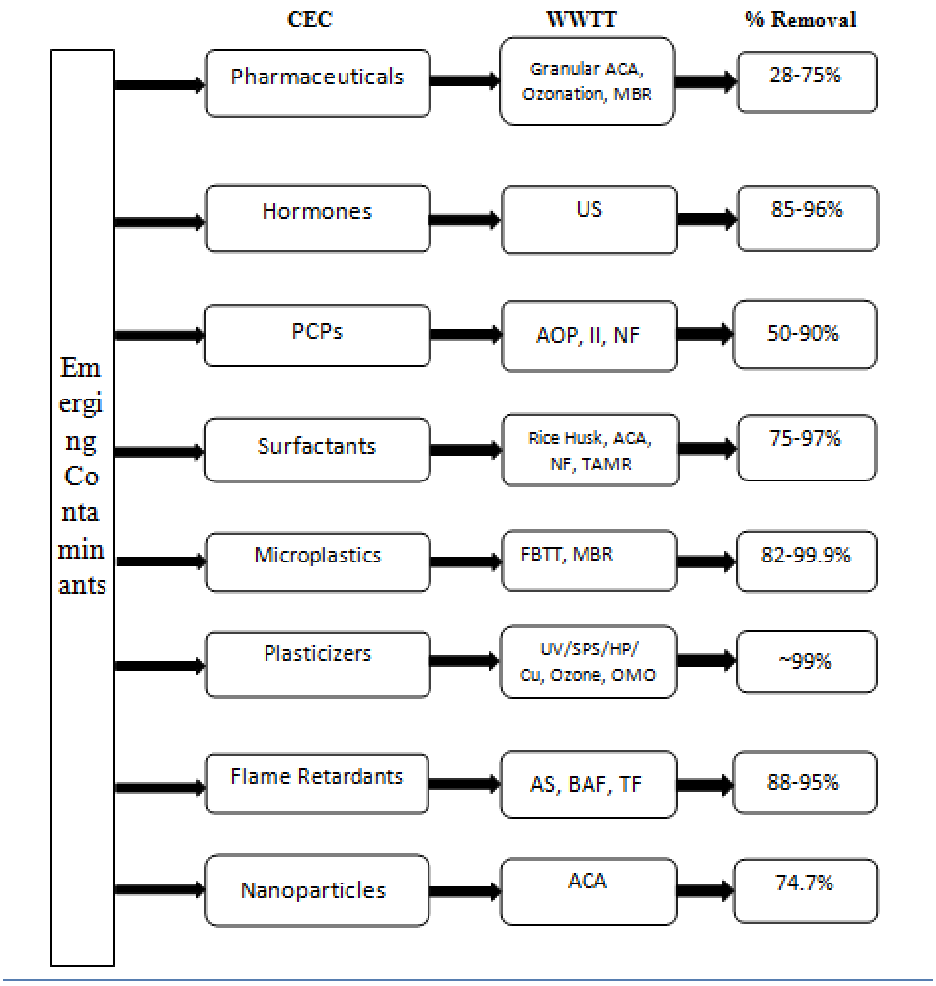

Figure 1: Emerging contaminants and removal efficiencies using advanced technologies

CEC: Contaminants of emerging concern
ACA: Activated carbon adsorption
MBR: Membrane Bio-Reactor
US: Ultrasound
AOP: Advanced oxidation processes
II: Ionizing Irradiation
NF: Nanofiltration
TAMR: Thermophilic aerobic membrane reactor
FBTT: Filter-based treatment technologies
UV: Ultraviolet
SPS: Sodium persulfate
HP: Hydrogen peroxide
Cu: Copper
OMO: Ozone microbubble oxidation
AS: Activated sludge
BAF: Biological active filter
TF: Trickling filter