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# REMOVAL OF MICRO-POLLUTANTS USING GREEN SYNTHESIZED NANO IRON PARTICLES BY THE ADVANCED OXIDATION PROCESS

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**ABSTRACT**

**Advanced oxidation is a process of removal of pollutants and leads to the combustionof organic and inorganic pollutants or chemical components in the environment especially in water sources. Even though there are different effective processes, many studies have indicated that advanced oxidation process (AOPs) is a more reliable and sustainable method. Therefore, this paper explored the efficacy in the treatment and degradation of micro-pollutants especially using green synthesised iron nanoparticles. Micro-pollutants are mainly found in water bodies as a result of the anthropogenic activities, however, the chemical oxidation methods of AOPs has been found to be effective. The use of green synthesised nanoparticles are sustainable and more efficient than traditional AOPs. Therefore, based on the current findings the study has recommended the use of hybrid green synthesised Iron (Fe)nanoparticles for future applications in mass degradations of micro-pollutants. Another important finding was that green synthesized nanoparticles degrade pollutants that cannot be done by traditional methods of AOPs. Evidently, there is a need to conduct further research on hybrid green synthesised Iron (Fe)nanoparticles and AOPs towards degradations of micro-pollutants. Future scope of the current study has also been presented at the end of the study.**

**KEY WORDS :** Advanced oxidation process, Iron nanoparticles, Micro-pollutants, Green synthesis

## INTRODUCTION

The issue of micro-pollutants in surfaces like air, water and solid has been a growing concern for many environmentalists and majority of these micro-pollutants are sourced from industrial effluents like pharmaceutical companies, chemical manufacturing companies, or leaching from dumps and spillage or runoffs from agricultural lands and others (Warner *et al.,* 2019). These results in multiple issues to the environment causing pollution, diseases and contaminations in animals as well as humans and contamination of agricultural produces and may even infect aquatic organisms (Khan *et al*., 2018). Researches have termed them as "anthropogenic in nature" or caused by human activities usually have no natural background because most of these micro-pollutants are synthetic chemicals in nature. Numerous organic and inorganic chemicals such as chloride, tritium, nitrate, chlorine, bromide, coprostanol, artificial sweeteners like cyclamate and acesulfame, and others have been discovered from pesticides, pharmaceuticals and personal care products caused by human actions(Khazaei *et al*., 2017; Katz *et al*., 2011; Murtaugh and Bunch 1967; Zirlewagen *et al*., 2016).

The main issue with respect to treating these micro-pollutants are that they are unavailable in the nature. As a result, it is very different for environmentalists and researchers to use effective detecting technologies or methods to treat them. However, over the years various processes has been developed and one of the most common methods used in removal of micro-pollutants is Wastewater Treatment Plants (WWTPs) (Pomies *et al*., 2013).

Similarly, there are methods like coagulation–flocculation (Reungoat *et al.*, 2010), advanced oxidation processes (AOPs) (Reungoat *et al*., 2010), membrane processes and membrane bioreactor (Hai *et al.*, 2011), activated carbon adsorption (Zietzschmann *et al.*, 2014), different nano-particles (Hou *et al.*, 2014; Plakas *et al.*, 2016) and more recently use of green synthesised nanoparticles and methods (Hassan *et al.*, 2018; Devatha *et al.*, 2016). Green methods of micro-pollutant treatment are adopted as they are easier to extract from natural sources and are more effective than traditional methods of treatment. Green methods are nothing but the materials or components used in the treatment are sourced from natural extracts like leaves, bio-enzymes, secondary metabolites and others.

Amongst the most commonly used treatment methods AOPs and nano-particles are the most effective techniques (Plakas *et al.*, 2016; Silva *et al.*, 2017; Jinetal., 2012). Activated oxidation processes have mostly used chemicals where the chemicals react with hydroxyl radicals and thereby remove all organic and inorganic pollutants in water and waste water mostly (Deng *et al.*, 2015). Similarly, a few studies have included iron nano-particles or other types of nanoparticles in the treatment of micro-pollutants along with AOPs, usually termed as hybrid AOP's, in the detection and removal of micro-pollutants and in some cases these nano-particles are green synthesised (Bethi *et al.*, 2016; Mansur *et al.*, 2019). Therefore, the current study explores the micro-pollutant removal with the help of hybrid AOP method whereby nano-particles are used and the nano-particles are green synthesised. The objectives of the study are to explore different green sources or extracts for iron nanoparticle in removal of micro-pollutants, the process of removal of micro-pollutants using AOPs and nanoparticles, and the efficacy of iron nanoparticles in removal of micro-pollutants.

**What are micro-pollutants?**

Micro-pollutants are basically pollutants with traces of sources from toxic effluents of industries, chemical effluents from agricultural lands like pesticides, insecticides and others and none the less pollutants from waste burial grounds (Warner *et al.*, 2019). Stamm *et al.*, stated that micro-pollutants as "anthropogenic chemicals that occur in the (aquatic) environment well above a (potential) natural background level due to human activities but with concentrations remaining at trace levels"(Stamm *et al.*, 2016). The main sources of micro-pollutants are from human activities like agriculture, industrial manufacturing chemical spillage in supply water or sewage water, landfill leachate, pharmaceutical company effluents, and many other human created sources or anthropogenic sources. Micro-pollutants are usually inorganic or organic and even biological components like chromium oxide, zinc, cadmium, copper oxides, gram-positive and gram- negative bacteria, hexavalent chromium, acid dyes, chlorophenols, and other metallic ions (Bethi *et al.*, 2016; Alvarez-Ayuso *et al.*, 2003; Cui *et al.*, 2013). These micro-pollutants have much harmful and even life threating impact on all living organisms as well as the environment and therefore, their treatment is very important (Warner *et al.*, 2019; Bethi *et al.*, 2016). The contamination of micro-pollutants will not only impact the biotic components but has a strong impact on the entire ecosystem. For instance, micro-pollutants are found to impact the productivity and yield of agriculture and mutations organisms including humans and death of aquatic organisms (Stamm *et al.*, 2016).

**Advanced oxidation processes and its effectiveness**

Advanced oxidation process (AOPs) is a technique whereby hydroxyl radicals are used because they have high reduction potential that can combust or oxidise many organic and inorganic pollutants or chemical components in mater (Siréset *al.*, 2014). The hydroxyl radicals are basically secondary oxidants produced by hydrogen peroxide or ozone and very low rest concentrations that causes very high reaction against organic compounds. This method helps to accelerate the oxidation and degradation of numerous inorganics as well as organic elements by the combustion process and even degrades elements and chemicals that cannot be treated with conventional treatment methods (Wang *et al.*, 2003; Karimi *et al.*, 2013). The main process that involves in the technique is that hydroxyl radicals convert these chemical compounds into mineral acids or $H_2O$ and/or $CO_2$ (Joseph *et al.*, 2009). There are different methods that are used in AOPs like the use ofsonophotocatalysis (Joseph *et al.*, 2009) or nano-particles (Kamat *et al.*, 2002)and these methods have been found to be very effective than traditional chemical methods of oxidation-based water treatments (Wang *et al.*, 2003).In sonophotocatalysis the oxidation process is supported by ultraviolet radiations, and ultrasonic sound waves resulting in the formation of free radicals and degradation of pollutants. On the other hand, semiconductor nanoparticles are reactive in nature and cause the catalysis of the pollutants by activating oxidation process. However, traditional AOPs are chemical processes that help in aromatic micro-pollutant removal and some of these chemical processes like Fenton and Photo-Fenton are still considered to be very effective. In this chemical reaction, the ferrous and hydrogen peroxide reacts with each other that lead to the formation of hydroxyl radical and the oxidation of the radicals reacts on the pollutant by catalysis of $H_2O_2$ (Hydrogen peroxide) with the help of an iron ion (Atharizade *et al.,* 2015; Du *et al.,* 2011).

$$Fe(III)OH_2+ + uv \rightarrow Fe(II) + {}^{\bullet}OH \quad .. 1$$

**Applications of AOPs**

AOP's are mostly used in waste water treatment, drinking water filtration processes, andtreatment of landfill leachate water or running water from meeting the water bodies. These processes included the use of "ozonation (O3)"(Rosenfeldt *et al.,* 2006), "ozone combined with hydrogen peroxide (O3/ $H_2O_2$)"(Arslan *et al.,* 1999) and "UV irradiation (O3/ UV)" or both ".(O3/H2O2/UV)"(Lucas *et al.,* 2010), "ozone combined with catalysts (O3/ catalysts)"(Choi *et al.,* 2012), "UV/H2O2" (Lucas *et al.,* 2010), "Fenton"(Atharizade *et al.,* 2015), "photo-Fenton processes (Fe2+/$H_2O_2$ and Fe2+/H2O2/ UV)" (Atharizade *et al.,* 2015), "the ultrasonic cavitation process"(Torres *et al.,* 2007) and "photo catalysis"(Joseph *et al.,* 2009) have been effective in treatment of pollutants from waste waters from running into water bodies and filtration units for drinking water. Many studies have reported over 80% treatment for contaminants in waste water like diclofenac using AOP and ozonation (Huber *et al.,* 2005), estradiol and ethinylestradiolusing UV/ chlorine and Chlorine dioxide (ClO2) (Sichel *et al.,* 2011; Jiang *et al.,* 2005), ketoprofen using UV lamp (Szabó *et al.,* 2011) and carbamazepine using UV lamp (Avisar *et al.,* 2010). However, studies have indicated that ozonation process along with AOPs are the most effective methods because they treat almost 100% of all organic and inorganic pollutants in the waste water (Huber *et al.,* 2005; Liu *et al.,* 2019; Renge *et al.,* 2012). Apart from this the use of nano-particles in AOPs has been widely used because of its cost effectiveness than other methods as well as the efficacy of the treatment process is far effective and advanced than ozonation or UV methods (Hou *et al.,* 2014; Nasirian *et al.,* 2017; Moussavi *et al.,* 2014). However, with the rise in green products and sustainability, green synthesized nano-particles have been gaining popularity in treatment of micro-pollutants (Devatha *et al.,* 2016; Mansur *et al.,* 2014).

**Green synthesis of nano-particles**

Green production or green synthesis to be more specific is the process where nano-particles are extracted from natural sources like leaves, plant extracts, microbial metabolites and others (Devatha *et al.,* 2016). Various researches have been conducted until now whereby plant extracts as well as microbial extracts has been usedin development of nano-particles like iron based or titanium dioxide based, that has the ability to oxidise pollutants. The main reason for using green synthesized nano-particles is because of its sustainability, being cost effective, higher level of efficiency in pollutant degradation and reduces time for reaction (Devatha *et al.,* 2016; Shahwan *et al.,* 2011). Different sources of green nanoparticles for AOPs have been presented in Table 1.

In most cases, the use of green synthesis nanoparticles helps to efficiently degrade micro-pollutants in waste water treatment or running water to water bodies (Shahwan *et al.,* 201; Wang *et al.,* 2 014; Machado *et al.,* 2013; Kumar *et al.,* 2013; Huang *et al.,* 2014; Njagi *et al.,* 2011; Thakur *et al.,* 2014; Senthil *et al.,* 2012; Smuleac *et al.,* 2011; Ehrampoush *et al.,* 2015; Pattanayak *et al.,* 2013; Goutam *et al.,* 2018; Rao *et al.,* 2015; Khade *et al.,* 2015; Shen *et al.,* 2017; Sood *et al.,* 2015; Joseph *et al.,* 2015; Das *et al.,* 2018; Kataria *et al.,* 2018; Bhattacharjee *et al.,* 2014; Pandian *et al.,* 2015. However, in one case, the study of Rao *et al.,* used orange waste in synthesis of TiO2 nanoparticles (Rao *et al.,* 2015). Different forms of nano-particles found to be used in micro-pollutant treatment were iron nanoparticles, TiO2NPs, Ce-doped TiO2NPs (Titanium dioxide), Strontium or Sr-doped TiO2NPs, silver nano-particles, cupric oxide NPs, Silver/Silver Chloride nano-particles, Iron (II,III) Oxide nanoparticles, Tin-oxide nanoparticles and nickel nanoparticles (Shahwan *et al.,* 2011; Pattanayak *et al.,* 2013;; Goutam *et al.,* 2018; Rao *et al.,* 2015; Khade *et al.,* 2015; Shen *et al.,* 2017; Sood *et al.,* 2015; Joseph *et al.,* 2015; Das *et al.,* 2018; Kataria *et al.,* 2018; Bhattacharjee *et al.,* 2014; Pandian *et al.,* 2015).

One of the best advantages of using green nanoparticles is that the pH level is about 4-5 and makes it safe for the environment and with lower pH the reaction between iron bearing minerals and hydrogen peroxide is much higher and effective (Shahwana *et al.,* 2011). The efficiency of the decomposition of dyes and others organic matter is reduced when the pH level is above 4 and mostly in cases of use of Iron or Fenton oxidation reaction. Lower the formation of ferric hydroxide precipitation in case of Iron based oxidation process higher is the efficiency of degradation of dyes. During Fenton reaction sludge and anions are formed in higher concentrations which causes the conversion of hydrogen peroxide to reduce or inefficient and thereby the pH also reduces Shahwana *et al.,* 2011). The advantage of using plant-based Iron particles in the degradation of dyes is that the plant-based cell cultures are easier to control and are more stable plus the reaction time does not degradewith timebut in traditional or synthetically produced nanoparticles the degradation is faster (Ajitha *et al.,* 2015). In addition, theuse of plant or green based nanoparticles for AOPs can be easily scaled up for large scale synthesis in the degradation of organic elements. Furthermore, they are also economic and can function in optimal temperatures and reduce the concerns of eco-friendly water treatment processes. The use of plant-based components as nanoparticles for the degradation processis stable and also improves the biocompatible functionalities enhancing the action of the nanoparticles to be used in antibacterial activity in water treatment process (Njagi *et al.,* 2015).

In addition, most of the treatment procedures using green synthesised nanoparticles showed an efficacy of more than 80% on an average indicating the feasibility and sustainability of using green synthesized nanoparticles for micro-pollutant treatment (Sood *et al.,* 2015). Use of green products are more stable during the reaction process and the reaction dos not easily degrade thereby, increasing the potency of degradation process to a maximum of 80% (Ajitha *et al.,* 2015). The most advantageous point of using Titanium dioxide has been a proven method of highly efficient method in the degradation of methyl orange (MO) and are economic as well as environmental friendly (Khade *et al.,* 2015). The use of surfactants that helps to maintain the "shape-controlled synthesis" of nanoparticles because of presence of both hydrophobic and hydrophilic components and thereby does not allow the agglomeration of the chemical or the particles being used with nanoparticles to ensure that the toxic dye is effectively degraded (Bhattacharjee *et al.,* 2014). Also, the advantage of using these surfactants is that they act as capping agents and therefore, improves the processes like flocculation in the treatment of waste water or dye degradation. However, using this method was found to be effective in degradation of methyl violet 6B dye.

**Efficacy of different green synthesised iron nano-particles (FeNP) in micro-pollutant treatment**

Green synthesis of FeNPs has been categorised into three main sourcing methods; one being direct plant extracts, secondly plant biomasses, and lastly, use of plant biomass as template (Herlekar *et al.,* 2014). Furthermore, FeNP variants nZVI (Zerovalent iron nanoparticles) and iron oxide have been mostly used because they are the only compounds that can be extracted with ease and reduced efforts and efficiently. One of the most commonly used plant extracts is from tea plants or green tea variants like Camellia sinensis or tea plant (Hoag *et al.,* 2009), Oolong and black tea (Huang *et al.,* 2014). Tea plant extracts are mainly used because they are easy to extract, can be extracted in normal room temperatures, reduced extraction time and effort and effective tea polyphenols acted as the reducing and capping agent (Herlekar *et al.,* 2014). Polyphenols from tea usually comprise of theaflavins or flavonoids and others and are usually and are good capping agents because of their ability to reduce nanoparticle overgrowth as well as aggregation of the particles used in degradation process (Herlekar *et al.,* 2014). Furthermore, these polyphenols also act as stabilising agents thereby increasing the efficacy of the reaction process of the nanoparticles and thereby improves the degradation of toxic elements. As it is known the capping agents comprises of polar head and non-polar tail and therefore, it helps to keep the nanoparticles from overreaction when in contact with organic elements and the polar had keeps the nanoparticle stable in their activity. In other words, these capping agents act in colloidal synthesis of nanoparticles which is an important process in green synthesis of nanoparticles in waste water treatment processes (Khade *et al.,* 2015; Herlekar *et al.,* 2014). Surfactants also acts as capping agents and their processes are the same and their main function is to ensure that the agglomeration of the nanoparticles with high surface energy is maintained (Bhattacharjee *et al.,* 2014). By providing colloidal stability the costs of nanoparticle stabilisation reduce and there is no need for external stabilising agents and by stabilising the uncontrolled growth in the initial stages also improves the costs of degradation processes and therefore, effective as a cost reducing agent as well as a capping agent and thereby effective in degradation of bromothymol blue. The exteracted FeNP from Camellia sinensisor tea plantwas seen to have above 70% of effectiveness in the degradation of micro-pollutant like bromothymol blue, borohydride and a few other organic chemicals. Similarly, green synthesis of Fenton-like catalyst was found to be effective in the degradation or oxidation of cationic dyes and anionic dyes (pollutants) like methylene blue and methyl orange respectively (Shahwan *et al.,* 2011). The efficacy in case of methylene blue was found to be between 96.3% and 86.6% for different concentrations, whereas, methyl orange (pollutant) was found to degrade between 61.6% and 47.1% for different concentrations.

The use of other forms of plant extracts has been termed as "plant extract derived from agrowaste" (Herlekar *et al.,* 2014), like the use of Sorghum sp. (Njagi *et al.*, 2011) or the use of leaf extract from Eucalyptus sp. (Wang *et al.*, 2014) or the use of plantain peel extract(Venkateswarlu *et al.,* 2013). In case of using Sorghum sp. it was used to extract Fe and silver nanoparticles to degrade bromothymol blue in waste water and drinking water. The extracted Fe and silver nanoparticles were found to be very effective by approximately 80% degradation or oxidation of bromothymol blue. Besides, the reduction of COD was also achieved by 80% in comparison to the studies reported. (Nasirian *et al.,* 2017; Avisar *et al.,* 2010; Moussavi *et al.,* 2014; Shahwan *et al.,* 2011; Jiang *et al.,* 2005; Senthil *et al.,* 2012; Kumar *et al.,* 2013; Machado *et al.,* 2013), which may be because the reducing agent was combined with UV treatment of the ground water. Wang's study found that using Iron nanoparticles helped in achieving 80% of oxygen usage for chemical reaction to degrade the chemicals or organic materials in the water (Wang *et al.,* 2014). This level was even higher than Jiang and colleague whereby the oxygen usage for chemical reaction was around 30% and therefore, it may be stated that ferrate (VI) oxidation has less COD demand than FeNPs. However, the effectiveness of removal of organic and toxic components from water surfaces using green synthesised nanoparticles show an estimated degradation between 30% and 80%. By reduction of the COD by nanoparticles, it helps in better removal of the pollutants in the water, because higher COD

**Table 1.** List showing the types of green synthesised nano-particles for micro-pollutant treatment

| Type of nanoparticle | Source of green synthesis | Reference |
|---|---|---|
| Fe or iron nanoparticles (NPs) | Green tea leaf | Shahwan *et al.*, (2011) |
| | Eucalyptus leaf extracts | Wang *et al.*, (2014) |
| | Tree extract | Machado *et al.*, (2013) |
| | Terminaliachebula fruit extract | Kumar *et al.*, (2013) |
| | Oolong and black tea leaf extract | Huang *et al.*, (2014) |
| | Sorghum bran extract | Njagi *et al.*, (2011) |
| | Colocasiaesculenta leaves extract | Thakur *et al.*, (2014) |
| | Tridaxprocumbens | Senthil *et al.*, (2012) |
| | Green tea extract | Smuleac *et al.*, (2011) |
| | Tangerine peel extract | Ehrampoush *et al.*, (2015) |
| | *Azadirachta indica* extract | Pattanayak *et al.*, (2013) |
| Titanium dioxide or $TiO_2$ | *Jatropha curcas* L. leaf extract | Goutam *et al.*, (2018) |
| | Orange fruit waste extract | Rao *et al.*, (2015) |
| | Plant leaf-based extract | Khade *et al.*, (2015) |
| Cerium or Ce-doped $TiO_2$ | Plant based extract | Shen *et al.*, (2017) |
| Strontium or Sr-doped $TiO_2$ | Plant based extract | Sood *et al.*, (2015) |
| Silver Nano-particles | Mukiamaderaspatna plant extract | Joseph *et al.*, (2015) |
| Cupric oxide | Madhucalongifolia plant extract | Das *et al.*, (2018) |
| Silver/Silver Chloride or Ag/Ag Clnano-particles | Momordicacharantia plant extract | Devi *et al.*, (2016) |
| Iron (II, III) Oxide or $Fe_3O_4$ nanoparticles | Plant based extract | Kataria *et al.*, (2018) |
| Tin-oxide nanoparticlesor SnO2 | Plant based extract | Bhattacharjee *et al.*, (2014) |
| Nickel nanoparticles (NPs) | Ocimum sanctum extract | Pandian *et al.*, (2015) |

in water means more toxic pollutants and low COD the vice versa. Similarly, the use of plantain peel extract was also found to be very effective in the reduction of micro-pollutants like toxic metals and dyes by a minimum of 60% and was termed as potent green synthesised FeNPs for environmental remediation of groundwater toxic elements and dump-fill toxic leachates (Venkateswarlu *et al.*, 2013). The FeNPs were extracted from banana peel ash as well as Colocasia esculenta or Taro leaves extract with the aim to oxidize and degrade pharmaceutical elements and toxic micro-pollutants like tetrabromobisphenol and cadmium (Thakur and Karak., 2014). The use of this nanoparticle found that it took a maximum of 30 minutes to bio-remediate the water body with an efficacy level of 70% and more. Similar, high and effective and efficient green synthesis of FeNPs has been informed in many studies where the minimum reductions of micro-pollutants are recorded at 50% and the maximum by 98%.

**Summary and Conceptual Protocol**

AOPs and nanoparticles are two most commonly used methods in the reduction and degradation of anthropogenic elements commonly termed as micro-pollutants (Bethi *et al.*, 2016; Plakas *et al.*, 2016). Even though synthetically produced nanoparticles have been used till date with AOPs for oxidation of micro-pollutants, but the use of green synthesised nanoparticles have not yet been used along with AOPs for reduction of micro-pollutants. Therefore, following conceptual framework has been formed that shows the process to be used and followed for using a hybrid green synthesised Fe nanoparticle and AOPs. It is conceptualised that ground water or waste water or sewage water can be treated by combination of traditional AOP method whereby hydroxyl radicals from the chemicals will covert these pollutants into mineral acids or $H_2O$ and/or $CO_2$ (Joseph *et al.*, 2009) and with the help of tea plant extracts (Huang *et al.*, 2014; Hoag *et al.*, 2009) iron nanoparticles can be extracted which reacts with pollutants like toxic elementsand dyes by oxidation process. It has already been seen that the combination of AOP to other methods like $UV/O_3/H_2O_2$ and nanoparticles are very effective (Bethi *et al.*, 2016; Lucas *et al.*, 2010) and therefore, the combination of green synthesised nanoparticles and AOP will also be effective as well as sustainable.

Rising levels of micro-pollutants in water bodies like ground water or riverine and oceans as well as in supply drinking water has been alarming in the past decade and this has led to development of numerous technologies and chemical processes that helps in the treatment of micro-pollutants in water bodies as well as waste water. Different types of reduction methods includecoagulation–flocculation, advanced oxidation processes (AOPs), membrane processes and membrane bioreactor, activated carbon adsorption, different nanoparticles, and more recently use of green synthesised nanoparticles. Micro-pollutants in water bodies have been mainly rising from the uncontrolled and reduced measures against anthropogenic activities. In this regard it was found that AOPs are the most effective conventional methods of micro-pollutant reduction and oxidation because they are effective and have higher efficiency. However, there is one issue of using nanoparticles and AOPs as hybrid method in reduction of toxic pollutants, which is the risk of sedimentary chemicals remaining in the water from the AOP process; which means the process of oxidising has to be performed again and is therefore considered to be less effective. However, the use of plant extracts and natural extract called green synthesis of nanoparticles are sustainable and reduces the mentioned threat. The use of green synthesised nanoparticle in reduction and degradation of micro-pollutants has been mainly researched with respect to iron nanoparticles and are very effective, even more effective than AOPs. The main gaps found from this review paper are that there is lack of study on green synthesised FeNPs and AOPs as hybrids in the oxidation and degradation of micro-pollutants; secondly, the past papers fail to mention the extraction process from natural sources because in most cases laboratory methods were used and lastly, there is lack of research on other alternative nanoparticles for the same purpose. Therefore, the main future scope of the study is to apply both green synthesised FeNPs and AOP hybrid method in the oxidation and reduction of certain micro-pollutants under controlled environment to compare the efficacy to previous publications.

**Conflict of Interest**

None.

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