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# A Critical Review of Conventional and Emergency Domestic Sewage Treatment Technology

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**Abstract.** As an important part of environmental protection, domestic sewage treatment is inseparable from our daily life. With the increasing public attention to it, domestic sewage treatment technology needs to be constantly optimized to meet the public demand. This paper will focus on the main components of domestic sewage, including pathogens, persistence organic pollutants, and heavy metal pollutants and emerging pollutants. At the same time, this paper will also introduce the corresponding treatment methods for different pollutants. Treatment methods will be divided into traditional and emerging technologies (except emerging pollutants, which have a short history of discovery) for comparison and evaluation. For emerging pollutants, this paper will separately introduce its detection methods, as well as treatment methods in the experimental stage.

## 1. Introduction

As the environment preservation gradually becomes a matter of major social concern and more strict legislations are being imposed on effluent discharge [1]. However, with the rapid development of urbanization and industry, the composition of domestic sewage becomes more and more complex, the current wastewater treatment plans have been unable to cope with increasingly complex domestic sewage. In this paper, the classification of major pollutants in domestic sewage will be introduced and the advantages and disadvantages of corresponding treatment technology will be discussed. This paper introduces a group of technologies for wastewater treatment, including a traditional technology and an emerging technology, then, compares the two and explores what can be improved with traditional technologies, as well as the prospects and drawbacks of new technologies. For the classification of pollutants, this paper will classify them into four categories: pathogens, heavy metal pollutants, organic pollutants and new pollutants. Of course, for domestic sewage, the classification of pollutants is far more than these four categories. However, due to the limited space, this paper only selects the four most profound categories of our daily life. In addition, for emerging pollutants, compared with other pollutants, there is no mature technology that can be applied to actual sewage treatment. Therefore, this paper will take the new pollutant as a separate chapter to introduce its properties, and explore its detection methods and the feasibility of treatment methods.

## 2. Brief survey of pollutants in sewage wastewater

### 2.1. Pathogens

Pathogens, is a public health hazard with risk factors in nearly all parts of the world, which includes bacteria, viruses, and parasites, is particularly widespread in raw sewage. Also, in raw sewage Pathogens



can breed rapidly and survive for a long time. Soil and sanitary waste are two main sources to produce Pathogens in sewage. Example of Pathogens commonly found in wastewater are Hepatitis and Norwalk virus and a common fungus is Candida. Not only all sewage Pathogens can lead to serious gastroenteritis illness but also can cause some other diseases like Hepatitis A, bloody diarrhea, fever, abdominal pain etc., which is significant reason of death worldwide [2]. At present, most countries can solve the threat of pathogens in sewage. However, how to improve treatment efficiency and safety of by-products is still a problem which need to be further discussed in the field of sterilization.

Table 1. Category and harm of pathogens in raw sewage

<b>Type of Pathogen</b>	<b>CATEGORY</b>	<b>HARM</b>
<b>Viruses</b>	Norwalk virus, rotavirus, Hepatitis A, Poliomyelitis Virus, Adenovirus	<b>Gastroenteritis</b> Diarrhea, Vomiting, Abdominal Pain, Nausea, Cramping <b>Hepatitis A</b> Jaundice, Fever, Diarrhea, Cramping, Loss of Appetite, Nausea <b>Poliomyelitis</b> Sore Throat, Vomiting, Nausea, Cramping, Constipation, Diarrhea
<b>Bacteria</b>	Campylobacter, E. coli, Leprosaria Salmonella, Shigella	<b>Campylobacteriosis</b> Bloody Diarrhea, Fever, Cramping, Nausea, Vomiting <b>Escherichia coli (E. Coli)</b> Bloody Diarrhea, Fever, Cramping, Nausea, Vomiting <b>Leptospirosis</b> Fever, Headaches, Body Aches, Chills, Diarrhea, Vomiting, Jaundice <b>Salmonellosis</b> Diarrhea, Fever, Cramping <b>Shigellosis (Bacillary Dysentery)</b> Bloody Diarrhea, Fever, Cramping
<b>Parasites</b>	Cryptosporidium parvum Giardia intestinalis	<b>Cryptosporidiosis</b> Diarrhea, Loose Stool, Cramping, Slight Fever <b>Giardiasis</b> Diarrhea, Loose Stool, Cramping, Slight Fever

## 2.2. Organic pollutants

Along with the rapid development of modern chemical industry, it not only greatly enriches and meets people's demand for production and living materials, but also produces a large number of refractory organic pollutants, which poses a huge environmental threat. Refractory organic matter refers to the organic matter that is difficult to be completely metabolized by microorganisms under normal conditions or to be completely degraded and removed by general physical and chemical methods. Traditional treatment methods have been difficult to achieve the objective of treatment of refractory pollutants. Therefore, it is a great challenge for environmental protection workers to use efficient and economical means of prevention and control to reduce their harm to the environment and to thoroughly degrade them in a proper way [3]. Two methods for treating organic pollutants, including conventional chemical processes and Fenton reaction processes, are presented in this paper to provide references for the development of related industries in the future.

### 2.3. Heavy metal

The conception of heavy metal can be understood as a group of metallic chemicals that have a relatively high density and is poisonous at low concentrations. In sewage, the main harmful heavy metal includes Lead, Chromium, Cadmium, Arsenic, Mercury, Copper, Zinc and Nickel. With the rapid development of industries, heavy metal is increasingly detected in our sewage wastewater. In the environment, heavy metal, cannot be spontaneously degraded and pollute our drinking-water and tend to accelerate in our body, which are known to be toxic or carcinogenic. For example, Zinc is a trace element that is essential for human health. It is important for the physiological functions of living tissue and regulates many biochemical processes. However, too much zinc can cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anemia [4].

Table 2. WHO and US EPA limitations of selected heavy metal in drinking water

Contaminant	EPA limitations		WHO provisional guideline value (mg/L)
	Maximum Contamination level (MCL)(mg/L)	Maximum Contamination limit (MCLG)(mg/L)	
Lead	0.015	0	0.01
Chromium	0.1	0.1	0.05
Cadmium	0.005	0.005	0.003
Arsenic	0.010	0	0.01
Mercury	0.002	0.002	0.006
Copper	1.3	1.3	2
Zinc	5	-	3
Nickel	-	-	0.07

## 3. Introduction of Sewage Wastewater Treatment Technology

### 3.1. Treatment Technology for Pathogens

#### 3.1.1. Chemistry disinfection

Traditional water disinfection techniques use chemical reagents such as liquid chlorine, chloramine, chlorine dioxide or ozone. Liquid chlorine can react with natural organics in halogen ions such as water, pesticide, bromine and iodine to produce disinfection byproducts such as trihalomethanes, halo acetic acid, halo acetonitrile, halophenol, halo acetaldehyde and halothane [5]. Traditional chemical methods may seem to have good economic and antimicrobial effects, but they pose unpredictable risks to our environment and health. Chloramine forms nitrosamine with nitrates, nitrite with inorganic salts, and halogen amide or halide with organics. Carbon dioxide reacts with inorganic ions in water to form chlorate and chlorite, causing damage to red blood cells, limiting the transport of oxygen and interfering with the absorption of iodine. Ozone in the process of disinfection oxidizes bromine ions in the water to produce bromate, and organic substances in the water produce carboxylic acid, formaldehyde and ketone. These products also have carcinogenic and genetic toxicity, and some may cause animal hearing damage [6]. Therefore, our sterilization technology needs further optimization.

### 3.1.2. UV-light

UV-light disinfection is defined as a photochemical process. In microbial cell structures, proteins and DNA absorb ultraviolet light. When UV-light is absorbed through the cell wall, which contains abundant protein and DNA, it will cause adjacent thymine to intertwine to form a dimer, prevent normal DNA on the RNA from duplicating the genetic code and the cell will lose its genetic ability and even die. UV disinfection does not require to add any additional corrosive chemicals, so no by-products will be produced. In addition, due to its advantages of low operation cost, safe operation and simple management, UV disinfection is superior to chlorine oxidation and ozone oxidation disinfection methods.

UV-light disinfection has a broad spectrum, not only have effective inactivation for general pathogenic bacteria and virus, but can also neutralize chlorine-resistant cryptosporidium and giardia. Currently, there is no UV-resistant microorganisms have been found, but the sensitivity of various microorganisms to UV-light differs by nearly 100 times. Microorganisms with large cell sizes or large amounts of DNA or RNA are less sensitive to ultraviolet light. For example, *e. coli*, *e. coli*, *staphylococcus aureus*, humic acid bacteria, phage bacteria, and the most sensitive to UV light compared with mice, typhoid bacteria, salmonella, yeast has high UV resistance, and spores, the fungal spores, mildew, bacteria and *bacillus subtilis* has high UV resistance. The sensitivity to ultraviolet light varies at different stages of the microbial life cycle. For example, spores are highly resistant to ultraviolet light, but can be greatly reduced during germination [7].

UV-light disinfects quickly. The inactivation of common pathogenic bacteria and viruses under the standard dose (42 mJ/cm<sup>2</sup>) of UV disinfection of domestic sewage only takes a few seconds. Compare with UV-light, traditional sterilization technique like adding chlorine, chloramine, chlorine dioxide or ozone generally requires dozens of times of residence time. The advantages of short residence time and taking less area, which is significant to practical engineering. In addition, UV-light technology is widely used in the field of wastewater treatment in China. The application of UV-light technology also gradually increases in the field of water disinfection. However, UV disinfection is found as not persistent in practical use, because some cells can recover from the damage of UV light. Many bacteria have the ability to repair, such as *Streptomyces* and *E. Coli*, yeast, aerobe, etc. Thus, how to overcome the problem of photoreactivation while retaining the advantages of rapid UV disinfection, no selectivity and no by-product is one of the hot topics in this field [8].

## 3.2. Treatment Technology for Persistent Organic Pollutants

### 3.2.1. Membrane Bioreactor

The MBR process was introduced by the late 1960s. The original process is combining the use of an activated sludge bioreactor with a crossflow membrane filtration loop which was introduced by Dorr-Olivier Inc. Although the idea of replacing the settling tank of the conventional activated sludge process was attractive, it was unjustified to acknowledge the good economic benefit of this process because of the high cost of membranes, low economic value of the product (tertiary effluent) and the potential rapid loss of performance due to fouling. The breakthrough for the MBR came in 1989 with the idea of Yamamoto et al. to submerge the membranes in the bioreactor. Since then, further improvements in the MBR design and operation have been introduced and incorporated into larger plants [9]. MBRs are being increasingly used in wastewater treatment plant that requires better water quality. MBRs allow high concentrations of mixed liquor suspended solids (MLSS) and low production of excess sludge, enable high removal efficiency of biological oxygen demand (BOD) and chemical oxygen demand (COD), and water reclamation. Membrane bioreactor (MBR) is a conspicuous promotion to conventional wastewater treatment. However, membrane fouling is one of the most serious barriers to further development of the MBR technology since it has a detrimental effect on system performance and stability [10]. Additionally, large-scale use of MBRs in wastewater treatment will occur an intensity price dropping of the membranes.

### 3.2.2. Fenton reaction

Currently, a large amount of organic pollutant is discharged to our natural water body. What's more, POPs tend to become more stable to sunlight irradiation and stronger to resistance the degradation from microbial. Thus, it is indispensable to develop an advancing technology to address the serious issue. In this background, Fenton process award a high concern in the field of environmental engineering.

Fenton reaction is one of the typically photocatalytic oxidation technologies. The principle of Fenton reaction is exploiting the strengthen oxidation characteristic of the mixture of hydrogen peroxide ( $H_2O_2$ ) and ferric ions to oxidize many currently known organic compounds, like carboxylic acid, alcohol, ester etc., to inorganic state. The basic principle of Fenton reaction can be expressed as [11]:

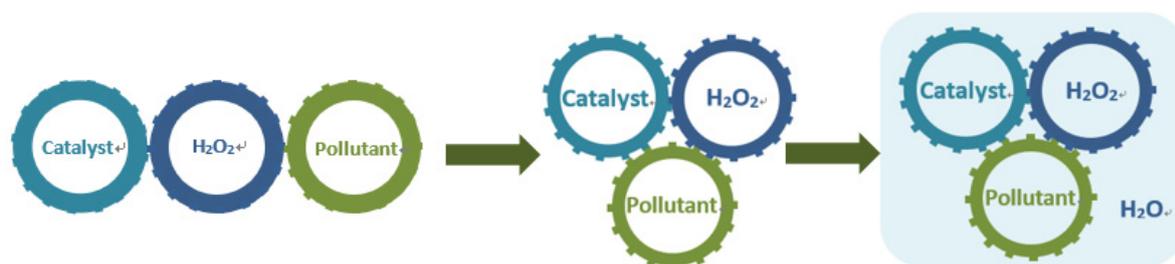


Figure1. Schematic diagram of the mechanism of Fenton reaction

In traditional Fenton reaction, hydrogen peroxide ( $H_2O_2$ ) is used as a strong oxidant, but it is not effective to degradation POPs which in a high concentration. Thus, promotions will be attained by utilizing metal salts, ozone or UV-light to activate  $H_2O_2$  transfer to hydroxyl radicals, which own a more strengthen oxidizability[12]. Although, compare with the other oxidation technologies, traditional Fenton process have such advantages like, simplicity equipment, easily operating, non-persistent environmental threats and low latency, traditional Fenton process also have some shortcoming which limit its application range, like sludge production, PH fluctuation and catalyst losing. Because of these imperfections of traditional Fenton reaction, scientific community start to draw more attention on improving Fenton reaction and heterogeneous Fenton was created [13].

In this context, the use of solid catalysts in so-called catalytic wet peroxide oxidation (CWPO) or heterogeneous Fenton oxidation is a promising option [14]. the supporting catalyst can be used to disperse the metal particles by providing the matrix, thus increasing the surface area of the metal type. The sintering of active phase is reduced and the thermochemical stability of catalyst is improved. Although CWPO has advantages over the traditional Fenton process, its commercial application in wastewater treatment has been limited so far due to its general activity and low stability of the catalyst studied [15]. Other researchers also have some other studied about heterogeneous Fenton reactions. For example, Barreto - Rodrigues, etc. reported zero-valent iron and Fenton reaction combined with TNT industrial wastewater treatment, they found that the removal rate of system of TNT and total nitrogen removal rate can reach 100%, the total phenol removal rate can reach 87.5%, COD removal rate is as high as 95.4% [16]. Zhu et al. used porous magnetite  $Fe_3O_4$  as Fenton catalyst to degrade xylenol orange. It was found that the polyphase Fenton system was able to degrade the xylenol orange efficiently with the combination of ultrasound treatment, and the activity was slightly reduced after cyclic use for seven times[17]. Kondru et al. used Fe - Y zeolite as a heterogeneous Fenton catalysts for degradation of azo dye Congo red. Results show that under the condition of initial pH7 reaction temperature 90 °C, Fenton reaction 4 h, the removal rate of Congo red is as high as 97%, COD removal rate was 58% [18]. Sash kina using synthetic iron iron source by hydrothermal methods, such as in situ doping silicon molecular sieve nanocrystalline iron, it will be used in heterogeneous Fenton 60 Co catalyst activation of hydrogen peroxide degradation of radioactive isotope labeling (II) - EDTA [19]. Last, selective bioelectronics

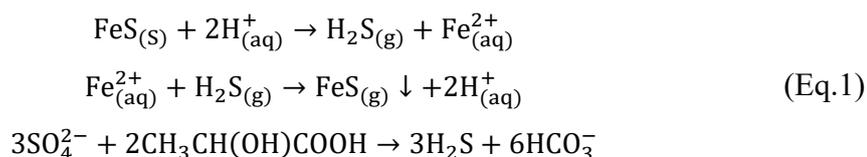
oxygen reduction (ORR) of Fenton oxidation reaction on the integrated cathode is a promising environmental recovery method [20].

### 3.3. Treatment Technology for Heavy metal

#### 3.3.1. Chemical precipitation

The most widely used chemical precipitation technique is hydroxide precipitation due to its relative simplicity, low cost and ease of pH control. The solubilities of the various metal hydroxides are minimized in the pH range of 8.0–11.0. The metal hydroxides can be removed by flocculation and sedimentation. A variety of hydroxides has been used to precipitate metals from wastewater, based on the low cost and ease of handling, lime is the preferred choice of base used in hydroxide precipitation at industrial settings [21].

Sulfide precipitation is also an effective process for the treatment of toxic heavy metals ions. One of the primary advantages of using sulfides is that the solubilities of the metal sulfide precipitates are dramatically lower than hydroxide precipitates and sulfide precipitates are not amphoteric. Thus, the sulfide precipitation process can achieve a high degree of metal removal over a wide pH range compared with hydroxide precipitation. Metal sulfide sludges also exhibit better thickening and dewatering characteristics than the corresponding metal hydroxide sludge [22]. The principle of sulfide precipitation can be defined as the below equation (iron is shown as example):



In additional, González-Muñoz reported sulfide precipitation to reuse and recover heavy metal ions and employed nanofiltration as a second step. Results indicated sulfide precipitation was successful in reducing the metal content and nanofiltration yielded solutions capable to being directly reused in the plant [23].

#### 3.3.2. Carbon nanotubes

Carbon has the property to exist in many molecular forms, known as allotropes of carbon. These allotropes can be considered as different structural modifications of carbon element. Carbon nanotubes (CNTs) are composed of cylindrical graphite sheets (allotropic form of carbon) rolled up in a tube-like structure. CNTs have been widely employed for the removal of various contaminants from aqueous solutions due to their large surface area, light mass density, high porous and hallow structure, and strong interaction between the pollutant molecules and CNTs. Various experimental studies have reported the adsorption of heavy metal ions, small molecules, organic chemicals and radionuclides on different CNTs.

In recent years, CNTs have been employed extensively as a new adsorbent for the removal of a number of heavy metals from water. In most of the studies, the maximum adsorption capacity is determined using Langmuir isotherm model. Furthermore, the adoption capacity of the acid modified CNTs is higher, almost in all studies, as compared to the raw CNTs. This might be due to electrostatic interaction between the negative charge on the CNTs surface after acid treatment and the divalent heavy metal ions [24].

The processing of the transformation of raw CNT to acid modified CNT can be explained by the below figure [25]:

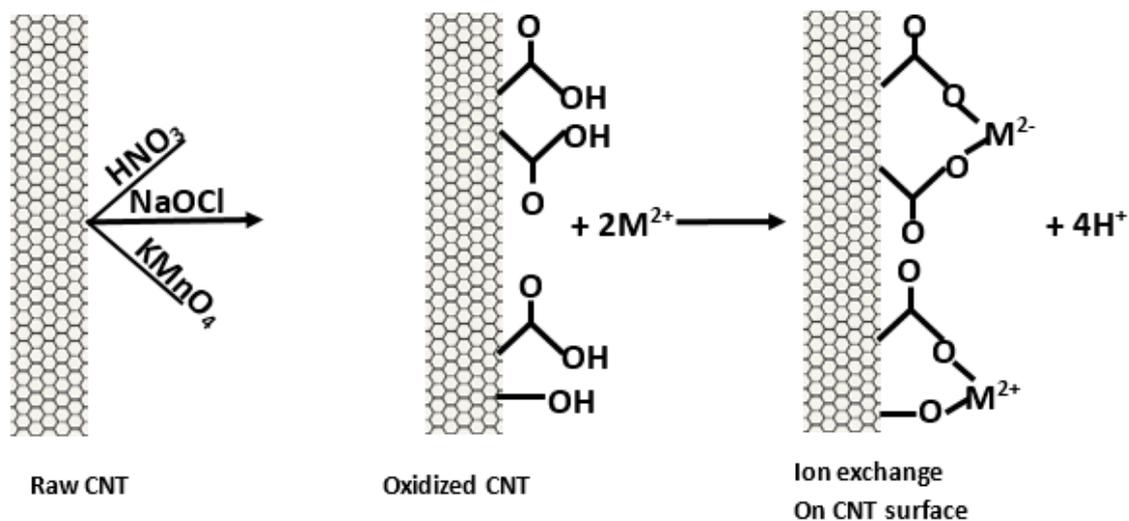


Figure 2. Transformation process from Raw CNT to Ion exchanged CNT

#### 4. Emergency Contaminant

##### 4.1. Briefly Introduction of Emergency Contaminants

With the public start to pay more attention to environmental protection and dedicate to expanding the scope of environmental protection law. In the last decade, numerous evidences can strength prove that emergency contaminants (ECs), which include pharmaceuticals, personal care products, steroid hormones, industrial chemicals, pesticides and many other emerging compounds make threaten to our environment in different levels. Unfortunately, there is a lack of suspended particulate matter analysis due to further preparation requirements and a lack of analytical approaches. Thus, current evidences are equivocal to determine jeopardize, characteristic and by-product of ECs. However, according to the historical data analysis, traditional wastewater treatment plant cannot successfully remove ECs in sewage wastewater. It is fair to say our current knowledge to detect or remove the ECs in sewage wastewater is limited.

##### 4.2. Sampling and Detection Method

ECs detection in wastewater and environment is a very significant process. The most important step in monitoring ECs in wastewater and the environment is sampling. Because that's the basis for getting representative data. In order to monitor the treatment performance of ECs removal, corresponding extraction samples can be used to compensate the hydraulic residence time (HRT) [26]. For example, removal of pollutants is not allowed during peak daily flow periods (between 7am and 9am) and low-flow periods (between 3pm and 5pm). At present, the relatively accurate detection methods are mainly divided into two steps: Firstly, obtain the composite sample with system representativeness within a relatively long time (such as 24-hour time cycle, flow rate or volume ratio). Secondly, using appropriate preservation techniques, which acidification or addition of sodium azide is required to be applied [27]. It is reliable that obtaining final emissions throughout the sampling process.

The figure at below is a series of data about ECs which collected at UK [28]:

Table 3. Emissions and monitoring of emerging pollutants in the UK

Emerging contaminant	Influent (ngl <sup>-1</sup> )	Final effluent (ngl <sup>-1</sup> )	Surface water (ngl <sup>-1</sup> )
Pharmaceuticals			
Estrone	49	4.3-12	-

17 $\beta$ -estradiol	20	0.4-1.3	-
Metoprolol	75-110	41-69	<0.5-10
Salbutamol	0.1-130	63-66	<0.5-2
Atenolol	12,913-14,223	2123-2,870	<1-487
Carbamazepine	950-2,593	826-3,117	<0.5-251
Gabapentin	15,034-18.474	2592-21,417	<0.6-1,879
Acetaminophen	6924-492,340	20-11,733	<1.5-1,388
Diclofenac	69-1,500	58-599	<0.5-154
Ibuprofen	1681-33,764	143-4,239	1-2,370
Naproxen	838-1,173	170-370	1-59

#### 4.3. Emergency Contaminants Treatment Technology

With the deepening understanding of ECs and the continuous progress of related technologies, more and more advancing progress has been created in the region of ECs treatment. For example, Lam studied four drugs, atorvastatin, carbamazepine, levofloxacin and sulfamethoxazole, under the sun. These compounds have been observed or may exist in surface water and are susceptible to direct and indirect photodegradation. Products produced by direct and indirect photolysis also appear to be susceptible to photodegradation, suggesting that they do not persist in water systems exposed to sunlight [29]. Tran reported different operating parameters such as ultrasonic power, which current intensity and reaction time were studied. When current intensity decreases, the degree of synergistic effect increases and increases with the effect of ultrasonic wave [30]. Exposito reported the application of hydrodynamic acoustic cavitation technology has good synergistic effect. Under the optimal condition, the ql-1 value of carbamazepine is 96 percent of > within 15 minutes, which is changed by quasi-first-order kinetics to some extent (27 percent by hydraulic cavitation and 33 percent by acoustic cavitation) [31]. Zupanc researched different traditional and alternative wastewater treatment processes and their combination methods to improve drug removal rate. All the processes include, two different lab-scale biological processes: the suspension of activated sludge and the attachment of biomass, a hydrodynamic cavitation - hydrogen peroxide process and ultraviolet treatment. Five drugs were researched, including ibuprofen, naproxen, ketoprofen, carbamazepine and diclofenac, as well as the active metabolites of the lipid regulator clofibrac acid [32]. Thanekar reported the research on CBZ (carbamazepine) degradation using vacuolar reactor and ultraviolet light [33].

#### 5. Conclusion

More and more technologies have been developed for the increasingly complex domestic sewage. This paper discusses the corresponding treatment technologies for pathogens, heavy metal pollutants, persistence organic pollutants and new pollutants.

For pathogens, traditional chemical treatment methods are mentioned in this paper, using chemical reagents such as liquid chlorine, chloramine, chlorine dioxide or ozone to sterilize domestic sewage. Although this treatment method has good economic benefits, some toxic by-products will be produced and cause certain damage to human body. The ultraviolet disinfection method is safer and more reliable for traditional chemical disinfection because it produces fewer toxic by-products. Due to its short residence time and small footprint, it has a good prospect in domestic wastewater treatment. However,

the environmental engineering community has demonstrated that UV-irradiation, by observing that some pathogens recover from exposure to ultraviolet light, still needs to be further enhanced in terms of disinfection. In this paper, MBR technology and Fenton technology are introduced for the treatment of organics in domestic wastewater. As a relatively mature process, MBR technology has achieved good economic benefits and stable operation. However, membrane fouling is a major obstacle to the development of MBR technology. How to solve the problem of membrane fouling to reduce its backwash time is the hot spot in this field. Fenton reaction is a relatively new technology compared with MBR. After a period of development, from the traditional Fenton technology at the very beginning to heterogeneous Fenton, although defects such as sludge production, PH fluctuation and catalyst loss were solved, a large number of oxidants, mainly H<sub>2</sub>O<sub>2</sub>, were consumed in the process of treatment, which caused certain defects in economic benefits. About heavy metal pollutants, traditional chemical treatment and carbon nanotube technology are introduced. Although the chemical treatment method has good economic benefits and easy operation, it cannot achieve high removal rate in the wastewater with low heavy metal concentration due to the weak selectivity. In comparison, carbon nanotube technology, an adsorption technology, can achieve a higher removal rate in wastewater with low heavy metal concentration by virtue of its high selectivity, but because of its high price and unknown environmental damage, the technology is not capable of mass production and remains in the experimental testing stage.

Finally, for emerging pollutants, the early scientific community has been stuck in the testing phase, mainly for sampling of emissions from sewage treatment plants. Until now, more treatments have been developed, including photolysis and hydrodynamic acoustic cavitation. Of course, these technologies are still in the experimental stage, and it is hoped that in the future more relevant technologies will be developed and put into actual waste water treatment.

## References

- [1] Brillas, E., Martinez-Huitle, C.A. (2015) Decontamination of wastewaters containing synthetic organic dyes by electrochemical methods. *Applied Catalysis B Environmental*, 166: 603-643
- [2] Tauxe, R.V. (1997) Emerging foodborne diseases: An evolving public health challenge. *Emerging Infectious Diseases*, 3: 425-434
- [3] YE Yong-gen (2015) Progress in treatment technology of refractory organic pollutants. *Applied Chemical Industry*, 44:
- [4] Oyaro, N., Juddy, O., Murago, E., Gitonga, E. (2007) The contents of Pb, Cu, Zn and Cd in meat in nairobi, Kenya. *Journal of Food Agriculture and Environment*, 5(3)
- [5] Kim, B.R., Anderson, J.E., Mueller, S.A., Gaines, W.A., Kendall, A.M. (2002) Literature review - efficacy of various disinfectants against *Legionella* in water systems. *Water Research*, 36(18): 4433-4444
- [6] Alexandrou, L., Meehan, B.J., Jones, O.A.H. (2018) Regulated and emerging disinfection by-products in recycled waters. *Science of the Total Environment*, 637: 1607-1616
- [7] Zou, X.Y., Lin, Y.L., Xu, B., Cao, T.C., Tang, Y.L., Pan, Y., Gao, Z.C., Gao, N.Y. (2018) Enhanced inactivation of *E. coli* by pulsed UV-LED irradiation during water disinfection. *Science of the Total Environment*, 650:210-215
- [8] Yu, H., Chen, S., Quan, X., Zhang, Z. (2017) The Mechanism, Materials and Reactors of Photocatalytic Disinfection in Water and Wastewater Treatment. *Progress in Chemistry*,
- [9] Chen, V., Fane, A.G. Le-Clech, P. (2006) Fouling in membrane bioreactors used in wastewater treatment. *Journal of Membrane Science*, 284(1-2):17-53
- [10] Kulesha, O., Maletskyi, Z., Ratnaweera, H. (2018) State-of-the-art of membrane flux enhancement in membrane bioreactor. *Cogent Engineering*, 5(1)
- [11] Neyens, E., Baeyens, J.A. (2003) A review of classic Fenton's peroxidation as an advanced oxidation technique. *Journal of Hazardous Materials*, 98(1): 33-50
- [12] Rai, P.K., Lee, J., Kailasa, S. K., Kwon, E. E., Tsang, Y. F., Ok, Y. S., Kim, K. H. (2018) A critical review of ferrate (VI)-based remediation of soil and groundwater. *Environmental Research*, 160: 420-448

- [13] Koutchma, T (2009) Advances in Ultraviolet Light Technology for Non-thermal Processing of Liquid Foods. *Food & Bioprocess Technology*, 2(2):138-159
- [14] Munoz, M., Pedro, Z. M., Casas, J. A., Rodriguez, J. J. (2015) Preparation of magnetite-based catalysts and their application in heterogeneous Fenton oxidation – A review. *Applied Catalysis B Environment*, 176-177: 249-265
- [15] Satishkumar, G., Landau, M.V., Buzaglo, T., Frimet, L., Ferentz, M., Vidruk, R., Wagner, F., Gal, Y., Herskowitz, M., (2013) Fe/SiO<sub>2</sub> heterogeneous Fenton catalyst for continuous catalytic wet peroxide oxidation prepared in situ by grafting of iron released from LaFeO<sub>3</sub>. *Applied Catalysis B Environment*, 138–139: 276–284.
- [16] Barreto-Rodrigues M, Silva FT, Paiva TCB. *Journal of Hazardous Materials*, 2009, 168:1065
- [17] Zhu, M., Diao, G. (2011) Synthesis of porous Fe<sub>3</sub>O<sub>4</sub> nanospheres and its application for the catalytic degradation of xylenol orange. *J. Phys. Chem. C*, 115:18923–18934
- [18] Kondru, A.K., Kumar, P., Chand, S. (2009) Catalytic Wet Peroxide Oxidation of Azo Dye (Congo Red) Using Modified Y Zeolite as Catalyst. *Journal of Hazardous Materials*, 166:342
- [19] Sashkina, K.A., Polukhin, A.V., Labko, V.S., Ayupov, A.B., Lysikov, A.I., Parkhomchuk, E.V. (2016) Fe-silicalites as heterogeneous Fenton-type catalysts for radiocobalt removal from EDTA chelates. *Applied Catalysis B Environmental*, 185:353-361
- [20] Zhao, H., Qian, L., Chen, Y., Wang, Q., Zhao, G. (2018) Selective catalytic two-electron O<sub>2</sub> reduction for onsite efficient oxidation reaction in heterogeneous electro-Fenton process. *Chemical Engineering Journal*, 332: 486-498
- [21] Huisman, J.L., Schouten, G., Schultz, C. (2006) Biologically produced sulphide for purification of process streams, effluent treatment and recovery of metals in the metal and mining industry. *Hydrometallurgy*, 83: 106-113
- [22] Özverdi, A., Erdem, M. (2006) Cu<sup>2+</sup>, Cd<sup>2+</sup> and Pb<sup>2+</sup> adsorption from aqueous solutions by pyrite and synthetic iron sulphide. *Journal of Hazardous Materials*, 137(1):626–632
- [23] González-Muñoz, M.J., Rodríguez, M.A., Luquea, S., Álvarez, J.R. (2006) Recovery of heavy metals from metal industry waste waters by chemical precipitation and nanofiltration. *Desalination*, 200: 742-744
- [24] Ihsanullah. Abbas, A., Al-Amer, A. M., Laoui, T., Al-Marri, M. J., Nasser, M. S., Khraisheh, M., Atieh, M.A. (2016) Heavy metal removal from aqueous solution by advanced carbon nanotubes: Critical review of adsorption applications. *Separations & Purification Technology*, 157:141-161
- [25] Rao, G.P. Lu, C., Su, F. (2007) Sorption of divalent metal ions from aqueous solution by carbon nanotubes: a review. *Separations & Purification Technology*, 58: 224-231
- [26] Petrie, B., McAdam, E.J., Richards, K.H., Lester, J.N., Cartmell, E. (2013) Application of ultra-performance liquid chromatography-tandem mass spectrometry for the determination of steroid oestrogens in wastewaters. *Int. J. Environ. Anal. Chem*, 93: 1343-1355,
- [27] Hillebrand, O., Musallam, S., Scherer, L., Nödler, K. Licha, T. (2013) The challenge of sample-stabilisation in the era of multi-residue analytical methods: a practical guideline for the stabilisation of 46 organic micropollutants in aqueous samples. *Sciences of the Total Environment*. 454-455: 289-298
- [28] Petrie, B., Barden, R., Kasprzyk-Hordern, B. (2015) A review on emerging contaminants in wastewaters and the environment: Current knowledge, understudied areas and recommendations for future monitoring. *Water Research*, 72:3-27
- [29] Lam, M.W., Mabury, S.A. (2005) Photodegradation of the pharmaceuticals atorvastatin, carbamazepine, levofloxacin, and sulfamethoxazole in natural waters. *Aquatic Science*, 67: 177-188
- [30] Tran, N., Drogui, P., Brar, S.K., De, C.A. (2017) Synergistic effects of ultrasounds in the sonoelectrochemical oxidation of pharmaceutical carbamazepine pollutant 34: 380-388
- [31] Exposito, A.J., Patterson, D.A., Monteagudo, J.M., Duran, A. (2017) Sono-photo-degradation of carbamazepine in a thin falling film reactor: operation costs in pilot plant. *Ultrasonics*

Sonochemistry, 34: 496-503

- [32] Zupanc, M., Kosjek, T., Petkovšek, M., Dular, M., Kompare, B., Širok, B., Blazeka, Z. (2013) Ester Heath, removal of pharmaceuticals from wastewater by biological processes, hydrodynamic cavitation and UV treatment. *Ultrasonics Sonochemistry*, 20:1104–1112
- [33] Thanekar, P., Panda, M., Gogate, P. R. (2018) Degradation of carbamazepine using hydrodynamic cavitation combined with advanced oxidation processes. *Ultrasonics Sonochemistry*, 40:567-576