Applications of Biological Magnetic Effects in Water Treatment

Li Tianhang\textsuperscript{1a}, Jia Xinqiang\textsuperscript{2}, Wang Xiaoyu\textsuperscript{1}, Yu Cong\textsuperscript{1} and Wang Jiabin\textsuperscript{1b}

1 School of Architecture and Civil Engineering, University of Jinan, Jinan, China
2 IOP Publishing SAES Environmental Science and Science and Technology Co., Ltd., Jinan, China
E-mail: a 474386519@qq.com; corresponding author: b cea_wangjb@ujn.edu.cn

Abstract. In order to enhance the efficiency of wastewater treatment, magnetic field is usually used to promote microbial activity, and it has become a novel water treatment technology. In this paper, the biological magnetic effect in water treatment are systematically and logically reviewed with respect of mechanisms and applications. The major problems existing in the current magnetic field strengthening technology are pointed out, and the promising application of the biological magnetic effect in water treatment is prospected.

1. Introduction
Recently, serious pollutions of water environment attract more attentions. One of the general water treatment technology is aerobic biological treatment, but with disadvantages of low volume load and unstable treatment efficiency. Aiming at these disadvantages, magnetic field was introduced and it could affect the growth and metabolic activity of microbes, which is called the biological magnetic effect\textsuperscript{[1]-[3]} and is expected to improve the volume load of traditional biological treatment technology and improve its ability to resist impact load\textsuperscript{[4]-[5]}. The issues in the applications of the biological magnetic effect have been paid much attention in the scientific fields of water treatment. This novel water treatment technology based on the biological magnetic effect have a good application potential.

2. Current Research in the Biological Magnetic Effect
There are various forms of biological magnetic effects in water treatment. They often reflected through the rate of biological metabolism, the growth cycle, the treatment efficiency of the characteristic pollutants, and the form of the biological enrichment rate.

2.1. Roles of Magnetic Field in Microorganism Sensitivity
Xing Yicun\textsuperscript{[6]} studied the growth and metabolism of microbes under the condition of low frequency magnetic field. The study found that the sensitivity of different microbes to the magnetic field was different. The growth and reproduction of microorganism can be promoted or suppressed under the same magnetic field. By comparing the effects of different intensity magnetic fields on the growth of microorganisms, Li Jie and others\textsuperscript{[7]} found that: 100 mT field strength showed a positive effect on actinomycetes and fungi, while 100 mT field strength showed an inhibitory effect on the growth of bacteria. However, the number of soil microbes of different groups also increased in varying degrees under the effect of 300mT field strength.

2.2. Effects of the Biological Magnetic Effect on Metabolic Rate
Justo[8] in the extremely low frequency magnetic field under the condition of cultivation of Escherichia coli 1 ~ 12 hours, found the activity of Escherichia coli is 100 times of the group without magnetic field under the magnetic field strength of 0.1 T for 6.5 hours. And under the magnetic field intensity of 0.055T for 12 h, the maximum dry weight of Escherichia coli appeared, which indicated the growth rate of the fastest.

2.3. **Effects of the Biological Magnetic Effect on Pollutant Removal Efficiency**

ShiBo[9] investigated the start-up characteristics of the membrane of the reactor under the magnetic field intensity between 0-400Gs. The study found: 100Gs magnetic field can inhibit the growth of microorganisms and reduce the removal effect of organics; 200Gs, 260Gs and 320Gs magnetic field can improve the removal effect of organics. Among them, the 260Gs magnetic field has the greatest increase in the removal rate of organic matter, and the time required for the biofilm to achieve steady state operation is the shortest. Tu Ningyu[10] found that the magnetic field promoted the growth of the strain and the promotion became stable as the time of magnetization prolonged by studying the effect of magnetic field on a strain of copper bacteria. Xu Yanbin[11] [12] studied the colony size, bacterial density, the number of mixed bacteria and the effect of chromium removal of two anaerobic chromium removal bacteria (A, B) under different magnetic induction intensity (0 mT, 2.4 mT, 6 mT, 10 mT, 17.4 mT). The results showed that the magnetic field has a cumulative effect on the growth of microbes, and the biological magnetic effect is lagging, and the sensitivity of different strains to magnetic field intensity is also different. Under the magnetic induction intensity of 10 mT, two strains of anaerobic chromium removal showed inhibition of growth. Under the magnetic induction intensity of 6 mT, the colony of B bacteria reached the maximum, and the A bacteria showed the strongest adaptability. And A and B mixed bacteria (ratio 1 to 1) had the fastest propagation speed, and bacterial density increased by 65%. The removal rate of chromium is 36.17%, which is 8.84% higher than that of the unadded magnetic field.

2.4. **Mechanisms in the Biological Magnetic Effect**

Wang Hongshuo[13] et al investigated the effect of the extremely alternating magnetic field on the relative absorbance of the leaks in the cell and the DNA of the thalliEscherichia coli, staphylococcus aureus and yeast as experimental strains. The results showed that the two polar alternating magnetic fields could damage the cell wall of microorganism and change the structure of DNA. Gu Jiguang[14] studied the changes of catalase, pulse enzyme and polyphenol oxidase activity in soil microorganism under different magnetic field strength. The results showed that the effect of magnetic field intensity on soil microbial enzyme activity is also different. Han Qingxiang[15] and others studied the effect of magnetic field effect on water treatment. It was found that under medium magnetic field (below 50mT), the activity of microbial enzymes increased, and the processing efficiency increased by 11%. Coneracka[16] and others have found that if the proteins and enzymes are immobilized on the surface of the magnetic particles, the activity can be kept above 90% of the original activity. Wang Xiangan[17] determined the effect of magnetic treatment on dehydrogenase activity by measuring the decolorization time of methyl blue. It was found that the time needed for decolorization of methyl blue reduced from 29 hours to 24 hours with the increase of magnetic field intensity, indicating that magnetic treatment enhanced the ability of microorganism to oxidize pollutants. The main reason for improving the efficiency of water treatment by the biological magnetic effect is that the existence of magnetic field improves the activity of microbial enzyme.

3. **Applications of the Biological Magnetic Effect in Water Treatment**

3.1. **Applications of Biological Magnetic Effect in Activated Sludge Process**

Hulya Yawz and other [18] set the magnetic field outside the reactor of the activated sludge process to treat the simulated wastewater. It was found that the removal rate of organic pollutants was 44% higher than that in the non magnetic field. Geng Shuying [19] found that adding a magnetic field to SBR can improve the removal efficiency to a certain extent. When the magnetic field intensity is 700Gs, the total nitrogen removal rate is increased by 30.89%, and the abundance of the biological
community is also the highest. Lu Guangli[20] and other add the right amount of magnetic powder to the reflux sludge. The results showed that the removal rate of COD can be increased by about 15%, the structure of the sludge flocs and settling performance can be improved compared with the conventional activated sludge process. Sun Shuiyu and other [21] think that the effect of magnetic particle enhanced activated sludge process is better than the traditional activated sludge process. The removal rate of COD and turbidity is greatly improved, and the floc structure and sedimentation performance of sludge are improved obviously. Sui Weiyan[22] studied the effect of nitrogen and phosphorus removal under the conditions of magnetic field intensity of 1500Gs and 800Gs, respectively. The results showed that: COD, ammonia nitrogen and total phosphorus removal rate has improved to a certain extent in the two kinds of magnetic field intensity, and activated sludge under the action of 1500Gs magnetic field can rapidly improve the removal capacity of organic matter in the early stage of the experiment, and activated sludge under the action of 800Gs magnetic field can improve the removal ability of organic matter and phosphate.

Zhao Xiang [23] used magnetic flyash fillers in MBBR reactor for hanging film experiment. The results showed that magnetic fly ash fillers were better than non magnetic fly ash fillers in film-forming performance and pollutant removal efficiency of sewage, and the time of hanging film was shorter. Zhu Ling Li [24] quickly activated anammox reactor by adding magnetic particles. It was found that the activity of anammox bacteria was the strongest and the total nitrogen removal rate was the highest under the 0.78mT magnetic field intensity. Zhang Dong[25] put the new high-strength magnetic particles prepared into the self nutrient denitrification system, and studied the effect of magnetic field intensity on the enrichment rule and pollutant removal efficiency of anammox bacteria. The results showed that the start-up time of the reactor adding magnetic particles is shorter, and the removal rate of total nitrogen and ammonia is higher, and the abundance of the biological community is higher.

3.2. Application of the Biological Magnetic Effect in Biofilm Method

Pan Yongzhang[26] applied new magnetic carrier to biofilm reactor for experiment of wastewater treatment. It was found that the removal rate of COD and NH3-N in magnetic carrier biofilm reactor is 5% and 20% higher than that of non magnetic carrier. The amount of biofilm and the amount of suspended sludge in the magnetic carrier reactor is only 70% of the non magnetic carrier reactor, which indicated that the presence of magnetic field is more beneficial to sludge reduction. Wang Weisheng[27] compared the magnetic biological carbon filler and ordinary biochar biofilm performance and pollutant removal in BAF. It was found that the biofilm formation time of magnetic biochar BAF increased by 13.3% compared with the conventional biochar BAF. The removal rate of ammonia nitrogen and total phosphorus of magnetic biochar BAF was significantly higher than that of conventional biochar BAF, and the impact load was stronger. Li Chihao[28] developed an integrated magnetic filter based on A/O technology, and hung the membrane into two kinds of fillers, ordinary activated carbon filter and magnetic activated carbon filter in turn. It was found that the magnetic packing was higher than the ordinary filter at the speed of film hanging and the removal rate of COD and ammonia nitrogen. Jiao Fuqiang[29] prepared magnetic filter media and started the hanging film experiment under 6mT magnetic field strength. The removal efficiency of simulated sewage was studied under four conditions of 12mT, 20mT, 30mT and 40mT at room temperature and low temperature respectively. It was found that the magnetic field of 12mT has an inhibitory effect on the removal efficiency of the filter, and the removal rate of COD and NH3-N was reduced. Under the magnetic field intensity of 20mT, 30mT and 40mT, the magnetic field played a positive role in the removal effect of the filter. The average removal rate of COD increased by 4.23%, 8.41% and 3.87% respectively, and the average removal rate of ammonia nitrogen increased by 4.28%, 14.38% and 6.72%, respectively. The removal of phosphorus can be promoted under the magnetic field intensity of 12mT and 20mT and the removal of phosphorus was inhibited under the magnetic field intensity of 30mT and 40mT. Cheng Yangyang[30] used magnetic anaerobic biofilter to treat acid polynmetallic smelter wastewater. It was found that when the magnetic carrier dosage was 6g/L, the removal rates of COD, F- and Cd2+ in wastewater could reach 60%, 70% and 90%, respectively. Compared with anaerobic biological system without magnetic carriers, the removal rate of COD, F- and Cd2+...
increased by 7.84%, 7.37% and 1.32%, respectively. Jin Xiao Bei[31] immobilized the microorganism after acidity of acidic copper plating wastewater under the presence of magnetic field on the surface of magnetic carrier to treat acid copper plating wastewater. The results showed that the magnetic field had a significant effect on the immobilization of microbes and the removal of copper ions, but the magnetic field intensity needed was different. When the center magnetic field of the carrier is 260Gs, the fixed amount of microorganism is the largest. While the center of the carrier is 140Gs, the removal rate of copper ion is the highest

4. Conclusion
In summary, the water treatment process based on the biological magnetic effect are promising of water treatment with the advantages of high efficiency, without secondary pollution and low energy consumption. However, the mechanisms and process of the biological magnetic effect is still confused. Their key influencing factors should be determined and then optimized on account of biological growth. The behaviors and mechanisms in the biological magnetic effect promoting the degradation of characteristic pollutants should be further investigated.

5. References
[1] Xu Xilin, Guo Siyuan, Li Lin. Effect of Dynamic Magnetic Field on Microorganisms[J]. Journal of South China University of Technology.2006, (12):47-50.
[2] In vitro biological effects of magnetic nanoparticles[J]. Chinese Science Bulletin,2012,57(31):3972-3978.
[3] Chathurika, D.A., Peter, M.F., Malka, N.H. Analysis of biological effects and limits of exposure to weak magnetic fields[P]. Information and Automation for Sustainability (ICIAFs), 2010 5th International Conference on,2010.
[4] Yang Fang, Yao Cuang, Luo Huan. The effect of magnetic microorganism and its application in waste water treatment[J]. Pearl River. 2014,35(05):76-79.
[5] Bingrui Maac;Sen Wangb;Zhiwei Lia;Mengchun Gaoac .Magnetic Fe3O4 nanoparticles induced effects on performance and microbial community of activated sludge from a sequencing batch reactor under long-term exposure[J].Bioresource Technology,2017Vol.225: 377-385
[6] Xing Yicun,Zhou Yifan, Effects of low frequency magnetic fields on microorganisms[J].Journal of Hainan Normal University. 2001,(03):34-39.
[7] Li Jie, Yi Yanli, Jiao Ying. Effect of Magnetic Field on Soil Microbes and Soil EnzymeActivities in Brown Earth[J]. Chinese Journal of Soil Science. 2007,(05):957-961.
[8] Justo O R,Perez V H,Alvarez D C,et al.Growth of Escherichia coli under extremely low-frequency electromagnetic fields[J].AppliedBiochemistry and Biotechnology,2006,134:155~163.
[9] Shi Bo Study on the Effects of Low-intensity Steady Magnetic Field onWastewater Treatment with Biofilm Reactor[D]. Jinan University,2010
[10] Tu Ningyu. Study on the effect of magnetic powder on the treatment of heavy metal wastewater by biological method[D]. Guangdong University of Technology, 2004.
[11] Xu Yanbin, LI Xun, Sun Shuiyu. Effect of magnetic field on the growth of two strains ofanaerobic Cr(VI)-removing bacteria[J]. Electroplating&Finishing,2005,(07):46-49.
[12] Xu Yanbin, LI Xun, Sun Shuiyu. Effect of magnetic field on removal efficiency of Cr6+ in an ASBR[J]. Water Resources protection,2005,(04):26-29+46.
[13] Wang Hongshuo, Ye Shengyin, Song Xianliang, et al. Effect of two-pole alternating magnetic fields on microbes at the micro-level[J].Transactions of the CSAE, 2007,23(8): 253-256.
[14] Gu Jiguang, Zhou Qixing. Effects of Soil Magnetization on DefensiveEnzymes in Rape Plants[J]. Journal of basic science and Engineering,2002,10(3):263-267.
[15] Han Qingxiang, Shao Fengjin. The Increasing Effect of Magnetic Field on WastewaterTreatment by Activated Sludge Process[J]. Journal of Fushun Petroleum Institute ,2002,(03):8-10
[16] M. Koneraka, Kopcansky P, Antalik M et al. Immobilization of proteins and enzymes to finemagnetic particles. Journal of Magnetism and Magnetic Materials. 1999, 201(1): 427-430
[17] Wang Xiangsan, Wang Ping. Biological effects of magnetization in sewage treatment[J]. Environmental Science and Technology, 2000, (02): 33-36
[18] Hulya Yavuz, Serdar Swastewater treatment with celebrity. A typical application of magnetic field influenized bed biofilm reactor. Chen Eng Commun, 2003, 190: 5-8
[19] Geng Shuying, Fu Weizhang, Wang Jing. Treatment Efficiency and Microbial Community Diversity in a Magnetic Field Enhanced Sequencing Batch Reactor (SBR) [J]. Environmental Science, 2017, (11): 1-12
[20] Lu Guanli, Zhao Qingxiang. Investigation on the Ferromagnetic Powder Supplemented Activated Sludge Process Technology[J]. Urban environment and urban ecology. 1998,11(2): 10-12.
[21] Shuiyu, Liu Hong, Xie Guangyan, et al. A study on the treatment of restaurant wastewater by magnetic powder-intensified activated sludge process[J]. Environmental Pollution and Prevention, 2003, 25(3): 170-172.
[22] Sui Weiyan, Song peng, Han Tiantian. Contrastive Studies on Experiment of Activated Sludge Method Enhanced by Magnetic Field for Treating Urban Wastewater[J]. Journal of Anhui Agricultural Sciences, 2011, (33): 20469-20471+20540.
[23] Zhao Xiang, Membrane Experimental Study of Magnetic Fly Ash Ceramsite[J]. Guangdong chemical industry, 2017, (09): 36-38+63.
[24] Zhu LingLi. Magnetic Particles Induce Anammox bacteria Enrichment and the Autotrophic Nitrogen Removal System quickly Start[D]. University of Jinan, 2016
[25] Zhang Dong. Study on the Start up and Operating Characteristics of Autotrophic Nitrogen Removal Process Enhanced by NdFeB Magnetic Particle[D]. University of Jinan, 2017
[26] Pan Yongzhang, Zhang Zhiyong, Shi Bo. Domestic sewage treatment using a magnetic carrier bioreactor[J]. China Environmental Science, 2011, 31(05): 734-739.
[27] Wang Weisheng. Experimental investigation on municipal wastewater treatment by BAF packed with magnetic biochar[D]. Jiangsu University, 2016
[28] Li Chihao. A Dissertation Presented to Kunming University of Science and Technology for Master Degree of Engineering[D]. Kunming University of Science and Technology, 2015
[29] Jiao Fuqiang. The Magnetic Strengthen Biological Filter Building Based on The Microbial Magnetic and Its Application Research[D]. University of Jinan, 2016
[30] Cheng Yangyang. The characteristic analysis on disposal of acid multi-metal and organic smelting compositewastewater through the magnetism-anaerobicbiofilter[D]. Xiangtan University, 2014
[31] Jin Xiaobei, Chao Yunlong, Li Hongjun. Treatment of acid copper plating wastewater by magnetic combinedimmobilized microorganism technique[J]. Chinese Journal of Environmental Engineering, 2016, 10(03): 1041-1047.