

方知库
Eco-Environmental
Knowledge Web

环境科学

ENVIRONMENTAL SCIENCE

ISSN 0250-3301 CODEN HCKHDV
HUANJING KEXUE

冠状病毒气溶胶传播及环境影响因素

李雪, 蒋靖坤, 王东滨, 邓建国, 贺克斌, 郝吉明



■ 主办 中国科学院生态环境研究中心

■ 出版 科学出版社



2021年7月

第42卷 第7期
Vol.42 No.7

目次

冠状病毒气溶胶传播及环境影响因素	李雪, 蒋靖坤, 王东滨, 邓建国, 贺克斌, 郝吉明 (3091)
新冠肺炎疫情期间气象条件和排放变化对 PM _{2.5} 的影响	逯世泽, 史旭荣, 薛文博, 雷宇, 严刚 (3099)
基于网格的长三角 PM _{2.5} 分布影响因素及交互效应	黄小刚, 赵景波, 辛未冬 (3107)
ARIMA 时间序列分析模型在臭氧浓度中长期预报中的应用	李颖若, 韩婷婷, 汪君霞, 权维俊, 何迪, 焦热光, 吴进, 郭恒, 马志强 (3118)
中国长三角背景点冬季大气棕碳污染特征及来源解析	赵宇, 吴灿, 王益倩, 陈玉宝, 吕少君, 汪芳琳, 杜伟, 刘仕杰, 李志健, 王格慧 (3127)
四川盆地 PM _{2.5} 浓度时空变化特征遥感监测与影响因子分析	李梦真, 张廷斌, 易桂花, 秦岩宾, 李景吉, 刘贤, 蒋杰 (3136)
河网连续动态模型构建及其在典型杀虫剂时空迁移模拟中的应用	邢成, 张芊芊, 蔡雅雅, 烟晓婷, 应光国 (3147)
九龙江流域河流氮输出对土地利用模式和水文状况的响应	黄亚玲, 黄金良 (3156)
滇池近岸水体微塑料污染与富营养化的相关性	袁海英, 侯磊, 梁启斌, 李佳琛, 任甲 (3166)
白洋淀夏季入淀区沉积物间隙水-上覆水水质特征及交换通量分析	张甜娜, 周石磊, 陈召莹, 张紫薇, 孙悦, 姚波, 崔建升, 李再兴, 罗晓 (3176)
镇江市古运河和金山湖河湖上覆水体和沉积物氮及有机质分布特征及污染评价	原璐彬, 邢书语, 刘鑫, 周晓红, Adelaide Angela Dadzie (3186)
洪湖国际重要湿地沉积物磷空间分布特征及释放风险	刘永九, 黄素珍, 张璐, 彭雪, 张心怡, 葛芳杰, 刘碧云, 吴振斌 (3198)
苏州古城区域河道底泥的重金属污染分布及生态风险评价	白冬锐, 张涛, 包峻松, 陈坦, 王洪涛, 金曦, 金军, 杨婷 (3206)
武汉集中式饮用水源地土壤重金属的时空分布特征及生态风险评价	朱静, 侯耀宗, 邹书成, 曹梦华, 涂书新 (3215)
升金湖湖交汇区地表-地下水水化学特征及成因分析	崔玉环, 王杰, 刘友存, 郝洸, 高祥 (3223)
青岛市农区地下水硝态氮污染来源解析	寇馨月, 丁军军, 李玉中, 毛丽丽, 李巧珍, 徐春英, 郑欠, 庄姗 (3232)
三峡库区支流浮游植物群落稳定性及其驱动因子分析	何书晗, 欧阳添, 赵璐, 纪璐璐, 杨安琪, 施军琼, 吴忠兴 (3242)
哈尔滨城市河网丰水期浮游植物群落分布特征及驱动因子	路枫, 李磊, 齐青松, 陆欣鑫, 刘妍, 范亚文 (3253)
湖泊沉积物中微生物群落对天然有机质输入的响应	居琪, 章奇, 曹驰程, 白雷雷, 张晖 (3263)
补给水质与社会活动对白洋淀湿地微生物的影响特征	赵志瑞, 吴会清, 毕玉方, 展庆周, 吴海森, 袁凯悦, 孟祥源, 李方红 (3272)
蓝藻衰亡过程中上覆水溶解性有机物变化特征	李翔, 李致春, 汪旋, 张思远, 王慧敏, 厉荣强, 王国祥, 李启蒙 (3281)
长江下游快速城市化地区水污染特征及源解析:以秦淮河流域为例	马小雪, 龚畅, 郭加汛, 王腊春, 徐蕴韵, 赵春发 (3291)
长江下游居民区降水地表径流的污染特征	郭文景, 张志勇, 闻学政, 张瀚文, 王岩 (3304)
潮河流域降雨径流事件污染物输出特征	包鑫, 江燕, 胡羽聪 (3316)
不透水地表粗糙度对城市面源颗粒物的累积和冲刷影响	单溪环, 谢文霞, 廖云杰, 房志达, 杨晓晶, 苏静君, 赵洪涛, 李叙勇 (3328)
基于概率方法的中国居民饮水途径暴露健康风险评估	秦宁, 刘运炜, 侯荣, 王彩云, 王贝贝, 段小丽 (3338)
蛋白类有机质在水厂各处理单元中的去除特性	李梦雅, 宋钰莹, 张晓岚, 黄海鸣 (3348)
污水处理厂不同单元工艺水中重金属及其纳米颗粒的分布	王杜珈, 何帅, 周小霞 (3358)
基于宏基因组技术分析 MBR 膜清洗后污泥中抗性基因	杜彩丽, 李中涵, 李晓光, 张列宇, 陈素华, 黎佳茜, 李曹乐 (3366)
石化废水处理厂中耐药菌和耐药基因的分布特征与去除效能解析	唐振平, 肖莎莎, 段毅, 刘迎九, 高媛媛, 吴月月, 陈怡雯, 周帅 (3375)
一段式亚硝化厌氧氨氧化 SMBBR 处理中低浓度氨氮废水	吕恺, 邵贤明, 王康舟, 姚雪薇, 彭党聪, 韩芸 (3385)
外加固体缓释碳源的两段反硝化工艺脱氮性能	唐义, 马懿文, 王金泉, 王艳, 叶刚 (3392)
臭氧投量对 SBR 系统污泥沉降性能及脱氮除磷的影响	吕永涛, 朱传首, 张旭阳, 徐超, 潘永宝, 刘爽, 崔双科, 王磊 (3400)
间歇梯度曝气下首段延时厌氧强化好氧颗粒污泥脱氮除磷	张玉君, 李冬, 王歆鑫, 张富国, 张杰 (3405)
提盐速率对序批式生物反应器性能和微生物群落结构的影响	古铂铭, 金春姬, 温淳, 侯金源, 赵阳国, 高孟春 (3413)
低温驯化对自养脱氮颗粒污泥功能活性与菌群结构的影响分析	钱飞跃, 刘雨馨, 王建芳, 刘文如 (3422)
矿渣基改性剂对城市污泥重金属稳定化	张发文, 董明坤, 陈辰慧, 赵长民 (3430)
2000~2018 年长三角土地利用变化对农田生态系统氮排放的影响	王文锦, 王卿, 朱安生, 黄凌, 顾莹, 王杨君, 王敏, 李莉 (3442)
麦秸水热炭及其改良产物对水稻产量和稻田氮挥发排放的影响	韩晨, 侯朋福, 薛利红, 冯彦房, 余姗, 杨林章 (3451)
水肥管理对热带地区双季稻田 CH ₄ 和 N ₂ O 排放的影响	李金秋, 邵晓辉, 缙广林, 邓艺欣, 谭诗敏, 徐文娟, 杨秋, 刘文杰, 伍延正, 孟磊, 汤水荣 (3458)
耐盐碱水稻土壤产甲烷菌群落特征及产甲烷途径	杨雨虹, 贺惠, 米铁柱, 刘玥腾, 刘佳音, 张国栋, 李明月, 甄毓 (3472)
铁碳微电解填料对人工湿地温室气体排放的影响	赵仲婧, 郝庆菊, 涂婷婷, 胡曼利, 张尧钰, 江长胜 (3482)
农地土壤重金属 Pb 和 Cd 有效性测定方法的筛选与评价	陈莹, 刘汉燚, 刘娜, 蒋珍茂, 魏世强 (3494)
亚热带高山森林土壤典型重金属的空间分布格局及其影响因素:以云南哀牢山为例	刘旭, 王训, 王定勇 (3507)
深圳市不同土类的重金属环境背景值与理化性质特征	林挺, 赵述华, 郝秀平, 杨坤, 吴静雅, 朱艳, 罗飞 (3518)
同步钝化土壤 Cd 和 As 材料的筛选	周嗣江, 刘针延, 熊双莲, 马烁, 黄倚豪, 雷寅, 曹梦华, 涂书新 (3527)
两种铁基材料对污染农田土壤砷、铅、镉的钝化修复	袁峰, 唐先进, 吴骥子, 赵科理, 叶正钱 (3535)
青藏高原东缘冻土中有机磷酸酯的污染特征	刘丽娅, 印红玲, 蹇林洁, 徐子文, 熊远明, 罗怡, 刘小雯, 徐维新 (3549)
成都平原氮磷化肥施用强度空间分布及影响因素分析	刘奇鑫, 王昌全, 李冰, 赵海岚, 方红艳, 邓茜, 李启权 (3555)
土壤中溶解性有机质对不同类型堆肥的响应差异	席北斗, 王燕, 檀文炳, 余红, 崔东宇, 程东会, 党秋玲 (3565)
《环境科学》征订启事 (3315)	
《环境科学》征稿简则 (3357)	
信息 (3391, 3441, 3564)	

臭氧投量对 SBR 系统污泥沉降性能及脱氮除磷的影响

吕永涛^{1,2,3}, 朱传首^{1,2,3}, 张旭阳^{1,2,3}, 徐超^{1,2,3}, 潘永宝⁴, 刘爽⁴, 崔双科⁴, 王磊^{1,2,3*}

(1. 西安建筑科技大学环境与市政工程学院, 西安 710055; 2. 陕西省环境工程重点实验室, 西安 710055; 3. 陕西省膜分离技术研究院, 陕西省膜分离重点实验室, 西安 710055; 4. 陕西省现代建筑设计研究院, 西安 710024)

摘要: 以污水厂冬季膨胀期污泥($SVI = 280 \text{ mL} \cdot \text{g}^{-1}$)为对象,研究了臭氧投量对 SBR 系统污泥沉降性能及脱氮除磷效果的影响。结果表明,低浓度投加臭氧($0.085 \text{ g} \cdot \text{g}^{-1}$,以 O_3/MLSS 计)20 d 后,菌丝体被打断, SVI 降至 $125 \text{ mL} \cdot \text{g}^{-1}$,消除了污泥膨胀,且硝化、除磷效果不受影响。高浓度投加臭氧,污泥的沉降性能反而开始恶化,除磷效率也降至 60% 左右。进一步研究表明,PS/PN 与 SVI 呈正相关关系($R^2 = 0.9381$),可表征污泥的沉降性能;臭氧除打断菌丝体外,还通过改变 EPS 的含量及组分影响着污泥的沉降性能。

关键词: 膨胀期污泥; 臭氧投量; 污泥沉降性能; 脱氮除磷; 胞外聚合物

中图分类号: X703 文献标识码: A 文章编号: 0250-3301(2021)07-3400-05 DOI: 10.13227/j.hjxx.202012051

Effect of Ozone Dosage on Sludge Settleability and Biological Nutrient Removal in SBR System

LÜ Yong-tao^{1,2,3}, ZHU Chuan-shou^{1,2,3}, ZHANG Xu-yang^{1,2,3}, XU Chao^{1,2,3}, PAN Yong-bao⁴, LIU Shuang⁴, CUI Shuang-ke⁴, WANG Lei^{1,2,3*}

(1. School of Environmental and Municipal Engineering, Xi'an University of Architecture and Technology, Xi'an 710055, China; 2. Shaanxi Key Laboratory of Environmental Engineering, Xi'an 710055, China; 3. Key Laboratory of Membrane Separation of Shaanxi Province, Research Institute of Membrane Separation Technology of Shaanxi Province, Xi'an 710055, China; 4. Shaanxi Modern Architecture Design & Research Institute, Xi'an 710024, China)

Abstract: The effect of ozone dosage on sludge settleability and biological nutrient removal performance in a sequencing batch reactor was investigated by inoculating the bulking sludge with the SVI of $280 \text{ mL} \cdot \text{g}^{-1}$ from a wastewater treatment plant in winter. The filamentous mycelium was interrupted, and the SVI was decreased to $125 \text{ mL} \cdot \text{g}^{-1}$ after ozone dosage with a low concentration of $0.085 \text{ g} \cdot \text{g}^{-1}$ (O_3/MLSS) for 20 days, which indicated the disappearance of the sludge bulking. The performance of nitrification and phosphorus removal efficiency was not affected obviously. However, the sludge settleability deteriorated with a high dosage of ozone, and the phosphorus removal efficiency was decreased to around 60%. Further study showed that PS/PN had a positive correlation with SVI with the correlation coefficient of 0.9381, which can be used to characterize sludge settleability. A low ozone dosage not only interrupted the filamentous mycelium, but it also affected the content and composition of the EPS, which led to improved settleability.

Key words: bulking sludge; ozone dosage; sludge settleability; biological nitrogen and phosphorus removal; extracellular polymeric substances

污泥膨胀是活性污泥系统常见的运行问题之一,不仅导致污泥流失,影响水处理效果,还影响剩余污泥处理,严重时使整个处理系统瘫痪^[1~4]。

投加次氯酸钠等氧化剂能有效消除污泥膨胀^[5,6],同样具有氧化作用且不产生二次污染的臭氧对污泥沉降性能的影响备受关注^[7,8]。Nilsson 等^[9]对污水厂回流污泥投加臭氧时发现,不仅可消除污泥膨胀,还能降低污泥沉降指数($\text{sludge volume index, SVI}$);刘振超等^[10]的研究发现,低温条件下臭氧能抑制丝状菌生长,改善污泥的絮体结构。但臭氧改善污泥沉降性能的机制尚不清楚,且对系统处理效果的影响有待进一步研究。

本研究接种膨胀期污泥,采用 SBR 反应器分析了臭氧投量对污泥沉降性能及脱氮除磷效果的影

响,并探索了相关机制,旨在为臭氧改善污泥沉降性能的工程应用提供理论依据。

1 材料与方法

1.1 试验装置和设备

采用 SBR 反应器,有效容积 3 L,排水比 0.33。每天运行 4 周期,单周期 6 h,具体为:进水 5 min,搅拌 300 min,曝气搅拌 120 min,沉淀 50 min,排水 5 min。采用微孔曝气并磁力搅拌。室温条件运行,水温为 $12 \sim 23^\circ\text{C}$ 。

收稿日期: 2020-12-07; 修订日期: 2021-01-04

基金项目: 陕西省重点研发计划项目(2020SF-415); 陕西省重点科技创新团队计划项目(2017KCT-19-01); 陕西省技术创新引导专项(2018HJCG-18)

作者简介: 吕永涛(1980~),男,博士,副教授,主要研究方向为污水处理与资源化,E-mail: hybos2000@126.com

* 通信作者,E-mail: wl0178@126.com

1.2 污泥来源和试验用水

种泥取自西安市某污水处理厂,为冬季膨胀期污泥. 接种后反应器中初始污泥浓度为 $4\,500\text{ mg}\cdot\text{L}^{-1}$ 左右,泥龄控制为 15 d 左右.

试验用水人工配制,由乙酸钠、氯化铵、磷酸二氢钾、碳酸氢钠和微量元素组成. 进水 COD 为 $400\sim 450\text{ mg}\cdot\text{L}^{-1}$,氨氮为 $40\sim 50\text{ mg}\cdot\text{L}^{-1}$,总磷(TP)为 $6\sim 8\text{ mg}\cdot\text{L}^{-1}$. 另外,微量元素按文献[11]配制,投加量为 $1\text{ mL}\cdot\text{L}^{-1}$.

1.3 试验方案

每天投加臭氧 1 次,沉淀初始 3 min 内将臭氧发生器(型号 HW-XS-3G)接入微孔曝气头,持续通入 60 s,通过流量计控制臭氧投加量(以 O_3/MLSS 计,下同)分别为 0.085 、 0.17 和 $0.34\text{ g}\cdot\text{g}^{-1}$. 尾气用碘化钾溶液吸收,不同投加量连续运行 60 d.

1.4 分析方法

常规指标按标准方法^[12]测定:COD 采用重铬酸钾法;总磷采用过硫酸钾-钼锑抗分光光度法;氨氮采用纳氏试剂分光光度法;VSS 采用马弗炉燃烧减重法.

采用热处理法提取胞外聚合物(extracellular polymeric substances, EPS)^[13]:多糖(polysaccharides, PS)采用蒽酮比色法测定,蛋白质(protein, PN)采用福林酚比色法测定. 利用尼康 50i 显微镜对污泥形态进行镜检.

2 结果与讨论

2.1 臭氧投量对 SBR 系统污泥沉降性能的改善

接种污泥的 SVI 为 $280\text{ mL}\cdot\text{g}^{-1}$,为膨胀期污泥,本文研究了不同臭氧投加量对系统 SVI 和污泥浓度的影响,结果见图 1.

由图 1 可见,臭氧投加($0.085\text{ g}\cdot\text{g}^{-1}$)3 d 后,SVI 开始迅速下降,到第 20 d 时降至 $125\text{ mL}\cdot\text{g}^{-1}$,消除了污泥膨胀. 之后,稳定在 $110\sim 130\text{ mL}\cdot\text{g}^{-1}$.

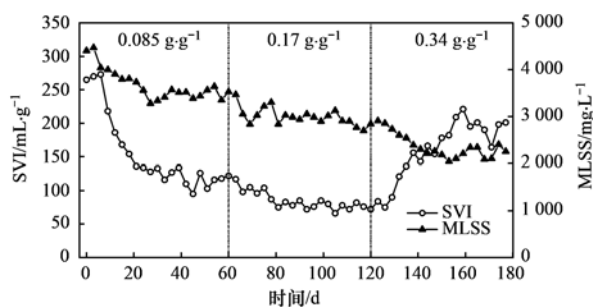


图 1 SVI 和 MLSS 随臭氧投加量的变化规律

Fig. 1 Variation in SVI and MLSS with ozone dosage

当臭氧投量升至 $0.17\text{ g}\cdot\text{g}^{-1}$ 时,初始 20 d 内(第 60~80 d)SVI 继续降至 $75\text{ mL}\cdot\text{g}^{-1}$,之后稳定在 $80\text{ mL}\cdot\text{g}^{-1}$ 左右. 当臭氧进一步升至 $0.34\text{ g}\cdot\text{g}^{-1}$ (第 120 d 后)时,SVI 反而开始升高,污泥沉降性能开始变差,SVI 最大值为 $210\text{ mL}\cdot\text{g}^{-1}$.

投加臭氧后,部分微生物被杀死并洗选出反应器,导致污泥浓度有所降低,当投量为 0.085 和 $0.17\text{ g}\cdot\text{g}^{-1}$ 时,基本稳定在 $2\,500\sim 3\,000\text{ mg}\cdot\text{L}^{-1}$; 当进一步加大投量后,污泥浓度继续降至 $2\,000\text{ mg}\cdot\text{L}^{-1}$ 左右,因为过量投加氧化剂会进一步杀死菌胶团细菌导致污泥减量^[14~16].

综上,低浓度臭氧投加可迅速消除污泥膨胀现象,投加量增大后,反而会使 SVI 升高.

2.2 臭氧改善污泥沉降性能的机制

2.2.1 臭氧投加对污泥形态的影响

图 2 显示了臭氧投加前后的污泥形态.

从图 2 中可见,接种污泥结构疏松[图 2(a)],丝状菌含量多,菌丝长,相互缠绕. 投加臭氧 20 d 后[图 2(b)],丝状菌的菌丝变短,相互不再缠绕,因为与絮体污泥相比,氧化剂更易作用于形态较长的菌丝体^[17],因而打断菌丝能消除污泥膨胀,使絮体结构紧实^[18].

2.2.2 臭氧投加对 EPS 的影响

EPS 在一定程度上影响着污泥的沉降性能,对

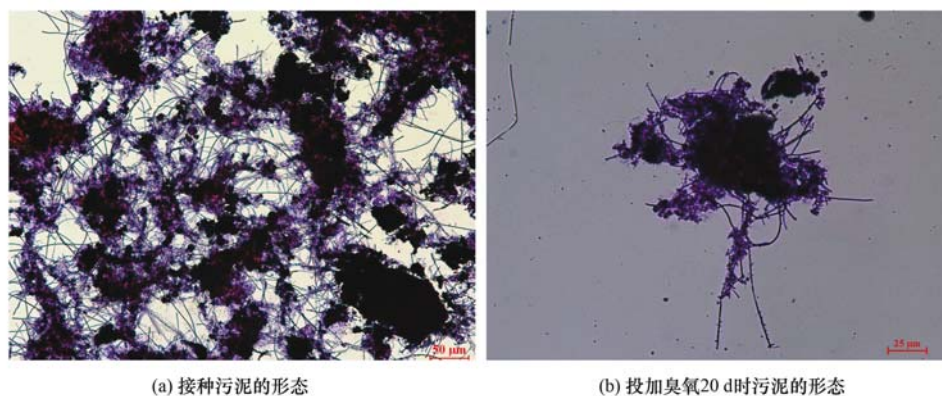


图 2 投加臭氧对污泥形态的影响

Fig. 2 Effect of ozone on sludge morphology

不同臭氧投加阶段的 EPS、PS 和 PN 进行测定,结果见图 3.

由图 3 可知, EPS 随时间呈先降后升的趋势,与 SVI 变化一致. 臭氧投量较低 ($0.085 \text{ g} \cdot \text{g}^{-1}$ 和 $0.17 \text{ g} \cdot \text{g}^{-1}$) 时, EPS、PS 和 PN 的含量(分别以 EPS/VSS、PS/VSS 和 PN/VSS 计,下同)均随时间呈降低趋势,分别由 125、75 和 $50 \text{ mg} \cdot \text{g}^{-1}$ 左右降至 88、48 和 $40 \text{ mg} \cdot \text{g}^{-1}$. 当进一步提高臭氧投量至 $0.34 \text{ g} \cdot \text{g}^{-1}$ 时,三者反而分别升至 127、74 和 $53 \text{ mg} \cdot \text{g}^{-1}$.

为了进一步探索 EPS 与污泥沉降性能间的相关关系,分别将 EPS、PS/PN 与 SVI 之间的数据进行处理,结果如图 4 所示.

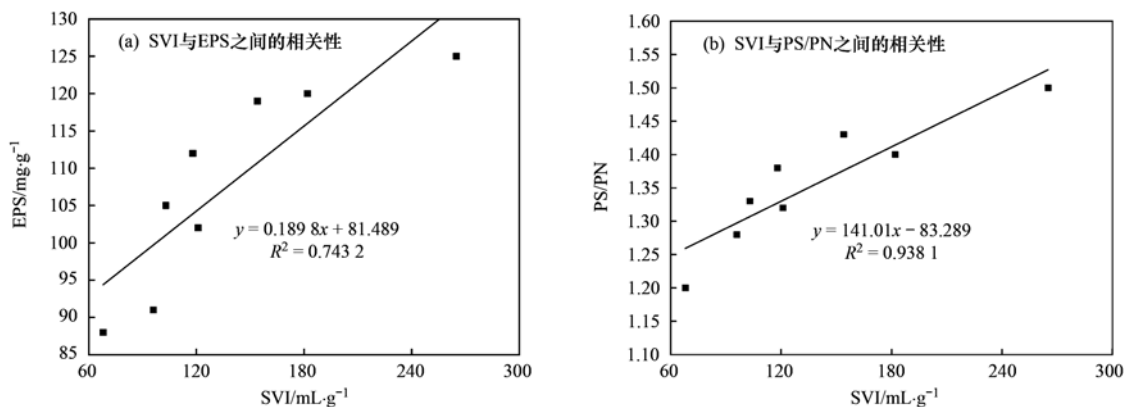


图 4 SVI 与 EPS 及 PS/PN 之间的相关性

Fig. 4 Correlation between SVI, EPS, and PS/PN

由图 4(a)可知, EPS 总量与 SVI 值变化呈正相关关系, R^2 为 0.7432, 即 EPS 含量越高污泥沉降性能越差. 因为 EPS 与菌胶团结合较疏松, 其总量增加导致活性污泥变得松散^[19,20]. 同时, EPS 内部的密实凝胶结构会截留大量水分^[20~22], 降低了污泥与水之间的密度差, 从而增加污泥沉降的难度.

由图 4(b)可知, PS/PN 值与 SVI 值也呈正相关关系, 相关系数高达 0.9381, 可用于表征污泥的沉降性能. 由于 PN 多以疏水键为主, 而 PS 多以亲水基团为主^[21~23], 因此, PS/PN 值越大, 亲水性基团越多, 污泥沉降性能越差. 据拟合结果, 当比值大于 1.4 时, SVI 将大于 $180 \text{ mL} \cdot \text{g}^{-1}$.

综上, 除打断菌丝体外, 臭氧影响着 EPS 的含量及其组成, 低投量条件下, EPS 含量及 PS/PN 值的降低是污泥沉降性能改善的原因; 高投加量后, EPS 及 PS 占比的升高导致污泥沉降性能恶化.

2.3 臭氧投量对 SBR 系统脱氮除磷性能的影响

不同臭氧投量对 SBR 系统 COD、氨氮和总磷去除性能的影响见图 5.

由图 5 可知, 不同投量条件下, 出水 COD 浓度均维持在 $20 \sim 50 \text{ mg} \cdot \text{L}^{-1}$ 之间, 去除率均高于 90%.

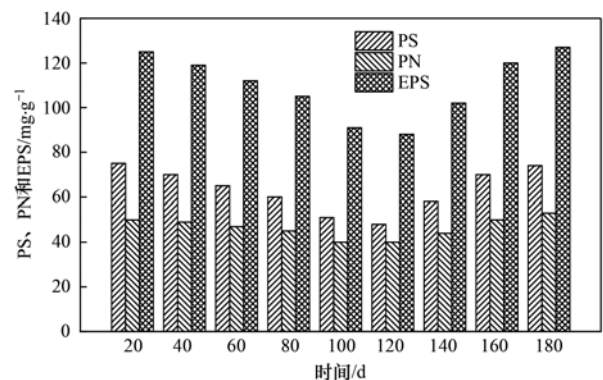


图 3 投加臭氧后 EPS 及各组分的变化关系

Fig. 3 Variation of the EPS and its components after ozone dosage

投加臭氧初始 20 d 内, 出水氨氮浓度略有上升, 之后, 稳定在 $3 \text{ mg} \cdot \text{L}^{-1}$ 以下, 去除率在 95% 以上. 故臭氧投加对除碳和硝化的效果影响不大.

随着臭氧投量的升高, 总磷的去除率呈下降的趋势: $0.085 \text{ g} \cdot \text{g}^{-1}$ 时, 出水总磷在 $0.5 \text{ mg} \cdot \text{L}^{-1}$ 以下, 去除率大于 92%; $0.17 \text{ g} \cdot \text{g}^{-1}$ 时, 去除率降至 75%~92%; 进一步升至 $0.34 \text{ g} \cdot \text{g}^{-1}$ 时, 除磷率大幅降至 60%.

臭氧会优先作用于丝状菌, 膨胀现象消除后, 进一步杀死菌胶团细菌, 杀死的微生物含有磷, 并以 SS 的形式流出反应器, 导致污泥浓度不断降低(见图 1), 并使出水总磷浓度上升, 除磷效率大幅下降. 而本系统氨氮负荷仅为 $0.03 \text{ kg} \cdot (\text{kg} \cdot \text{d})^{-1}$, 即本系统对硝化要求较低, 因此, 臭氧氧化对少量硝化菌的抑制尚未影响到硝化效果.

投加次氯酸钠等氧化剂也能有效消除污泥膨胀^[5,6,17,24], 且该方法相对简单, 配制一定浓度药剂加至生物池或沉淀池即可, 但会产生消毒副产物等新污染物^[25]. 臭氧投加需要新增制臭氧设备并投加至回流污泥管道, 该方法虽相对复杂, 但不会引入新污染物, 在水环境保护日趋严格的背景下, 提供了一种可选择的方法.

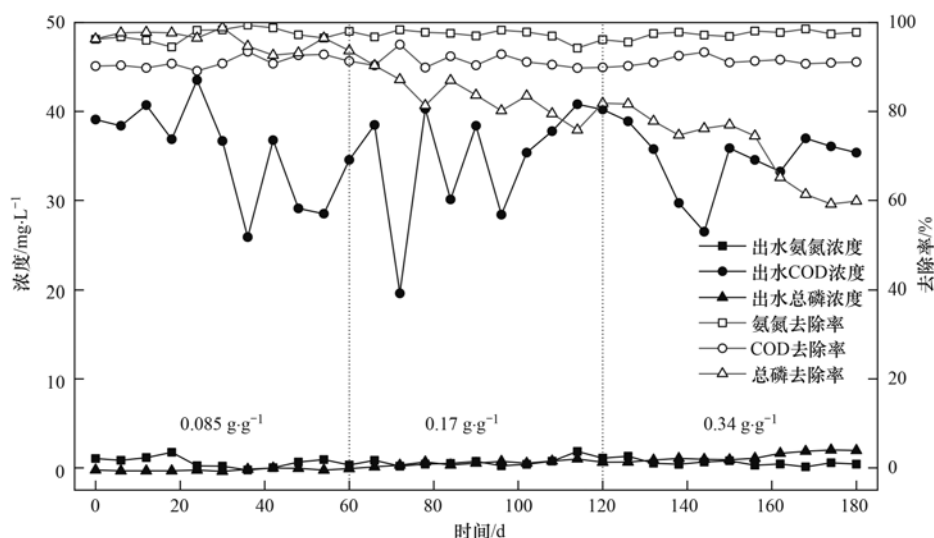


图5 臭氧投量对 SBR 系统处理效果的影响

Fig. 5 Effect of ozone dosage on SBR pollutants removal performance

3 结论

(1) 低浓度投加臭氧可在较短时间内消除污泥膨胀, 且不影响除碳、硝化与除磷的效果; 高浓度臭氧会杀灭更多菌胶团细菌, 并以 SS 形式流出反应器, 导致除磷效率大幅下降。

(2) 投加臭氧除能打断菌丝体消除污泥膨胀外, 还通过改变 EPS 含量及组分进而影响着污泥的沉降性能, 低浓度臭氧降低了 EPS 含量以及亲水性基团为主的 PS 占比, 从而改善了污泥的沉降性能。

参考文献:

- [1] Fan N S, Wang R F, Qi R, *et al.* Control strategy for filamentous sludge bulking: bench-scale test and full-scale application[J]. *Chemosphere*, 2018, **210**: 709-716.
- [2] Fan N S, Qi R, Huang B C, *et al.* Factors influencing *Candidatus Microthrix parvicella* growth and specific filamentous bulking control: a review[J]. *Chemosphere*, 2020, **244**, doi: 10.1016/j.chemosphere.2019.125371.
- [3] Liu R Y, Qi R, Wang J, *et al.* Phage-host associations in a full-scale activated sludge plant during sludge bulking[J]. *Applied Microbiology and Biotechnology*, 2017, **101**(16): 6495-6504.
- [4] Fiałkowska E, Pajdak-Stós A, Fyda J, *et al.* *Lecane tenuiseta* (Rotifera, Monogononta) as the best biological tool candidate selected for preventing activated sludge bulking in a cold season[J]. *Desalination and Water Treatment*, 2016, **57**(59): 28592-28599.
- [5] 陈琳凤, 王怡, 王若卿. 高浓度消毒剂对活性污泥系统中微生物的影响[J]. *中国给水排水*, 2020, **36**(9): 7-11.
- [6] 赵倩迪, 彭党聪, 姚倩, 等. 次氯酸钠控制城市污水处理厂微丝菌污泥膨胀[J]. *中国给水排水*, 2018, **34**(7): 21-25.
- [7] Zhao Q D, Peng D C, Yao Q, *et al.* Control of sludge bulking caused by *Microthrix parvicella* using sodium hypochlorite[J]. *China Water & Wastewater*, 2018, **34**(7): 21-25.
- [8] Lyko S, Teichgräber B, Kraft A. Bulking control by low-dose ozonation of returned activated sludge in a full-scale wastewater treatment plant[J]. *Water Science & Technology*, 2012, **65**(9): 1654-1659.
- [9] Nilsson F, Hagman M, Mieleczarek A T, *et al.* Application of ozone in full-scale to reduce filamentous bulking sludge at Öresundsverket WWTP[J]. *Ozone: Science & Engineering*, 2014, **36**(3): 238-243.
- [10] 刘振超, 李凤, 李倩. 低温下投加臭氧控制丝状菌膨胀的生产性试验研究[J]. *中国给水排水*, 2015, **31**(15): 35-39.
- [11] Liu Z C, Li F, Li Q. Effect of ozone on filamentous bulking under low temperature[J]. *China Water & Wastewater*, 2015, **31**(15): 35-39.
- [12] Scherson Y D, Wells G F, Woo S G, *et al.* Nitrogen removal with energy recovery through N_2O decomposition[J]. *Energy & Environmental Science*, 2013, **6**(1): 241-248.
- [13] 国家环境保护总局. 水和废水监测分析方法[M]. (第四版). 北京: 中国环境科学出版社, 2002. 258-284.
- [14] Liu J D, Ju X, Gao B, *et al.* Effect of electrocoagulation on MBR under different power supply conditions[J]. *Biochemical Engineering Journal*, 2019, **152**, doi: 10.1016/j.bej.2019.107371.
- [15] Böhler M, Siegrist H. Partial ozonation of activated sludge to reduce excess sludge, improve denitrification and control scumming and bulking[J]. *Water Science & Technology*, 2004, **49**(10): 41-49.
- [16] 汪鲁, 贲伟伟, 李彦刚, 等. 污泥臭氧原位减量工艺中抗生素的去除[J]. *环境科学*, 2018, **39**(4): 1739-1747.
- [17] Wang L, Ben W W, Li Y G, *et al.* Removal of antibiotics during in-situ sludge ozone-reduction process[J]. *Environmental Science*, 2018, **39**(4): 1739-1747.
- [18] Saktaywin W, Tsuno H, Nagare H, *et al.* Advanced sewage treatment process with excess sludge reduction and phosphorus recovery[J]. *Water Research*, 2005, **39**(5): 902-910.
- [19] 徐亚同, 黄民生. 废水生物处理的运行管理与异常对策[M]. 北京: 化学工业出版社, 2003. 148.
- [20] Xie B, Dai X C, Xu Y T. Cause and pre-alarm control of bulking and foaming by *Microthrix parvicella*—A case study in triple oxidation ditch at a wastewater treatment plant[J]. *Journal*

parvicella and sludge bulking by ozone in a full-scale WWTP[J]. *Water Science & Technology*, 2016, **73**(4): 866-872.

- of Hazardous Materials, 2007, **143**(1-2): 184-191.
- [19] 孙洪伟, 陈翠忠, 吴长峰, 等. 交替好氧/缺氧运行模式对生物脱氮效能及活性污泥胞外聚合物的影响[J]. 环境科学, 2018, **39**(1): 256-262.
- Sun H W, Chen C Z, Wu C F, *et al.* Influence of operating modes for the alternating anoxic/oxic process on biological nitrogen removal and extracellular polymeric substances of activated sludge[J]. Environmental Science, 2018, **39**(1): 256-262.
- [20] He Q L, Zhang J, Gao S X, *et al.* A comprehensive comparison between non-bulking and bulking aerobic granular sludge in microbial communities[J]. Bioresource Technology, 2019, **294**, doi: 10.1016/j.biortech.2019.122151.
- [21] 谢璐琳, 王建芳, 钱飞跃, 等. 室温低氨氮基质单级自养脱氮颗粒污泥启动效能与污泥特性[J]. 环境科学, 2019, **40**(3): 1396-1404.
- Xie L L, Wang J F, Qian F Y, *et al.* Start-up performance and sludge characteristics of single-stage autotrophic nitrogen removal System with granular sludge at low ammonia nitrogen concentration at room temperature[J]. Environmental Science, 2019, **40**(3): 1396-1404.
- [22] Li W M, Liao X W, Guo J S, *et al.* New insights into filamentous sludge bulking: The potential role of extracellular polymeric substances in sludge bulking in the activated sludge process[J]. Chemosphere, 2020, **248**, doi: 10.1016/j.chemosphere.2020.126012.
- [23] Sheng G P, Yu H Q, Li X Y. Extracellular polymeric substances (EPS) of microbial aggregates in biological wastewater treatment systems: a review[J]. Biotechnology Advances, 2010, **28**(6): 882-894.
- [24] 徐亚同, 谢冰. 废水生物处理的运行与管理[M]. (第二版). 北京: 中国轻工业出版社, 2009. 100.
- [25] 刘静, 陈超, 张晓健. 组合氯化消毒工艺的卤代消毒副产物生成特性[J]. 环境科学, 2009, **30**(9): 2538-2542.
- Liu J, Chen C, Zhang X J. Disinfection by-products reduction of combined disinfection by chlorine and monochloramines in distribution system[J]. Environmental Science, 2009, **30**(9): 2538-2542.



CONTENTS

Transmission of Coronavirus via Aerosols and Influence of Environmental Conditions on Its Transmission	LI Xue, JIANG Jing-kun, WANG Dong-bin, <i>et al.</i> (3091)
Impacts of Meteorology and Emission Variations on PM _{2.5} Concentration Throughout the Country During the 2020 Epidemic Period	LU Shi-ze, SHI Xu-rong, XUE Wen-bo, <i>et al.</i> (3099)
Factors and Their Interaction Effects on the Distribution of PM _{2.5} in the Yangtze River Delta Based on Grids	HUANG Xiao-gang, ZHAO Jing-bo, XIN Wei-dong (3107)
Application of ARIMA Model for Mid- and Long-term Forecasting of Ozone Concentration	LI Ying-ruo, HAN Ting-ting, WANG Jun-xia, <i>et al.</i> (3118)
Pollution Characteristics and Sources of Wintertime Atmospheric Brown Carbon at a Background Site of the Yangtze River Delta Region in China	ZHAO Yu, WU Can, WANG Yi-qian, <i>et al.</i> (3127)
Spatio-temporal Variation Characteristics Monitored by Remotely Sensed Technique of PM _{2.5} Concentration and Its Influencing Factor Analysis in Sichuan Basin, China	LI Meng-zhen, ZHANG Ting-bin, YI Gui-hua, <i>et al.</i> (3136)
Construction of Continuous Dynamic Model for River Networks and Its Application in Simulation of Spatiotemporal Migration of Typical Biocides	XING Cheng, ZHANG Qian-qian, CAI Ya-ya, <i>et al.</i> (3147)
Response of Riverine Nitrogen Exports to Land Use Pattern and Hydrological Regime in the Jiulong River Watershed	HUANG Ya-ling, HUANG Jin-liang (3156)
Correlation Between Microplastics Pollution and Eutrophication in the Near Shore Waters of Dianchi Lake	YUAN Hai-ying, HOU Lei, LIANG Qi-bin, <i>et al.</i> (3166)
Analysis of Water Quality and Exchange Flux of Interstitial Water-Overlying Water in Sediments of Baiyangdian Entrance Area in Summer	ZHANG Tian-na, ZHOU Shi-lei, CHEN Zhao-ying, <i>et al.</i> (3176)
Distribution Characteristics and Pollution Evaluation of Nitrogen and Organic Matter in Overlying Water and Sediment of Guyun River and Jinshan Lake in Zhenjiang City	YUAN Lu-bin, XING Shu-yu, LIU Xin, <i>et al.</i> (3186)
Spatial Distribution Characteristics of Phosphorus Fractions and Release Risk in Sediments of Honghu International Importance Wetland	LIU Yong-jiu, HUANG Su-zhen, ZHANG Lu, <i>et al.</i> (3198)
Pollution Distribution and Ecological Risk Assessment of Heavy Metals in River Sediments from the Ancient Town of Suzhou	BAI Dong-rui, ZHANG Tao, BAO Jun-song, <i>et al.</i> (3206)
Spatio-temporal Distribution Characteristic and Risk Assessment of Heavy Metals in Soils Around Centralized Drinking Water Sources in Wuhan	ZHU Jing, HOU Yao-zong, ZOU Shu-cheng, <i>et al.</i> (3215)
Hydro-chemical Characteristics and Ion Origin Analysis of Surface Groundwater at the Shengjin Lake and Yangtze River Interface	CUI Yu-huan, WANG Jie, LIU You-cun, <i>et al.</i> (3223)
Identifying the Sources of Groudwater NO ₃ ⁻ -N in Agricultural Region of Qingdao	KOU Xin-yue, DING Jun-jun, LI Yu-zhong, <i>et al.</i> (3232)
Analysis of Phytoplankton Community Stability and Influencing Factors in a Tributary of the Three Gorges Reservoir	HE Shu-han, OUYANG Tian, ZHAO Lu, <i>et al.</i> (3242)
Distribution Characteristics and Influencing Factors of Phytoplankton Community in Harbin Urban River Network During Wet Season	LU Feng, LI Lei, QI Qing-song, <i>et al.</i> (3253)
Response of Microbial Community to Natural Organic Matter Input in Lake Sediments	JU Qi, ZHANG Qi, CAO Chi-cheng, <i>et al.</i> (3263)
Effects of Water Supply Quality and Social Activity on the Microbial Community in Baiyangdian Wetland	ZHAO Zhi-rui, WU Hui-qing, BI Yu-fang, <i>et al.</i> (3272)
Characteristics of Dissolved Organic Matter in Overlying Water During Algal Bloom Decay	LI Xiang, LI Zhi-chun, WANG Xuan, <i>et al.</i> (3281)
Water Pollution Characteristics and Source Apportionment in Rapid Urbanization Region of the Lower Yangtze River: Considering the Qinhuai River Catchment	MA Xiao-xue, GONG Chang, GUO Jia-xun, <i>et al.</i> (3291)
Contamination Characteristics of Surface Runoff in Densely Populated Areas in Downstream Yangtze River, China	GUO Wen-jing, ZHANG Zhi-yong, WEN Xue-zheng, <i>et al.</i> (3304)
Characteristics of Pollutant Dynamics Under Rainfall-Runoff Events in the Chaohe River Watershed	BAO Xin, JIANG Yan, HU Yu-cong (3316)
Influence of Impervious Surface Roughness on Accumulation and Erosion of Urban Non-Point Source Particles	SHAN Xi-huan, XIE Wen-xia, LIAO Yun-jie, <i>et al.</i> (3328)
Probabilistic Risk Assessment of Arsenic Exposure Through Drinking Water Intake in Chinese Residents	QIN Ning, LIU Yun-wei, HOU Rong, <i>et al.</i> (3338)
Removal Behavior of Protein-like Dissolved Organic Matter During Different Water Treatment Processes in Full-Scale Drinking Water Treatment Plants	LI Meng-ya, SONG Yu-ying, ZHANG Xiao-lan, <i>et al.</i> (3348)
Distribution of Heavy Metals and Their Corresponding Nanoparticles in Different Treatment Unit Processes in the Sewage Treatment Plant	WANG Du-jia, HE Shuai, ZHOU Xiao-xia (3358)
Metagenomic Analysis of Resistance Genes in Membrane Cleaning Sludge	DU Cai-li, LI Zhong-hong, LI Xiao-guang, <i>et al.</i> (3366)
Distribution and Removal of Antibiotic-Resistant Bacteria and Antibiotic Resistance Genes in Petrochemical Wastewater Treatment Plants	TANG Zhen-ping, XIAO Sha-sha, DUAN Yi, <i>et al.</i> (3375)
Treatment of Medium Ammonium Wastewater by Single-stage Partial Nitrification-ANAMMOX SMBBR	LÜ Kai, SHAO Xian-ming, WANG Kang-zhou, <i>et al.</i> (3385)
Two-Stage Denitrification Process Performance with Solid Slow-Release Carbon Source	TANG Yi, MA Yong-wen, WAN Jin-quan, <i>et al.</i> (3392)
Effect of Ozone Dosage on Sludge Settleability and Biological Nutrient Removal in SBR System	LÜ Yong-tao, ZHU Chuan-shou, ZHANG Xu-yang, <i>et al.</i> (3400)
First Extended Anaerobic Phase Enhanced Nitrogen and Phosphorus Removal by Aerobic Granular Sludge Under Intermittent Gradient Aeration	ZHANG Yu-jun, LI Dong, WANG Xin-xin, <i>et al.</i> (3405)
Effect of Rate of Salinity Increase on the Performance and Microbial Community Structure of Sequencing Batch Reactors	GU Bai-ming, JIN Chun-ji, WEN Chun, <i>et al.</i> (3413)
Effects of Cold Acclimation on the Activity of Autotrophic Nitrogen Removal in Granular Sludge and Its Bacterial Population Structure	QIAN Fei-yue, LIU Yu-xin, WANG Jian-fang, <i>et al.</i> (3422)
Stabilization of Heavy Metals in Municipal Sludge Using a Slag-Based Modifying Agent	ZHANG Fa-wen, DONG Ming-kun, CHEN Chen-hui, <i>et al.</i> (3430)
Role of Land Use Changes on Ammonia Emissions from Agricultural Ecosystems in the Yangtze River Delta Region from 2000 to 2018	WANG Wen-jin, WANG Qing, ZHU An-sheng, <i>et al.</i> (3442)
Effects of Wheat Straw Hydrochar and Its Modified Product on Rice Yield and Ammonia Volatilization from Paddy Fields	HAN Chen, HOU Peng-fu, XUE Li-hong, <i>et al.</i> (3451)
Effects of Water and Fertilization Management on CH ₄ and N ₂ O Emissions in Double-rice Paddy Fields in Tropical Regions	LI Jin-qiu, SHAO Xiao-hui, GOU Guang-lin, <i>et al.</i> (3458)
Community Characteristics of Methanogens and Methanogenic Pathways in Salt-tolerant Rice Soil	YANG Yu-hong, HE Hui, MI Tie-zhu, <i>et al.</i> (3472)
Effect of Ferric-carbon Micro-electrolysis on Greenhouse Gas Emissions from Constructed Wetlands	ZHAO Zhong-jing, HAO Qing-ju, TU Ting-ting, <i>et al.</i> (3482)
Screening and Evaluation of Methods for Determining Available Lead (Pb) and Cadmium (Cd) in Farmland Soil	CHEN Ying, LIU Han-yi, LIU Na, <i>et al.</i> (3494)
Spatial Distribution Trends and Influencing Factors of Typical Heavy Metals in Subtropical Alpine Forest Soils: A Case Study from Ailao Mountain in Yunnan Province	LIU Xu, WANG Xun, WANG Ding-yong (3507)
Environmental Background Values of Heavy Metals and Physicochemical Properties in Different Soils in Shenzhen	LIN Ting, ZHAO Shu-hua, XI Xiu-ping, <i>et al.</i> (3518)
Screening of Amendments for Simultaneous Cd and As Immobilization in Soil	ZHOU Si-jiang, LIU Zhen-yan, XIONG Shuang-lian, <i>et al.</i> (3527)
Simultaneous Immobilization of Arsenic, Lead, and Cadmium in Paddy Soils Using Two Iron-based Materials	YUAN Feng, TANG Xian-jin, WU Ji-zi, <i>et al.</i> (3535)
Pollution Characteristics of Organophosphate Esters in Frozen Soil on the Eastern Edge of Qinghai-Tibet Plateau	LIU Li-ya, YIN Hong-ling, JIAN Lin-jie, <i>et al.</i> (3549)
Analysis of Spatial Distribution and Influencing Factors of Nitrogen and Phosphorus Fertilizer Application Intensity in Chengdu Plain	LIU Qi-xin, WANG Chang-quan, LI Bing, <i>et al.</i> (3555)
Different Responses of Soil Dissolved Organic Matter to Different Types of Compost	XI Bei-dou, WANG Yan, TAN Wen-bing, <i>et al.</i> (3565)