环境科学

ENVIRONMENTAL SCIENCE

ISSN 0250-3301 CODEN HCKHDV

HUANJING KEXUE

■ 主办 中国科学院生态环境研究中心

■ 出版 科学出版社

2019

Vol.40 No.3

第40卷 第3期

环境科学
(HUANJING KEXUE)
ENVIRONMENTAL SCIENCE
第40卷 第3期
2019年3月15日

目 次

2014~2017北京市气象条件和人为排放变化对空气质量改善的贡献评估 …… 尹晓梅，李梓铭，熊亚军，乔林，邱雨露，孙兆彬，寇星霞(1011)
利用多元线性回归方法评估气象条件和控制措施对APEC期间北京空气质量的影响 …… 李颖若，汪君霞，韩婷婷，王垚，何迪，权维俊，马志强(1024)
京津冀郊区站点秋冬季大气$PM_{2.5}$来源解析 …… 王彤，华阳，许庆成，王书肖(1035)
四川省典型工业行业$PM_{2.5}$成分谱分析 …… 冯小琼，陈军辉，熊文朋，梅林德，徐雪梅，尹寒梅，范武波，姜涛，钱骏，叶宏(1043)
典型物流城市2016年冬季2次污染过程$PM_{2.5}$污染特征及来源解析 …… 赵雪艳，杨文，王静，刘盈盈，白雯宇，徐艳萍，王歆华，白志鹏(1052)
沈阳市采暖期与非采暖期空气$PM_{2.5}$污染特征及来源分析 …… 张显，田莎莎，刘盈盈，赵雪艳，余浩，张辉，陈莉，王歆华(1062)
新乡冬季$PM_{2.5}$中金属元素与水溶性离子年际变化及其来源解析 …… 闫广轩，雷豪杰，张靖雯，唐明双，张佳羽，曹治国，李云蓓，王跃思，樊静，李虎(1071)
烟台市环境受体$PM_{2.5}$四季污染特征与来源解析 …… 刘童，王晓军，陈倩，温杰，黄渤，朱红霞，田瑛泽，冯银厂(1082)
常州市冬季$PM_{2.5}$中类腐殖质昼夜特征分析 …… 顾远，李清，黄雯倩，赵竹子，马帅帅，叶招莲(1091)
西北某电子垃圾拆解厂室内外重金属污染特征及暴露风险 …… 曹红梅，赵留元，穆熙，李尧捷，毛潇萱，黄韬，马建民，高宏(1101)
京津冀一次污染过程的星地同步动态监测分析 …… 邱昀，李令军，姜磊，王新辉，赵文慧，张立坤，鹿海峰(1111)
中国城市O_3浓度时空变化特征及驱动因素 …… 黄小刚，赵景波，曹军骥，宋永永(1120)
基于卫星和地面观测的2013年以来我国臭氧时空分布及变化特征 …… 张倩倩，张兴赢(1132)
舟山市臭氧污染分布特征及来源解析 …… 王俏丽，董敏丽，李素静，吴成志，王刚，陈必新，李伟，高翔，叶荣民(1143)
中国建筑涂料使用VOCs排放因子及排放清单的建立 …… 高美平，邵霞，聂磊，王海林，安小栓(1152)
异戊二烯和甲苯二次有机示踪物的臭氧非均相氧化 …… 黄亚娟，曹罡，朱荣淑，欧阳峰(1163)
兰州市农牧业源氨排放清单及其时空分布特征 …… 栗世学，郭文凯，何昕，朱玉凡，陈强(1172)
成都次降水稳定氢氧同位素特征及水汽来源分析 …… 胡月，刘国东，孟玉川，张文江，夏成城(1179)
基于TBL模型的闽江口围垦养虾塘水-大气界面CO_2扩散通量估算 …… 张逸飞，杨平，赵光辉，李玲，谭立山，仝川(1188)
渤海和北黄海有色溶解有机物(CDOM)的分布特征和季节变化 …… 刘兆冰，梁文健，秦礼萍，唐建辉(1198)
思林水库荧光溶解性有机质的特征、来源及其转化动力学 …… 劳心宇，原杰，刘瑜，Khan M. G. Mostofa(1209)
厦门湾海滩微塑料污染特征 …… 刘启明，梁海涛，锡桂莉，胡欣，葛健(1217)
高分辨率监测下的漓江省里断面生物地球化学特征分析 …… 王奇岗，肖琼，赵海娟，王建力，郭永丽，张清华(1222)
鲜水河断裂带虾拉沱盆地断面地下水化学特征及控制因素 …… 何锦，张幼宽，赵雨晴，韩双宝，刘元晴，张涛(1236)
成都市锦江表层水和沉积物中有机磷酸酯的污染特征 …… 吴迪，印红玲，李世平，王增武，邓旭，罗怡，罗林(1245)
丹江口库区表层浮游细菌群落组成与PICRUSt功能预测分析 …… 张菲，田伟，孙峰，陈彦，丁传雨，庞发虎，姚伦广，李玉英，陈兆进(1252)
蓝藻水华对太湖水柱反硝化作用的影响 …… 刘志迎，许海，詹旭，朱广伟，秦伯强，张运林(1261)
基于微生物生物完整性指数的城市河道生态系统健康评价 …… 苏瑶，许育新，安文浩，王云龙，何振超，楼颖雯，沈阿林(1270)
生物炭添加对湿地植物菖蒲根系通气组织和根系泌氧的影响 …… 黄磊，梁银坤，梁岩，罗星，陈玉成(1280)
城市不同材料屋面径流的污染负荷特性 …… 何湖滨，陈诚，林育青，严晗璐，董建玮，陈求稳(1287)
BiOCl-$(NH_4)_3PW_{12}O_{40}$复合光催化剂制备及其光催化降解污染物机制 …… 张文海，吉庆华，兰华春，李静(1295)
微米铁复合生物碳源对地下水中1,2-二氯乙烷的高效去除 …… 吴乃瑾，宋云，魏文侠，王海见，孙仲平(1302)
鸟粪石天然沸石复合材料对水中铅离子的去除 …… 邓曼君，王学江，成雪君，景焕平，赵建夫(1310)
Ca/Mg负载改性沼渣生物炭对水中磷的吸附特性 …… 易蔓，李婷婷，李海红，黄巧，杨金娥，陈玉成，杨志敏(1318)
两种生物炭的制备及其对水溶液中四环素去除的影响因素 …… 程扬，沈启斌，刘子丹，杨小莹，张太平，廖志钟(1328)
静止和水动力扰动状态下锆改性沸石添加对河道底泥磷迁移转化的影响 …… 俞阳，林建伟，詹艳慧，何思琪，吴小龙，王艳，赵钰颖，林莹，刘鹏茜(1337)
4种磺胺类药物及乙酰化代谢物在污水处理厂的去除及机制 …… 王大鹏，张娴，颜昌宙(1347)
以膜分离为主的物化法对城市污水中污染因子的去除特性分析 …… 徐婷，李勇，朱怡嘉，薛梦婷，汤同欢(1353)
进水氨氮浓度对生物除磷颗粒系统的影响 …… 李冬，曹美忠，郭跃洲，梅宁，李帅，张杰(1360)
除磷亚硝化颗粒工艺启动及性能恢复 …… 李海玲，李冬，张杰，刘博(1367)
CAST工艺高温短程硝化的实现及其除磷性能 …… 马娟，杨蕊春，俞小军，周猛，陈永志(1375)
不同曝气量和好氧时间下SPNDPR系统处理低C/N城市污水的脱氮除磷性能 …… 袁梦飞，于德爽，巩秀珍，王晓霞，陈光辉，杜世明，甄建园(1382)
ABR除碳-亚硝化耦合厌氧氨氧化处理城市污水 …… 李田，曹家炜，谢凤莲，沈耀良，吴鹏，宋吟玲(1390)
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 …… 谢璐琳，王建芳，钱飞跃，张泽宇，沈耀良，齐泽坤(1396)
不同种泥的厌氧氨氧化反应器的启动及动力学特征 …… 任君怡，陈林艺，李慧春，秦玉洁，曹雁，王桐屿，周少奇(1405)
降温过程中生物膜CANON反应器的运行特征 …… 付昆明，廖敏辉，周厚田，付巢，姜姗，仇付国，曹秀芹(1412)
IEM-UF同步分离反硝化系统脱氮特性及种群结构分析 …… 刘子奇，张岩，马翔山，张博康，曹孟京，陈昌明(1419)
温度对硝化杆菌(*Nitrobacter*)活性动力学影响 …… 于雪，孙洪伟，李维维，祁国平，马娟，陈永志，吕心涛(1426)
零价铁和微波预处理组合强化污泥厌氧消化 …… 牛雨彤，刘吉宝，马爽，李亚明，解立平，魏源送，孟晓山(1431)
牛粪堆肥系统环境因子对抗性基因的影响 …… 彭晶，王科，谷月，王爱杰(1439)
环境因子对土壤微生物呼吸及其温度敏感性变化特征的影响 …… 张彦军，郭胜利(1446)
三峡库区典型林分土壤呼吸及其组分对模拟酸雨的响应 …… 李一凡，王玉杰，王彬，王云琦(1457)
三峡库区柑橘园施肥量对土壤氮淋失及残留量的影响 …… 王甜，黄志霖，曾立雄，肖文发，宋文梅(1468)
长期施肥下水稻根际和非根际土壤微生物碳源利用特征 …… 宁赵，程爱武，唐海明，葛体达，邓扬悟，苏以荣，陈香碧(1475)
不同碳负荷梯度下稻田土壤有机碳矿化特征 …… 童瑶瑶，王季斐，祝贞科，邓扬悟，陈珊，葛体达，袁红朝，吴金水(1483)
桂林会仙喀斯特湿地水位梯度下不同植物群落土壤有机碳及其组分特征 …… 徐广平，李艳琼，沈育伊，张德楠，孙英杰，张中峰，周龙武，段春燕(1491)
缙云山4种森林植被土壤团聚体有机碳分布特征 …… 王富华，吕盛，黄容，高明，王子芳，徐畅(1504)
大气污染对居民健康影响研究进展 …… 秦耀辰，谢志祥，李阳(1512)
《环境科学》征订启事(1042)　《环境科学》征稿简则(1162)　信息(1208，1235，1286)

Eco-Environmental Knowledge Web
环 境 科 学
Environmental Science
第40卷 第3期 2019年3月
Vol. 40, No. 3 Mar., 2019

厦门湾海滩微塑料污染特征

刘启明[1], 梁海涛[1,2], 锡桂莉[1], 胡欣[1], 葛健[1]
(1. 集美大学食品与生物工程学院, 厦门 361021; 2. 中国科学院城市环境研究所, 厦门 361021)

摘要: 以厦门湾6个典型海滩为工作区, 分析海滩微塑料的污染特征. 结果表明: ①厦门湾6个海滩的微塑料丰度数据范围介于(28.1±9.4)~(312.7±35.2)n·kg^{-1}之间. ②厦门湾海滩微塑料分为碎片类、发泡类、薄膜类和纤维类等4种类型. 各站位点均以碎片类和发泡类为主, 占总数量的80%左右, 薄膜类和纤维类所占比例较少. ③厦门湾海滩粒径<1 mm的微塑料占最大比例, 超过60%. 粒径为1~3 mm和3~5 mm的微塑料所占比例较小. ④通过红外光谱分析, 确认厦门湾海滩微塑料碎片类和纤维类的主要成分是聚乙烯, 发泡类和薄膜类的主要成分是聚苯乙烯. ⑤通过扫描电镜观测, 大部分微塑料表面粗糙、凹凸不平, 带有明显裂痕. 整体而言, 厦门湾海滩微塑料污染处于中等偏下的程度, 陆源污染是厦门湾海滩微塑料污染的最主要来源.

关键词: 厦门湾; 海滩; 微塑料; 丰度; 污染
中图分类号: X708 **文献标识码**: A **文章编号**: 0250-3301(2019)03-1217-05 **DOI**: 10.13227/j.hjkx.201807217

Microplastic Pollution of the Beaches in Xiamen Bay, China

LIU Qi-ming[1], LIANG Hai-tao[1,2], XI Gui-li[1], HU Xin[1], GE Jian[1]
(1. College of Food and Biological Engineering, Jimei University, Xiamen 361021, China; 2. Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China)

Abstract: Microplastics are tiny ubiquitous plastic particles smaller than five millimeters (5 mm) in size. Coastal and bay areas are constantly under continuous and increasing pressure from the activities of humans. Microplastic pollution is now recognized as a great threat to these areas. This study was designed to understand the microplastic pollution of the beaches in Xiamen Bay. The results showed that microplastic abundance was from (28.1±9.4) to (312.7±35.2) n·kg^{-1}. Four main types of microplastics were identified in Xiamen Bay, including fragments, foams, thin films, and fibers. Of the particles analyzed, over 80% were predominantly microplastic fragments and foam, while the films and fiber microplastics accounted for less than 20% of the particles. Studies on the particle size of microplastics also indicated that the microplastics with particle size less than 1 mm accounted for over 60% of the total microparticles, and the abundance of microplastics trend to decrease with increase in the particle size. Fourier transform infrared spectroscopy analysis demonstrated that the major component of the fragments and fibers was identified as polyethylene, and that of foams and films was identified as polystyrene. The scanning electron microscope studies showed that the microplastics presented obvious signs of cracks. In general, Xiamen Bay beach microplastic pollution is at a lower middle level, and land source pollution is the main source of the microplastic pollution.

Key words: Xiamen Bay; beaches; microplastic; abundance; pollution

塑料具有优良的物理化学特性, 能广泛应用于工业、农业及日常生活中. 使用后的塑料垃圾未被有效处理与处置后会以不同形态进入海洋. 在机械作用、生物降解、光降解等过程的共同作用下, 海洋中的塑料垃圾会逐渐被分解成碎片, 并随海洋水动力过程进行迁移. 2018世界环境日主题为"塑战速决(beat plastic pollution)", 塑料污染已是全球共同关注的热点环境问题之一.

微塑料(microplastics)一词由Thompson等[1]在2004年首次提出, 是指粒径从几微米到几毫米的非均匀塑料颗粒混合体的统称. 学术界较常采用的上限阈值是5 mm. 海岸带区域是人类社会经济活动最为活跃的地区, 更是海洋微塑料污染最为集中分布的区域. 因此, 关于海洋微塑料污染的研究, 大部分集中在各沿海岸线地区[2~10].

厦门海域面积390 km^2, 海岸线总长234 km, 是一个复式港湾. 由于相对封闭, 海水交换周期长, 污染物扩散能力差、人类活动较为频繁等原因, 区域生态环境较为脆弱. 在发展经济的同时如何保护环境, 尤其是如何应对新兴污染物——海洋微塑料问题, 是厦门湾生态环境保护中迫切需要开展的工作. 本研究以厦门湾为工作区, 选择若干典型海滩, 从微塑料的丰度、类型、粒径、表面特征等角度, 综合分析微塑料的污染特征, 以期为半封闭海湾及海岸带区域的海洋微塑料污染防治和监管提供科学支持.

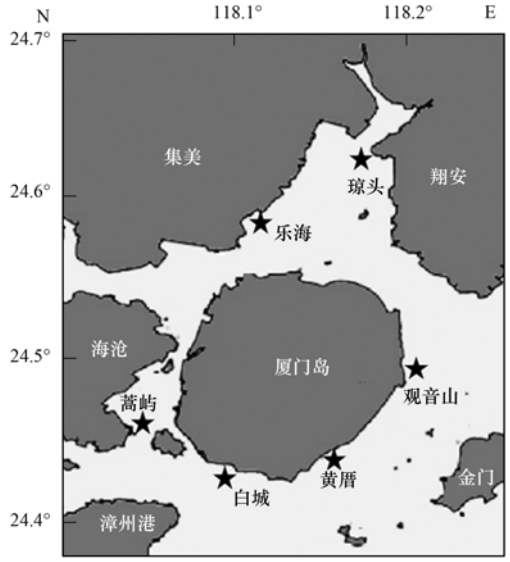
1 材料与方法

1.1 采样点位

厦门由厦门本岛、集美、海沧、同安、翔安及众

收稿日期: 2018-07-26; **修订日期**: 2018-09-28
基金项目: 国家自然科学基金项目(31500391); 福建省自然科学基金项目(2018J01501)
作者简介: 刘启明(1973~), 博士, 副教授, 主要研究方向为生态环境, E-mail: liuqm@jmu.edu.cn

多小岛屿等组成，位于福建省南部，属亚热带气候，年均气温 21℃，年均降雨量1 200 mm. 陆地面积 1 699 km^2，海域面积约 390 km^2. 厦门湾为半封闭港湾，包括厦门港、外港区、马銮湾、同安湾、九龙江河口区和东侧水道. 本研究采样站位选择 6 个典型海滩：嵩屿、乐海、琼头、白城、黄厝和观音山（图 1）. 既包括厦门湾不同方位，也包括外海及内湾.



黑色五角星表示采样点

图 1 厦门湾海滩采样站位

Fig. 1 Sampling sites of the beaches in Xiamen Bay, China

1.2 采样及实验流程

利用低潮水位时段，在海滩潮间带以 S 形选择 5 个样方大小为 0.5 m×0.5 m 正方形采样点，用不锈钢铲采集约 2～3 cm 的表层样. 采集的样品装入自封袋，带回实验室阴凉干燥处自然风干.

微塑料分离采用较为常用的饱和氯化钠密度浮选分离法[11～14]. 具体步骤如下，先将装有样品的烧杯放置在 40℃ 的恒温水浴锅中，加入已配制好的饱和氯化钠溶液（40℃，1.36 $g \cdot cm^{-3}$），用玻璃棒持续搅拌 1～2 min，静置 5 min. 然后将上清液用真空抽滤装置进行抽滤. 抽滤后的滤膜放置表面皿中待进一步分析.

微塑料的丰度、分类及形状特征采用体视显微镜（B1-220，Motic 公司）分析，并经拍照后用 Nano Measurer 1.2.5 软件进行计数. 微塑料的组成成分的确定采用傅里叶红外光谱仪（FT/IR480PLUS，JASCO 公司）扫描分析. 微塑料的微观表面特征采用扫描电镜（SEM，S-4800，Hitachi 公司）观测.

1.3 数据处理

本实验结果采用统计软件 Excel 2007 和 SPSS19.0 进行数据处理.

2 结果与分析

2.1 丰度

本研究以 5 mm 为微塑料的上限阈值，所采集样品中分离鉴定出的塑料小于 5 mm 的数量占塑料总数量的绝大部分（>96%），普通大尺寸塑料仅占很小比例. 区域微塑料污染程度的高低主要是通过丰度指标衡量. 目前对微塑料丰度指标的参数常用“n·质量$^{-1}$”方式表达（n 为 number，即微塑料数量）. 经分析统计，厦门湾 6 个海滩站位的微塑料丰度数据如表 1 所示. 琼头是微塑料丰度最大的海滩，丰度为（312.7±35.2）$n \cdot kg^{-1}$. 观音山是微塑料丰度最小的海滩，丰度为（28.1±9.4）$n \cdot kg^{-1}$. 其余 4 个海滩（嵩屿、乐海、白城、黄厝）的微塑料丰度介于（31.8±8.7）～（283.5±41.2）$n \cdot kg^{-1}$之间.

表 1 厦门湾海滩微塑料丰度/$n \cdot kg^{-1}$

Table 1 Abundance of microplastics on the beaches in Xiamen Bay/$n \cdot kg^{-1}$

海滩	嵩屿	乐海	琼头	白城	黄厝	观音山
丰度	283.5	165.9	312.7	67.6	31.8	28.1
标准偏差（SD）	±41.2	±23.1	±35.2	±14.4	±8.7	±9.4

2.2 类型

根据微塑料的形态差异，本研究中将所检出的微塑料分为碎片类、发泡类、薄膜类和纤维类等 4 种类型. 经分析统计，厦门湾 6 个海滩站位不同类型微塑料数量比例如图 2 所示. 各海滩站位点的薄膜类和纤维类微塑料所占比例均不高，分别为 5%～19% 和 4%～16% 之间，碎片类和发泡类微塑料占总数量的 80% 左右. 其中，嵩屿和琼头以发泡类微塑料为主，各占 50% 和 53%；乐海、白城、黄厝和观音山以碎片类微塑料为主，各占 48%、49%、51% 和 65%.

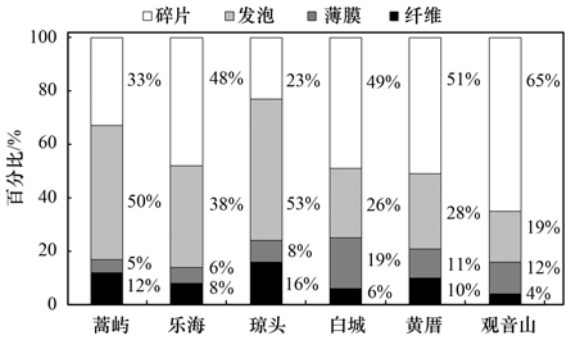


图 2 厦门湾海滩不同类型微塑料数量比例

Fig. 2 Percentage of different microplastic types on the beaches in Xiamen Bay

2.3　粒径

本研究中将所检出的微塑料粒径分为 <1、1 ~ 3 和 3 ~ 5 mm 这 3 个等级. 经分析统计，厦门湾 6 个海滩站位不同粒径微塑料数量比例如图 3 所示. 各海滩站位点粒径为 1 ~ 3 mm 和 3 ~ 5 mm 的微塑料所占比例不大，分别为 6% ~ 28% 和 4% ~ 17% 之间. 各海滩站位点粒径 <1 mm 的微塑料均占最大比例. 其中，观音山比例最高，为 84%；琼头比例最低，为 61%；嵩屿、乐海、白城和黄厝分别为 65%、78%、76% 和 81%.

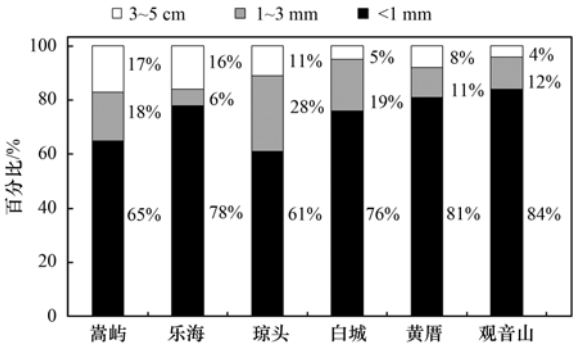


图 3　厦门湾海滩不同粒径微塑料数量比例

Fig. 3　Percentage of different particle sizes of microplastic on the beaches in Xiamen Bay

2.4　组成成分

对厦门湾各海滩检出的碎片类、发泡类、薄膜类和纤维类这 4 类微塑料进行红外光谱分析，以确定各类型的微塑料组成成分. 典型微塑料样品红外光谱如图 4 所示. 对比标准图谱及峰值数据，确认碎片类和纤维类的主要成分是聚乙烯，发泡类和薄膜类的主要成分是聚苯乙烯.

2.5　表面特征

微塑料的粒径上限阈值是 5 mm. 与同一类型大尺寸普通塑料[图 5(a)]比较，微塑料在肉眼可视尺度上较为圆润均一[图5(b)]. 但通过扫

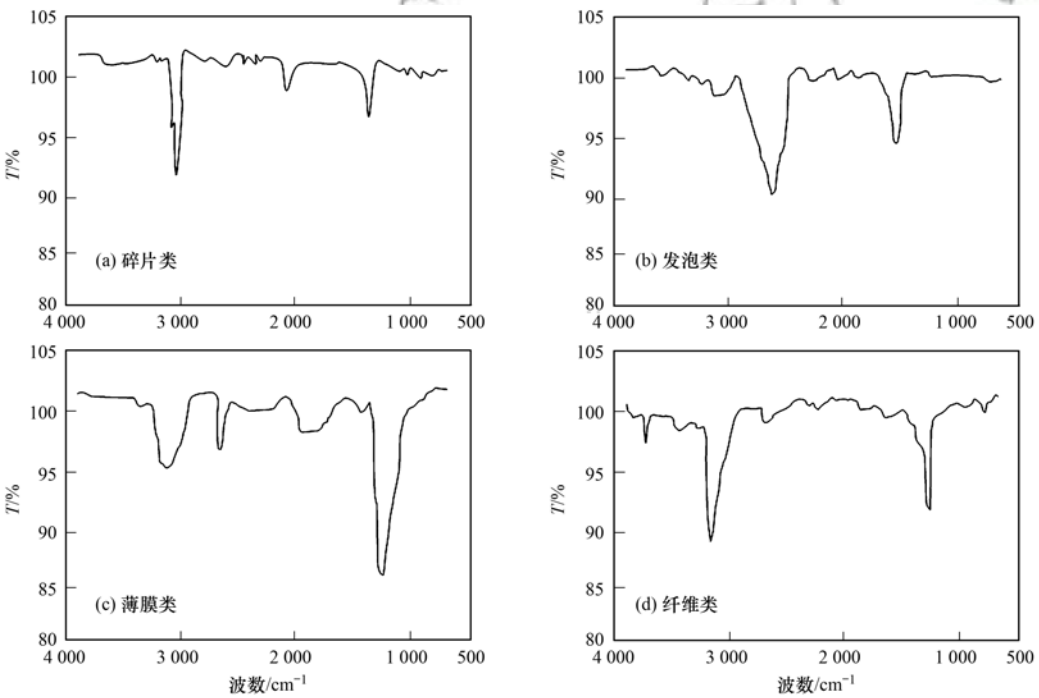


图 4　不同类型微塑料的红外光谱图

Fig. 4　FTIR spectrum of different microplastics samples

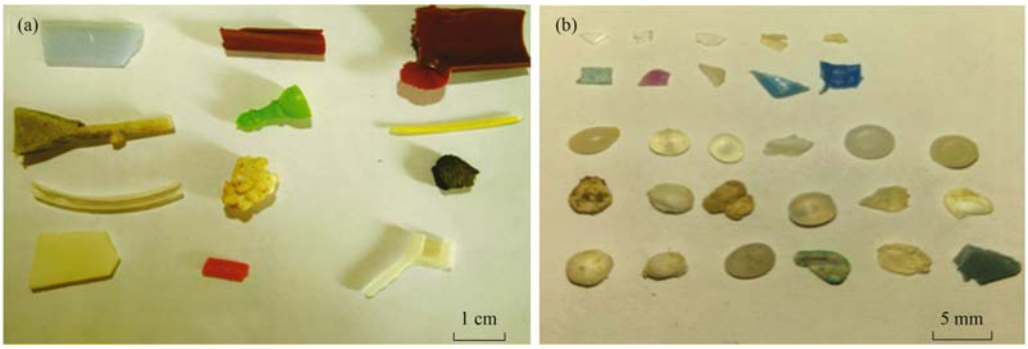


图 5　微塑料与普通大尺寸塑料对比

Fig. 5　Comparison between microplastics and larger plastic pieces

描电镜观测，大部分微塑料表面粗糙、凹凸不平，带有明显裂痕[图 6(a)]. 表面相对光滑，裂痕和破损痕迹不太明显的比较少见[图 6(b)].

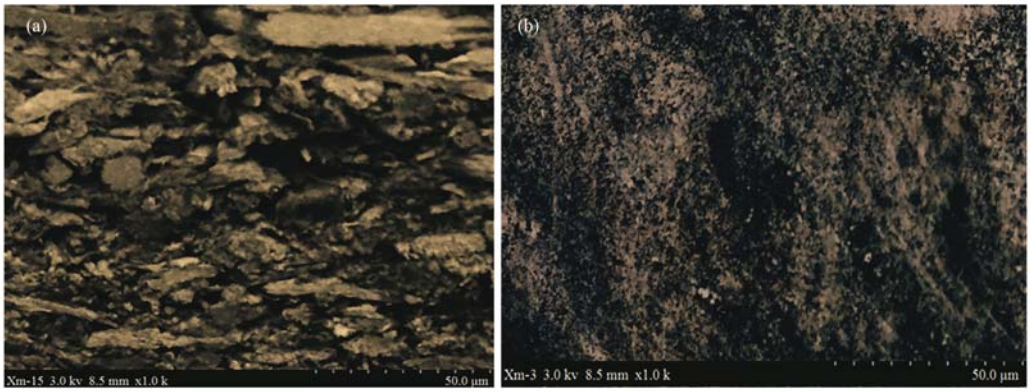


图 6 微塑料扫描电镜图

Fig. 6 Scanning electron micrography (SEM) images of the microplastics

3 讨论

3.1 微塑料来源

厦门湾海滩微塑料分为碎片类、发泡类、薄膜类和纤维类这 4 种类型. 经现场调查并参照相关研究，大致可判断厦门湾各海滩不同类型微塑料的主要来源. 碎片类微塑料来源最广，各类工业、农业以及生活塑料废弃物裂解破碎后均可形成碎片类微塑料[2]. 发泡类微塑料主要来源于废弃的泡沫包装箱、简易门(墙)的泡沫隔温层和一次性泡沫餐具. 另外，厦门湾常见小渔船将大块泡沫绑于船底或船侧以增加浮力，这些泡沫也是发泡类微塑料的重要来源之一. 薄膜类微塑料主要来源于普通塑料类食品包装袋，以及化肥袋、水泥袋等各类编织袋上的防水薄膜层[13, 15]. 纤维类微塑料主要来源于废弃的绳索或渔网. 此外，化纤类衣物碎裂掉落的细小纤维状残体也是纤维类微塑料的重要来源[16].

3.2 微塑料污染程度

本研究中，厦门湾 6 个海滩站位，粒径 <5 mm 的微塑料丰度范围介于(28.1 ± 9.4) ~ (312.7 ± 35.2) $n \cdot kg^{-1}$之间. 通过查阅国内外对沿海滩涂沉积物、沙滩土壤或海砂等的相关研究，以同样的粒径 <5 mm 计数、计量单位为“$n \cdot kg^{-1}$”作为对比标准. 巴西 Boa Viagem (2 900 $n \cdot kg^{-1}$)[17]、意大利 Venice (2175 $n \cdot kg^{-1}$)[18]、加拿大 Halifax (2 000 ~ 8 000 $n \cdot kg^{-1}$)[19]、中国长江入海口[(3 420 ± 1 310)] $n \cdot kg^{-1}$[20]等地的微塑料丰度较高. 曹妃甸围填海区(634 $n \cdot kg^{-1}$)[21]等地的微塑料丰度处于中位程度. 而比利时(120 $n \cdot kg^{-1}$)[22]、法国 Nantes [(67 ± 76) $n \cdot kg^{-1}$][23]、新加坡(12 ~ 63 $n \cdot kg^{-1}$)[24]等地的微塑料丰度相对较低. 此外，一项对欧洲沿海海滩沉积物的调查，统计出 13 个国家共 23 个站位的微塑料丰度范围是(72 ± 24) ~ (1 512 ± 187) $n \cdot kg^{-1}$[25]. 综合比较，厦门湾海滩微塑料污染处于中等偏下的程度.

3.3 各站位微塑料污染差异分析

本研究中厦门湾 6 个海滩站位，微塑料丰度大小依次为:琼头 > 嵩屿 > 乐海 > 白城 > 黄厝 > 观音山. 从各站点所处位置考虑，各类陆源垃圾的排放，雨水冲刷、陆源排污口或河流的输入，以及海流、潮汐的联合作用是造成微塑料地域分布差异的主要原因. 琼头、嵩屿和乐海均处于厦门内湾，水体交换程度低、污染物扩散能力差，易于滞留污染物质. 且琼头和嵩屿分别临近东西溪和九龙江入海口，大量河流污染物对海滩微塑料有显著的贡献. 而白城、黄厝和观音山则临近外海，水域较为开阔. 较为清洁的外海水体对海滩的不断冲刷，使得海滩微塑料丰度相对较低.

从物质的迁徙赋存角度考虑，微塑料有陆源和海源两大类. 陆源包括直接丢弃在海滩的各类塑料垃圾，以及通过雨水冲刷、陆源排污口或河流输入的塑料等. 海源主要是在洋流和潮汐的作用下迁移并滞留在海滩上的各类海漂塑料垃圾. 根据文献[26]的数据，白城、黄厝和观音山所在的厦门岛南部近岸海域水体基本符合第一、第二类海水水质标准，而琼头、嵩屿和乐海所在的厦门岛北部近岸海域水体水质较差，部分甚至为劣四类海水. 各站位海水水环境数据基本和海滩微塑料丰度大小较为一致. 由此说明，陆源污染是厦门湾海滩微塑料污染的最主要来源.

4 结论

厦门湾海滩微塑料丰度数据范围介于(28.1 ± 9.4) ~ (312.7 ± 35.2) $n \cdot kg^{-1}$之间之间，以粒径 <1

mm 的微塑料占最大比例. 微塑料以碎片类和发泡类为主，薄膜类和纤维类所占比例较少. 碎片类和纤维类的主要成分是聚乙烯，发泡类和薄膜类的主要成分是聚苯乙烯. 大部分微塑料表面粗糙、凹凸不平，带有明显裂痕. 对比分析表明，厦门湾海滩微塑料污染处于中等偏下的程度，陆源污染是厦门湾海滩微塑料污染的最主要来源.

参考文献：

[1] Thompson R C, Olsen Y, Mitchell R P, *et al*. Lost at sea: where is all the plastic? [J]. Science, 2004, **304**(5672): 838.

[2] Andrady A L. The plastic in microplastics: A review[J]. Marine Pollution Bulletin, 2017, **119**(1): 12-22.

[3] Auta H S, Emenike C U, Fauziah S H. Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solutions [J]. Environment International, 2017, **102**: 165-176.

[4] Bour A, Haarr A, Keiter S, *et al*. Environmentally relevant microplastic exposure affects sediment-dwelling bivalves [J]. Environmental Pollution, 2018, **236**: 652-660.

[5] Conkle J L, Báez Del Valle C D, Turner J W. Are we underestimating microplastic contamination in aquatic environments? [J]. Environmental Management, 2018, **61**(1): 1-8.

[6] Law K L, Thompson R C. Microplastics in the seas. Science, 2014, **345**(6193): 144-145.

[7] Zhang W, Ma X, Zhang Z, *et al*. Persistent organic pollutants carried on plastic resin pellets from two beaches in China [J]. Marine Pollution Bulletin, 2015, **99**(1-2): 28-34.

[8] Alimi O S, Budarz J F, Hernandez L M, *et al*. Microplastics and nanoplastics in aquatic environments: aggregation, deposition, and enhanced contaminant transport[J]. Environmental Science & Technology, 2018, **52**(4): 1704-1724.

[9] Yu X B, Ladewig S, Bao S W, *et al*. Occurrence and distribution of microplastics at selected coastal sites along the southeastern United States [J]. Science of the Total Environment, 2018, **613-614**: 298-305.

[10] Zhang H. Transport of microplastics in coastal seas [J]. Estuarine, Coastal and Shelf Science, 2017, **199**: 74-86.

[11] Nuelle M T, Dekiff J H, Remy D, *et al*. A new analytical approach for monitoring microplastics in marine sediments[J]. Environmental Pollution, 2014, **184**: 161-169.

[12] Cluzard M, Kazmiruk T N, Kazmiruk V D, *et al*. Intertidal concentrations of microplastics and their influence on ammonium cycling as related to the shellfish industry [J]. Archives of Environmental Contamination and Toxicology, 2015, **69**(3): 310-319.

[13] 简敏菲，周隆胤，余厚平，等. 鄱阳湖-饶河入湖段湿地底泥中微塑料的分离及其表面形貌特征[J]. 环境科学学报，2018，**38**(2)：579-586.
Jian M F, Zhou L Y, Yu H P, *et al*. Separation and microscopic study of microplastics from the sediments of the wetland in the estuary of Raohe River of Poyang Lake [J]. Acta Scientiae Circumstantiae, 2018, **38**(2): 579-586.

[14] 王昆，林坤德，袁东星. 环境样品中微塑料的分析方法研究进展[J]. 环境化学，2017，**36**(1)：27-36.
Wang K, Lin K D, Yuan D X. Research progress on the analysis of microplastics in the environment [J]. Environmental Chemistry, 2017, **36**(1): 27-36.

[15] Free C M, Jensen O P, Mason S A, *et al*. High-levels of microplastic pollution in a large, remote, mountain lake [J]. Marine Pollution Bulletin, 2014, **85**(1): 156-163.

[16] Browne M A, Galloway T S, Thompson R C. Spatial patterns of plastic debris along Estuarine shorelines [J]. Environmental Science & Technology, 2010, **44**(9): 3404-3409.

[17] Costa M F, Do Sul J A I, Silva-Cavalcanti J S, *et al*. On the importance of size of plastic fragments and pellets on the strandline: a snapshot of a Brazilian beach[J]. Environmental Monitoring and Assessment, 2009, **168**(1-4): 299-304.

[18] Vianello A, Boldrin A, Guerriero P, *et al*. Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification [J]. Estuarine, Coastal and Shelf Science, 2013, **130**: 54-61.

[19] Mathalon A, Hill P. Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia[J]. Marine Pollution Bulletin, 2014, **81**(1): 69-79.

[20] 朱晓桐，衣俊，强丽媛，等. 长江口潮滩表层沉积物中微塑料的分布及沉降特点[J]. 环境科学，2018，**39**(5)：2067-2074.
Zhu X T, Yi J, Qiang L Y, *et al*. Distribution and settlement of microplastics in the surface sediment of Yangtze Estuary[J]. Environmental Science, 2018, **39**(5): 2067-2074.

[21] 周倩，章海波，周阳，等. 滨海潮滩土壤中微塑料的分离及其表面微观特征[J]. 科学通报，2016，**61**(14)：1604-1611.
Zhou Q, Zhang H B, Zhou Y, *et al*. Separation of microplastics from a coastal soil and their surface microscopic features[J]. Chinese Science Bulletin, 2016, **61**(14): 1604-1611.

[22] Claessens M, De Meester S, Van Landuyt L, *et al*. Occurrence and distribution of microplastics in marine sediments along the Belgian coast[J]. Marine Pollution Bulletin, 2011, **62**(10): 2199-2204.

[23] Phuong N N, Poirier L, Lagarde F, *et al*. Microplastic abundance and characteristics in French Atlantic coastal sediments using a new extraction method [J]. Environmental Pollution, 2018, **243**: 228-237.

[24] Nor N H M, Obbard J P. Microplastics in Singapore's coastal mangrove ecosystems[J]. Marine Pollution Bulletin, 2014, **79**(1-2): 278-283.

[25] Lots F A E, Behrens P, Vijver M G, *et al*. A large-scale investigation of microplastic contamination: Abundance and characteristics of microplastics in European beach sediment[J]. Marine Pollution Bulletin, 2017, **123**(1-2): 219-226.

[26] 厦门市海洋与渔业局. 2017 年厦门市海洋生态环境状况公报[R]. 厦门：厦门市海洋与渔业局，2018.

HUANJING KEXUE Vol. 40 No. 3
Environmental Science (monthly) Mar. 15, 2019

CONTENTS

Contribution Assessment of Meteorology Conditions and Emission Change for Air Quality Improvement in Beijing During 2014-2017 ····· YIN Xiao-mei, LI Zi-ming, XIONG Ya-jun, *et al.* (1011)
Using Multiple Linear Regression Method to Evaluate the Impact of Meteorological Conditions and Control Measures on Air Quality in Beijing During APEC 2014 ····· LI Ying-ruo, WANG Jun-xia, HAN Ting-ting, *et al.* (1024)
Source Apportionment of $PM_{2.5}$ in Suburban Area of Beijing-Tianjin-Hebei Region in Autumn and Winter ····· WANG Tong, HUA Yang, XU Qing-cheng, *et al.* (1035)
Fine Particulate Matter Source Profile of Typical Industries in Sichuan Province ····· FENG Xiao-qiong, CHEN Jun-hui, XIONG Wen-peng, *et al.* (1043)
Source Apportionment and Pollution Characteristics of $PM_{2.5}$ During the Two Heavy Pollution Episodes in the Winter of 2016 in a Typical Logistics City ····· ZHAO Xue-yan, YANG Wen, WANG Jing, *et al.* (1052)
Pollution Characteristics and Source Apportionment of $PM_{2.5}$ in Heating and Non-heating Periods in Shenyang ····· ZHANG Xian, TIAN Sha-sha, LIU Ying-ying, *et al.* (1062)
Interannual Variation of Metal Elements and Water-Soluble Ions in $PM_{2.5}$ During Wintertime in Xinxiang and Their Source Apportionment ····· YAN Guang-xuan, LEI Hao-jie, ZHANG Jing-wen, *et al.* (1071)
Pollution Characteristics and Source Apportionment of Ambient $PM_{2.5}$ During Four Seasons in Yantai City ····· LIU Tong, WANG Xiao-jun, CHEN Qian, *et al.* (1082)
Day-night Characteristics of Humic-like Substances in $PM_{2.5}$ During Winter in Changzhou ····· GU Yuan, LI Qing, HUANG Wen-qian, *et al.* (1091)
Pollution Characteristics and Occupational Exposure Risk of Heavy Metals in Indoor and Outdoor Ambient Particles at a Scaled Electronic Waste Dismantling Plant, Northwest China ····· CAO Hong-mei, ZHAO Liu-yuan, MU Xi, *et al.* (1101)
Analysis of a Pollution Process in the Beijing-Tianjin-Hebei Region Based on Satellite and Surface Observations ····· QIU Yun, LI Ling-jun, JIANG Lei, *et al.* (1111)
Spatial-temporal Variation of Ozone Concentration and Its Driving Factors in China ····· HUANG Xiao-gang, ZHAO Jing-bo, CAO Jun-ji, *et al.* (1120)
Ozone Spatial-temporal Distribution and Trend over China Since 2013: Insight from Satellite and Surface Observation ····· ZHANG Qian-qian, ZHANG Xing-ying (1132)
Characteristics of Ozone Pollution Distribution and Source Apportionment in Zhoushan ····· WANG Qiao-li, DONG Min-li, LI Su-jing, *et al.* (1143)
Establishment of VOCs Emissions Factor and Emissions Inventory from Using of Architectural Coatings in China ····· GAO Mei-ping, SHAO Xia, NIE Lei, *et al.* (1152)
Heterogeneous Oxidation of Secondary Organic Tracers of Isoprene and Toluene by Ozone ····· HUANG Ya-juan, CAO Gang, ZHU Rong-shu, *et al.* (1163)
Inventory and Spatiotemporal Distribution of Ammonia Emission from Agriculture and Animal Husbandry in Lanzhou City ····· LI Shi-xue, GUO Wen-kai, HE Xin, *et al.* (1172)
Analysis of Stable Hydrogen and Oxygen Isotope Characteristics and Vapor Sources of Event-based Precipitation in Chengdu ····· HU Yue, LIU Guo-dong, MENG Yu-chuan, *et al.* (1179)
Diffusive CO_2 Flux Across the Water-air Interface of Reclaimed Shrimp Ponds in the Minjiang River Estuary Based on the TBL Model ····· ZHANG Yi-fei, YANG Ping, ZHAO Guang-hui, *et al.* (1188)
Distribution and Seasonal Variations of Chromophoric Dissolved Organic Matter(CDOM) in the Bohai Sea and the North Yellow Sea ····· LIU Zhao-bing, LIANG Wen-jian, QIN Li-ping, *et al.* (1198)
Sources, Characteristics and Transformation Dynamics of Fluorescent Dissolved Organic Matter in the Silin Reservoir ····· LAO Xin-yu, YUAN Jie, LIU Yu, *et al.* (1209)
Microplastic Pollution of the Beaches in Xiamen Bay, China ····· LIU Qi-ming, LIANG Hai-tao, XI Gui-li, *et al.* (1217)
Biogeochemical Characteristics in Shengli Site of Lijiang River Under the High Resolution Monitoring ····· WANG Qi-gang, XIAO Qiong, ZHAO Hai-juan, *et al.* (1222)
Hydrochemical Characteristics and Possible Controls of Groundwater in the Xialatuo Basin Section of the Xianshui River ····· HE Jin, ZHANG You-kuan, ZHAO Yu-qing, *et al.* (1236)
Pollution Characteristics of OPEs in the Surface Water and Sediment of the Jinjiang River in Chengdu City ····· WU Di, YIN Hong-ling, LI Shi-ping, *et al.* (1245)
Community Structure and Predictive Functional Analysis of Surface Water Bacterioplankton in the Danjiangkou Reservoir ····· ZHANG Fei, TIAN Wei, SUN Feng, *et al.* (1252)
Influence of Cyanobacterial Blooms on Denitrification Rate in Shallow Lake Taihu, China ····· LIU Zhi-ying, XU Hai, ZHAN Xu, *et al.* (1261)
Assessment of Ecosystem Health of an Urban River Based on the Microbe Index of Biotic Integrity (M-IBI) ····· SU Yao, XU Yu-xin, AN Wen-hao, *et al.* (1270)
Influences of Biochar Application on Root Aerenchyma and Radial Oxygen Loss of *Acorus calamus* in Relation to Subsurface Flow in a Constructed Wetland ····· HUANG Lei, LIANG Yin-kun, LIANG Yan, *et al.* (1280)
Pollution Load Characteristics of Runoff from Urban Roofs of Different Materials ····· HE Hu-bin, CHEN Cheng, LIN Yu-qing, *et al.* (1287)
Preparation of BiOCl-$(NH_4)_3PW_{12}O_{40}$ Photocatalyst and a Mechanism for Photocatalytic Degradation of Organic Pollutants ····· ZHANG Wen-hai, JI Qing-hua, LAN Hua-chun, *et al.* (1295)
High Efficiency Removal of 1,2-Dichloroethane from Groundwater by Microscale Zero-valent Iron Combined with Biological Carbon Source ··· WU Nai-jin, SONG Yun, WEI Wen-xia, *et al.* (1302)
Removal of Lead Ions from Water by Struvite Natural Zeolite Composite ····· DEND Man-jun, WANG Xue-jiang, CHENG Xue-jun, *et al.* (1310)
Characteristics of Phosphorus Adsorption in Aqueous Solution By Ca/Mg-Loaded Biogas Residue Biochar ····· YI Man, LI Ting-ting, LI Hai-hong, *et al.* (1318)
Preparation of Two Kinds of Biochar and the Factors Influencing Tetracycline Removal from Aqueous Solution ····· CHENG Yang, SHEN Qi-bin, LIU Zi-dan, *et al.* (1328)
Effect of Zirconium-Modified Zeolite Addition on Migration and Transformation of Phosphorus in River Sediments Under Static and Hydrodynamic Disturbance Conditions ····· YU Yang, LIN Jian-wei, ZHAN Yan-hui, *et al.* (1337)
Removal Efficiencies and Mechanism Research on Four Sulfonamides and Their Acetyl Metabolites in a Wastewater Treatment Plant ····· WANG Da-peng, ZHANG Xian, YAN Chang-zhou (1347)
Assessing Performance of Pollutant Removal from Municipal Wastewater by Physical and Chemical Methods Based on Membranes ····· XU Ting, LI Yong, ZHU Yi-jia, *et al.* (1353)
Effect of Influent Ammonia Concentration on a Biological Phosphorus Removal Granules System ····· LI Dong, CAO Mei-zhong, GUO Yue-zhou, *et al.* (1360)
Start-up and Performance Recovery of Granular Sludge for Phosphorus Removal and Nitrification ····· LI Hai-ling, LI Dong, ZHANG Jie, *et al.* (1367)
Realization of Short-cut Nitrification in a CAST Process at High Temperature and Its Phosphorus Removal Performance ····· MA Juan, YANG Rui-chun, YU Xiao-jun, *et al.* (1375)
Nitrogen and Phosphorus Removal from Low C/N Municipal Wastewater Treated by a SPNDPR System with Different Aeration and Aerobic Times ····· YUAN Meng-fei, YU De-shuang, GONG Xiu-zhen, *et al.* (1382)
ABR Decarbonization-Nitrosation Coupled with ANAMMOX to Treat Municipal Wastewater ····· LI Tian, CAO Jia-wei, XIE Feng-lian, *et al.* (1390)
Start-up Performance and Sludge Characteristics of Single-stage Autotrophic Nitrogen Removal System with Granular Sludge at Low Ammonia Nitrogen Concentration at Room Temperature ····· XIE Lu-lin, WANG Jian-fang, QIAN Fei-yue, *et al.* (1396)
ANAMMOX Reactor with Two Kinds of Inoculated Sludge: Start-up and Kinetics Characteristics ····· REN Jun-yi, CHEN Lin-yi, LI Hui-chun, *et al.* (1405)
Operation Characteristics of the Biofilm CANON Reactor During the Temperature Reduction Process ····· FU Kun-ming, LIAO Min-hui, ZHOU Hou-tian, *et al.* (1412)
Nitrogen Removal Characteristics and Analysis of Microbial Community Structure in an IEM-UF Simultaneous Separation and Denitrification System ····· LIU Zi-qi, ZHANG Yan, MA Xiang-shan, *et al.* (1419)
Effect of Temperature on the Activity Kinetics of *Nitrobacter* ····· YU Xue, SUN Hong-wei, LI Wei-wei, *et al.* (1426)
Enhancement for Anaerobic Digestion of Waste Activated Sludge Based on Microwave Pretreatment Combined with Zero Valent Iron ····· NIU Yu-tong, LIU Ji-bao, MA Shuang, *et al.* (1431)
Effects of Environmental Factors on Tetracyclines and Macrolides Resistance Genes in Cattle Manure Composting Systems ····· PENG Jing, WANG Ke, GU Yue, *et al.* (1439)
Effect of Environmental Factors on Variation Characteristics of Soil Microbial Respiration and Its Temperature Sensitivity ····· ZHANG Yan-jun, GUO Sheng-li (1446)
Response of Soil Respiration and Its Components to Simulated Acid Rain in a Typical Forest Stand in the Three Gorges Reservoir Area ····· LI Yi-fan, WANG Yu-jie, WANG Bin, *et al.* (1457)
Effects of Fertilization on the Nitrogen Residual Amounts and Leaching from Citrus Orchard Soil in the Three Gorges Reservoir Area ····· WANG Tian, HUANG Zhi-lin, ZENG Li-xiong, *et al.* (1468)
Microbial Carbon Source Metabolic Profile in Rice Rhizosphere and Non-rhizosphere Soils with Different Long-term Fertilization Management ····· NING Zhao, CHENG Ai-wu, TANG Hai-ming, *et al.* (1475)
Characterization of Soil Organic Carbon Mineralization Under Different Gradient Carbon Loading in Paddy Soil ····· TONG Yao-yao, WANG Ji-fei, ZHU Zhen-ke, *et al.* (1483)
Soil Organic Carbon Distribution and Components in Different Plant Communities Along a Water Table Gradient in the Huixian Karst Wetland in Guilin ····· XU Guang-ping, LI Yan-qiong, SHEN Yu-yi, *et al.* (1491)
Distribution of Organic Carbon in Soil Aggregates from Four Kinds of Forest Vegetation on Jinyun Mountain ····· WANG Fu-hua, LÜ Sheng, HUANG Rong, *et al.* (1504)
Review of Research on the Impacts of Atmospheric Pollution on the Health of Residents ····· QIN Yao-chen, XIE Zhi-xiang, LI Yang (1512)