

中国城镇供水排水协会2026年会



AOA[®]新技术对中低温污水的韧性 与氧化亚氮 (N₂O) 减排

彭永臻

北京工业大学

城镇污水深度处理与资源化利用技术---国家工程实验室

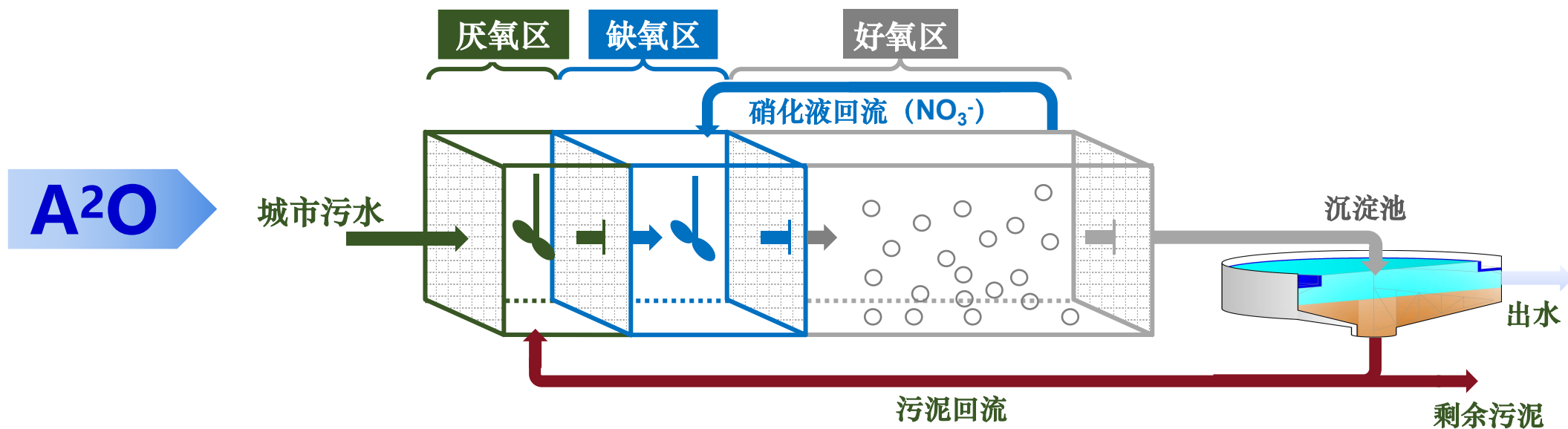
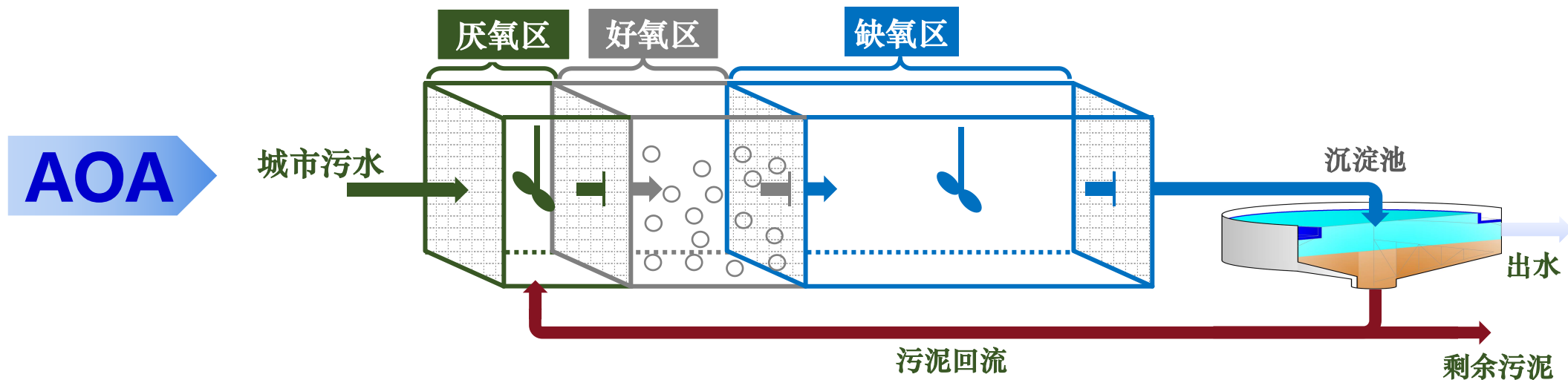
2026年4月



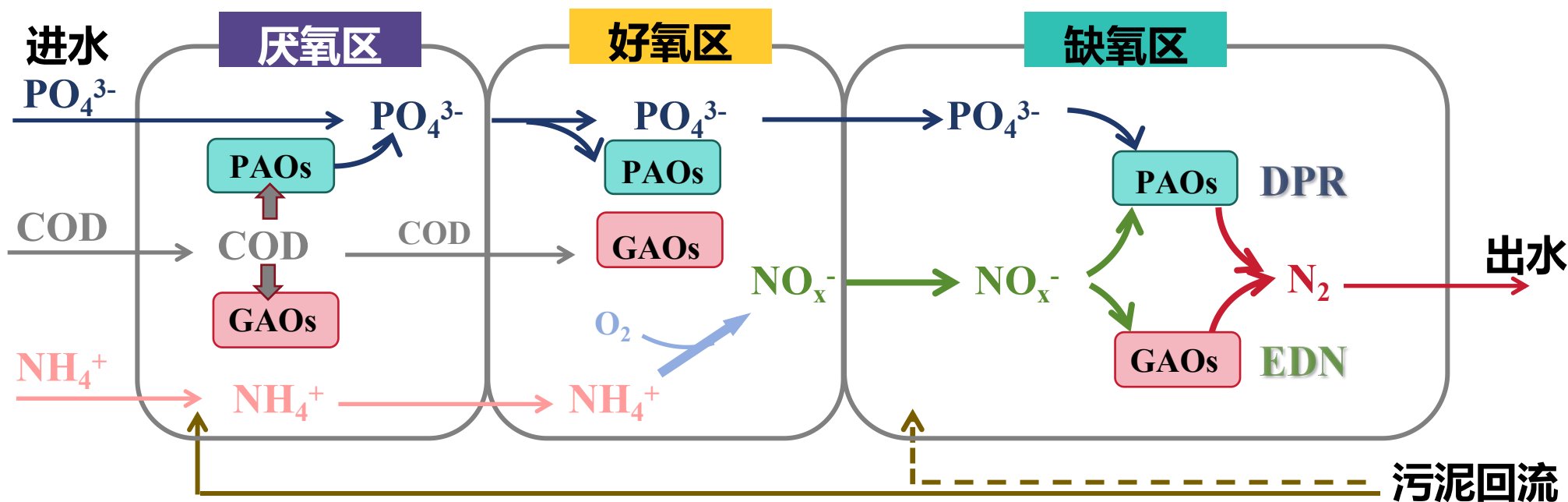
- 一 AOA[®]技术原理与优势**
- 二 对中低温污水处理的韧性**
- 三 氧化亚氮 (N₂O) 减排研究**
- 四 示范工程与应用**
- 五 结论与展望**

AOA[®]技术原理与优势—AOA[®]和A²O工艺比较

□ AOA与A²O (HRT) 比值都是：1:2:4+



AOA[®]技术原理与优势—AOA[®]技术原理上的优势



厌氧阶段(A_n):

- ① 污水中的有机物
贮存为内碳源
- ② 同时发生厌氧释磷
- ③ 反硝化过程

好氧阶段(O):

- ① 硝化作用与好氧吸磷
作用
- ② 去除少量剩余有机物
- ③ 发生同步硝化反硝化

缺氧阶段(A):

- ① 用厌氧阶段贮存的内碳源进行
内源反硝化, 实现深度脱氮
- ② 也可进行反硝化除磷
- ③ 如果C/N极低, 投加少量碳源
还可以实现极限脱氮

生物脱氮—硝化与反硝化

Biological Nitrogen Removal—Nitrification and Denitrification

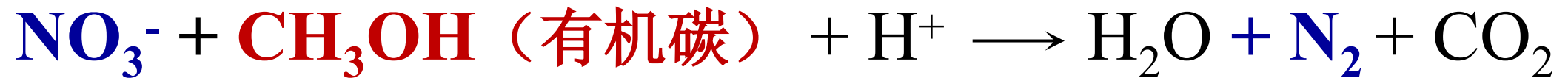
硝化过程 (曝气、耗能)

Nitrification (aeration、energy consumption)



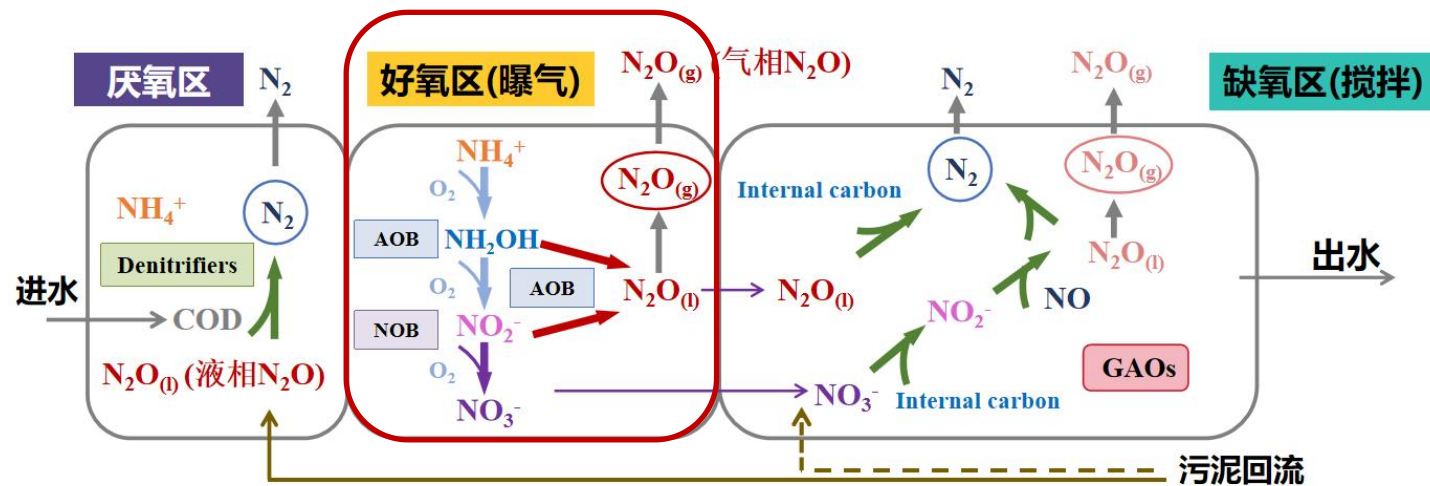
反硝化过程 (消耗有机碳源)

Denitrification (organic carbon source consumption)

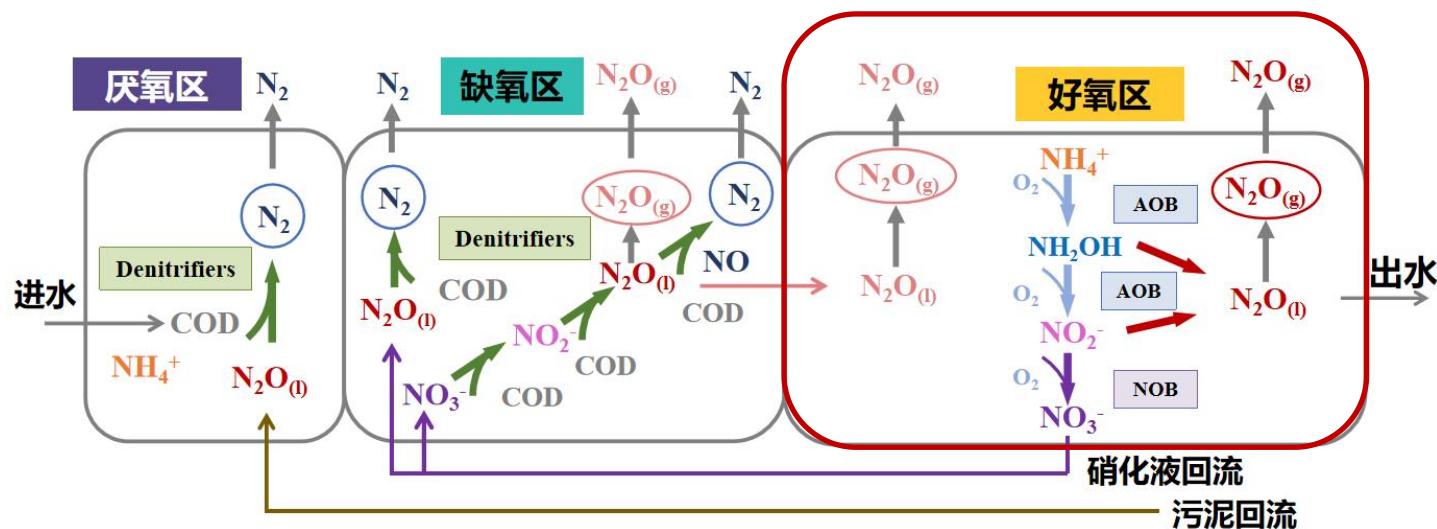


AOA[®]和A²O工艺—N₂O排放规律与特征

AOA



A²O



厌氧阶段(A_n)

相同: 反硝化菌利用进水中的有机物将溶解态N₂O进行充分还原, 绝大多数以N₂形式逸出。

好氧阶段(O):

相同: 通过羟胺氧化及AOB反硝化等作用产生的溶解态N₂O在曝气吹脱下逸散。

不同: **AOA工艺**适当降低曝气量可减少N₂O逸散, 充分发挥后置缺氧区的功能。

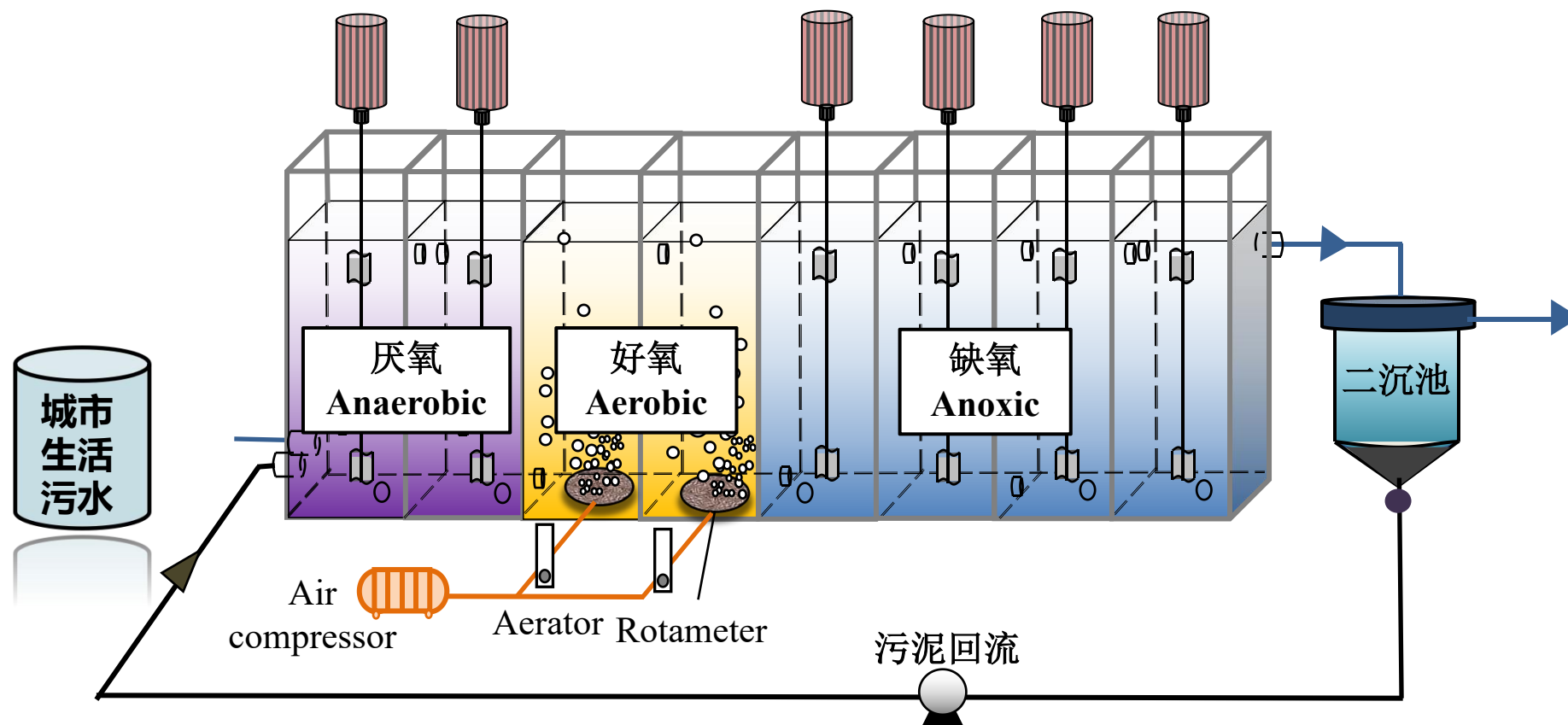
A²O工艺随即将上游缺氧区残留的N₂O吹脱且溶解态N₂O随出水流出。

缺氧阶段(A):

不同: **AOA工艺**后置缺氧区作为N₂O的汇, 利用内碳源进行内源反硝化作用, 将上游溶解态N₂O进行还原;

A²O工艺利用外碳源进行反硝化作用, N₂O在充分的碳源条件下被还原为N₂, 碳源不足则会积累N₂O, 提高在好氧区逸散的风险。

AOA[®]技术原理与优势—运行与工程上的优点



双回流 (SDR) 厌氧/好氧/缺氧 (Anaerobic/Aerobic/Anoxic AOA) 工艺

- 通常厌氧/好氧/缺氧容积及HRT比 $A:O:A=1:1:2$ ，好氧HRT仅占1/4，节能与减碳
- 无硝化液内循环，节能；而且避免了破坏厌氧(Anaerobic)环境，利于除磷
- 缺氧段出水，无外加碳源也可实现深度或极限脱氮

AOA[®]技术原理与优势—AOA[®]授权发明专利

序号	发明(设计)人	名称	专利号	专利权人	类型
1	彭永臻, 石亮亮, 王爱杰, 等	单级AOA-SBBR强化内源反硝化污水深度脱氮除磷的装置与方法	ZL201610816170.6	北京工业大学	发明
2	彭永臻, 张婷, 丁鹏霖, 等	污泥双回流AOA实现城市污水深度脱氮除磷的装置与方法	ZL201710269345.0	北京工业大学	发明
3	彭永臻, 张婷, 王爱杰, 等	一种通过污泥双回流AOA工艺实现城市污水短程硝化的方法	ZL201710269330.4	北京工业大学	发明
4	彭永臻, 高歆婕, 许载周, 等	一种污泥发酵强化内源反硝化的双污泥回流AOA深度脱氮方法	ZL201811489538.8	北京工业大学	发明
5	彭永臻, 高歆婕, 许载周, 等	污泥双回流AOA短程硝化耦合厌氧氨氧化与内源反硝化处理城市污水的方法与装置	ZL201811488113.5	北京工业大学	发明
6	彭永臻, 陈凯琦, 孙事昊, 等	AOA (PD-ANAMMOX) 生物膜技术深度脱氮的装置与方法	ZL201910189777.X	北京工业大学	发明
7	彭永臻, 高歆婕, 许载周, 等	AOA工艺缺氧区内源短程反硝化耦合厌氧氨氧化处理城市污水的方法与装置	ZL201910358952.3	北京工业大学	发明
8	彭永臻, 高歆婕, 许载周, 等	全流程厌氧氨氧化强化脱氮的AOA工艺处理城市污水的方法与装置	ZL201910358964.6	北京工业大学	发明
9	彭永臻, 冯岩, 刘博, 等	一种基于DEAMOX污泥双回流AOAO污水深度脱氮除磷的装置与方法	ZL201910871105.7	北京工业大学	发明
10	彭永臻, 李文宇, 高锐涛, 等	连续流AOA短程硝化与厌氧氨氧化耦合污泥发酵反硝化处理低碳氮比废水的装置与方法	ZL202010926804.X	北京工业大学	发明
11	彭永臻;冯岩;张琼	一种连续流城市污水AOAO自富集厌氧氨氧化实现自养与异养耦合脱氮的装置与方法	ZL202011057526.5	北京工业大学	发明
12	彭永臻, 丁静, 高歆婕, 等	通过异养与自养反硝化强化短程反硝化耦合厌氧氨氧化的AOA-SBR的装置和方法	ZL202011287643.0	北京工业大学	发明

— AOA[®]技术原理与优势— 在国内外发表前55篇AOA论文

围绕AOA工艺技术，在国内外率先发表前55篇论文 (46篇 为中科院一区SCI，中文核心3篇)

1. Li, Z.M., Wang, S.Y., Zhang, W.T., Miao, L., Cao, T.H., Peng, Y.Z.* Nitrogen removal from medium-age landfill leachate via post-denitrification driven by PHAs and glycogen in a single sequencing batch reactor. **Bioresource Technology**, 2014, 169, 773-777.
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3. Miao, L., Wang, S.Y., Li, B.K., Cao, T.H., Zhang, F.Z., Wang, Z., Peng, Y.Z.* Effect of carbon source type on intracellular stored polymers during endogenous denitrification (ED) treating landfill leachate. **Water Research**, 2016, 100, 405-412.
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8. Zhao, W.H., Huang, Y., Wang, M.X., Pan, C., Li, X.Y., Peng, Y.Z.*, Li, B.K. Post-endogenous denitrification and phosphorus removal in an alternating anaerobic/oxic/anoxic (AOA) system treating low carbon/nitrogen (C/N) domestic wastewater. **Chemical Engineering Journal**, 2018, 339, 450-458.
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10. Zhao, J., Wang, X.X., Li, X.Y., Jia, S.Y., Peng, Y.Z.* Combining partial nitrification and post endogenous denitrification in an EBPR system for deep-level nutrient removal from low carbon/nitrogen (C/N) domestic wastewater. **Chemosphere**, 2018, 210, 19-28.
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24. Zhang, L.Y., Lin, Y.G., Zhu, Z., Li, X.Y., Wang, S.Y., Peng, Y.Z.* Rapidly recovering and maintaining simultaneous partial nitrification, denitrification and anammox process through hydroxylamine addition to advance nitrogen removal from domestic sewage. **Bioresource Technology**, 2022, 360, 127645.
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35. Dan, Q.P., Du, R., Wang, T., Sun, T.T., Li, X.Y., Zhang, Q., Peng, Y.Z.* Endogenous partial denitrification as an efficient remediation to unstable partial nitrification-anammox (PNA) process: Bacteria enrichment and superior robustness. **Chemical Engineering Journal**, 2023, 454, 139851.
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城市污水AOA[®]前沿工艺技术中试20余座



北京工业大学AOA中试



海南白沙门污水厂AOA中试



中山中嘉污水厂AOA中试



天津张贵庄污水厂AOA中试



浙江杭州城西厂AOA中试



北京高碑店污水厂AOA中试



合肥王小郢污水厂AOA中试



深圳滨河水质净化厂AOA中试



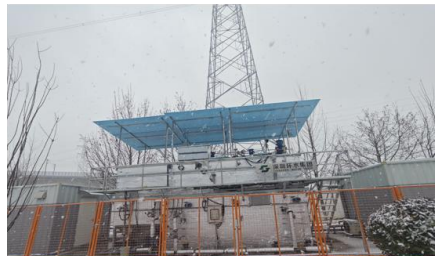
深圳福永水质净化厂AOA中试



佛山南庄净水厂AOA中试



郑州新区污水厂AOA中试



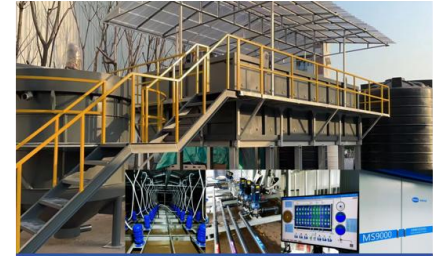
济南历城污水厂AOA中试



宁波岚山污水厂AOA中试



深圳福田水质净化厂AOA中试



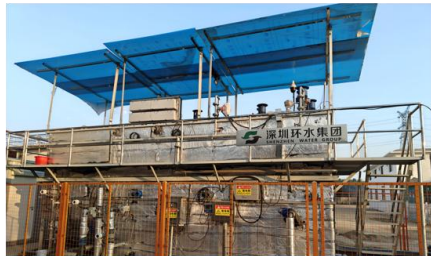
哈工大深圳AOA中试



惠州金山污水厂AOA中试



珠海拱北污水厂AOA中试



滕州一污污水厂AOA中试

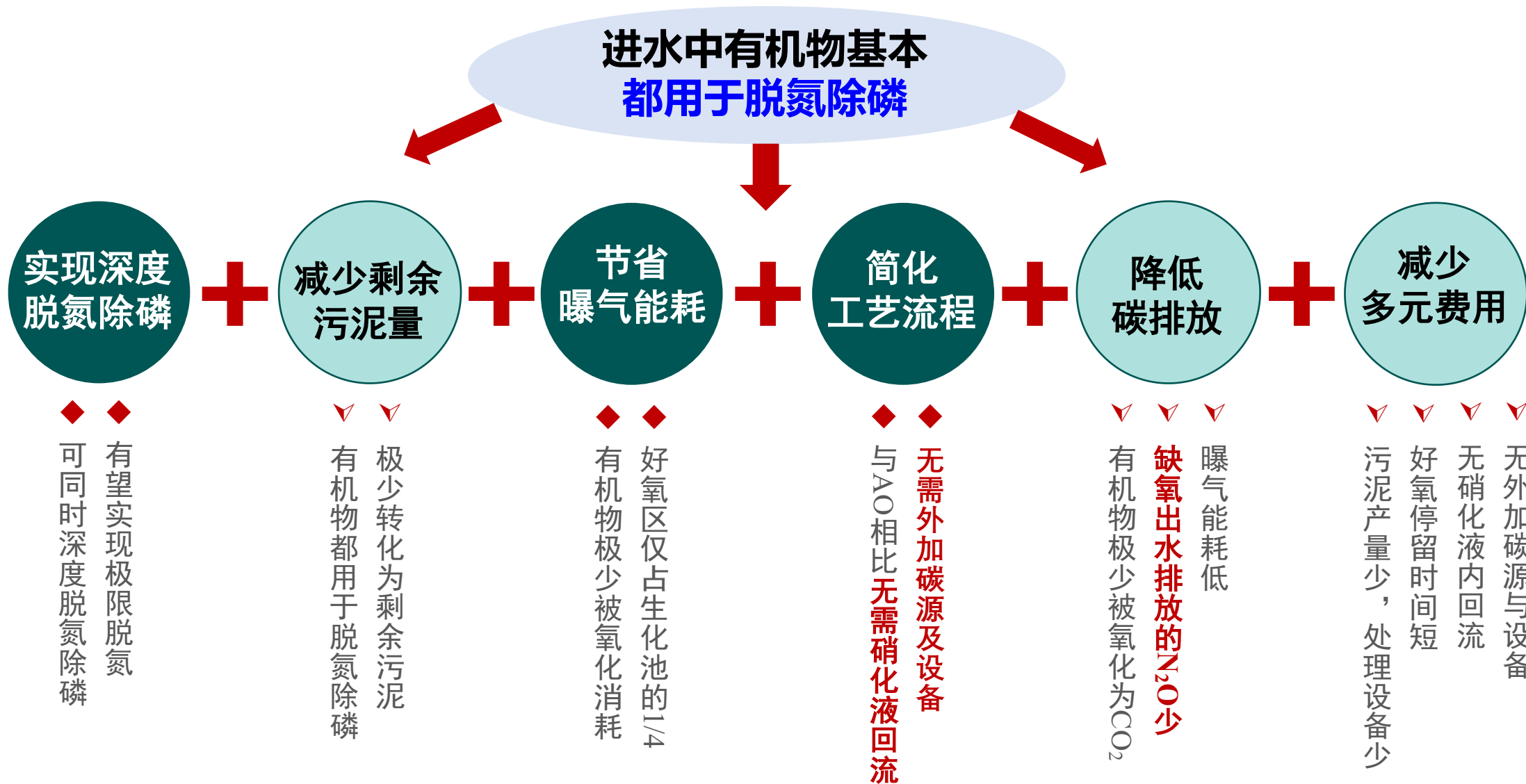


拱北水质净化厂AOA中试



广东深圳南山污水厂AOA中试

AOA[®]工艺技术优势— 优势总结



AOA[®]工艺技术优势 — 补充两条优点

进水中有机物基本都用于脱氮除磷

实现深度脱氮除磷

- ◆ 有望实现极限脱氮
- ◆ 可同时深度脱氮除磷

减少剩余污泥量

- ▽ 极少转化为剩余污泥
- ▽ 有机物都用于脱氮除磷

节省曝气能耗

- ◆ 好氧区仅占生化池的1/4
- ◆ 有机物极少被氧化消耗

对中低温的韧性

- ▽ AOA工艺体现了低温耐受性基本相同
- ▽ 种群类型与其他活性污泥法

简化工艺流程

- ◆ 无需外加碳源及设备
- ◆ 与AO相比无需硝化液回流

降低N₂O等碳排放

- ▽ 曝气能耗低
- ▽ 缺氧出水排放的N₂O少
- ▽ 有机物极少被氧化为CO₂

减少多元费用

- ◆ 无外加碳源与设备
- ◆ 无硝化液内回流
- ◆ 好氧停留时间短
- ◆ 污泥产量少，处理设备少

- 一 AOA[®]技术原理与优势
- 二 对中低温污水处理的韧性
- 三 氧化亚氮 (N₂O) 减排研究
- 四 示范工程与应用
- 五 结论与展望



北京高碑店污水厂中试



合肥王小郢污水厂中试



天津张贵庄污水厂中试

北京高碑店污水处理厂

合肥王小郢污水处理厂

天津张贵庄污水处理厂

国内外首次城市污水

中低温AOA工艺

中试研究



北排AOA中试装置

- 中试装置共分为21个格室，有效体积为 $3.5\text{m}^3 \times 21 = 73.5\text{m}^3$
- 中试各格室均安装曝气设备和搅拌器，方便实现系统厌氧、好氧、缺氧区的灵活切换

北排研发AOA中试



取样方法

□ 取样时间:

由于进水水质存在波动，取样，每天9:00、12:00、15:00、18:00和21:00进行取样，同体积混合，所有水样均为**全天混合水样**。

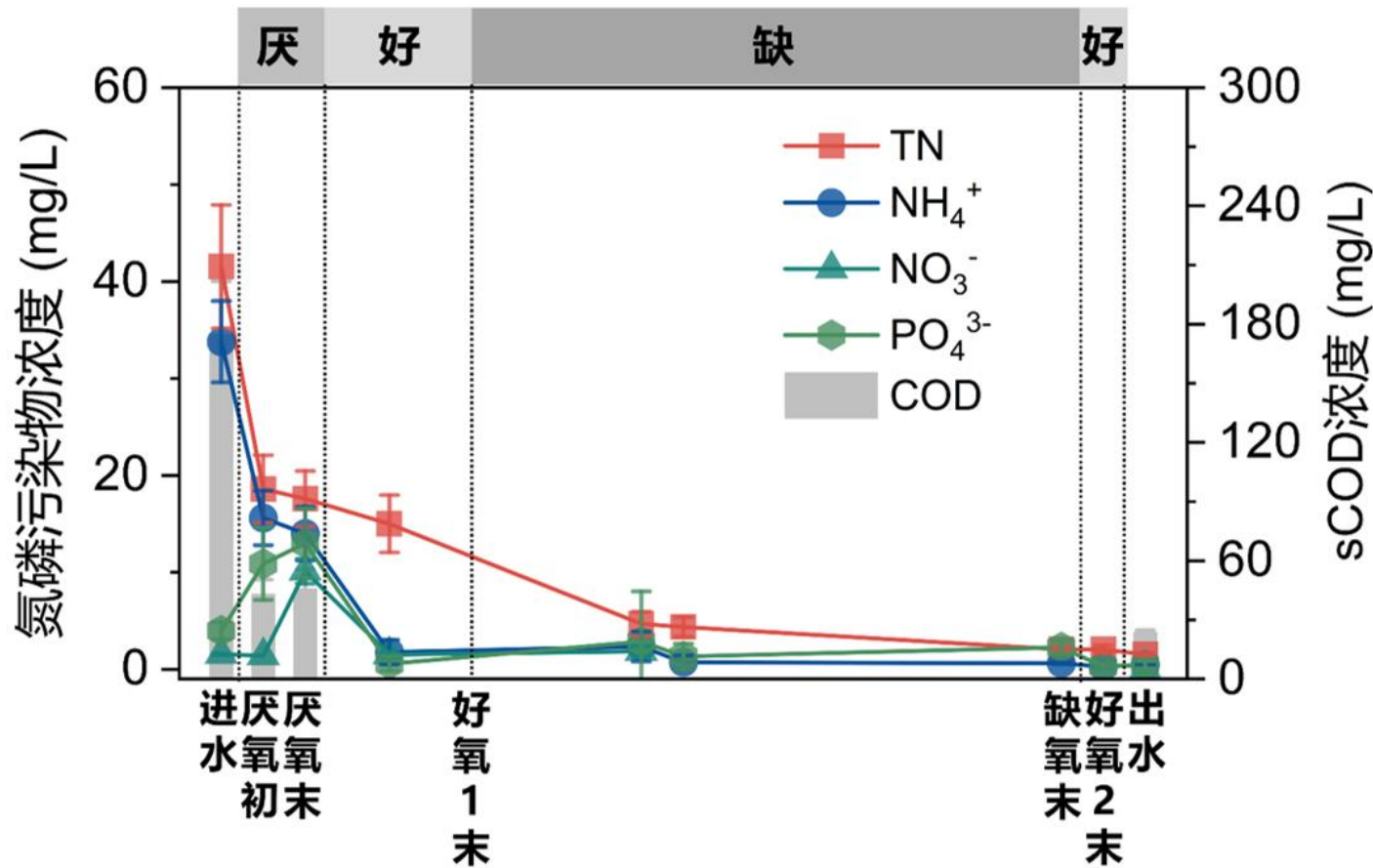
□ 样品前处理:

进水氮磷指标未过滤，COD分别测定过滤前和过滤后两个，其余水样菌通过滤纸（25-35 μm ）过滤后测定。

检测指标	检测方法
磷酸盐	标准方法 HJ670-2013
总磷	过硫酸钾消解法GB11893-89
COD	快速消解法 HJ399-2007
氨氮	纳氏分光光度法 HJ535-2009
总氮	过硫酸钾氧化法HJ636-2010
硝氮、亚硝	离子色谱

高碑店污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

□ 污染物沿程去除



□ 主要运行参数

运行时间: 2025年6月13日~7月2日

运行温度: **26.3 °C** ± 1.1 °C

进水COD/TN比: 4.17

总水力停留时间: 21.0 h

好氧水力停留时间: **3.3 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **41.5**

NH₄⁺-N: 33.8

PO₄³⁻-P: **4.0**

sCOD: **174.9**

TN: **1.5**

NH₄⁺-N: 0.5

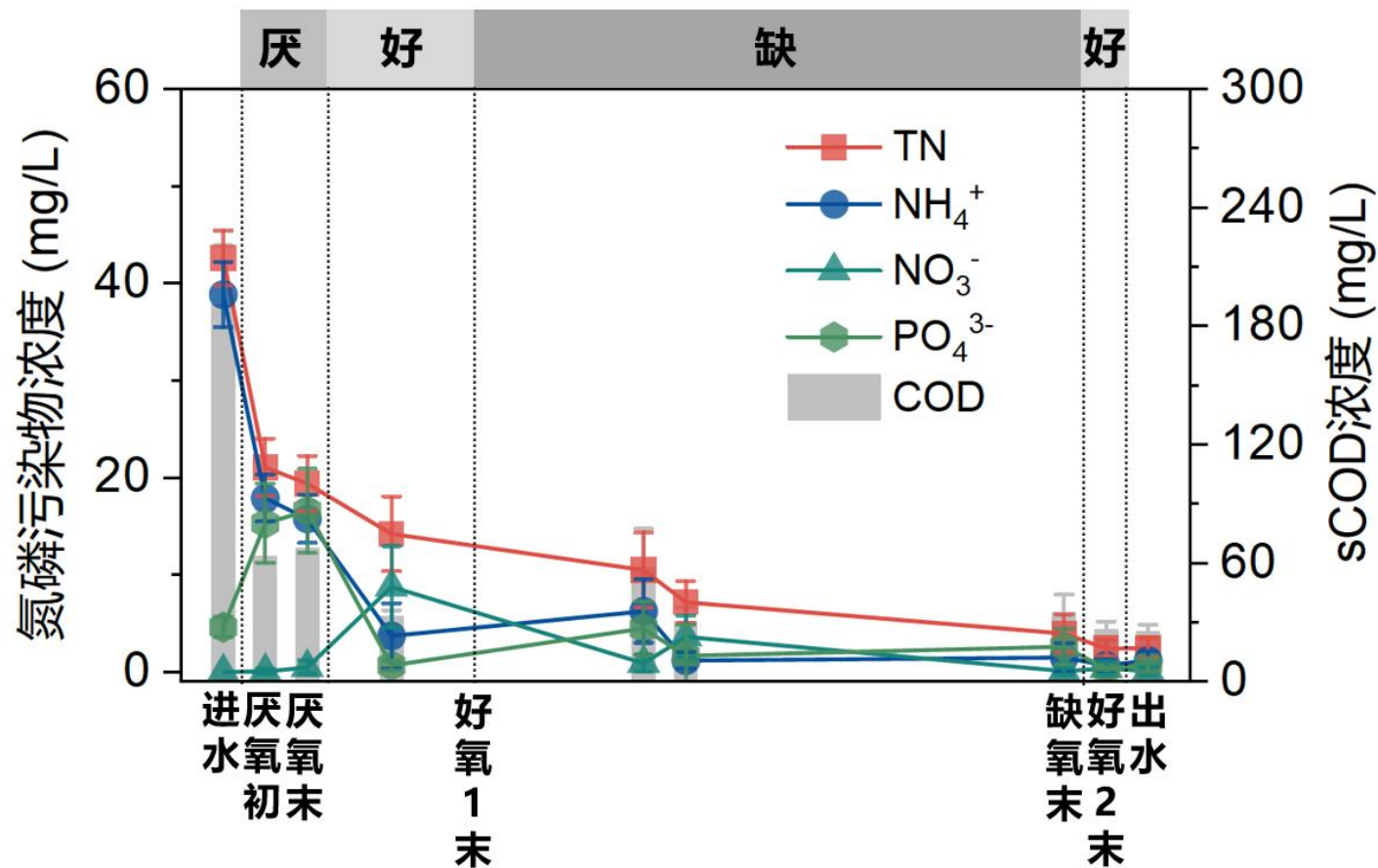
PO₄³⁻-P: **0.5**

sCOD: 23.5

连续20天出水总氮都低于2.0 mg-N/L, 平均为1.5 mg-N/L

北京高碑店AOA中试：连续33天沿流程水质分析 (混合水样)

□ 污染物沿程去除



□ 主要运行参数

运行时间：2025年5月8日~6月10日

运行温度：**22.1 °C** ± 1.9 °C

进水COD/TN比：4.49

总水力停留时间：20.5 h

好氧水力停留时间：**4.0 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **42.6**

NH₄⁺-N: 38.8

PO₄³⁻-P: **4.6**

COD: **191.0**

TN: **2.4**

NH₄⁺-N: 1.2

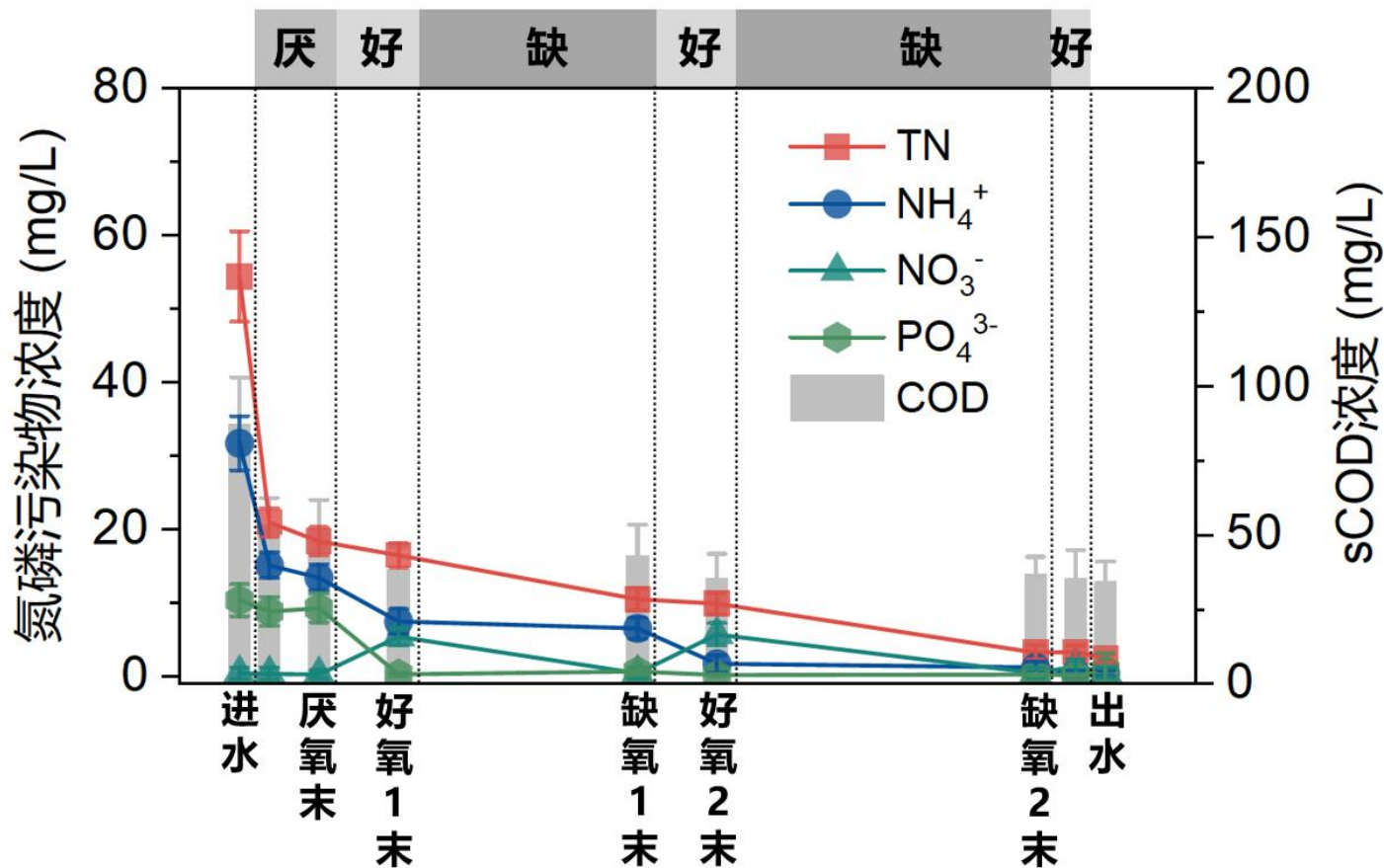
PO₄³⁻-P: **0.8**

COD: 25.4

连续33天，出水TN平均为2.4 mg/L，其中15天TN < 2.0 mg/L

高碑店污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

□ 污染物沿程去除



□ 主要运行参数

运行时间: 2025年10月20日~11月26日

运行温度: **18.0 °C** ± 0.8 °C

进水sCOD/TN比: 1.61 (sCOD测定过滤膜)

总水力停留时间: 14.0 h

好氧水力停留时间: **3.3 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **54.4**

NH₄⁺-N: 31.7

PO₄³⁻-P: **10.4**

sCOD: **87.4**

TN: **2.5**

NH₄⁺-N: 0.4

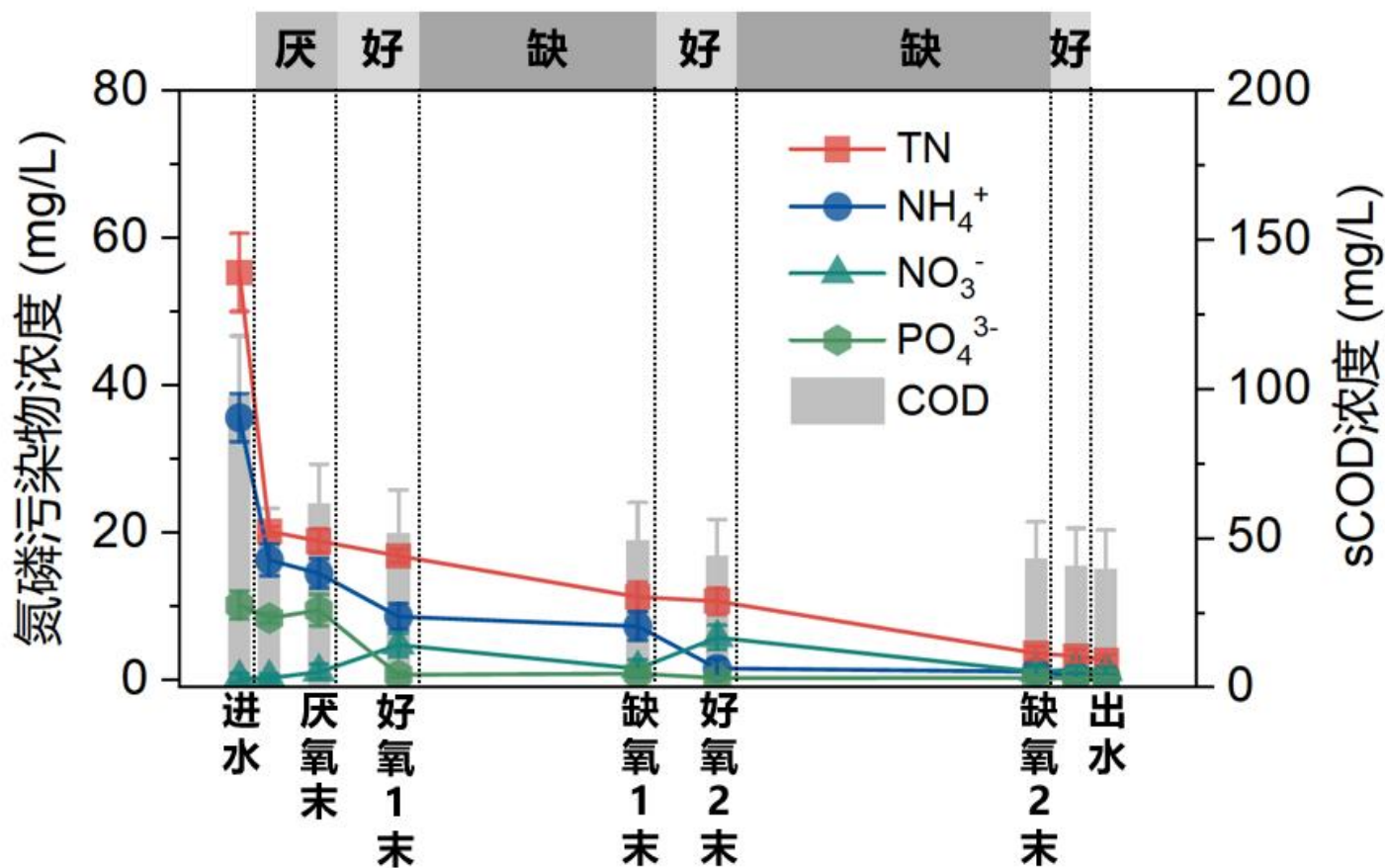
PO₄³⁻-P: **0.8**

sCOD: 34.3

连续37天出水总氮低于3.5 mg-N/L, 平均为2.5 mg-N/L

高碑店污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

□ 污染物沿程去除



□ 主要运行参数

运行时间: 2025年11月27日~12月29日

运行温度: **14.3 °C** ± 0.7 °C

进水sCOD/TN比: 1.76 (sCOD测定过滤膜)

总水力停留时间: 14.0 h

好氧水力停留时间: **3.3 - 4.0 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **55.3**

NH₄⁺-N: 35.6

PO₄³⁻-P: **10.2**

sCOD: **97.5**

TN: **2.7**

NH₄⁺-N: 0.4

PO₄³⁻-P: **0.3**

sCOD: 39.7

连续33天出水总氮低于3.8 mg-N/L, 平均为2.7 mg-N/L

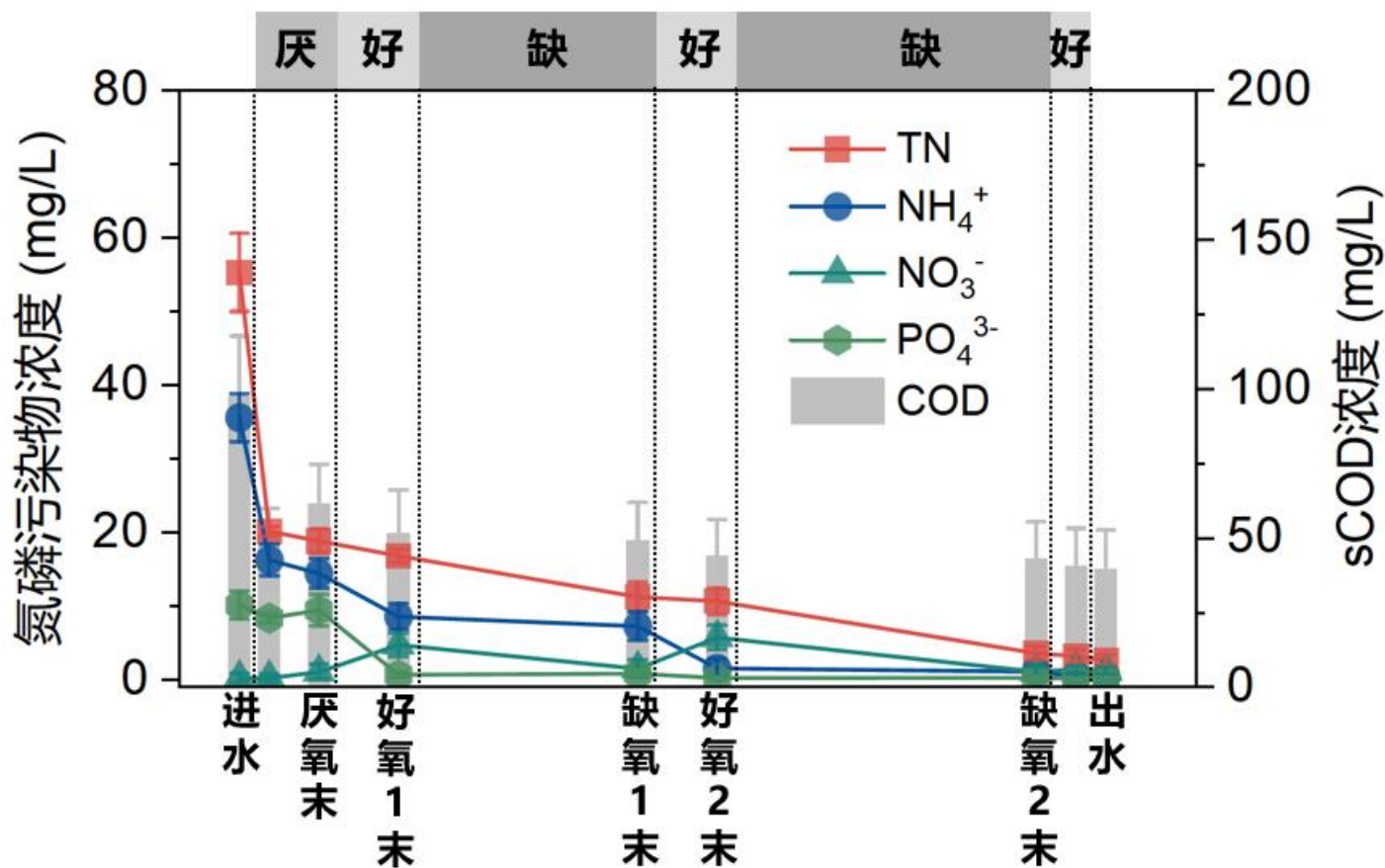
北京高碑店污水处理厂AOA中试研究—去除效果总结

□ 污染物去除效果总结 (高碑店初沉池进水直接进中试)

进水水质 (mg/L)				出水水质 (mg/L)				去除率 (%)			
TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD	TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD	TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD
2025年6月13日~7月2日 / 26.3 °C ± 1.1 °C											
41.5	33.8	4.0	174.9	1.5	0.5	0.5	23.5	96.4	98.5	87.5	86.6
2025年10月20日~11月26日 / 18.0 °C ± 0.8 °C											
54.4	31.7	10.4	87.4	2.5	0.4	0.8	34.3	95.4	98.7	92.3	60.7
2025年11月27日~12月29日 / 14.3 °C ± 0.7 °C											
55.3	35.6	10.2	97.5	2.7	0.4	0.3	39.7	95.0	98.9	97.1	59.3

高碑店污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

污染物沿程去除



主要运行参数

运行时间: 2026年3月9日~4月2日

运行温度: **16.0 °C** ± 1.1 °C

进水sCOD/TN比: 1.90 (sCOD测定过滤膜)

总水力停留时间: **11.7 h**

好氧水力停留时间: **3.3 h**

进水水质 (mg/L) 出水水质 (mg/L)

TN: **59.9**

NH₄⁺-N: 40.2

PO₄³⁻-P: **11.6**

sCOD: **113.9**

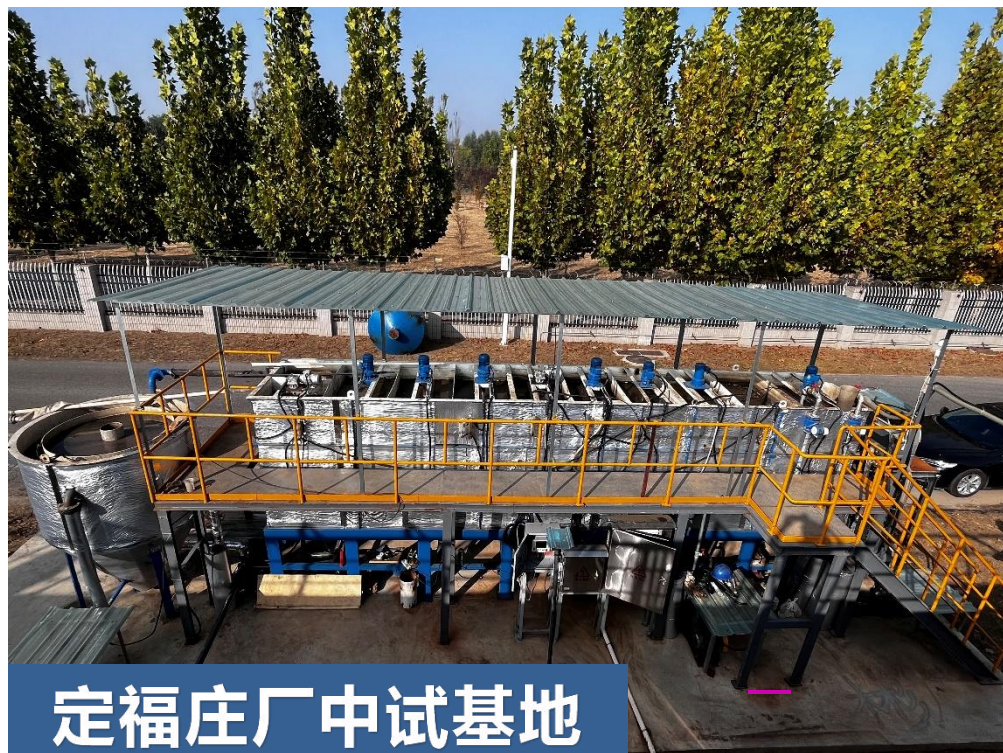
TN: **3.3**

NH₄⁺-N: 0.3

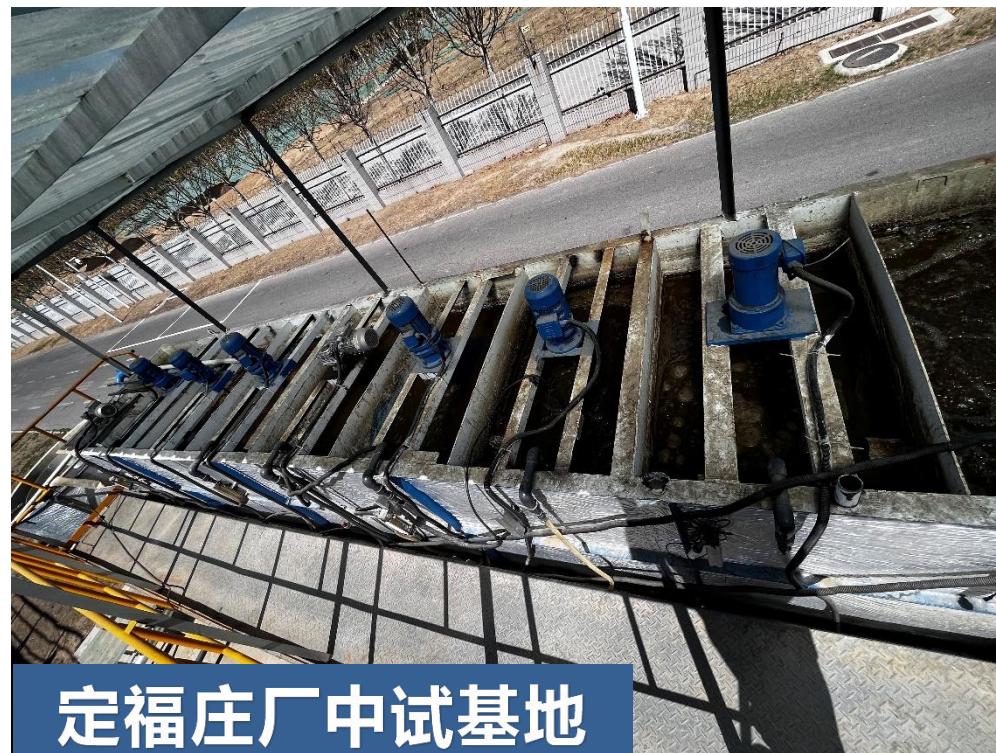
PO₄³⁻-P: **0.5**

sCOD: 44.7

24天运行期间, 平均出水总氮**3.3 mg-N/L**, 其中9天低于**2.0 mg-N/L**



定福庄厂中试基地



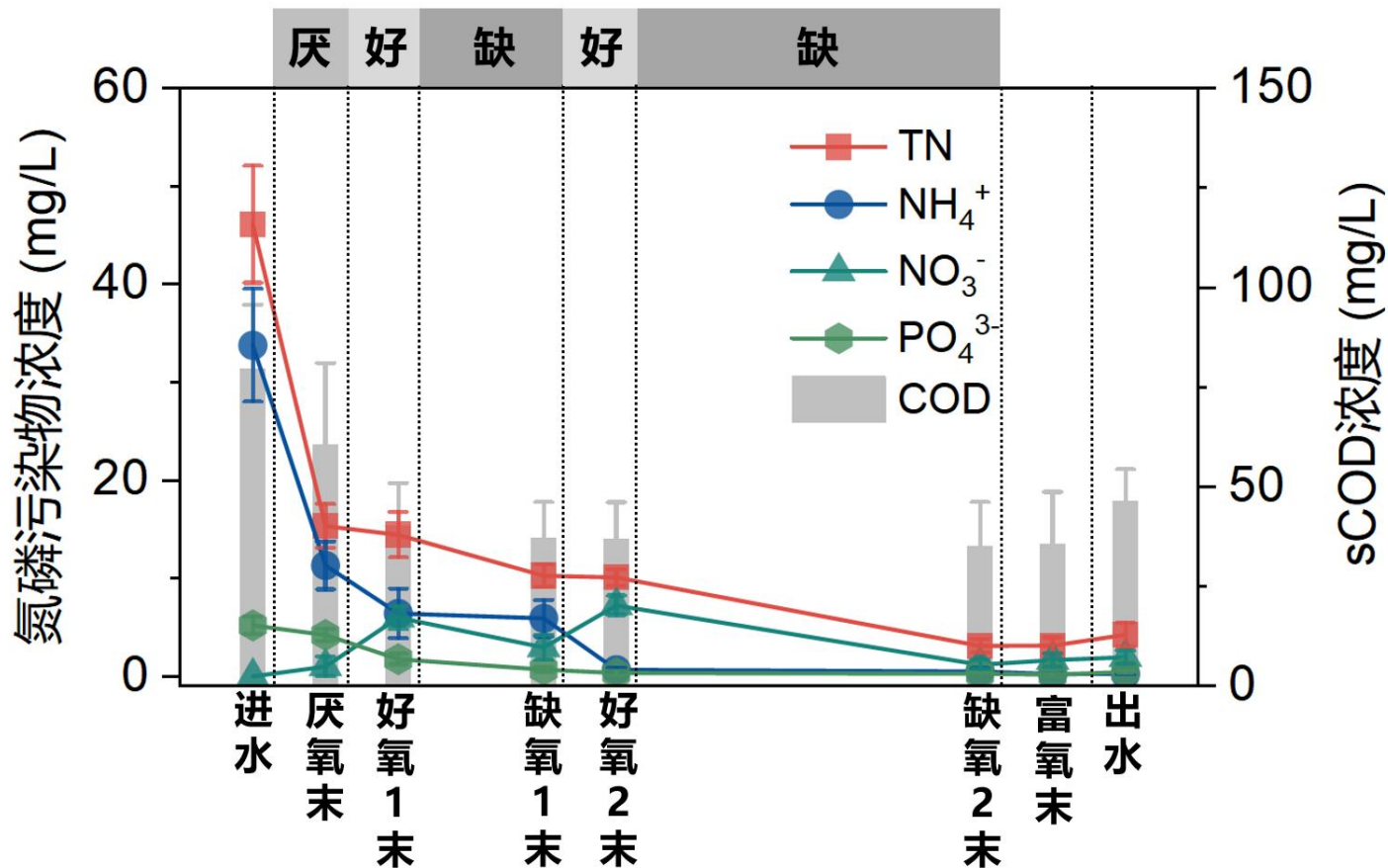
定福庄厂中试基地

北京定福庄污水处理厂AOA中试装置

- 中试装置有效容积为 $7.2 \times 1.2 \times 1.5 = 12.96 \text{ m}^3$ ，设计处理量为20~30 m^3/d
- 中试各格室均安装曝气设备和搅拌器，方便实现系统厌氧、好氧、缺氧区的灵活切换

北京定福庄AOA中试：秋季低温沿流程水质分析（混合水样）

□ 污染物沿程去除



□ 主要运行参数

运行时间：2025年11月1日~11月15日

运行温度：**16.7 °C** ± 0.2 °C

进水sCOD/TN比：1.72 (sCOD测定过滤膜)

总水力停留时间：21.0 h

好氧水力停留时间：**4.2 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **46.1**

NH₄⁺-N: 33.8

PO₄³⁻-P: **5.2**

sCOD: **79.5**

TN: **4.2**

NH₄⁺-N: 0.3

PO₄³⁻-P: **0.4**

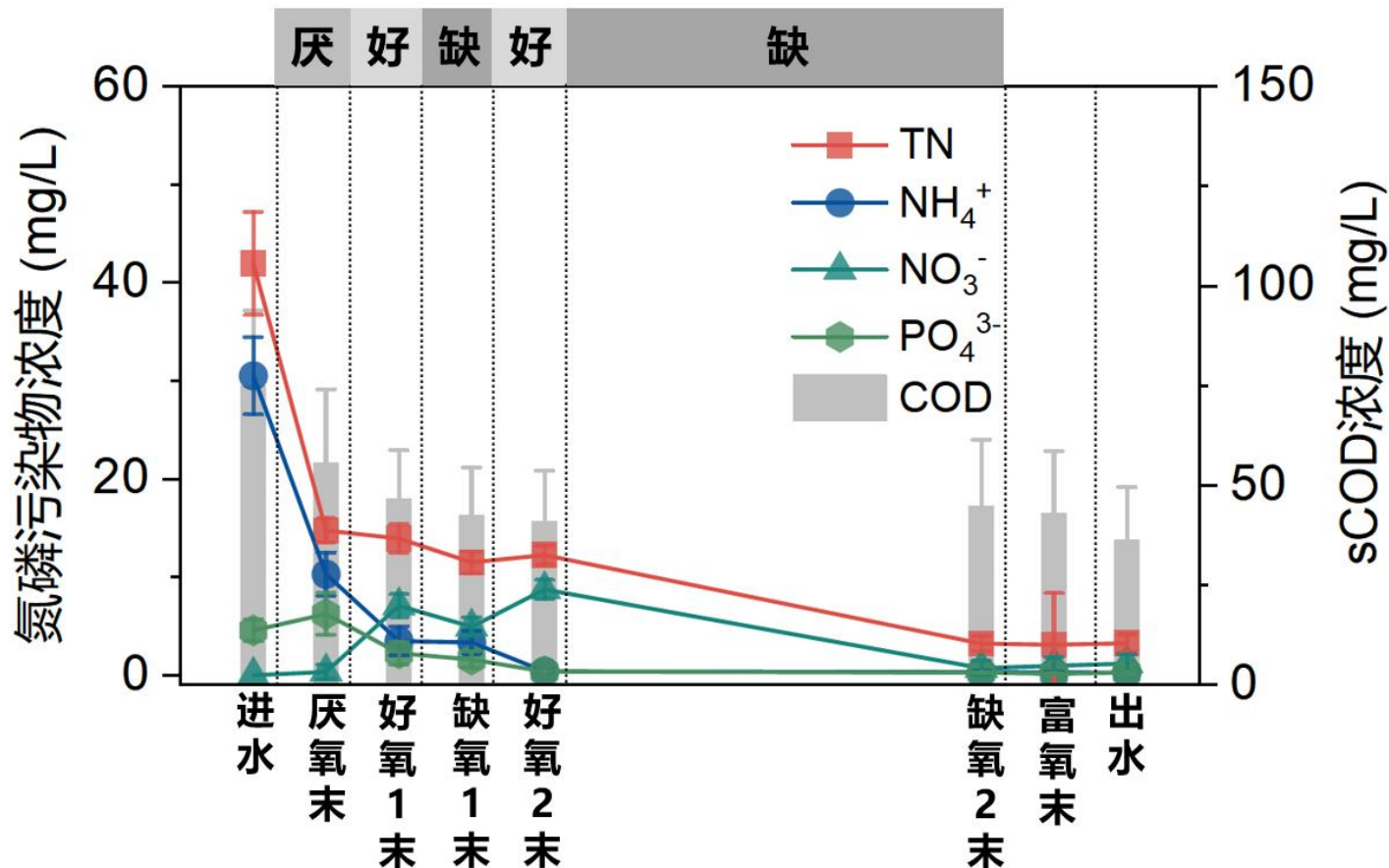
COD: 38.2

15天运行期间，平均出水总氮**4.2 mg-N/L**，其中8天低于**3.0 mg-N/L**

定福庄污水处理厂同期平均出水总氮为**8.3 mg-N/L** (投加碳源)

北京定福庄AOA中试：春季低温沿流程水质分析（混合水样）

□ 污染物沿程去除



□ 主要运行参数

运行时间：2026年3月2日~3月26日

运行温度：**14.3 °C** ± 1.3 °C

进水sCOD/TN比：1.79 (sCOD测定过滤膜)

总水力停留时间：21.0 h

好氧水力停留时间：**4.2 h**

□ 进水水质 (mg/L) 出水水质 (mg/L)

TN: **41.9**

NH₄⁺-N: 30.5

PO₄³⁻-P: **4.6**

sCOD: **75.0**

TN: **3.2**

NH₄⁺-N: 0.3

PO₄³⁻-P: **0.3**

sCOD: 36.4

25天运行期间，平均出水总氮**3.2 mg-N/L**，其中16天低于**3.0 mg-N/L**
定福庄污水处理厂同期平均出水总氮为**5.6 mg-N/L** (投加碳源、生物强化)

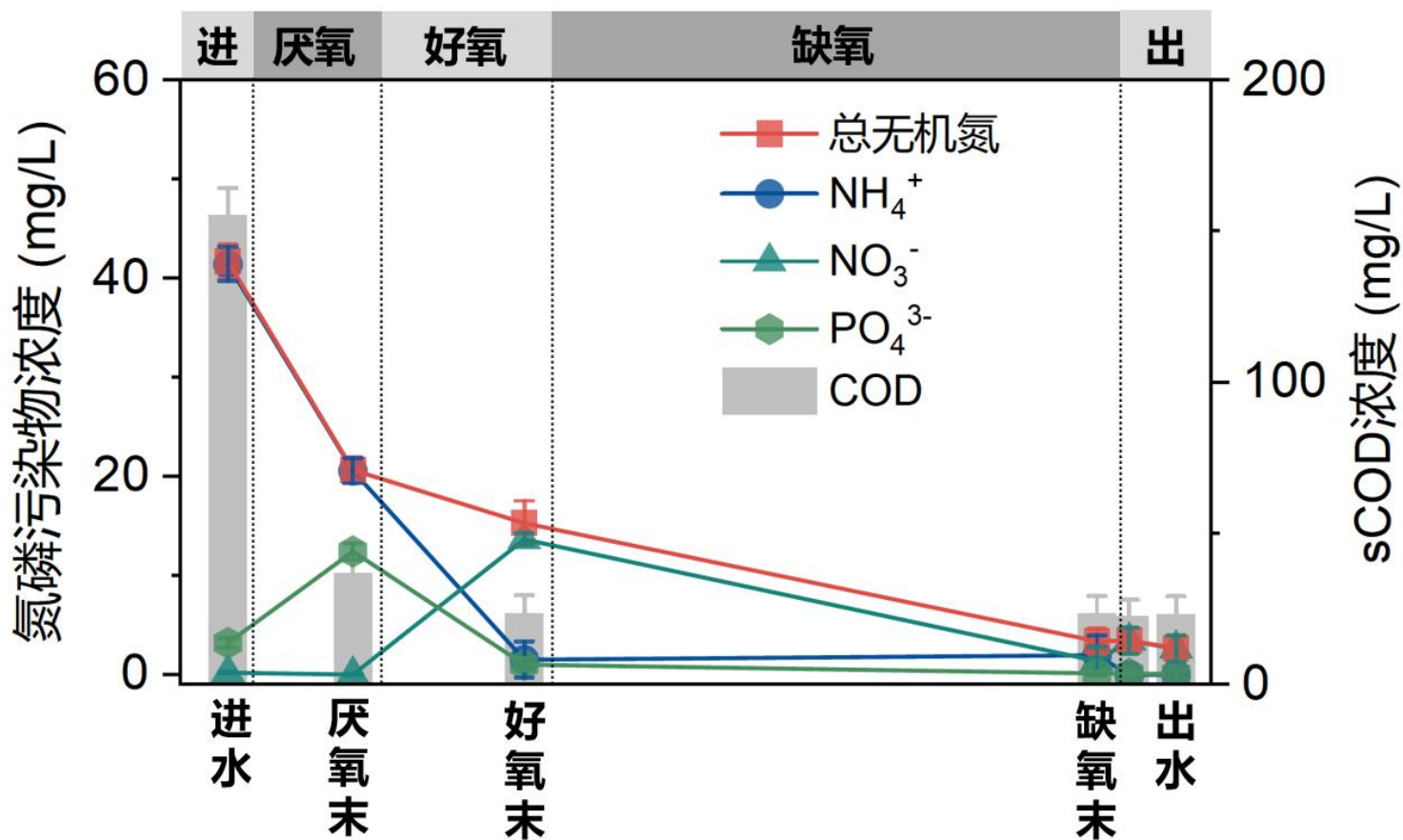
□ 合肥市王小郢污水处理厂氧化沟型AOA中试基地



□ 进水来自合肥王小郢污水处理厂格栅出水，实际水力停留时间约为**17.6 h**

□ 中试**有效体积43 m³**，设计处理量为60 m³/d

低温运行——污染物沿程去除



主要运行参数

运行时间: 2025年2月25日 ~ 27日
 运行温度: **13.4 °C** ±0.6 °C
 进水C/N比: **3.7 (基于sCOD)**
 总水力停留时间: 19.3 h
 好氧水力停留时间: **3.7 h**

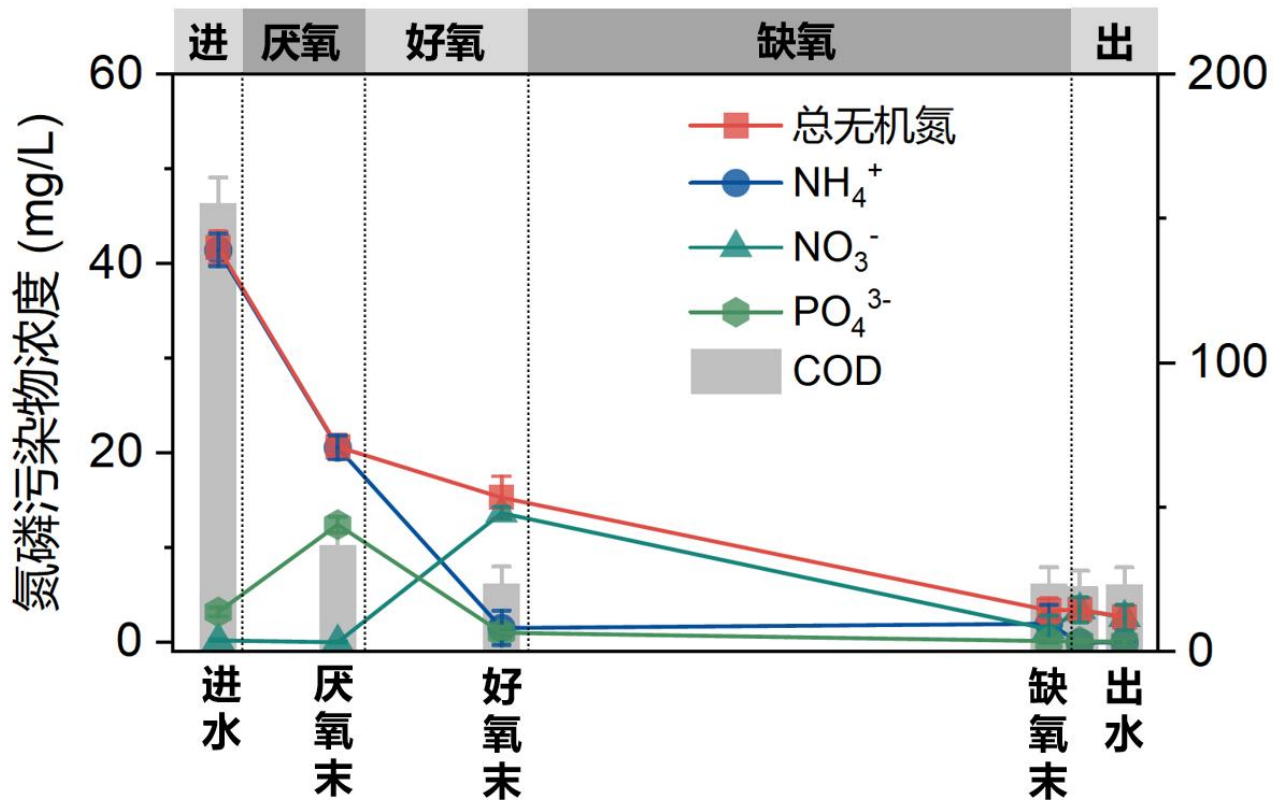
进水水质 (mg/L) 出水水质 (mg/L)

总无机氮: **41.7**
 NH₄⁺-N: 40.4
 PO₄³⁻-P: 3.2
 COD: **155.4**

总无机氮: **2.8**
 NH₄⁺-N: 0.03
 PO₄³⁻-P: **0.1**
 COD: 23.3

AOA中试在稳定运行阶段具备**低温低C/N比城市污水极限脱氮除磷的潜力**

污染物沿程去除（同为污水厂进水）



主要运行参数

运行时间：2025年2月25日 ~ 3月21日

运行温度：**14.7 °C ± 1.3 °C**

进水sCOD/TN：**4.1**

总水力停留时间：19.3 h（水厂二期为18.6 h）

好氧水力停留时间：**3.7 h**（水厂二期为7.8 h）

缺氧水力停留时间：**12.2 h**（水厂二期为7.4 h）

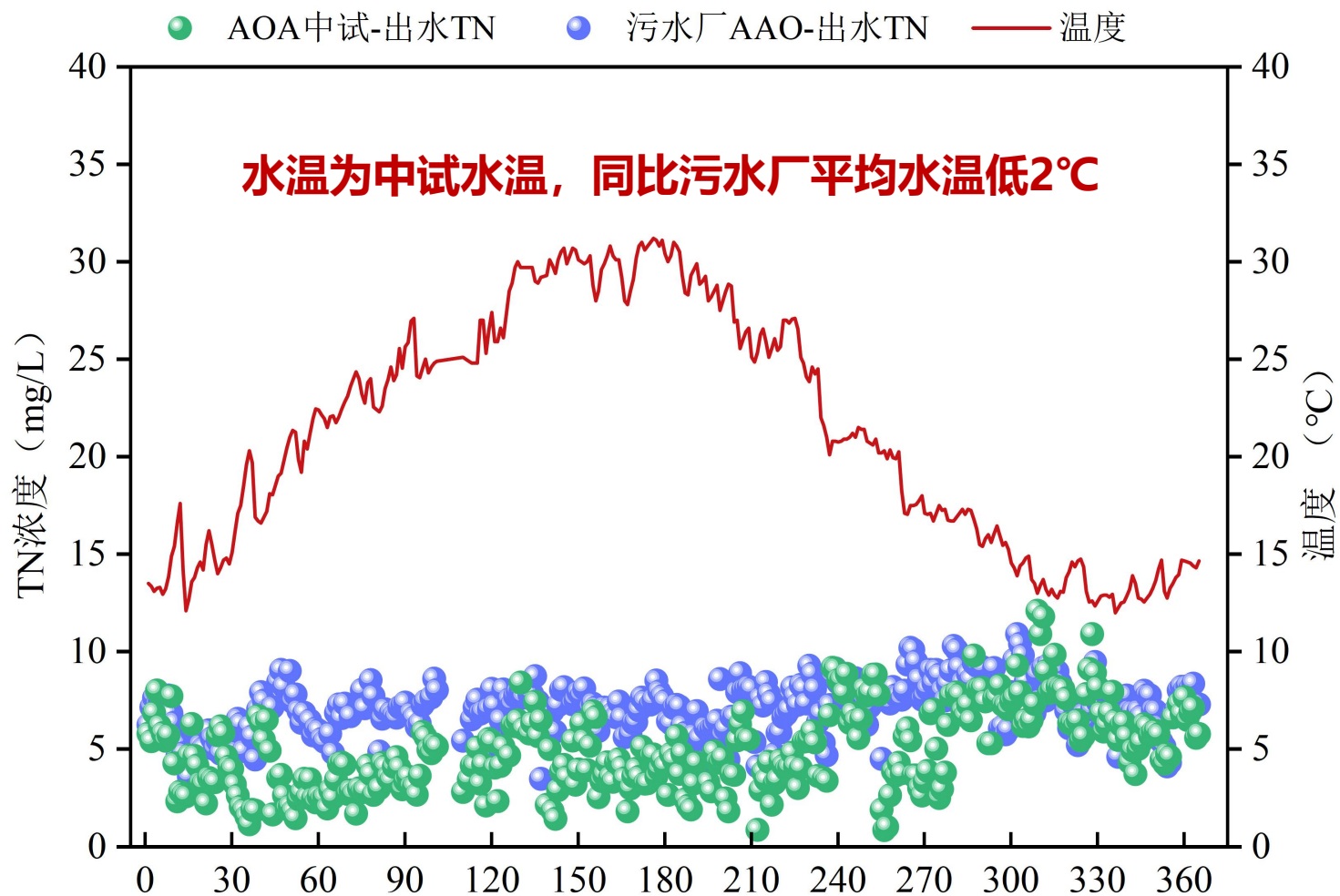
进水水质 (mg/L)

TN: **36.6**
 NH₄⁺-N: 29.5
 PO₄³⁻-P: **5.5**
 COD: 285.8

出水水质 (mg/L)

TN: **3.6**
 NH₄⁺-N: 0.5
 PO₄³⁻-P: **0.2**
 COD: 25.4

连续25天平均出水总氮为3.6mg N/L

□ AOA中试与污水厂(A²O)出水TN对比 (2025年2月19日-2026年2月28日)

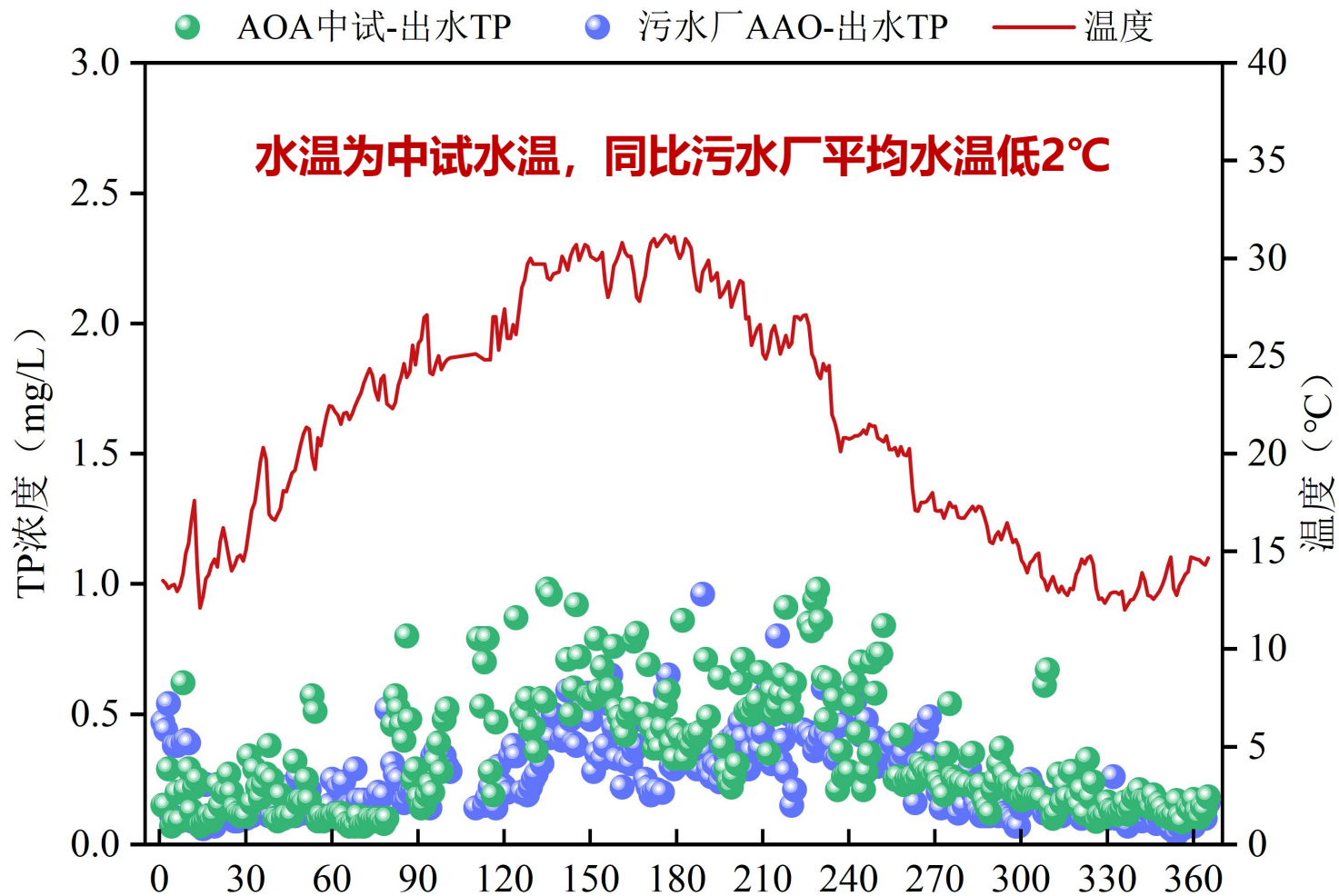
1、污水处理厂:

出水TN平均为**7.2mg/L**±1.3mg/L
(冬季投加碳源)

2、AOA中试:

出水TN平均为**4.9mg/L**±2.1mg/L, 较
污水处理厂低2.3mg/L

AOA中试系统无外加碳源条件下,
脱氮效果明显**优于**同源污水处理厂
AAO系统

□ AOA中试与污水厂(A²O)出水TP对比 (2025年2月19日-2026年2月28日)

1、污水处理厂:

出水TP平均为**0.26 mg/L**±0.15mg/L

2、AOA中试:

出水TP为**0.33mg/L** ±0.22mg/L,
略高于污水处理厂

AOA中试在**无外加除磷药剂条件下**,
除磷效果与同源水厂AAO系统 (投加
除磷药剂) 相差不大

合肥王小郢污水处理厂AOA中试中低温实验总结

(2025年3月1日~5月23日)

试验工况	日期	水温 /°C	水力停留时间/h				进水水质/mg/L			出水水质/mg/L			小结
			厌氧	好氧	缺氧	复氧	COD	TN	TP	COD	TN	TP	
1 AOA工况	3月1日~3月21日	11.9~18.1	2.57	3.35	11.1 5	0.68	280 ±69	35.6 ±6.8	5.42 ±1.1 5	26± 7	3.94 ±1.2 3	0.16 ±0.0 7	① 中试出水TN平均为 3.94mg/L , 出水TP为0.16mg/L; ② 同期污水厂出水TN为 5.21mg/L , TP为 0.1mg/L
2 阶段曝气 AOA	3月22日~4月15日	16.2~21.8	2.66	3.19	11.2 2	0.68	326 ±45	44.3 ±4.4	6.41 ±0.9 1	24± 9	3.06 ±1.6 9	0.21 ±0.1 2	① 中试出水TN平均为 3.06mg/L , 出水TP为0.21mg/L; ② 同期污水厂出水TN为 7.04mg/L , TP为 0.14mg/L
3 AOA取消 缺氧池污 泥回流	4月16日~5月23日	20.3~25.3	2.56	3.21	11.2 7	0.68	267 ±55	41.1 ±6.9	5.97 ±1.0	20± 12	3.3± 0.9	0.26 ±0.4	① 中试出水TN平均为 3.19mg/L , 出水TP为0.22mg/L; ② 同期污水厂出水TN为 6.47mg/L , TP为 0.21mg/L

总结：间隔曝气AOA工况对比AOA工况，在平均水温由18.9°C升高至22.6°C情况下，出水平均TN由3.94mg/L降低到3.06mg/L，降低了0.88mg/L。**污泥单回流和污泥双回流对出水影响不大。**

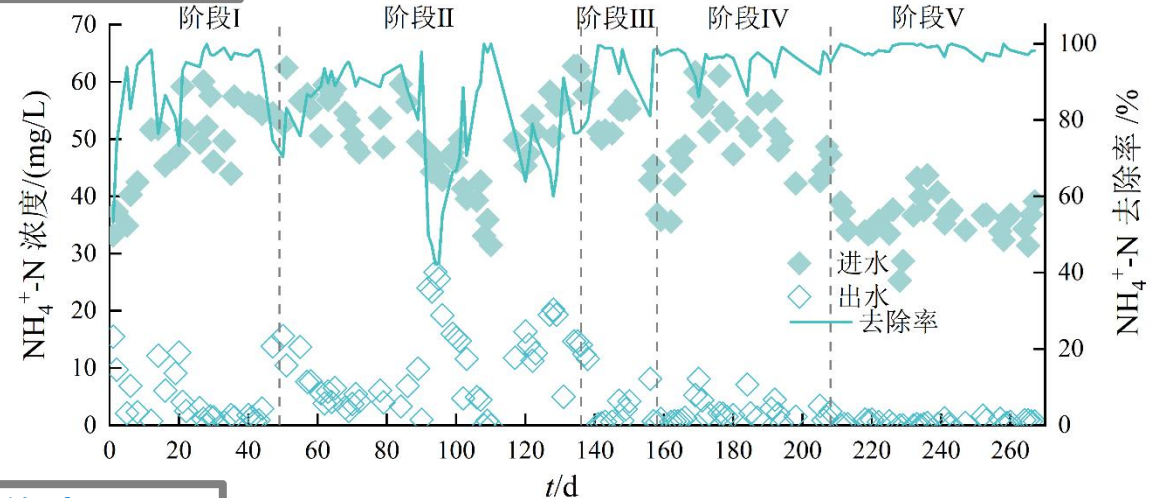
□ 天津张贵庄污水处理厂AOA中试基地



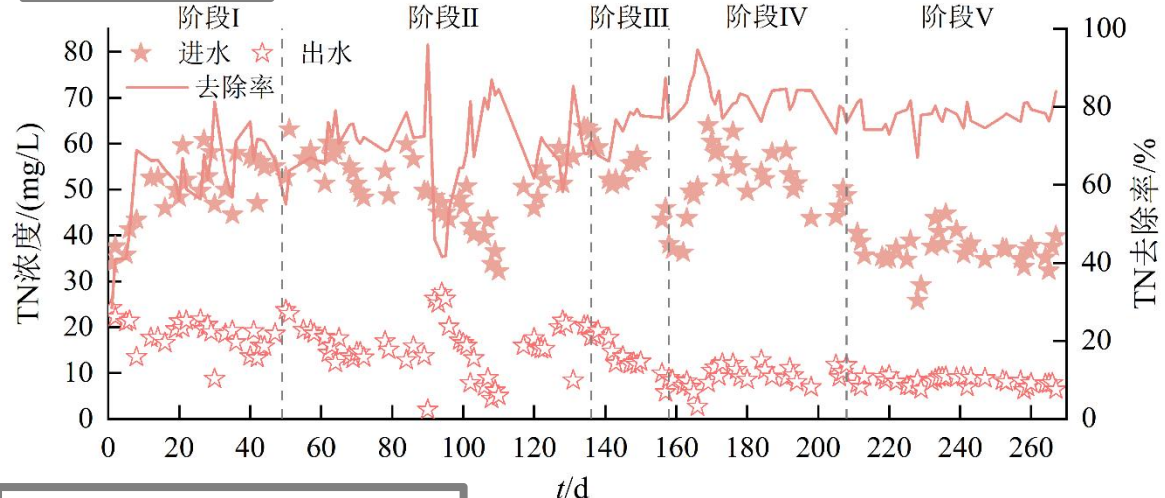
- 进水来自**天津张贵庄污水处理厂进水**
- 设计水力停留时间为16.8 h，实际水力停留时间为**18.75 h**
- 中试装置共12个格室，**有效体积75 m³**，设计处理量为108 m³/d，日处理量为**96 m³/d**
(4 m³ /h)

天津张贵庄污水处理厂AOA中试研究——长期数据分析

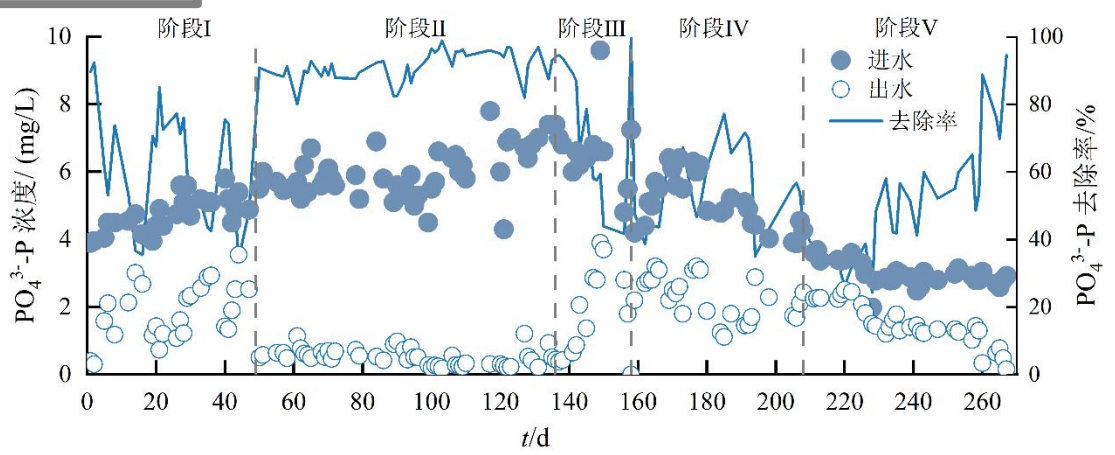
氨氮 (NH₄⁺)



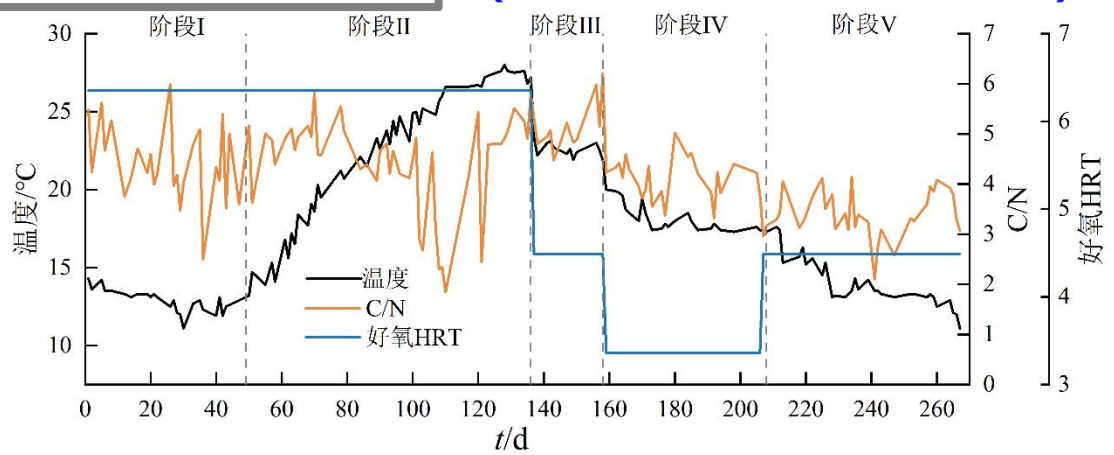
总氮 (TN)



总磷 (TP)



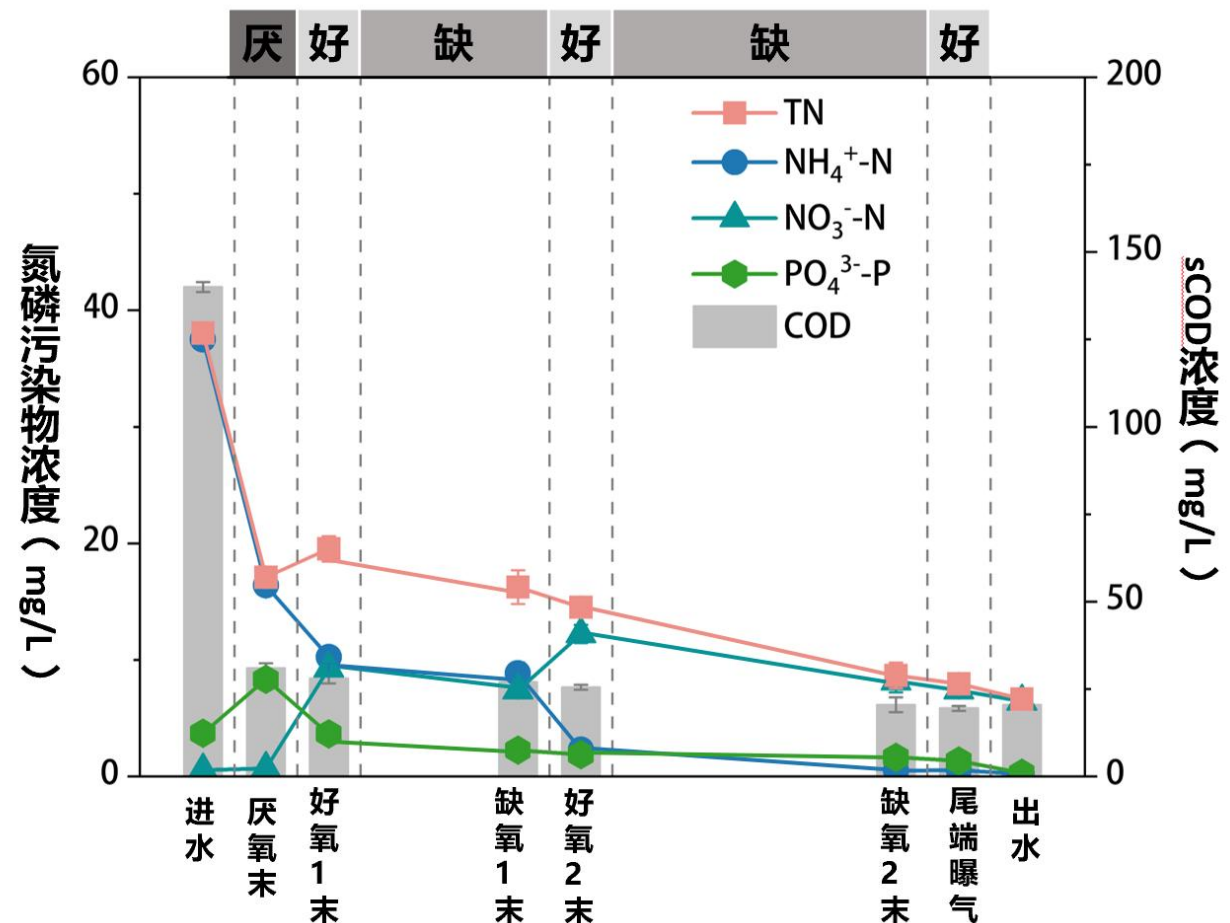
温度、C/N、好氧HRT (14.6°C→27.2°C→13.0°C)



- 在267天的运行时间里，平均C/N仅为**3.5**，TN去除率最高达**81.8%**
- 在**低温（约13.0°C）**，TN去除率维持在**78.3%**，出水TN仅为**8.0mg/L**（完全无外加碳源）

天津张贵庄污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

污染物沿程去除 (同为污水厂进水)



主要运行参数

运行时间: 2025年11月1日~2025年11月28日
运行温度: **16.7 °C ± 1.2 °C**
进水sCOD/TN比: **3.7**
总水力停留时间: 18.8 h (污水厂为23.7h)
好氧水力停留时间: **4.5 h** (污水厂为13.2h)
缺氧水力停留时间: **11.6 h** (污水厂为8.3h)

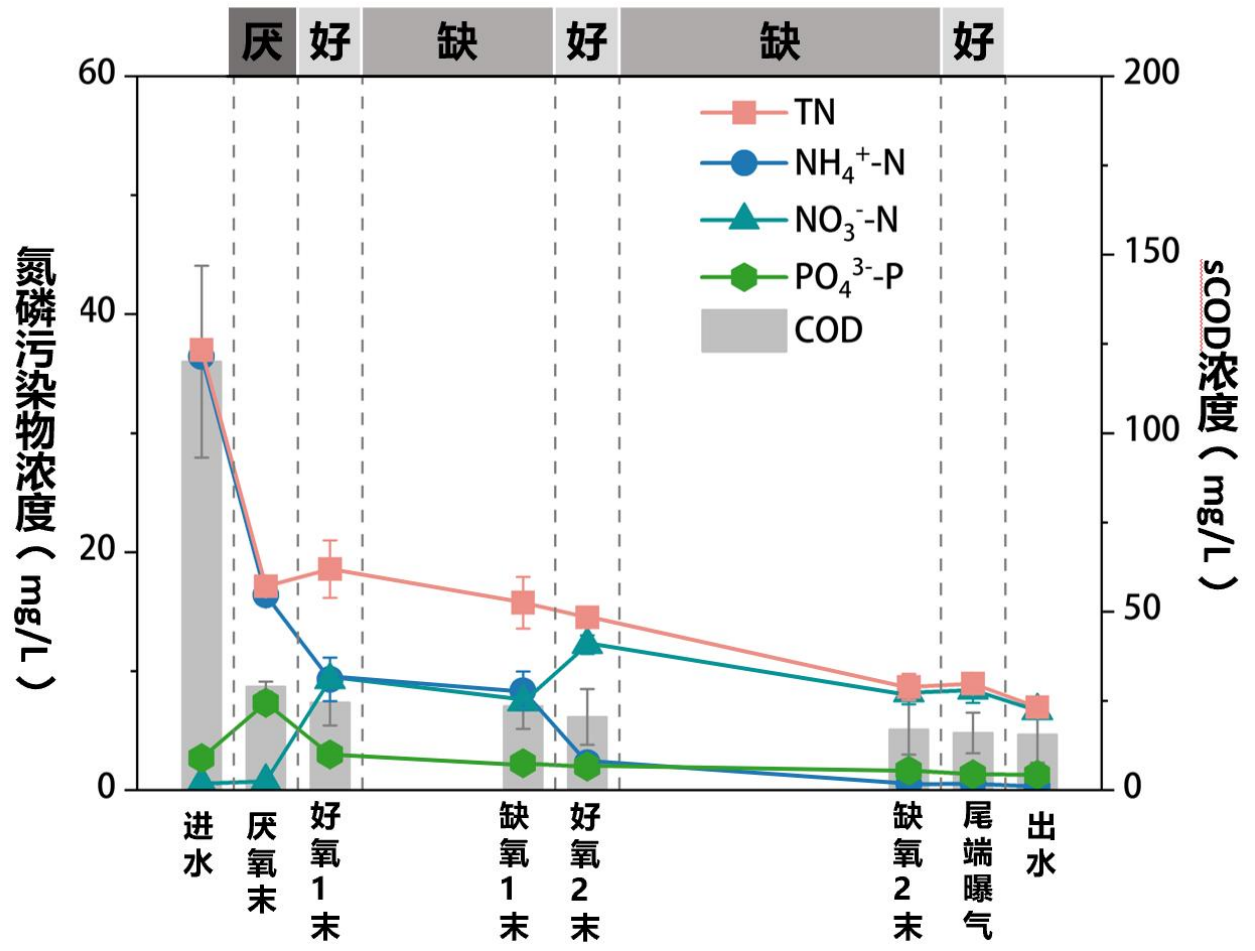
进水水质 (mg/L) 出水水质 (mg/L)

参数	进水水质 (mg/L)	出水水质 (mg/L)
TN	38.0	6.7
NH ₄ ⁺ -N	37.5	0.2
PO ₄ ³⁻ -P	3.6	0.3
sCOD	140.2	20.8

连续28天平均出水总氮为**6.7 mg-N/L**

天津张贵庄污水处理厂AOA中试研究—沿流程水质分析 (混合水样)

污染物沿程去除 (同为污水厂进水)



主要运行参数

运行时间: 2025年12月2日~2026年1月8日
运行温度: **13.0 °C ± 0.8 °C**
进水sCOD/TN比: **3.2**
总水力停留时间: 18.8 h (污水厂为23.7h)
好氧水力停留时间: **4.5 h** (污水厂为13.2h)
缺氧水力停留时间: **11.6 h** (污水厂为8.3h)

进水水质 (mg/L) 出水水质 (mg/L)

参数	进水水质 (mg/L)	出水水质 (mg/L)
TN	37.0	8.0
NH ₄ ⁺ -N	36.5	0.3
PO ₄ ³⁻ -P	2.7	1.3
sCOD	120.0	15.5

连续38天平均出水总氮为**8.0 mg-N/L**

天津张贵庄污水处理厂AOA中试研究--总结(无外加碳源)

□ 污染物去除效果总结 (同为污水厂进水) , HRT=18.8 h, 好氧HRT=4.5 h

2025年7月17日~8月5日 (连续20天) / 27.2 °C ± 0.5 °C

进水水质 (mg/L)				出水水质 (mg/L)			
TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD	TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD
35.6	34.3	3.5	156.5	5.6	0.7	2.4	19.6

2025年11月1日~11月28日 (连续28天) / 16.7 °C ± 1.2 °C

进水水质 (mg/L)				出水水质 (mg/L)			
TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD	TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD
38.0	37.5	3.6	140.2	6.7	0.2	0.3	20.8

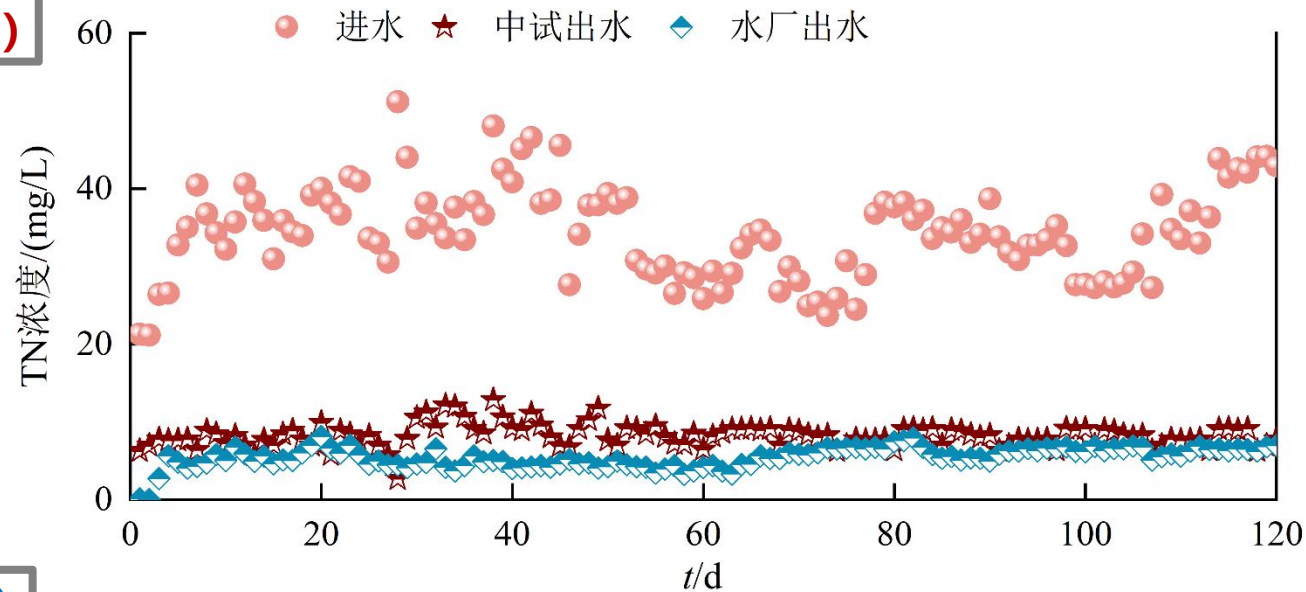
2025年12月2日~2026年1月8日 (连续38天) / 13.0 °C ± 0.8 °C

进水水质 (mg/L)				出水水质 (mg/L)			
TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD	TN	NH ₄ ⁺	PO ₄ ³⁻	sCOD
37.0	36.5	2.7	120.0	8.0	0.3	1.3	15.5

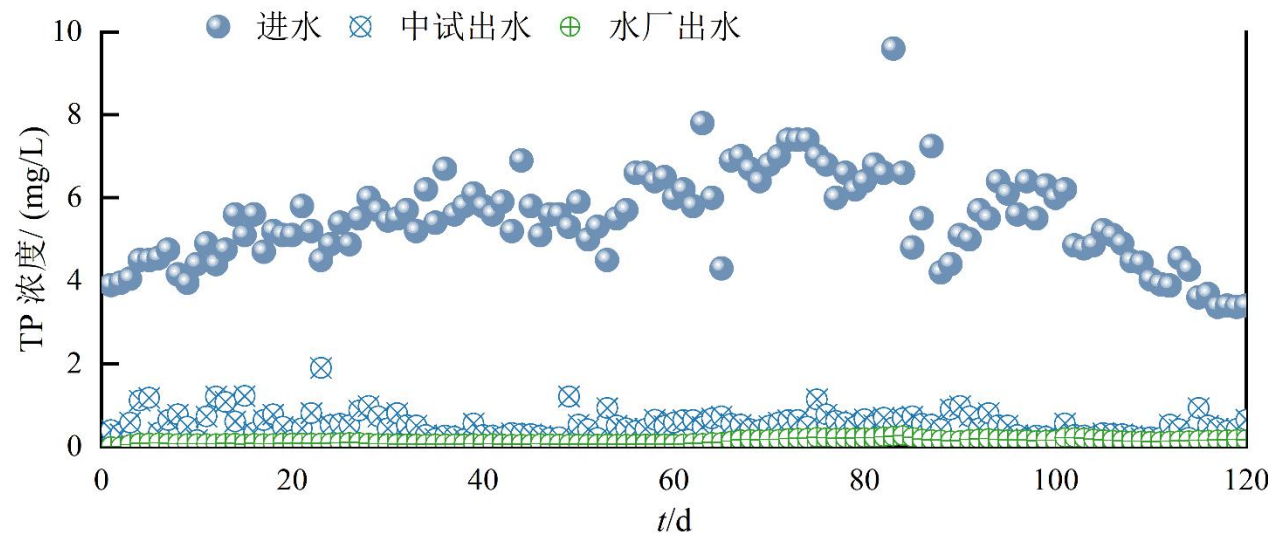
天津张贵庄污水处理厂（一期）与AOA中试去除效果对比

中低温运行阶段 2025.11.1-2026.02.28 (13.0°C -16.7°C)

总氮 (TN)



总磷 (TP)



TN

中试系统平均出水TN为**8.0 mg/L**
(无外加碳源)
污水厂二沉池出水TN为**5.4 mg/L**
(外加碳源)

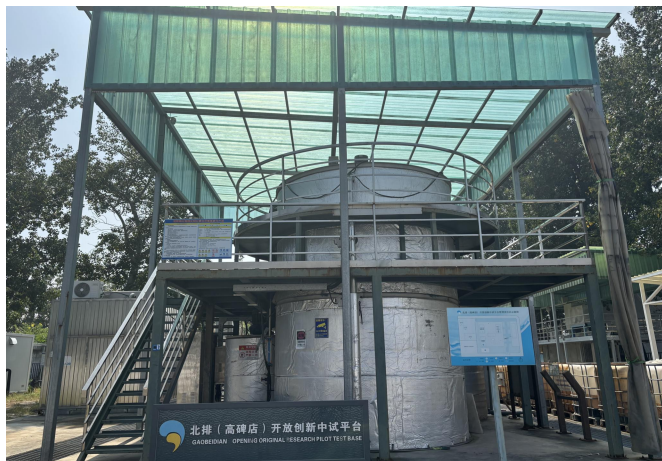
TP

中试系统平均出水TP为**0.5 mg/L**
(无外加除磷剂)
污水厂二沉池出水TP为**0.1 mg/L**
(投加除磷剂)

天津张贵庄污水厂每年投加碳源总费用高达2000余万!

二 对中低温污水的韧性—SBR-AOA[®] 中低温中试

□ 北京市高碑店污水处理厂SBR-AOA中试（不锈钢）



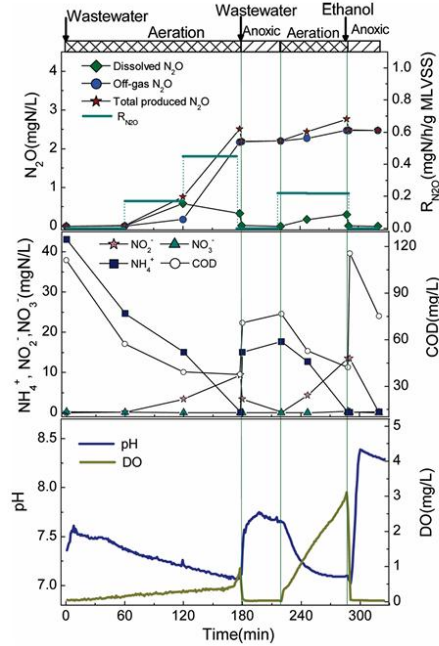
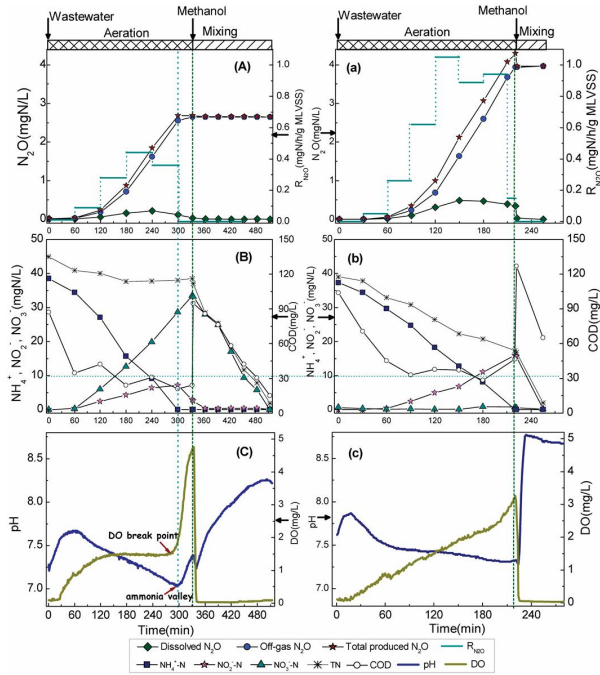
中试规模AOA-SBR系统

1. 厌氧/好氧/缺氧的HRT比为 $A:O:A=1:1:2$ ，好氧HRT仅占1/4，节能与减碳。
2. 根据AOA[®]技术原理，增加后置缺氧段，充分利用原水碳源，提高脱氮效率。
3. 缺氧段出水，无外加碳源也可实现深度或极限脱氮。
4. 发现了SBR-AOA的除磷优势，可实现好氧吸磷与缺氧反硝化除磷，可实现极限除磷。

- 一 AOA[®]技术原理与优势
- 二 对中低温污水处理的韧性
- 三 氧化亚氮 (N₂O) 减排研究
- 四 示范工程与应用
- 五 结论与展望

早在2009年我团队在 *Environmental Science & Technology* 上发表文章证实:

1. 氨氧化是城市污水处理过程N₂O生成的主要来源
2. NO₂⁻积累是N₂O排放的主要诱因!



Environmental Science & Technology > Vol 43/Issue 24 > Article

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ARTICLE | November 12, 2009

N₂O Production during Nitrogen Removal via Nitrite from Domestic Wastewater: Main Sources and Control Method

Qing Yang[†], Xiuhong Liu[†], Chengyao Peng[†], Shuying Wang[†], Hongwei Sun[†], and Yongzhen Peng^{†*}

View Author Information

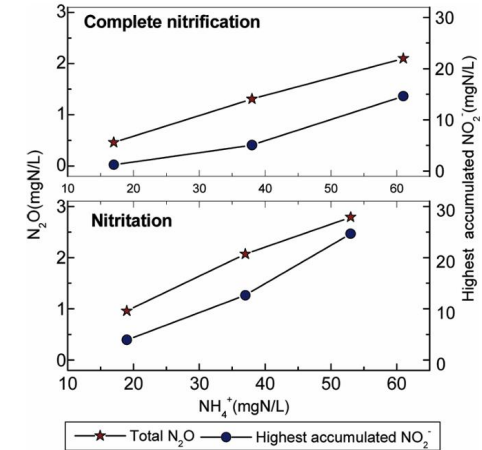
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Supporting Information (1)

S·F·X

Abstract

Nitrite has been commonly recognized as an important factor causing N₂O production, which weakened the advantages of nitrogen removal via nitrite. To reduce and control N₂O production from wastewater treatment plants, both long-term and batch tests were carried out to investigate main sources and pathways of N₂O production during nitrogen removal via nitrite from real domestic wastewater. The obtained results showed that N₂O production during nitrogen removal via nitrite was 1.5 times as much as that during nitrogen removal via nitrate. It was further demonstrated that ammonia oxidation were main source of N₂O production during nitrogen removal from domestic wastewater; whereas, almost no N₂O was produced during nitrite oxidation and anoxic denitrification. N₂O production during nitrogen removal via nitrite decreased about 50% by applying the step-feed SBR, due to the effective control of nitrite and ammonia, the precursors of N₂O production. Therefore, the step-feed system is recommended as an effective method to reduce N₂O production during nitrogen removal via nitrite from domestic wastewater.



Yang Q, Liu X, Peng C, Wang S, Sun H, Peng Y. N₂O Production during Nitrogen Removal via Nitrite from Domestic Wastewater: Main Sources and Control Method. *Environmental Science & Technology* 43, 9400-9406 (2009).

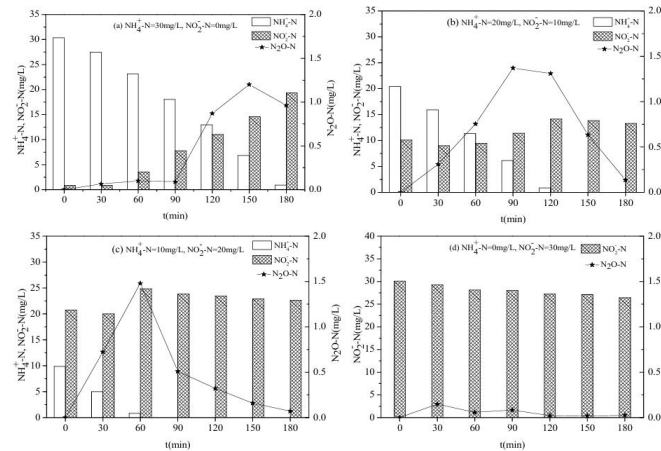
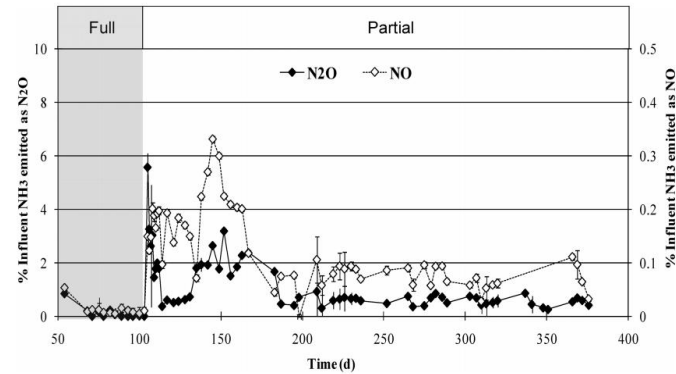
2011年美国哥伦比亚大学Kartik 教授团队在

*Environmental Science & Technology*上发表论文:

1、短程硝化过程中的瞬态和稳定态的N₂O和NO排放均高于全程硝化过程。

我团队研究同样证明:

2、短程硝化过程中的N₂O排放是全程硝化的2.8-65.2倍。



ARTICLE
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Comparison of Partial and Full Nitrification Processes Applied for Treating High-Strength Nitrogen Wastewaters: Microbial Ecology through Nitrous Oxide Production

Joon Ho Ahn, Tiffany Kwan, and Kartik Chandran*

Department of Earth and Environmental Engineering, Columbia University, 500 West 120th Street, New York, New York 10027, United States

Supporting Information

ABSTRACT: The goal of this study was to compare the microbial ecology, gene expression, biokinetics, and N₂O emissions from a lab-scale bioreactor operated sequentially in full-nitrification and partial-nitrification modes. Based on sequencing of 16S rRNA and ammonia monooxygenase subunit A (*amoA*) genes, ammonia oxidizing bacteria (AOB) populations during full- and partial-nitrification modes were distinct from one another. The concentrations of AOB (X_{AOB}) and their respiration rates during full- and partial-nitrification modes were statistically similar, whereas the concentrations of nitrite oxidizing bacteria (X_{NOB}) and their respiration rates declined significantly after the switch from full- to partial-nitrification. The transition from full-nitrification to partial nitrification resulted in a protracted transient spike of nitrous oxide (N₂O) and nitric oxide (NO) emissions, which later stabilized. The trends in N₂O and NO emissions correlated well with trends in the expression of *nirK* and *norB* genes that code for the production of these gases in AOB. Both the transient and stabilized N₂O and NO emissions during partial nitrification were statistically higher than those during steady-state full-nitrification. Based on these results, partial nitrification strategies for biological nitrogen removal, although attractive for their reduced operating costs and energy demand, may need to be optimized against the higher carbon footprint attributed to their N₂O emissions.



Article
N₂O Emission from Partial Nitrification and Full Nitrification in Domestic Wastewater Treatment Process

Pengzhang Li¹, Yongzhen Peng^{2,*}, Shuying Wang² and Yue Liu²

¹ Department of Municipal Engineering, Yancheng Institute of Technology, Yancheng 224051, China
² Engineering Laboratory for Advanced Municipal Wastewater Treatment and Reuse Technology, Engineering Research Center of Beijing, Beijing University of Technology, Beijing 100124, China
* Correspondence: pyz@bjut.edu.cn; Tel./Fax: +86-10-67392627

Abstract: Using actual domestic wastewater as the research object, nitrogen compounds and their combinations were added to different nitrification (partial nitrification, full nitrification) processes to investigate nitrous oxide (N₂O) emission and its nitrification mechanisms. The presence of influent NH₄⁺ was the driving force of N₂O emission during nitrification. Compared with full nitrification, NO₂⁻ in partial nitrification more readily generated N₂O by denitrification. Under the proportional gradient of NH₄⁺-N:NO₂⁻-N:NO₃⁻-N, 30:0, 20:10, 10:20, and 0:30, total N₂O emissions during partial nitrification were 2.81, 11.30, 65.20, and 11.67 times greater than the total N₂O emissions during full nitrification. Full nitrification was more beneficial to N₂O emission reduction. This provides a control strategy for N₂O emission reduction in wastewater treatment processes under the background of reducing the production of greenhouse gases.

Keywords: N₂O; domestic wastewater; partial nitrification; full nitrification; greenhouse gas reduction

- Ahn JH, Kwan T, Chandran K. Comparison of Partial and Full Nitrification Processes Applied for Treating High-Strength Nitrogen Wastewaters: Microbial Ecology through Nitrous Oxide Production. *Environmental Science & Technology* 45, 2734-2740 (2011).
- Li, P.; Peng, Y.; Wang, S.; Liu, Y. N₂O Emission from Partial Nitrification and Full Nitrification in Domestic Wastewater Treatment Process. *Water* 2022, 14, 3195.

2019年, 东京农工大学联合丹麦技术大学在

Environmental Science & Technology 采用同位素示踪等

手段表明: **Anammox反应器的N₂O产量极低。**

ENVIRONMENTAL
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Article

Combination of ¹⁵N Tracer and Microbial Analyses Discloses N₂O Sink Potential of the Anammox Community

Toshikazu Suenaga, Takumi Ota, Kohei Oba, Kentaro Usui, Toshiki Sako, Tomoyuki Hori, Shohei Riya, Masaaki Hosomi, Kartik Chandran, Susanne Lackner, Barth F. Smets, and Akihiko Terada*

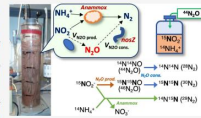
Cite This: *Environ. Sci. Technol.* 2021, 55, 9231–9242

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ABSTRACT: Although nitrogen removal by partial nitrification and anammox is more cost-effective than conventional nitrification and denitrification, one downside is the production and accumulation of nitrous oxide (N₂O). The potential exploitation of N₂O-reducing bacteria, which are resident members of anammox microbial communities, for N₂O mitigation would require more knowledge of their ecophysiology. This study investigated the phylogeny of resident N₂O-reducing bacteria in an anammox microbial community and quantified individually the processes of N₂O production and N₂O consumption. An up-flow column-bed anammox reactor, fed with NH₄⁺ and NO₂⁻ and devoid of oxygen, emitted N₂O at an average conversion ratio (produced N₂O: influent nitrogen) of 0.284%. Transcriptionally active and highly abundant *nosZ* genes in the reactor biomass belonged to the *Burkholderiaceae* (clade I type) and *Chloroflexus* genera (clade II type). Meanwhile, less abundant but actively transcribing *nosZ* strains were detected in the genera *Rhodospirillum*, *Azospirillum*, *Lautropia*, and *Bifidobacterium* and likely act as an N₂O sink. A novel ¹⁵N tracer method was adapted to individually quantify N₂O production and N₂O consumption rates. The estimated true N₂O production rate and true N₂O consumption rate were 3.98 ± 0.15 and 3.03 ± 0.18 mg_N g_{SS}⁻¹ day⁻¹, respectively. The N₂O consumption rate could be increased by 51% (4.57 ± 0.51 mg_N g_{SS}⁻¹ day⁻¹) with elevated N₂O concentrations but kept comparable irrespective of the presence or absence of NO₂⁻. Collectively, the approach allowed the quantification of N₂O-reducing activity and the identification of transcriptionally active N₂O reducers that may constitute as an N₂O sink in anammox-based processes.

KEYWORDS: N₂O-reducing bacteria, *nosZ*, transcription, nitrogen isotopes, microrespirometry, biokinetics



Journal of Cleaner Production 203 (2018) 559–573



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Coupling of partial nitrification and anammox in two- and one-stage systems: Process operation, N₂O emission and microbial community

Romain Connan^a, Patrick Dabert^a, Marina Moya-Espinosa^a, Gilbert Bridoux^b, Fabrice Béline^a, Albert Magrí^{a,*}

^a Irstea, UR OPAALE, 17 Avenue de Cucillé-CS 64427, F-35044 Rennes, France
^b SAUR, Recherche et développement, 2 rue de la Bresle, F-78310 Maurepas, France

一段式PN/A的N₂O排放远低于两段式PN/A工艺

此外, 大量研究通过Anammox作用来减少短程硝化过程N₂O的高排放问题。

1. Suenaga T, et al. Combination of ¹⁵N Tracer and Microbial Analyses Discloses N₂O Sink Potential of the Anammox Community. *Environmental Science & Technology* 55, 9231-9242 (2021).
2. Rathnayake RMLD, et al. Source identification of nitrous oxide on autotrophic partial nitrification in a granular sludge reactor. *Water Research* 47, 7078-7086 (2013).
3. Okabe S, Oshiki M, Takahashi Y, Satoh H. N₂O emission from a partial nitrification–anammox process and identification of a key biological process of N₂O emission from anammox granules. *Water Research* 45, 6461-6470 (2011).
4. Connan R, Dabert P, Moya-Espinosa M, Bridoux G, Béline F, Magrí A. Coupling of partial nitrification and anammox in two- and one-stage systems: Process operation, N₂O emission and microbial community. *Journal of Cleaner Production* 203, 559-573 (2018).

Water Research 102 (2016) 147–157



Contents lists available at ScienceDirect

Water Research

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Source identification of nitrous oxide emission pathways from a single-stage nitrification-anammox granular reactor

Muhammad Ali^{a,b}, Rathnayake M.L.D. Rathnayake^{a,c}, Lei Zhang^a, Satoshi Ishii^{a,d}, Tomonori Kindaichi^e, Hisashi Satoh^a, Sakae Toyoda^f, Naohiro Yoshida^f, Satoshi Okabe^{a,*}

^a Division of Environmental Engineering, Faculty of Engineering, Hokkaido University, North-13, West-8, Sapporo, Hokkaido 060-8628, Japan
^b Water Desalination and Reuse Center (WDRC), Biological and Environmental Science and Engineering (BESE), King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia
^c Department of Civil Engineering, Faculty of Engineering, University of Peradeniya, Peradeniya 20400, Sri Lanka
^d Department of Soil, Water and Climate, University of Minnesota, 258 Borlaug Hall, 1991 Upper Buford Circle, St. Paul, MN 55108, USA
^e Department of Civil and Environmental Engineering, Graduate School of Engineering, Hiroshima University, 1-4-1 Kagamiyama, Higashihiroshima, Hiroshima 739-8527, Japan
^f Department of Environmental Science and Technology, Tokyo Institute of Technology, 4259 Nagatsuta, Midori-ku, Yokohama 226-8502, Japan



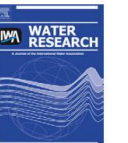
WATER RESEARCH 45 (2011) 6461–6470



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N₂O emission from a partial nitrification–anammox process and identification of a key biological process of N₂O emission from anammox granules

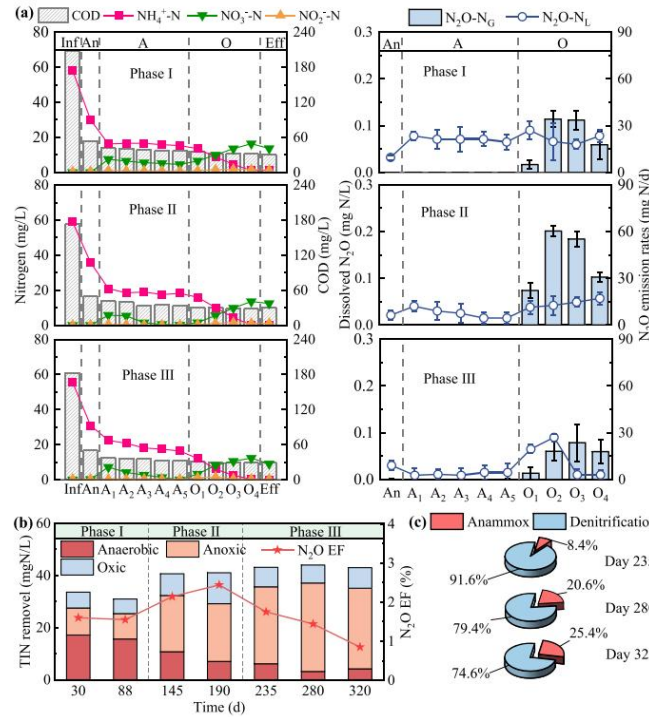
Satoshi Okabe^{a,b,*}, Mamoru Oshiki^{a,b}, Yoshitaka Takahashi^a, Hisashi Satoh^a

2025年，我团队在 *Water research* 上发表关于

A²O工艺的文章，研究表明：

1、控制合理的溶解氧条件 (1-2mg/L) 能有效降低 N₂O排放；

2、前端缺氧区N₂O的减少依赖于外部碳源的输入。



Optimization of AAO process for reduced N₂O emissions and enhanced nitrogen removal in municipal wastewater treatment: Exploring carbon supplementation and DO control strategies

Zeming An, Qiong Zhang, Xinjie Gao, Baishuo Shao, Yongzhen Peng

National Engineering Laboratory for Advanced Municipal Wastewater Treatment and Reuse Technology, Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, P.R. China

ARTICLE INFO

Keywords:
Anaerobic/anoxic/oxic
N₂O
Carbon supplementation
Dissolved oxygen
Anammox

ABSTRACT

The anaerobic/anoxic/oxic (AAO) process remains a common nutrient removal process in municipal wastewater treatment, yet research focusing on concurrent optimization of process performance and N₂O emissions reduction is scarce. This study aimed to investigate the mitigation of N₂O emissions and enhance nitrogen removal efficiency in an AAO system treating low C/N domestic wastewater by establishing a fully enclosed gas-collecting continuous flow reactor and implementing carbon supplementation and dissolved oxygen (DO) control strategies. The results indicated that carbon supplementation in the anoxic zone effectively reduced nitrate concentrations and mitigated the accumulation of dissolved N₂O below 0.1 mgN/L. The moderate DO control (1–2 mg/L) could ensure the nitrification efficiency while reducing the gaseous N₂O emission rate to 63.48 mgN/d, and decreasing the dissolved N₂O concentration in the effluent to below 0.01 mgN/L. Both too high and too low DO levels were detrimental to N₂O emission mitigation. The optimized AAO process achieved a significant reduction in the N₂O emission factor to 0.85 % and an increase in nitrogen removal efficiency to 81.81 %. Additionally, the enrichment of anammox bacteria, *Candidatus brocadia* (0.15 %), positively contributed to the improvement in nitrogen removal efficiency. In conclusion, this study provides valuable insights into optimizing AAO process to mitigate N₂O emissions, enhance nitrogen removal, and lower carbon footprints associated with wastewater treatment.

1. Introduction

Amidst the escalating global challenges of water scarcity and contamination, the efficient operation and low-carbon emission of wastewater treatment plants (WWTPs) have become pivotal research areas within the environmental protection domain (Chen and Liu, 2024). The anaerobic/anoxic/oxic (AAO) process, a widely adopted sewage treatment technology, holds a prominent position in secondary and tertiary wastewater treatment owing to its commendable performance in nitrogen removal (Sun et al., 2023; Zhang et al., 2024c). According to the statistical data of China Urban Drainage Statistical Yearbook - 2020, the AAO process is the most widely used type of wastewater treatment process, accounting for 33 % of the statistics (Liu et al., 2020). With the global carbon neutrality goal clearly stated, the performance requirements of the AAO process have been further

increased. This necessitates not only the refinement of nitrogen removal efficiency but also a heightened emphasis on minimizing greenhouse gas emissions.

Nitrous oxide (N₂O) stands as a prominent greenhouse gas emitted during wastewater treatment, with 3 % of global N₂O emissions produced in WWTPs (Ramírez-Melgarejo et al., 2019). This potent greenhouse gas and atmospheric pollutant has garnered increasing attention owing to its contributions to global warming and its potential for adverse health impacts, including ozone depletion and the formation of tropospheric photochemical smog. (An et al., 2024b). It is of paramount importance to mitigate N₂O emissions from WWTPs in order to reduce the overall carbon footprint of these facilities. In the wastewater treatment process, carbon sources serve as the nutritional supply for microbial growth and metabolism, directly influencing not only nitrogen removal efficiency but also tightly impacting the emission of N₂O,

Long-Term Low Dissolved Oxygen Operation Decreases N₂O Emissions in the Activated Sludge Process

Guoqiang Liu,^{*} Xianwei Wu, Deyong Li, Lugao Jiang, Ju Huang, and Li Zhuang

 Cite This: *Environ. Sci. Technol.* 2021, 55, 6975–6983

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Short Communication

Characteristics of methane and nitrous oxide emissions from the wastewater treatment plant



Kum-Lok Hwang^a, Cheon-Hee Bang^b, Kyung-Duk Zoh^{a,*}


^aDepartment of Environmental Health Sciences, School of Public Health, Seoul National University, Seoul 08826, South Korea

^bKorea Environment Corporation, 42 Hwangyeong-ro, Seo-gu, Incheon 22689, South Korea

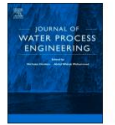
大量研究同样表明，好氧区曝气控制是减少N₂O排放的关键策略



Full-scale experiments to mitigate nitrous oxide emissions in wastewater treatment plants through optimizing aeration strategy

Malte Thormann, Tobias Morck^{*} 

University of Kassel, Chair of Urban Water Engineering, Kurt-Wolters-Street 3, Kassel 34125, Germany



Nitrous oxide emission and microbial community of full-scale anoxic/aerobic membrane bioreactors at low dissolved oxygen setpoints

Jianfeng Wen^{a,c}, Mark W. LeChevallier^b, Wendong Tao^{c,*}, Yanjin Liu^a

^aAmerican Water, 1 Water Street, Camden, NJ, 08102, USA

^bDr. Water Consulting, LLC, 4838 South Coors Court, Morrison, CO, 80465, USA

^cDepartment of Environmental Resources Engineering, College of Environmental Science and Forestry, State University of New York, 1 Forestry Drive, Syracuse, NY, 13210, USA

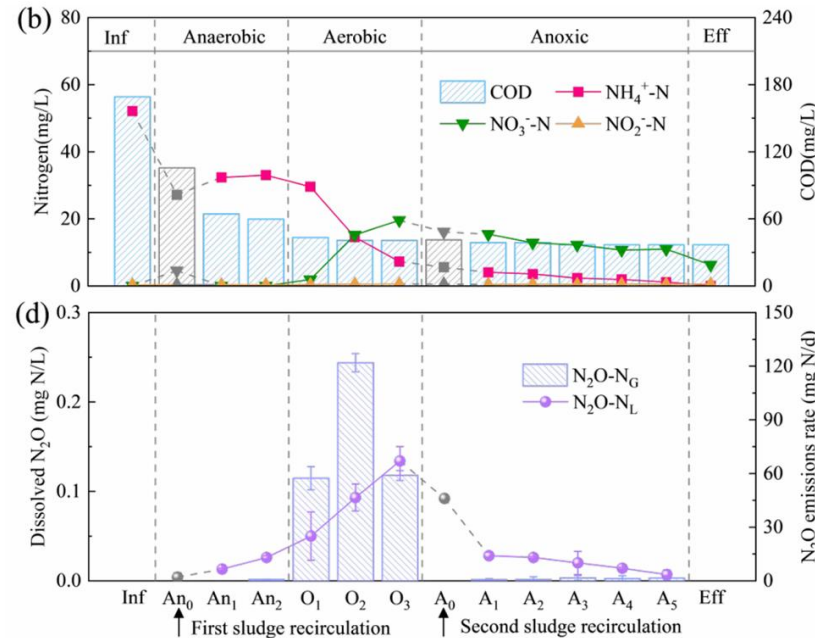
1. Liu G, Wu X, Li D, Jiang L, Huang J, Zhuang L. Long-Term Low Dissolved Oxygen Operation Decreases N₂O Emissions in the Activated Sludge Process. *Environmental Science & Technology* 55, 6975–6983 (2021).
2. Hwang K-L, Bang C-H, Zoh K-D. Characteristics of methane and nitrous oxide emissions from the wastewater treatment plant. *Bioresource Technology* 214, 881–884 (2016).
3. Thormann M, Morck T. Full-scale experiments to mitigate nitrous oxide emissions in wastewater treatment plants through optimizing aeration strategy. *Environmental Technology & Innovation* 40, 104469 (2025).
4. Wen J, LeChevallier MW, Tao W, Liu Y. Nitrous oxide emission and microbial community of full-scale anoxic/aerobic membrane bioreactors at low dissolved oxygen setpoints. *Journal of Water Process Engineering* 38, 101654 (2020).

2024年我团队在 *Environmental Science &*

Technology 上发表关于AOA工艺的N₂O研究论文，首次在连续流模拟试验中原位监测N₂O排放，研究表明：

1、强化内源反硝化能够同时实现内源反硝化速率的提高以及N₂O排放减量

2、出水中的溶解态N₂O浓度低于0.01mg-N/L。



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Article

Synchronous Achievement of Advanced Nitrogen Removal and N₂O Reduction in the Anoxic Zone in the AOA Process for Low C/N Municipal Wastewater

Zeming An, Xinjie Gao, Baishuo Shao, Qiong Zhang, Jing Ding, and Yongzhen Peng*

Cite This: *Environ. Sci. Technol.* 2024, 58, 2335–2345

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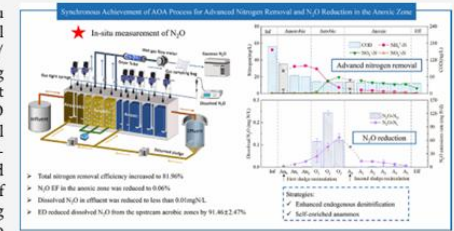
Metrics & More

Article Recommendations

Supporting Information

ABSTRACT: Continuous flow processes for the in situ determination of N₂O emissions during low C/N municipal wastewater treatment have rarely been reported. The anaerobic/aerobic/anoxic (AOA) process has recently shown promising potential in energy savings and advanced nitrogen removal, but it still needs to be comprehensively explored in relation to N₂O emissions for its carbon reduction advantages. In this study, a novel gas-collecting continuous flow reactor was designed to comprehensively evaluate the emissions of N₂O from the gas and liquid phases of the AOA process. Additionally, the measures of enhancing endogenous denitrification (ED) and self-enriching anaerobic ammonium oxidation (Anammox) were employed to optimize nitrogen removal and achieve N₂O reduction in the anoxic zone. The results showed that enhanced ED coupled with Anammox led to an increase in the nitrogen removal efficiency (NRE) from 67.65 to 81.96%, an enhancement of the NO₃⁻ removal rate from 1.76 mgN/(L h) to 3.99 mgN/(L h), and the N₂O emission factor in the anoxic zone decreased from 0.28 to 0.06%. Impressively, ED eliminated 91.46 ± 2.47% of the dissolved N₂O from the upstream aerobic zone, and the dissolved N₂O in the effluent was reduced to less than 0.01 mg/L. This study provides valuable strategies for fully evaluating N₂O emissions and N₂O reduction from the AOA process.

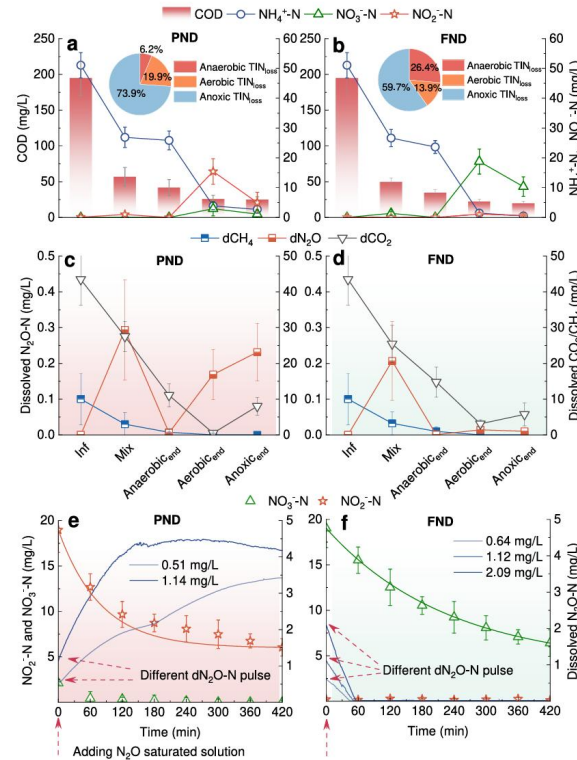
KEYWORDS: N₂O emissions, anaerobic/aerobic/anoxic, endogenous denitrification, anammox, municipal wastewater, advanced nitrogen removal



近日，我团队在 *Journal of Cleaner Production* 上发表论文进一步证实：

1、基于短程硝化反硝化的AOA工艺过程亚硝酸盐的积累同样会导致N₂O的高排放。

2、基于全程硝化反硝化的AOA工艺N₂O排放显著降低，且后置缺氧区内源反硝化过程具备强大的N₂O还原能力。



Unraveling greenhouse gas accumulation and emission characteristics of partial and full nitrification-denitrification in anaerobic/aerobic/anoxic municipal wastewater treatment systems

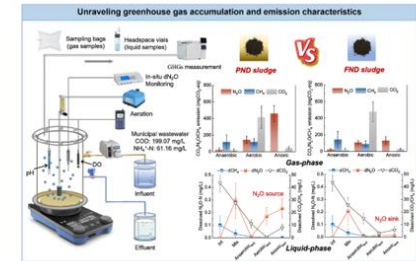
Zeming An, Xinjie Gao, Liang Zhang, Yuying Duan, Yongzhen Peng

National Engineering Laboratory for Advanced Municipal Wastewater Treatment and Reuse Technology, Key Laboratory of Beijing for Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing, 100124, P.R. China

HIGHLIGHTS

- First comprehensive assessment of gas-phase and liquid-phase GHG (N₂O, CH₄, CO₂) dynamics under the AOA operation mode.
- PND-SBR exhibited significantly higher GHG emissions than FND-SBR, mainly due to N₂O release.
- The anoxic phase of FND-SBR acted as a robust N₂O sink, while that of PND-SBR served as an additional N₂O source.
- Compared to PND-SBR system, FND-SBR exhibited stronger CH₄ oxidation potential and released more CO₂ and less CH₄.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords: N₂O, CH₄, Partial nitrification-denitrification, Full nitrification-denitrification, Anaerobic/aerobic/anoxic (AOA), Municipal wastewater

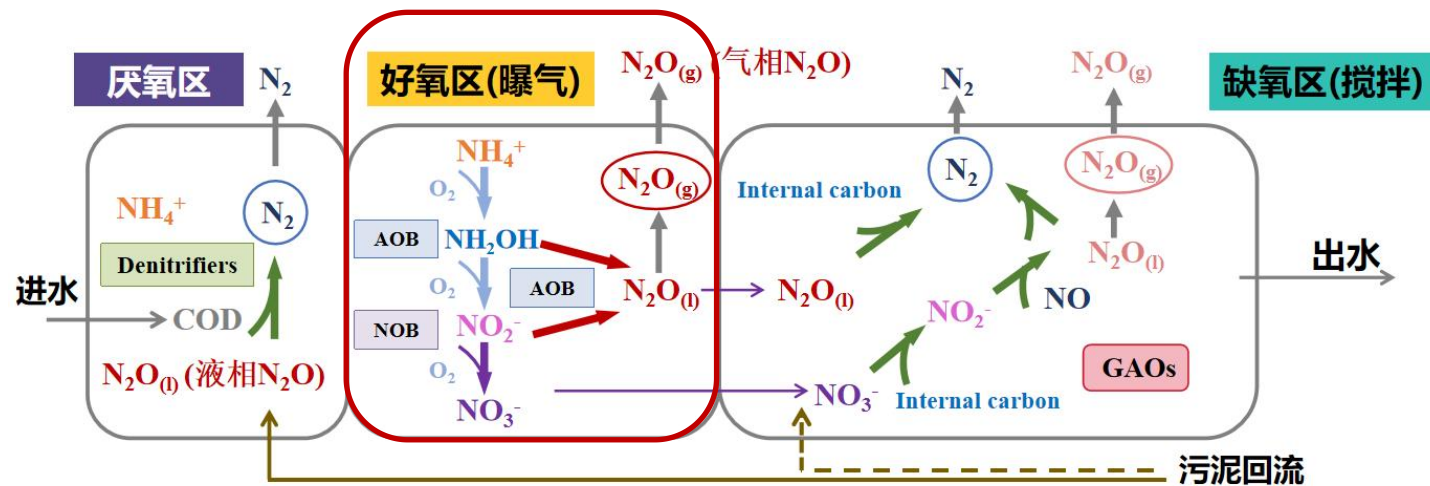
ABSTRACT

Greenhouse gas (GHG) emissions from biological nutrient removal in municipal wastewater treatment arise from multiple operational phases, yet the spatiotemporal patterns across gas-liquid phases remain poorly resolved. This study quantified gaseous and dissolved N₂O, CH₄ and CO₂ in two parallel sequencing batch reactors (SBRs) inoculated with partial and full nitrification-denitrification (PND and FND) sludge, treating identical municipal wastewater under an anaerobic/aerobic/anoxic operation mode. Results showed that the anaerobic phase was dominated by CH₄ release, with transient dissolved N₂O (dN₂O) generated after mixing being nearly completely reduced and both systems exhibiting strong N₂O reduction capacity. The aerobic phase was characterized by CO₂ release, while CH₄ was mainly stripped at aeration onset. The average N₂O emission rate in PND-SBR was 1.3 times that of FND-SBR. In the anoxic phase, N₂O dominated GHG emissions, with PND-SBR releasing 3.5-fold more N₂O than FND-SBR. dN₂O in PND-SBR increased from 0.17 ± 0.07 mg-N/L to 0.23 ± 0.08 mg-N/L.

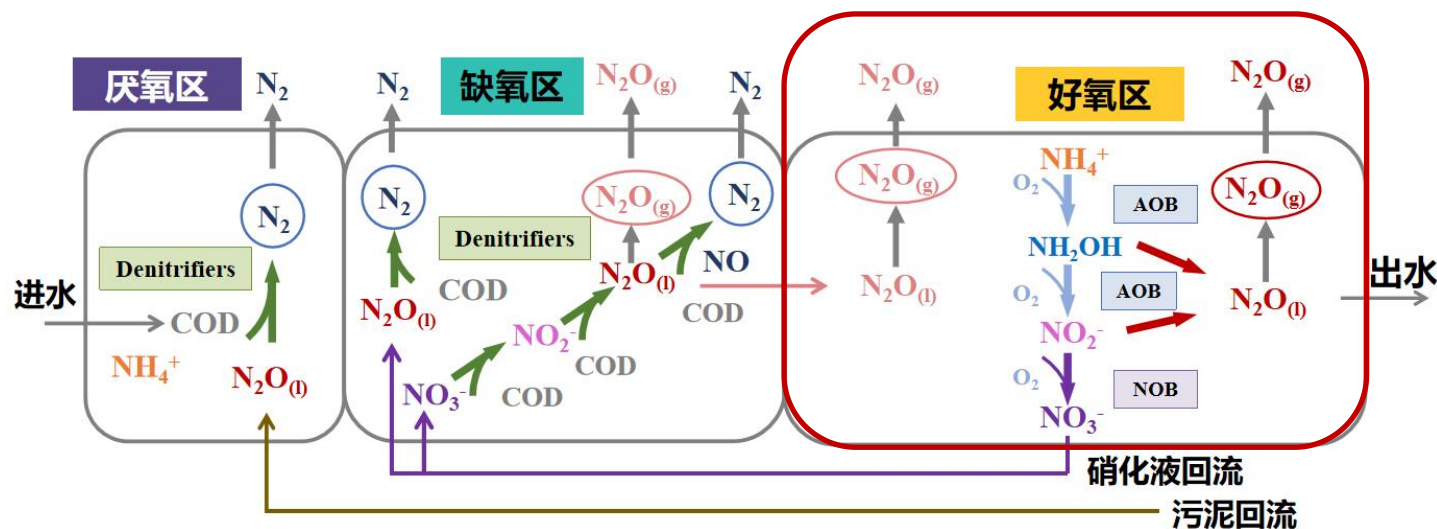
AOA比其他生物技术具有更强的N₂O减排的能力!

AOA[®]和A²O工艺—N₂O排放规律与特征

AOA



A²O



厌氧阶段(A_n)

相同: 反硝化菌利用进水中的有机物将溶解态 N_2O 进行充分还原, 绝大多数以 N_2 形式逸出。

好氧阶段(O):

相同: 通过羟胺氧化及AOB反硝化等作用产生的溶解态 N_2O 在曝气吹脱下逸散。

不同: **AOA工艺**适当降低曝气量可减少 N_2O 逸散, 充分发挥后置缺氧区的功能。

A²O工艺随即将上游缺氧区残留的 N_2O 吹脱且溶解态 N_2O 随出水流出。

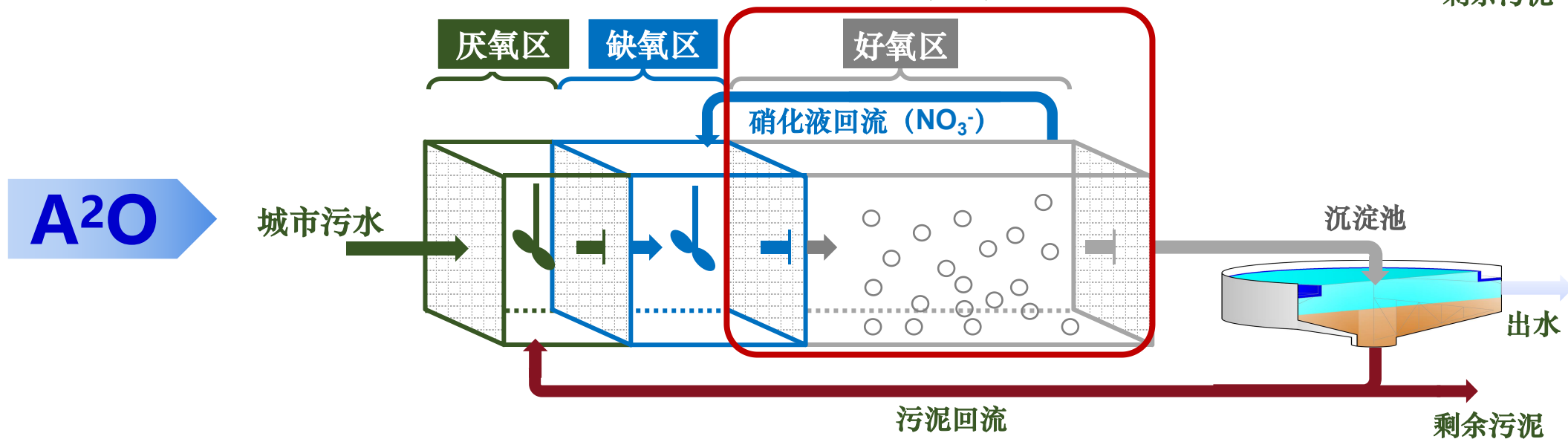
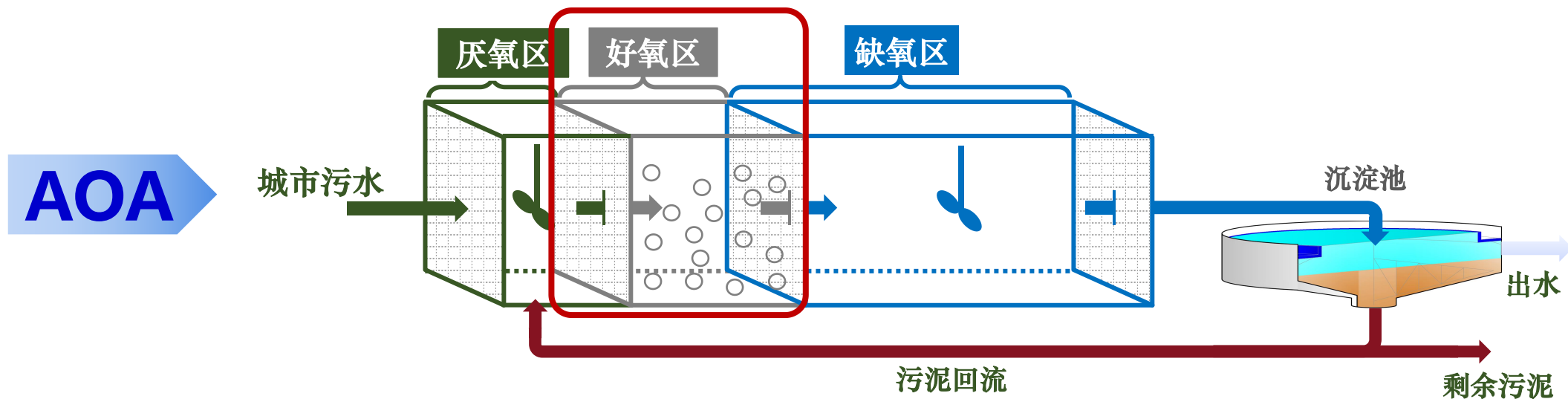
缺氧阶段(A):

不同: **AOA工艺**后置缺氧区作为 N_2O 的汇, 利用内碳源进行内源反硝化作用, 将上游溶解态 N_2O 进行还原;

A²O工艺利用外碳源进行反硝化作用, N_2O 在充分的碳源条件下被还原为 N_2 , 碳源不足则会积累 N_2O , 提高在好氧区逸散的风险。

AOA[®]和A²O工艺—工艺处理特征

□ AOA与A²O (HRT) 比值都是：1:2:4+



- 一 AOA[®]技术原理与优势
- 二 对中低温污水处理的韧性
- 三 氧化亚氮 (N₂O) 减排研究
- 四 示范工程与应用
- 五 结论与展望



AOA工艺技术在中国污水处理厂的应用

AOA工程应用现状

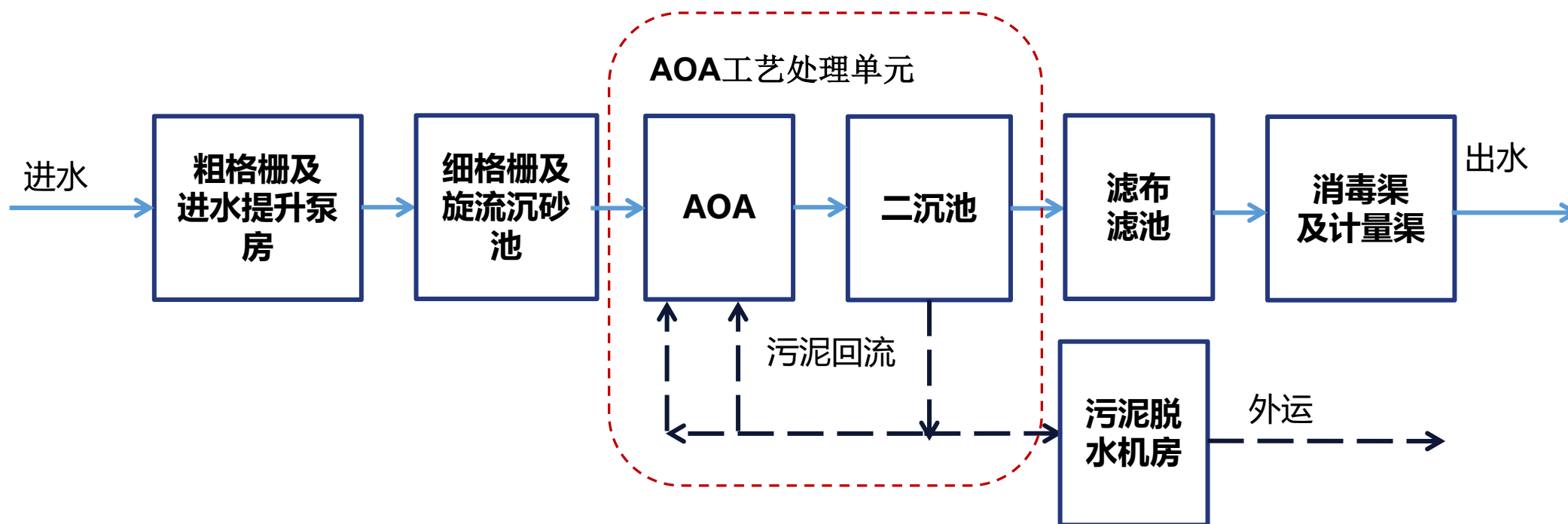
- 首座AOA工程于2021年建成，至今已**有20座污水处理厂通水运行**。位于我国山东，广西，广东与贵州等地。
- 此外，另有60余座水厂正在设计施工中，通水后AOA工艺总处理规模**预计可达900万吨/天**。

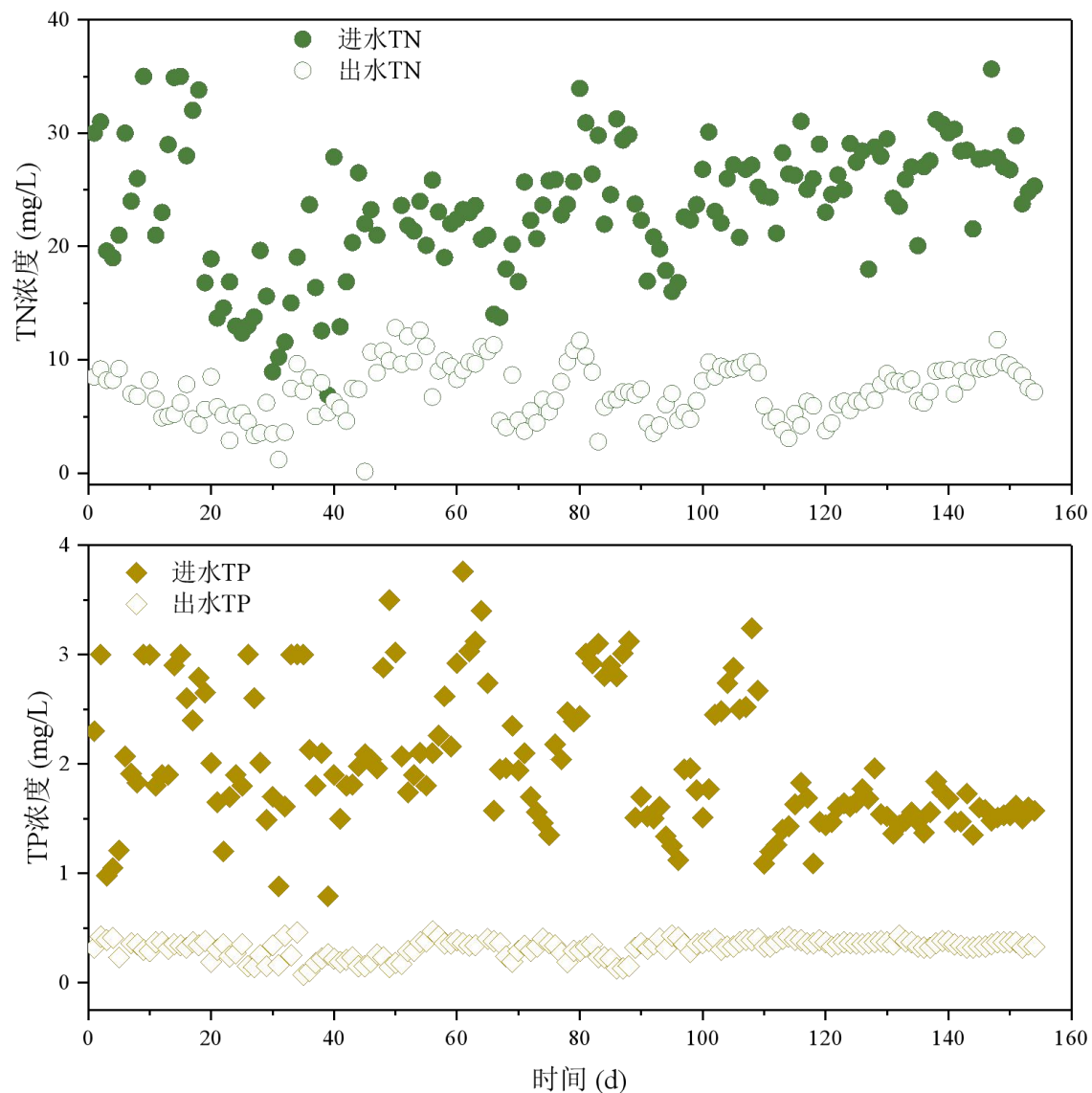


广西岑溪污水处理二期工程 AOA[®]技术应用

- 广西梧州岑溪市污水处理二期工程，**设计规模3.0万 m³/d**
- **设计水力停留时间12h**：容积比**A:O:A=1:1:2**，1.5h可切换好氧/缺氧区
- **工程建设费用为2000元/吨水**，共投入约**7000万元**
- 目前吨水处理费用约0.5元/吨水，节省了运行费用

岑溪污水处理厂二期工程AOA工艺处理流程：





□ AOA平均出水 (未投加碳源)

- ▶ 进水TN浓度为25.2mg/L,
出水TN浓度为5.5mg/L。
- ▶ 进水TP浓度平均为2.0mg/L,
出水TP浓度0.3mg/L。

□ AOA在11月出水 (未投加碳源)

- ▶ 11月水温18°C, 处理量4万 m³/d
- ▶ 双污泥回流量均为50%

进出水质如下:

指标(mg/L)	COD	氨氮	总氮
进水	110.4	20.9	21.1
出水	11.8	0.4	2.7

贵阳新庄污水处理厂二期二阶段 ——AOA[®]工艺工程应用

彭永臻 曹效鑫 高歆婕 丁静 安泽铭

北京工业大学

中国水环境集团

2025年7月

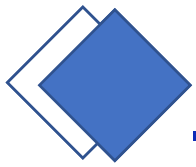


项目背景

- 新建的新庄二期二阶段总设计规模16万m³/d，分4个系列。每个系列设计处理规模**4万m³/d**，执行国家**一级A标准**。**多段AO工艺可以切换为AOA工艺运行。**
- 此次主要研究对象为**1号线**，总水力停留时间12h
- 进水为生活污水，**实际进水总氮在20mg/L左右，进入生化池COD仅为50mg/L左右，碳氮比极低。**

2023年进出水水质

来源	项目	进水水质					
		COD (mg/L)	BOD ₅ (mg/L)	SS (mg/L)	T-P (mg/L)	T-N (mg/L)	NH ₃ -N (mg/L)
	设计进水值	280	130	200	3	27	18
	设计出水值	50	10	10	0.5	15	5
	运行平均进水	47	27	90	1.74	21.7	16.7
	运行平均出水	12	2.4	5	0.16	6.59	0.83



1号线与其它系列对比 (均为A0A工艺)

第IV阶段 (2024.6--2024.7) 4个系列对比

	平均出水TN (mg/L)	平均出水NH ₄ ⁺ -N (mg/L)	平均气水比	好氧HRT (h)	好氧末DO (mg/L)
1号线(AOA)	3.25	0.61	0.73	3	0.83
2号线(AOA)	6.81	0.31	1.46	4.5	4.58
3号线(AOA)	8.79	0.22	3.00	4.5	3.66

相比其他系列，1号线平均出水总氮最低，气水比、好氧水力停留时间、好氧末DO均具较低，具有显著的节能降耗优势。



深圳环境水务集团

SHENZHEN WATER AND ENVIRONMENT GROUP CO.,LTD.



深圳30万吨/日滨河污水厂AOA极限脱氮

北京工业大学

深圳环境水务集团 深圳市利源水务设计咨询有限公司

2025年5月

四

示范工程与应用-深圳30万吨/日滨河污水厂7天调试成功



深圳滨河水质净化厂**30万吨/日**新建工程，采用**AOA工艺技术**，由深圳环境水务集团投资建设。**快速启动调试并成功实现极限脱氮与深度除磷。**

调试运行不到一周，就获得了令人振奋的结果，据运行负责人**2024年8月30日**发来的微信称：

- “彭老师，试运行第六天的出水混合样，结果不错，TN:2.21mg/L，TP:0.11mg/L，氨氮：0.15mg/L，硝氮：1.52mg/L，SS:小于5mg/L”
- “昨天进水COD:187，进水TN:28.4，HRT为10.9小时”



滨河水质净化厂示意图

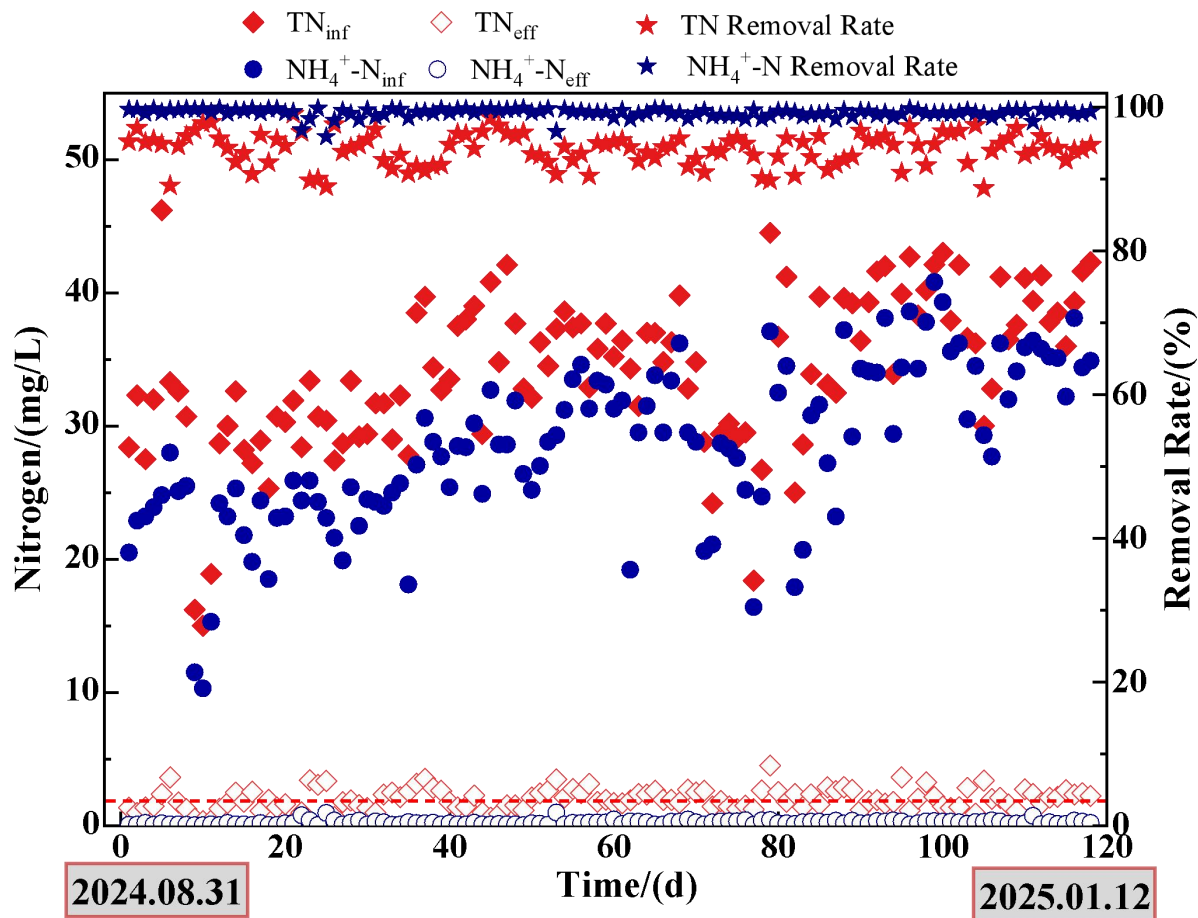


- “滨河水质净化厂8月27日开始满负荷运行；处理C/N比为6的城市生活污水，在进水总氮的为32.3 mg/L的情况下，实现出水总氮0.94 mg/L的极限氮去除效果。同时出水总磷仅为0.11mg/L。”

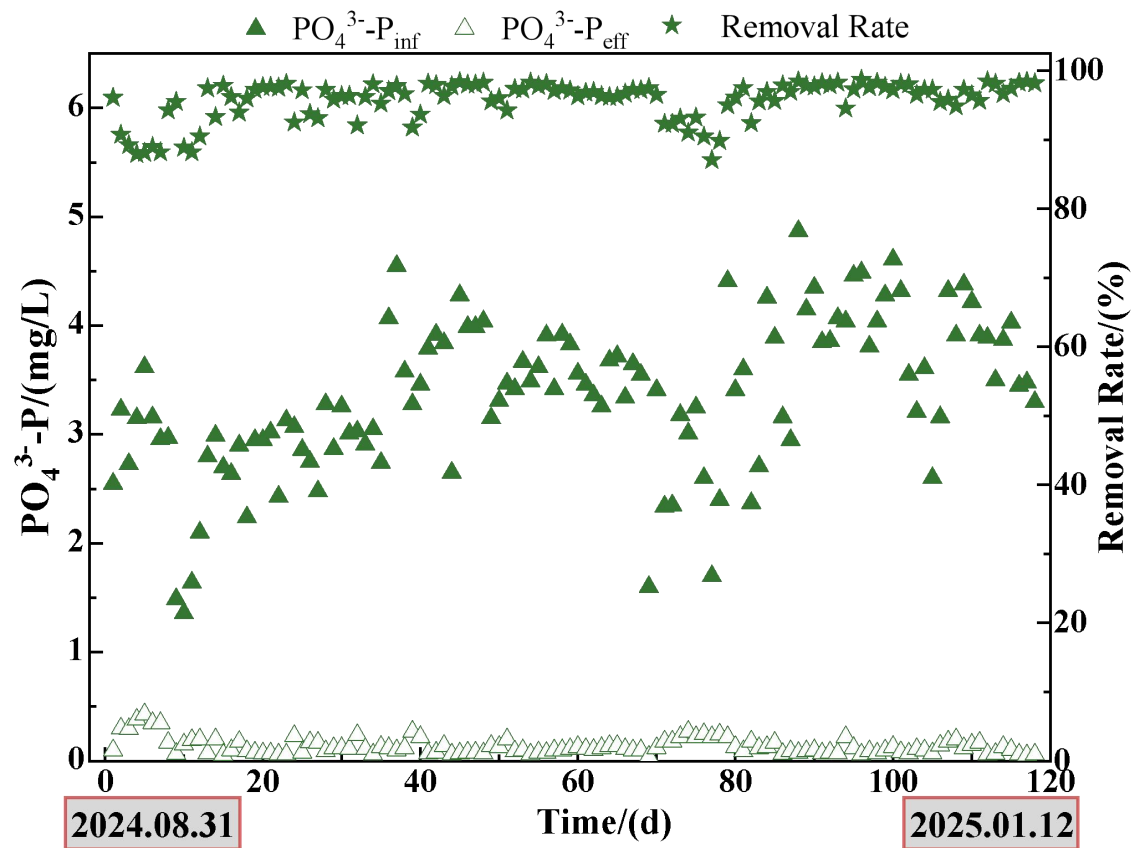
滨河水质净化厂二沉池实时监测（调试5天）



- 滨河水质净化厂采用AOA工艺，运行条件如下：
 - 1、满负荷运行，HRT为10.9h；
 - 2、没投加任何碳源，没投加载体；
 - 3、没有内循环的硝态氮回流。
 - 4、快速启动并成功实现极限脱氮与深度除磷。



- 平均进水TN=34.10 mg/L
- 平均出水TN=1.99 mg/L
- 平均TN去除率=94.2%
- 平均进水 NH_4^+-N =28.40 mg/L
- 平均出水 NH_4^+-N =0.22 mg/L
- 平均 NH_4^+-N 去除率=99.2%



- 平均进水TP=3.35 mg/L
- 平均出水TP=0.13 mg/L
- 平均TP去除率=95.7%
- 平均进水COD=278 mg/L
- 平均出水COD=12 mg/L
- 平均COD去除率=95.5%

刚建成的深圳福田AOA污水处理厂（30万吨/日）的初期调试运行结果，连续12天

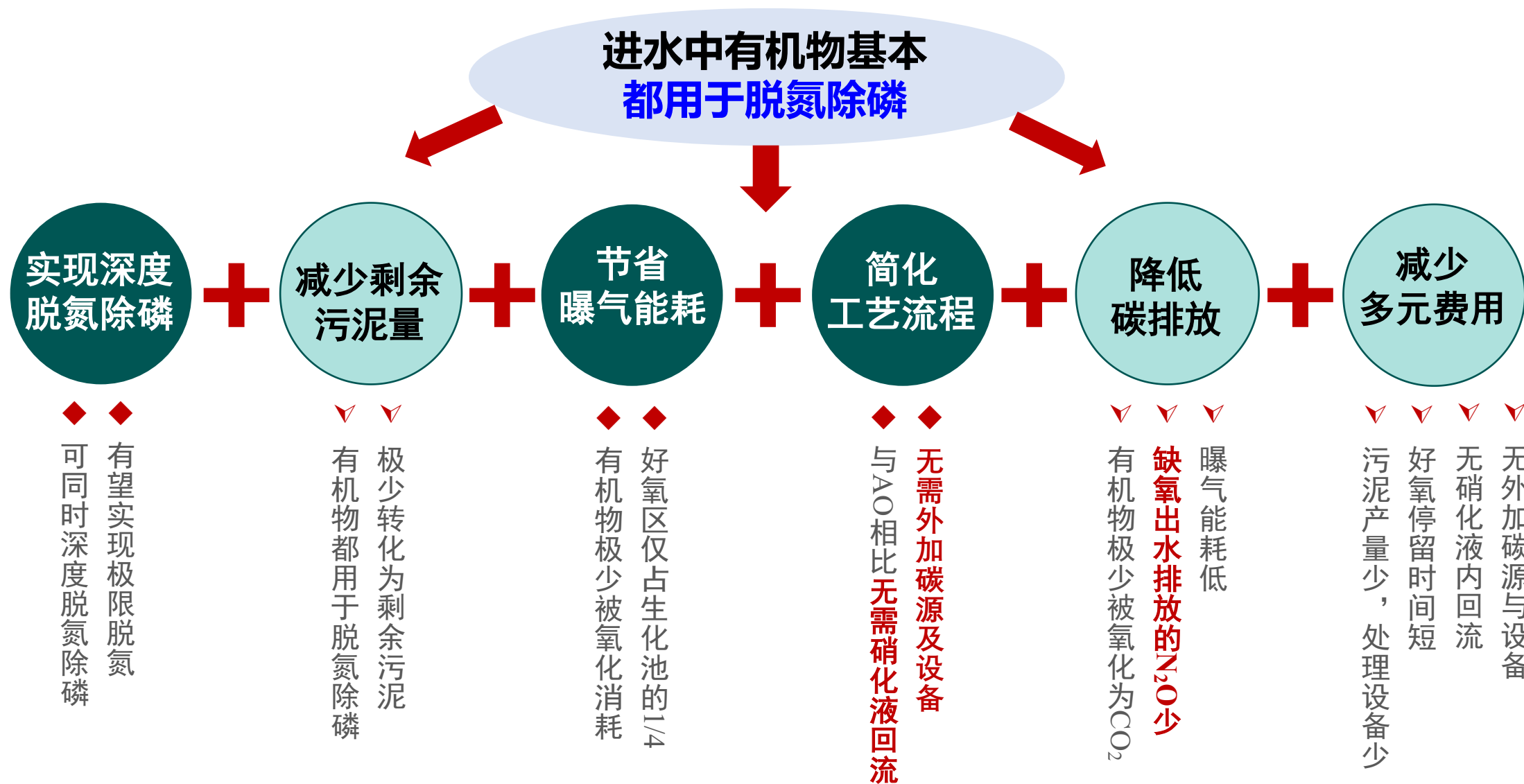
项目	COD (mg/L)		TN (mg/L)		NH ₄ ⁺ -N (mg/L)		NO ₃ ⁻ -N (mg/L)		TP (mg/L)	
	进水	出水	进水	出水	进水	出水	进水	出水	进水	出水
3月7日	207	6	31.9	1.91	29.4	0.282	1.33	1.30	3.26	0.16
3月8日	243	14	27.7	0.61	25.5	0.249	0.01	0.11	3.00	0.51
3月9日	203	10.8	34.7	0.29	30.4	0.235	0.01	0.03	3.53	0.53
3月10日	388	8.4	37.7	1.93	17.9	0.638	1.05	0.18	4.68	0.50
3月11日	407	8	34.5	1.30	28.8	0.177	1.32	1.01	4.80	0.44
3月12日	474	13	29.7	0.89	27.9	0.328	1.31	0.36	5.35	0.43
3月13日	318	14	30.0	0.74	22.5	0.372	1.26	0.30	3.70	0.39
3月14日	396	10.8	33.0	0.98	25.8	0.250	1.10	0.48	5.08	0.44
3月15日	674	9.0	33.1	1.20	16.3	0.285	1.40	0.45	4.98	0.43
3月16日	260	10.1	26.2	1.03	18.4	0.253	0.83	0.29	5.55	0.30
3月17日	238	14.1	24.6	1.05	22.2	0.268	0.78	0.14	3.75	0.42
3月18日	328	11.1	37.8	1.68	26.8	0.254	1.27	0.48	5.05	0.10

北京定福庄污水厂 AOA 示范工程启动13天以来的运行(10万吨/日)

(2026年3月30日通水, 3月31日开始监测, 每天取样6次组成混合水样)

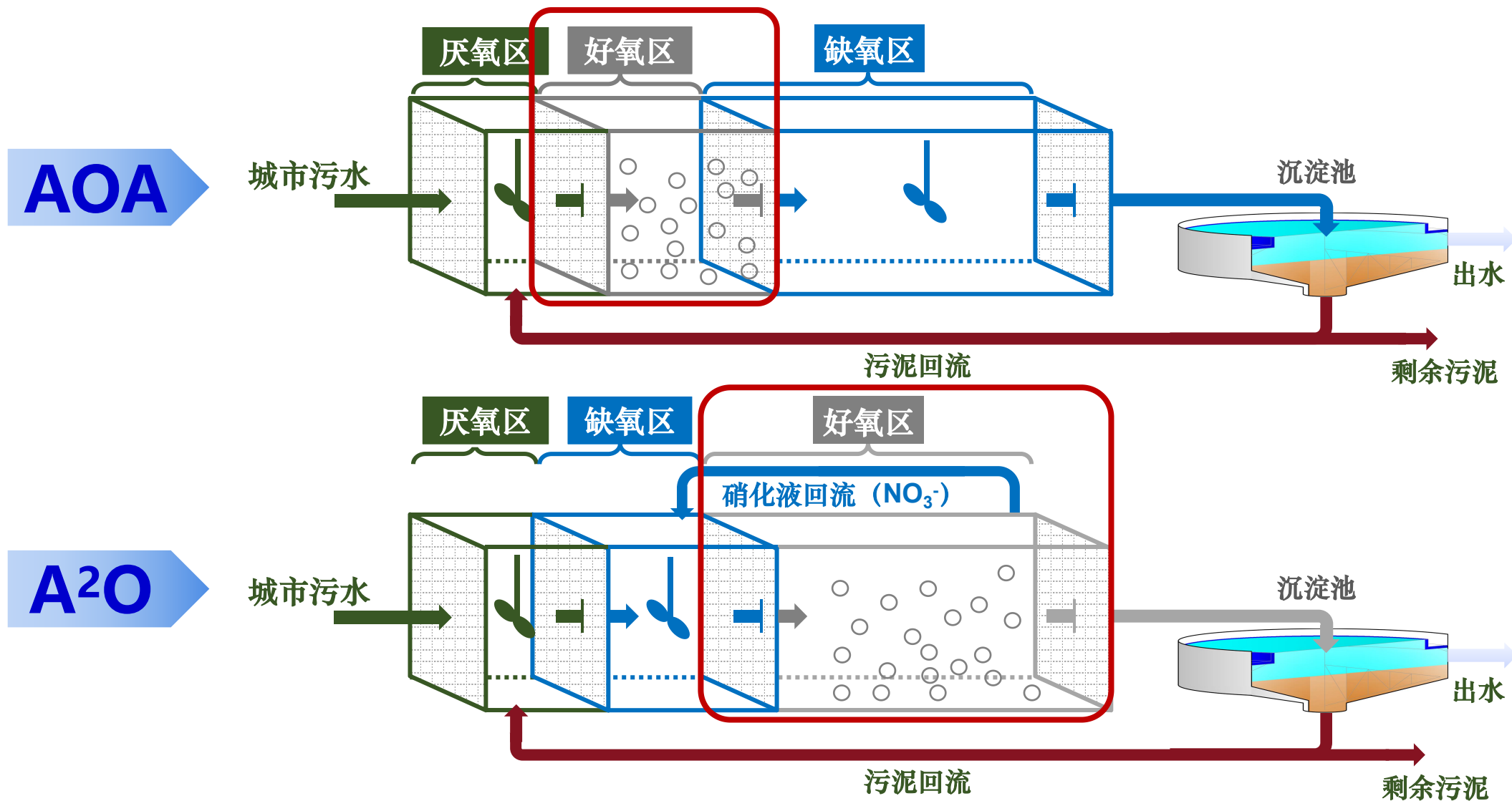
日期	水温 (°C)	进水水质 (mg/L)				AOA (示范工程, 10万吨/日)						A ² O (定福庄污水厂)					
						运行参数		出水水质 (mg/L)				运行参数		出水水质 (mg/L)			
		COD	NH ₄ ⁺	TN	TP	好氧HRT/ 总HRT (h/h)	MLSS (mg/L)	COD	NH ₄ ⁺	TN	TP	好氧HRT/ 总HRT (h/h)	MLSS (mg/L)	COD	NH ₄ ⁺	TN	TP
3月31日	17.5	635	22.3	40.1	7.9	8.6 / 38.0	4010	19.4	0.11	3.38	0.19	18.8 / 31.4	5350	18.6	0.12	4.46	0.18
4月1日	17.5	567	23.4	41.1	7.2	7.4 / 32.9	4200	18.6	0.13	2.86	0.17	18.3 / 30.4	5795	18.9	0.20	4.48	0.25
4月2日	17.4	321	24.5	38.9	5.0	7.4 / 32.7	4790	17.2	0.18	2.40	0.15	18.3 / 30.5	5570	19.6	0.20	5.06	0.26
4月3日	17.7	314	27.0	36.6	4.1	5.7 / 25.4	4530	19.0	0.16	3.04	0.14	14.6 / 24.4	5530	16.6	0.15	7.06	0.15
4月4日	17.7	668	30.0	44.9	5.7	5.2 / 23.0	5255	19.0	0.13	3.57	0.15	14.6 / 24.3	6050	18.0	0.12	7.15	0.21
4月5日	17.7	551	25.1	43.4	7.02	5.6 / 25.0	5635	26.3	0.17	4.24	0.22	15.3 / 25.5	6385	22.7	0.14	8.89	0.21
4月6日	17.5	492	24.7	41.3	5.86	4.8 / 21.4	5565	22.8	0.27	1.75	0.16	16.1 / 26.9	6265	22.0	0.24	5.56	0.14
4月7日	17.5	365	26.7	35.8	4.07	4.7 / 21.1	5900	26.0	0.29	3.88	0.15	14.3 / 23.8	6240	24.8	0.21	6.13	0.11
4月8日	17.7	539	25.7	34.7	6.49	4.6 / 20.5	5945	28.2	0.26	3.30	0.28	12.1 / 20.2	6210	25.0	0.21	7.33	0.19
4月9日	17.6	756	28.0	47.0	7.64	4.4 / 19.7	6530	29.8	0.32	1.94	0.27	13.6 / 22.7	6710	22.0	0.20	5.77	0.14
4月10日	17.8	511	26.8	43.4	5.62	4.4 / 19.4	6175	30.0	0.34	2.75	0.19	11.9 / 19.9	6305	23.0	0.26	6.90	0.17
4月11日	18.0	745	25.3	33.9	4.12	4.2 / 18.6	6070	29.1	0.10	2.26	0.31	10.8 / 18.1	6270	25.8	0.08	5.01	0.19
4月12日	18.2	638	27.4	44.2	6.45	4.3 / 19.2	5395	37.4	0.30	3.42	0.41	12.2 / 20.3	5970	30.8	0.13	6.82	0.16
平均	17.6	539	26.2	40.0	5.8	5.2 / 23.2	5499	25.3	0.22	2.95	0.22	14.3 / 23.9	6108	22.4	0.18	6.30	0.18

- 一 AOA[®]技术原理与优势
- 二 对中低温污水处理的韧性
- 三 氧化亚氮 (N₂O) 减排研究
- 四 示范工程与应用
- 五 结论与展望



AOA[®]和A²O工艺—工艺处理特征

□ AOA与A²O (HRT) 比值都是：1:2:4+



北京定福庄污水厂 AOA 示范工程启动13天以来的运行(10万吨/日)

(2026年3月30日通水, 3月31日开始监测, 每天取样6次组成混合水样)

日期	水温 (°C)	进水水质 (mg/L)				AOA (示范工程, 10万吨/日)						A ² O (定福庄污水厂)					
						运行参数		出水水质 (mg/L)				运行参数		出水水质 (mg/L)			
		COD	NH ₄ ⁺	TN	TP	好氧HRT/ 总HRT (h/h)	MLSS (mg/L)	COD	NH ₄ ⁺	TN	TP	好氧HRT/ 总HRT (h/h)	MLSS (mg/L)	COD	NH ₄ ⁺	TN	TP
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4月11日	18.0	745	25.3	33.9	4.12	4.2 / 18.6	6070	29.1	0.10	2.26	0.31	10.8 / 18.1	6270	25.8	0.08	5.01	0.19
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平均	17.6	539	26.2	40.0	5.8	5.2 / 23.2	5499	25.3	0.22	2.95	0.22	14.3 / 23.9	6108	22.4	0.18	6.30	0.18

结论与展望 — 7大优点将决定其广泛应用

进水中有机物基本都用于脱氮除磷

实现深度脱氮除磷

- ◆ 有望实现极限脱氮
- ◆ 可同时深度脱氮除磷

减少剩余污泥量

- ▽ 极少转化为剩余污泥
- ▽ 有机物都用于脱氮除磷

节省曝气能耗

- ◆ 好氧区仅占生化池的1/4
- ◆ 有机物极少被氧化消耗

对中低温的韧性

- ▽ AOA工艺体现了低温耐受性基本相同
- ▽ 种群类型与其他活性污泥法

简化工艺流程

- ◆ 无需外加碳源及设备
- ◆ 与AO相比无需硝化液回流

降低N₂O等碳排放

- ▽ 曝气能耗低
- ▽ 缺氧出水排放的N₂O少
- ▽ 有机物极少被氧化为CO₂

减少多元费用

- ◆ 无外加碳源与设备
- ◆ 无硝化液内回流
- ◆ 好氧停留时间短
- ◆ 污泥产量少，处理设备少

1. AOA[®]技术虽然可以应用于某些工业污水处理，但是**对于超低C/N的污水，很难满足不投加碳源的需求**。更不适用于几乎没有有机物的工业污水；
2. 对于虽然不是超低C/N的污水，但是，**具有较高的进水氨氮或总氮，也很难满足深度脱氮的要求**，例如进水氨氮或TN浓度大于100mg/L的城市污水或工业污水。
3. 虽然在当前还没有满意的AOA[®]技术的过程控制软件（更缺少AI元素），其中试和工程应用都很好，但是，**AOA[®]技术本身对于工艺设计与过程控制的要求还是要高一些**。

Thank You

请指正!