ATAL Engineering Group
安樂工程集團

ATAL Anaerobic Ammonia Oxidation Process
厌氧氨氧化系统 (AANAMMOX)

Engineering with passion
用心創造

Introduction 简介

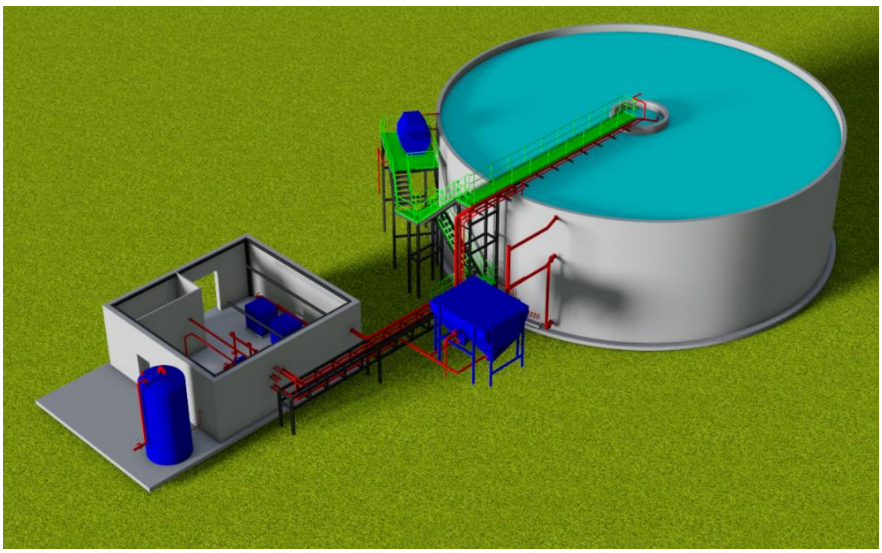
ATAL Anaerobic Ammonia Oxidation Process (AANAMMOX) 厌氧氨氧化系统

ATAL Anaerobic Ammonia Oxidation Process (AANAMMOX) was developed in the 1990s, which has been the most promising biological denitrification technology. Since the operation of first reactor in 2002, this technology has been promoted around the world in the area of municipal, fermentation industry and other industries. Our Group has accumulated rich experience and good performance in the process design, equipment integration and "turnkey" project. We have a team of engineers with strong technical capabilities and rich experience in project management. In the process design, equipment supply, installation, commissioning and operation of the process package, it is practical to achieve safety, reliability, economical application, advanced technology, and effluent standards.

厌氧氨氧化系统（AANAMMOX）产生于20世纪90年代，是目前最有前景的生物脱氮技术，自2002年首座反应器投入实际运行以来，该技术已在世界各地推广应用，包括：市政领域、发酵工业领域及其他工业领域。我司在此工艺的设计、成套设备集成和“交钥匙”工程上积累了丰富的经验和良好的业绩，并拥有一支专业技术能力强、工程管理经验丰富的工程师队伍。在工艺包的工艺设计、设备选购、施工、安装、调试和运营中，切实做到安全可靠、经济适用、技术先进、确保出水达标。

The discharge of nitrogen-containing sewage largely hurt the water body, thereby lead to water deterioration followed by the death of large number of organisms. Traditional nitrogen removal methods include biological, physical and chemical treatment methods such as nitrification and denitrification, air stripping and chemical precipitation etc. However, the traditional treatment methods have disadvantages of high energy consumption, requirement of additional carbon sources, high operating costs and equipment maintenance.

含氮污水的排放会对水体造成极大的危害，因其可引起水体富营养化，导致水体内溶解氧的减少，最终导致水质恶化和生物大量死亡。传统的氮去除方式包括生物、物理和化学的处理方式，例如：硝化和反硝化、空气吹脱法、化学沉淀法等。但传统的处理方法存在能耗高、需要外加碳源、运行费用高及设备维护等问题。



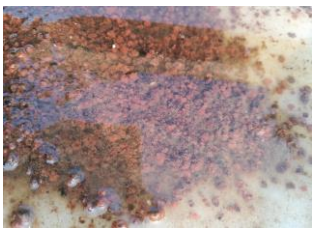
3D model of AANAMMOX
厌氧氨氧化系统设计及建造3D效果图

Major Features 主要特点

AANAMMOX Process Introduction 工艺介绍

The biological reaction in which nitrite is used as an oxidant to oxidize ammonia to nitrogen, or a biological reaction that uses ammonia as an electron donor to reduce nitrite to nitrogen is called anaerobic ammonium reaction. Microorganisms capable of anammox are called anammox bacteria.

以亚硝酸盐作为氧化剂将氨氧化成氮气，或以氨作为电子供体将亚硝酸盐还原为氮气的生物反应，称为厌氧氨氧反应。能够进行厌氧氨氧化的微生物，称为厌氧氨氧化菌。



Anammox bacteria
厌氧氨氧化菌

Anammox Bacteria 厌氧氨氧化菌

The anammox bacteria belongs to the Planctomycetales, and mainly exists in the wastewater treatment plant (WWTP) except two kinds of (Candidatus Scalinduaarabica and Candidatus Scalindua sorokinii), which mainly exist in the ocean. The classification of Anammox bacteria is illustrated in Table 1.

Anammox bacteria are red due to the presence of cytochrome c (see above figure), and their cells have independent organelles - anammox bodies, which are wrapped by a stepped alkane lipid layer, in which anammox reactions take place.

厌氧氨氧化菌属于浮霉状菌目（Planctomycetales）、化能自养型菌，除两种（Candidatus Scalinduaarabica和 Candidatus Scalindua sorokinii）主要存在于海洋环境之外，其余主要存在于污水厂构筑物，厌氧氨氧化菌种分类详见表1。厌氧氨氧化菌因含细胞色素c而呈红色（见上图），其胞内有被阶梯烷脂层包裹的独立细胞器 —— 厌氧氨氧化体，厌氧氨氧化反应就发生在其中。

Table 1 Classification of Anammox bacteria
表1 厌氧氨氧化菌种分类

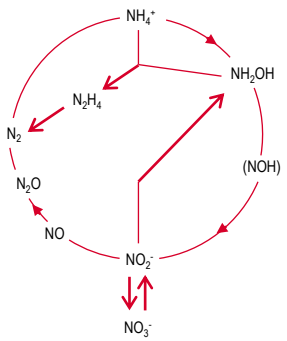
Genus 属	Species 种	Source 来源
Brocadia	Candidatus Brocadia anammoxidans	Sewage 污水
	Candidatus Brocadia fulgida	Sewage 污水
Kuenenia	Candidatus Kuenenia stuttgartiensis	Sewage 污水
	Candidatus Scalindua brodae	Sewage 污水
Scalindua	Candidatus Saclindua wagneri	Sewage 污水
	Candidatus Scalindua sorokinii	Sea water 海水
	Candidatus Scalindua Arabica	Sea water 海水
Others 其他	Candidatus Jettenia asiatica	Uncertain 尚不明确
	Candidatus Anammoxoglobus propionicus	Sewage 污水

Mechanism of Reaction 反应原理

Through the control of reaction conditions, ammonia is oxidized to nitrite nitrogen, nitrite nitrogen will not be further oxidized to nitrate nitrogen. The dominant bacteria in the system - anammox bacteria uses the remaining ammonia to continue the reaction with nitrous nitrogen to complete partial nitrification reaction and anaerobic ammonia oxidation (AAO) reaction (the principle is shown in figure below, and the reaction formula is shown in Eq.1).

通过对反应条件的控制，氨被氧化为亚硝态氮，亚硝态氮不再进一步的被氧化为硝态氮，系统中的优势菌种 —— 厌氧氨氧化菌利用反应剩余的氨继续与亚硝态氮反应，完成短程硝化反应及厌氧氨氧化反应（原理如下图所示，反应式见Eq.1）。

$$NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O \quad \text{Eq.1}$$



Partial nitrification and
AAO reaction principle
短程硝化+厌氧氨氧化原理图

Major Features 主要特点

Classification of Reactor 反应器的分类

1-stage Reaction 一段式反应

1-stage reaction is a method of simultaneously removing ammonia nitrogen and nitrite by completely autotrophic microorganisms under oxygen-limited conditions. There are two types of autotrophic microorganisms in the system: aerobic nitrifying bacteria and anaerobic ammonium oxidizing bacteria. Aerobic nitrifying bacteria oxidize NH_4^+ to NO_2^- (see Eq.2 for the reaction), while anammox bacteria convert NH_4^+ and NO_2^- into N_2 and a small amount of NO_3^- (see Eq.3 for the reaction, see Eq.4 for the overall anammox reaction). The above reactions are all completed in a single reactor or biofilm reactor.

一段式反应是指在限氧的条件下，利用完全自养性微生物将氨氮和亚硝酸盐同时去除的一种方法。系统中有两类自养微生物：好氧硝化细菌和厌氧氨氧化细菌。好氧硝化细菌将NH_4^+氧化成 NO_2^-（反应见Eq.2）；厌氧氨氧化细菌将NH_4^+和NO_2^-转变成N_2和少量的NO_3^-（反应见Eq.3，总的脱氮反应见Eq.4）。以上反应均在在单一反应器或生物膜反应器内完成。

$$NH_4^+ + 1.5O_2 \rightarrow 1.02NO_2^- + 2H^+ + H_2O \quad \text{Eq.2}$$
$$NH_4^+ + 1.3NO_2^- \rightarrow 1.02N_2 + 0.26NO_3^- + 2H_2O \quad \text{Eq.3}$$
$$NH_4^+ + 0.85O_2 \rightarrow 0.435N_2 + 0.13NO_3^- + 1.3H_2O + 1.4H^+ \quad \text{Eq.4}$$

2-stage Reaction 两段式反应

2-stage reaction refers that the partial nitrification and anammox processes are completed in separate reactors. Short-cut nitrification can use a complete mixed aerobic continuous reactor; anammox can use biofilm and biological fluidized bed process (the process schematic diagram is shown in figure below).

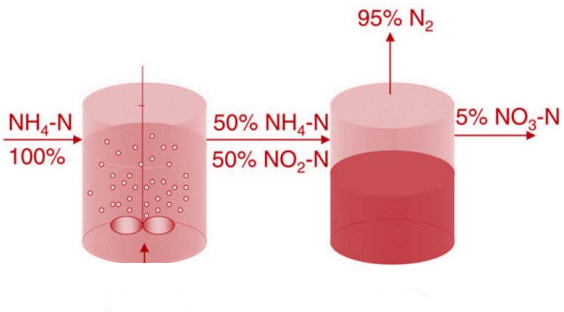
The effluent of the partial nitrification reactor (containing NH_4^+ and NO_2^-) is used as the influent of the anammox reactor. Anaerobic reaction occurs in the anammox reactor, 95% of nitrogen is converted into N_2, and a small amount of NO_3^- is discharged with the effluent.

The partial nitrification - anammox process is suitable for the treatment of high-concentration NH_4-N wastewater and high NH_4-N concentration industrial wastewater with low organic carbon content.

两段式反应是指短程硝化与厌氧氨氧化工艺分别在独立的反应器内完成。短程硝化可采用完全混合式好氧连续反应器；厌氧氨氧化可采用生物膜法和生物流化床（工艺示意图如下图所示）。

短程硝化反应器的出水（含有NH_4^+和NO_2^-）作为厌氧氨氧化反应器的进水。在厌氧氨氧化反应器内发生厌氧反应，有95%的氮转变成 N_2。另外，还有少量的NO_3^-随出水排出。

短程硝化 —— 厌氧氨氧化工艺适合处理高浓度NH_4-N废水和有机碳含量低的高NH_4-N浓度工业废水。



Schematic diagram of 2-stage reaction
两段式反应器示意图

Advantages 优点

Low Nitrogen Removal Cost 脱氮成本低

Compared with traditional biological nitrification/denitrification, AANAMMOX can reduce the aeration rate by around 60% without additional carbon source. The cost is approximately 46.4%-81.3% reduced compared with the traditional process. The comparison of nitrogen-containing wastewater treatment methods is shown in Table 2.

相对于传统生物硝化/反硝化脱氮，厌氧氨氧化系统（AANAMMOX）能够减少约60%的曝气量；并且完全不需要外加碳源；脱氮成本相比于传统生物脱氮成本减少了约46.4%-81.3%；含氮废水处理方式的比较见表2。

Small Construction Site 占地面积小

Compared with traditional biological nitrification/denitrification, the volume of AANAMMOX reactor for treating yeast production wastewater is only 500 m^3, which substitutes the original traditional A/O process in10,000 m^3.

相对于传统生物硝化/反硝化脱氮，厌氧氨氧化系统（AANAMMOX）的占地面积较传统工艺大为减少，处理酵母生产废水的AANAMMOX反应器只需500 m^3，便能取代了原来10,000 m^3的传统A/O工艺。

Table 2 Comparison of Nitrogen-containing Wastewater Treatment Methods

	Chemical Sludge	Biological Sludge	Chemical Dosage	Energy Consumption	Operation difficulty	Operation Cost USD/kgN	Operation Cost RMB/kgN
Air Stripping	Yes	NO	Yes	Medium	General	6.975	46.5
Steam Extraction	Yes	NO	Yes	High	Complicated	9.30	62
MAP/CAFR process	Yes	NO	Yes	Low	Complicated	6.975	46.5
Membrane Bioreactor	NO	Yes	Yes	High	General	3.255	21.7
Biofilm reactor	NO	Low	Yes	Medium	General	6.62625	44.175
AANAMMOX	NO	Low	Yes	Medium	Simple	1.74375	11.625

表2 含氮废水不同处理方式的比较

	化学污泥产量	生物污泥产量	药剂投加量	能耗	操作难易	运营成本 USD/kgN	运营成本 RMB/kgN
吹脱法	有	无	有	中	一般	6.975	46.5
蒸汽气提法	有	无	有	高	复杂	9.30	62
MAP/CAFR process	有	无	有	低	复杂	6.975	46.5
膜生物反应器	无	有	有	高	一般	3.255	21.7
生物膜反应器	无	低	有	中	一般	6.62625	44.175
AANAMMOX	无	低	有	中	简单	1.74375	11.625

Comparison between AANAMMOX and traditional biological treatment
厌氧氨氧化与传统生物处理对比

Job Reference 案例

Project Overview 项目概况

Source of wastewater: supernatant of anaerobic digestion and sludge dewatering of wastewater treatment plant

Project location: city in northern China

废水来源：市政污水处理厂沉淀池污泥厌氧消化+污泥脱水后的上清液

项目地点：中国北方城市

Major Influent Water Quality 主要进水水质

NH4-N concentration 1,000 mg/L, TN concentration 1,200 mg/L, COD content 1,200 mg/L

NH4-N浓度1,000 mg/L，TN浓度1,200 mg/L，COD含量1,200 mg/L

Reaction Tank Size 反应池尺寸

Effective volume 3,000 m³

有效容积3,000 m³

Treatment Performance 处理效果

Removal rate of NH4-N: higher than 90%. Removal rate of total nitrogen: higher than 80%. (see below table)

NH4-N去除率：高于90%，TN去除率：高于80%。（见下表）

Influent and Effluent Quality of Reactor 反应器进、出水水质

Parameter 指标	Unit 单位	Influent 入水	Effluent 出水
CODcr	mg/L	1,200	/
BOD_5	mg/L	400	/
SS	mg/L	400	≤100
NH_4^+-N	mg/L	1,000	≤100
TN	mg/L	1,200	≤240
TP	mg/L	8	/
pH	/	7.8	/
Conductivity 电导率	μs/cm	5630	/
Alkalinity 碱度	mg/L	4200	/

Headquarters 总部

13/F, Island Place Tower, 510 King's Road, North Point, Hong Kong
香港北角英皇道 510 号港运大厦 13 楼

(852) 2561 8278
info.env@atal.com

www.atal.com

Other Offices 其他办事处

UK 英國 | Beijing 北京 | Shanghai 上海 | Nanjing 南京 | Guangzhou 广州 | Macao 澳门

ATAL offices | ATAL LinkedIn | ATAL WeChat