低负荷运行对城市污水生物除磷的影响

Impact of Low Loading on Biological Phosphorus Removal from Municipal Sewage

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摘要 针对目前国内较多的城市污水处理厂长期处于低负荷运转的状态,进行了现场生产性与静态模型的试验研究。结果表明,长期低负荷运行是导致生物除磷效率下降的主要原因。长期低负荷运行使聚磷菌微生物细胞内储存物质(PHB、Glycogen、poly-P等)含量下降,使生物除磷能力丧失。为了保证生物脱氮除磷处理系统的除磷效率,可通过调节生化反应容积、控制好氧区的曝气等手段,使处理系统的负荷控制在适合的范围内。

关键词: 城市污水 污水处理厂 低负荷 运行状态 生物除磷 除磷效率

1 前言

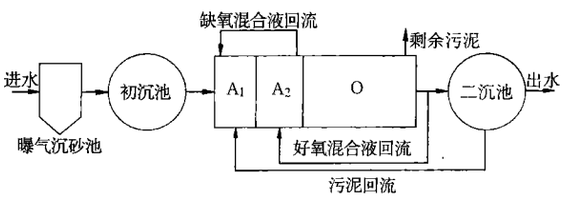
城市污水生物除磷包括一系列复杂的生化反应过程,微生物细胞内贮藏物质及其代谢产物在此过程中起着重要作用。除磷机制在于厌氧条件下聚磷菌利用细胞内积聚的聚磷(poly-P)和糖原(Glycogen),在分解代谢时产生的能量和还原动力,吸收细胞外的挥发性脂肪酸(VFAs),合成聚β-羟基丁酸(PHB)储存在细胞内,而后在缺氧或好氧条件下,用于微生物生长、糖原的合成和维持细胞代谢,还为细胞外磷的吸收及其在体内poly-P的合成提供能量[1,2]。通过厌氧/好氧生化反应过程,利用聚磷菌在好氧条件下的吸磷量和在厌氧条件下的释磷量特性,通过排除剩余污泥使磷得到有效去除。

国内新建的大部分具有脱氮除磷功能的城市污水处理厂,由于配套的城市排水系统通常滞后于城市污水厂的建设,造成进入城市污水厂的污水水量或污水水质远低于设计值,在试运行阶段甚至投入生产后正常运行的很长时期内,使污水处理厂处于低负荷运转状态。这些污水处理厂的实际运行结果表明,其总磷去除效果较差,通常总磷去除效率小于50%。针对上述问题,本文对长期处于低负荷运行状态下的具有氮磷脱除功能的城市污水处理厂进行调查研究,并结合国内外类似问题的研究报道,探讨了造成此类问题的原因,并寻求合理的解决办法。

2 试验方法

2.1 试验装置

选择具有氮磷脱除功能的青岛某城市污水处理厂为研究对象,结合该污水处理厂的实际情况,通过生产性试验考察在不同负荷条件下对污水生物除磷的影响。该污水处理厂采用改良的A_2/O工艺(见图1),设计处理能力为80000m^3/d,生化反应池理论水力停留时间为21h,非曝气容积比为0.35,污泥回流比为70%~100%,好氧混合液回流比为100%~200%,缺氧混合液回流比为100%。由于污水管网系统建设的滞后,该污水处理厂目前实际处理水量仅为40000m^3/d左右,如此状况导致该污水处理厂长期处



A_1-厌氧区; A_2-缺氧区; O-好氧区。

图1 改良A_2/O工艺流程示意
Figure 1 Flow chart of modified A_2/O process

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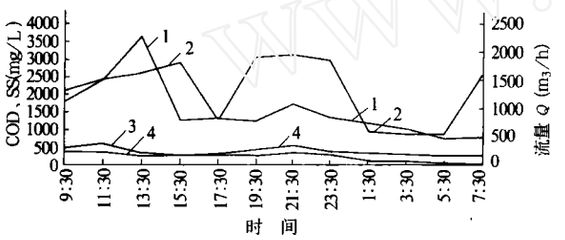
于低负荷运转，生化反应池水力停留时间达42h。试验过程中通过关闭2组平行运行的污水生化处理反应池中的1组反应池，达到提高负荷的目的。

2.2 废水水质

该污水处理厂的设计进、出水水质如表1。试验期间典型日进水水质、水量变化规律如图2、图3所示。

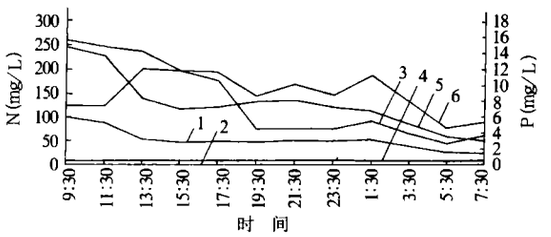
表1 污水处理厂设计进、出水水质(mg/L)
Table 1 Quality of designed influent and effluent in the sewage treatment plant

	COD	BOD_5	SS	NH_3-N	TKN	TP
设计进水	900	400	700	60	90	5
设计出水	150	30	30	25	/	1



1-COD; 2-Q; 3-SS; 4-溶解性COD.

图2 污水处理厂进水水质、水量变化
Figure 2 Changes of qualities and flows of influent in the sewage treatment plant



1-NH_3-N; 2-NO_3-N; 3-Orth-p; 4-pH; 5-TKN; 6-TP。

图3 污水处理厂进水水质变化
Figure 3 Changes of qualities of influent in the sewage treatment plant

2.3 分析方法

所有分析方法均按照国家标准分析方法进行(略)。

3 结果与讨论

3.1 生产性试验

自试运行以来长期处于低负荷运转状态，正常最终处理出水中除磷超标外，其余各项指标均可接近或达到国家一级排放标准(GB8978-1996)。为了提高处理系统的负荷，考察不同负荷对生物除磷的影响，本研究通过关闭1#生化反应池进水，使污水处理厂进水全部进入2#生化反应池来达到提高处理工艺系统负荷的目的，不同负荷条件下生产性运行结果如表2。

在调整处理系统有机负荷的同时，保持其它工艺运行参数(泥令、污泥回流比、缺氧/好氧混合液回流比、溶解氧控制等)不变。从表2可以看出，处理系统在不同负荷条件下，虽然COD、N与SS等指标处理效果未发生明显的变化，但TP处理效果却发生明显的变化。当处理系统负荷由0.165g(COD)/[g(MLSS)·d]提高到0.288g(COD)/[g(MLSS)·d]后，处理系统的TP去除率由40.1%提高到73.7%，由此可知，长期低负荷运行对污水生物除磷不利，甚至导致除磷效率的下降。

表2 不同负荷条件下生产性运行处理效果1)
Table 2 Full scale operational effect under different loading

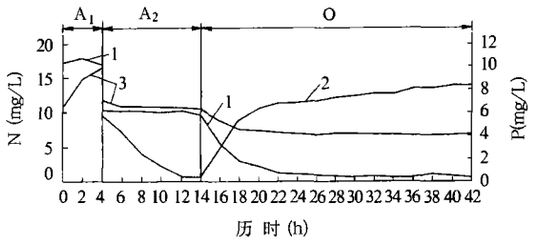
有机负荷		COD_{Cr}	NH_3-N	NO_3^--N	NO_2^--N	TKN	TN	Orth-P	TP	SS
0.165 g(COD)/[g(MLSS)·d]	进水	896	65.6	0.5	0.1	122.1	122.7	6.8	10.6	695
	出水	76	1.2	16.8	1.0	5.2	23.0	4.8	6.3	14
	去除率	91.5	/	/	/	95.7	81.2	/	40.1	98.0
0.288 g(COD)/[g(MLSS)·d]	进水	946	71.8	0.4	0.1	125.3	125.8	7.5	11.8	736
	出水	83	1.1	12.3	0.2	4.0	16.5	2.4	3.1	15
	去除率	91.2	/	/	/	97.0	86.9	/	73.7	98.0

1) 上述数据为试验期间该污水处理厂生产性运行进、出水数据平均值，去除率以%计，其它指标单位均为mg/L。

3.2 静态模型试验

为了发现长期低负荷条件下运行导致处理系统生物除磷效率下降的原因，本研究在生产性试验的不同阶段，分别利用在不同负荷条件下稳定运行的生产性生化反应系统内的活性污泥进行了静态模型试验。静态模型试验模拟改良A_2/O工艺反应过程，并通过测定NH_3-N、NO_3^--N、Orth-P的变化过程，探究生化反应规律，试验结果如图4、图5所示。

从图4可见，当生产性生化反应系统处于低负荷状态下，即污泥有机负荷为0.165g(COD)[/g(MLSS)·d]时，其静态模拟生化反应过程如下：在厌氧区段内

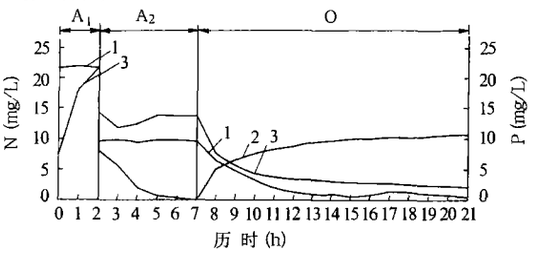


1-NH_3-N; 2-NO_3^--N; 3-Orth-P。

图4　低负荷条件下生化反应氮磷转化过程

Figure 4　Transform process of nitrogen and phosphorus under low loading

(A_1)，聚磷菌利用易降解有机物进行厌氧释磷，但厌氧释磷速率及释磷量均较低，在厌氧反应结束时释磷量仅为3.5mg/L；转入缺氧区段(A_2)后，由于污泥回流及好氧混合液回流的稀释作用，Orth－P下降到6.4mg/L，而由污泥回流及好氧混合液回流所携带的NO_3^--N在此进行反硝化反应，至缺氧结束时反硝化尚未进行彻底，剩余NO_3^--N为0.5mg/L，Orth-P略有下降；转入好氧区段(O)后，在有机物氧化的同时进行硝化反应，NH_3^--N浓度迅速下降，NO_3^--N浓度伴随硝化反应的进行而不断上升，且NO_3^--N的增加量往往大于NH_3^--N的减少量，这是由于进水中有机氮通过氨化及硝化作用被氧化为NO_3^--N。Orth-P在好氧区段内的变化过程表明，聚磷菌仅在好氧反应初期进行缓慢吸磷反应，随着好氧反应时间的延长，吸磷现象几乎停止，好氧反应结束时最终出水Orth-P含量高达4.4mg/L，也就是说聚磷菌在好氧条件下不具备进行大量的吸磷能力，这与厌氧条件下聚磷菌释磷量较少有关。



1-NH_3-N; 2-NO_3^--N; 3-Orth-P。

图5　常规负荷条件下生化反应氮磷转化过程

Figure 5　Transform process of nitrogen and phosphorus under routine loading

从图5可以看出，当该污水处理厂生产性生化反应系统处于常规负荷状态下，污泥有机负荷为0.288g(COD)/[g(MLSS)·d]时，其静态模拟生化反应过程如下：在厌氧区段内(A_1)，聚磷菌利用易降解有机物进行快速的厌氧释磷，在厌氧反应结束时释磷量达14.0mg/L；转入缺氧区段(A_2)后，同样由于污泥回流及好氧混合液回流的稀释作用，Orth－P下降到14.5mg/L，在污泥回流及好氧混合液回流所携带的NO_3^--N进行反硝化反应的同时，聚磷菌利用NO_3^--N作为电子受体进行缓慢的吸磷反应，当NO_3^--N降低到一定程度时，聚磷菌又出现少量的释磷反应，在缺氧结束时NO_3^--N通过反硝化完全被去除掉；转入好氧区段(O)后，在有机物氧化的同时进行硝化反应，NH_3-N浓度迅速下降，NO_3^--N浓度不断上升。Orth-P在好氧区段内的变化过程表明，聚磷菌在好氧反应初期进行快速吸磷反应，但随好氧反应时间的延长，聚磷菌吸磷速率不断下降，至好氧反应末段吸磷现象几乎停止，好氧反应结束时最终出水Orth-P含量为2.4mg/L。反应过程说明在此负荷条件下，聚磷菌具备良好的除磷能力。

生产性试验与静态模型对比试验结果表明，在其它工艺运行参数不变的情况下，处理系统负荷的变化对除磷能力产生不利影响，长期低负荷运行是导致处理系统生物除磷能力下降的根本原因。在生物除磷生化反应过程中，聚磷菌微生物在厌氧条件下利用细胞内储存的聚磷和糖原，通过分解代谢产生的能量和还原动力，用于细胞外挥发性脂肪酸(VFAs)的吸收与聚β-羟基丁酸(PHB)等的合成，并将其储存在细胞内。在缺氧或好氧条件下，聚磷菌微生物细胞内储存的PHB，除了通过氧化过程产生能量用于细胞外磷的吸收及在体内poly-P的合成外，同时还用于聚磷菌微生物自身的生长、细胞内糖原的合成，及维持微生物正常的新陈代谢。低负荷运行导致的好氧延时曝气，造成聚磷菌微生物细胞内PHB的过度消耗，其绝大部分用于维持微生物自身的新陈代谢，由此导致细胞内糖原合成的减少及好氧吸磷能力与细胞内poly-P含量的下降，甚至利用细胞内糖原以维持微生物自身的新陈代谢。在此情况下，聚磷菌微生物由于细胞内糖原与聚磷含量的减少，进而影响厌氧过程中磷的释放、VFAs的吸收及PHB的合成。如此周而复始，使处理系统内聚磷菌微生物细胞内储存物质(聚磷、糖原、PHB)数量降低，最终导致处理系统生物除磷能力丧失。有研究表明[3-5]，在生物除磷过程中，聚磷菌微生物在好氧条件下的吸磷速率和吸磷量均受细胞内PHB的含量影响，细胞内PHB含量减少将导致磷吸收速率和吸磷量的下降，甚至无法有效的吸收细胞外的磷酸盐在细胞内合成聚磷。Temmink等人[6]对细胞内PHB的含量与磷吸收速率的关系研究表明，生物降磷能力的下降不仅与较低的磷吸收速率有关，而且与好氧下PHB的消耗有关。Brdjanovic等人[7]

的研究也表明，好氧条件下磷吸收不仅取决于细胞内PHB的含量，而且取决于细胞内最大的聚磷储存能力。

4　结语

生产性试验与静态模型试验结果表明，长期低负荷运行是导致生物除磷效率下降的主要原因。低负荷运行导致的好氧延时曝气使细胞内的储存物质(PHB、糖原、聚磷)含量下降，最终导致生物除磷能力丧失。当处理系统负荷过低时，可以通过调节处理系统的反应容积，来保证生物脱氮除磷所需的正常负荷。此外，还可对城市污水处理厂的生化反应处理系统好氧区的曝气进行适当控制。这样不仅可以节省能量、降低运行费用，而且进一步保证生物处理系统运行的稳定性，提高生物除磷的效率。

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上海市党政主要领导考察上海水环境治理与保护工作

1月24日，上海市委书记黄菊、代市长陈良宇、副市长韩正以及市政府各委、办、局领导在现场视察了苏州河综合整治工作后，来到市环保局听取苏州河环境综合整治1期工程建设情况以及上海市水环境治理与保护规划汇报。黄菊同志指出，环境保护是上海可持续发展的关键，水环境治理是生态环境建设的重要内容，治水的关键是治污，治污的代表是苏州河。上海历届市委、市政府一直十分重视对苏州河的治理，第1阶段的整治是干流治黑臭、两岸治脏乱，到今年底可基本完成，取得阶段性成果；第2阶段要进一步改善苏州河水质，按照规划进行两岸开发建设。黄菊同志强调，要高度认识苏州河综合治理的意义，把苏州河治理好是全市人民的夙愿，是一项实事工程、民心工程。苏州河综合整治仍是上海进入新世纪进行环境建设的一项重要任务，它对进一步塑造上海城市形象具有重要意义，把苏州河治理好了，黄浦江水质才有可能改善。一定要积极拓展思路，与时俱进，知难而上，真抓实干，在新世纪再实施3个“三年行动计划”，让苏州河水质稳定下来，造福于民。当前苏州河整治工作要处理好3个关系：一是治理与开发的关系。把重点放在治理上，治理是为了改善环境、提升城市形象，促进上海城市综合功能的开发，开发是为了进一步深化治理，巩固治理的成果。二是开发与保护的关系。开发是要转换苏州河沿岸的功能，保护是要有重点地突出苏州河生气勃勃的历史文化内涵，对苏州河沿岸有历史文化内涵和特点的建筑精品进行重点保护；三是整体与局部的关系。一方面要全市一盘棋，深化苏州河的环境综合治理，同时又要发挥各区开发建设的积极性。

陈良宇同志指出，经过有关各方的共同努力，苏州河环境综合整治1期工程已取得阶段性成果，但要看到稳定改善苏州河干流水质，治理水系内支流污染和两岸环境依然任重道远。今年，要集中力量，确保全面实现苏州河整治1期工程目标。在此基础上，再接再厉，坚持以治水为中心，规划好苏州河环境综合整治2期工程。要充分重视巩固治理成果，深化整治工作。针对春秋时节苏州河水面出现浮萍和水葫芦等新情况，要采取切实有效措施，防止和解决水面污染问题。要结合治水治污、陆域整治工作，进一步推进苏州河两岸的开发建设，为人民群众提供更加优美的城市生活环境。

(本刊记者　**魏正明**)

ment with the theoretical model developed.

Key words: Ozone Hydrogen peroxide
Hydroxyl radical
Advanced oxidation process
o-Nitrotoluene

Comparison of Membrane Fouling between Direct Ultrafiltration and Coagulation Ultrafiltration

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Using Theoretical membrane fouling model—pore narrowing model and cake filtration model to analyze the experimental results of ultrafiltration with and without coagulation pretreatment on removing natural organic matter. It showed that the natural organic molecules agglomerated to form micro-flocs by pre-coagulation could avoid membrane pore fouling and reduce resistance of cake layer on the membrane surface. In companison with direct ultrafiltration and pretreatment with aluminum sulfate coagulant did improve removal of COD and UV254 from 28% and 40% to 53% and 78% respectively.

Key words: Pore narrowing model
Cake filtration model
Micro-flocs
Direct ultrafiltration
Coagulation ultrafiltration
Comparative experiment

A Novel Multi-layer Structure Solar Photocatalytic Reactor Connected with Aeration Web

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A novel shallow-gutter photocatalytic reactor packed with loaded photocatalyst has been designed. Methylene blue was used as simulated pollutant to evaluate the efficiency of the reactor. The experimental result showed that the stainless steel aeration web realized high effective with no dynamic aeration, and a stagger baffle arranged in the gutter could improve the photocatalytic efficiency significantly. The loaded TiO_2 photocatalyst attached on glass spring could enhance the transfer effect. The reactor could utilize direct and scattering ultraviolet light in sunlight sufficiently, and also work well on cloudy day.

Key words: TiO_2 Methylene blue Glass spring carrier
Solar photocatatytic reactor
Dcolorizing rate

Removal of Heavy Metal from Aqueous Solution by *Aspergillus sp*

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The biomass of *Aspergillus so jae* M146 and *Aspergillus oryzae* M149 is an effective agent for heavy metal removal. The effects of pH, temperature, equilibration time and pre-treatment reagents on the removal of Pb (II),Cd(II)from aqueous solutions by *Aspergillus sojae* M146 and *Aspergillus oryzae* M149 have been studied. The optimal conditions for both heavy metal removal were pH 5.5, equilibration temperature 30℃ and equilibration time 1 hour with 69.76% Pb(II) and 72.28% Cd(II) being removed by *Aspergillus so jae* M146 and 60. 64% Pb(II) and 81.34% Cd(II) by *Aspergillus oryzae* M149. Chemical treatment of cultivated fungal biomass (0.1mol/L NaOH, 0.1mol/L HCl, 30% ethanol and distilled water) affected the efficiency of metal removal by *Aspergillus so jae* M146 and *Aspergillus oryzae* M149. Pretreatment of biomass by NaOH enhanced Cd(II) and Pb(II) removal, while pretreatment by HCl, ethanol and distilled water reduced Cd(II) and Pb(II) removal. Once heavy metals were accumulated in the fungal biomass, the release back to the aqueous solutions was efficient (>80%) when the loaded-biomass was treated with 0.1mol/L Na_2CO_3 or 0.1mol/L EDTA indicating the potential for regeneration and reuse of the microbial biomass for further heavy metal removal.

Key words: Electro-plating wastewater
Heavy metal
Aspergillus sp.
Adsorption
Desorption
Mining wastewater
Removing efficiency

Impact of Loading on Biological Phosphorus Removal from Municipal Sewage

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Aimed at the status of long-time operation under

low loading in the municipal sewage treatment plant, the full-scale and static-model tests have been investigated. The test results showed that the deterioration of biological phosphorus removal has been attributed to long-time operation under low loading, which led to the depletion of the deposited substrates(PHB, Glycogen、poly-P) in the cell of bio-P and the deterioration of biological phosphorus removal capacity. In order to keep the efficiency of P-removal in the biological nitrogen and phosphorus removal system, an adequate and flexible controlling volume of biochemical reactor and the aeration in the aerobic have been done,which will control the treatment system in compatible range.

Key words: Municipal sewage
Sewage treatment plant
Low loading
Operational status
Biological phosphorus removal
Phosphorus removal efficiency

Application of Index Computing Method to Environmental Economic Cost-Benefit Analysis

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In this paper selecting Jiangqiao domestic refuse incineration plant and Zhabei domestic refuse incineration plant in Shanghai as examples, analyzing and studying the environmental economic cost-benefit in different areas by adopting index computing method. Static analysis results showed that the annual net benefit of environmental protection of Jinangqiao domestic refuse incineration plant was 6,706,900 yuan (RMB) and the benefit-cost ratio was 1.10.The annual net benefit of environmental protection of Zhabei domestic refuse incineration plant was -7,644,800 yuan (RMB) and the benefit-cost ratio was 0.64, which indicated that the construction investment of the project is unreasonable from the view of environmental economy. According to the assessment results mentioned above, Jiangqiao domestic refuse incineration plant was being constructed. Index computing method provided money quantification base for environmental economic cost-benefit analysis of these two domestic refuse incineration plants.

Key words: Environmental economic cost-benefit
Index computing method
Annual net benefit of environmental protection
Cost-benefit ratio

Approach on Sustainable Development of Eco-polis Planning

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Description on the concept of eco-polis and measuring index from ecological stand point of view, and taking eco-polis as goal to introduce sustainable development eco-planning thought, concerning city life supporting system, resident environment, eco-industry and environmental education etc. were presented.

Key words: Eco-polis Eco-planning
Sustainable development
Measuring index

Study on Water Pollution Control Planning in Huaian City

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Serious water pollution in Huaian city has already threatened the water quality of local water supply and the project of diverting water from south to north according to the situation of water pollution, a new strategy of water pollution control has been put forward, including controlling sources and diverting flow, controlling water quality corresponding to grade 3 standard etc. Based on the strategy, the control planning of water pollution in Huaian city will be consisted of controlling pollution sources, concentrated treatment of sewage and disposal of transfered treated sewage. The southern channel of water transfering channels of River Huaihe to Yellow Sea will be proposed to utilize as drainage passage and river stable pond of polluted water.

Finally, the framework of ecological engineering, transfering scheme of primary treated sewage and water quality analogy of sewerage system were also discussed.

Key words: Water pollution control planning
Divert polluted water from fresh water
Treated water
River stable pond
Huaian City