光合细菌接触氧化工艺的研究

史家樑　徐亚同　　孙珍娣*
（华东师范大学环科系）　（上海同兴袜厂）

一、前　言

光合细菌法（简称 PSB 法）具有负荷高、效果好、占地省等优点，菌体污泥又有很高的营养价值，可以回收利用。因此这是近年来引人注目的一种废水资源化及综合利用的新技术。有不少排出高浓度有机废水的工厂，地处人口稠密的闹市区，场地狭窄，一般的生物处理方法难以使用，甚至普通的 PSB 法也不易胜任。为此，我们进行了 PSB 接触氧化工艺处理高浓度有机废水的研究。试验结果表明，该工艺的容积负荷与处理效果均大大优于 PSB 悬浮污泥工艺。

二、PSB 法处理高浓度有机废水的原理

60 年代末，日本学者观察到自然放置的高浓度有机污水通过微生物的生态演替而被逐渐净化。例如，当 BOD 为 10000mg/L 以上的粪便污水自然放置时，首先看到异养细菌的大量生长。异养细菌把高分子的碳水化合物、脂肪、蛋白质等分解成低级脂肪酸、氨基酸等低分子物质。接着，光合细菌群利用低级脂肪酸等小分子有机物而迅速增殖，使污水 BOD 降到 1000 mg/L 以下，甚至低至 300 mg/L 左右。随后 PSB 逐渐减少，出现了藻类及其他好氧微生物的生长高峰，使 BOD 进一步降到每升数十毫克。这表明光合细菌在自然界被高浓度有机物污染水体的生物自净作用中占有十分重要的地位，这是发生于该过程中微生物生态演替变化的关键环节。

目前用于有机废水处理的 PSB 主要是红螺菌科（Rhodospirillaceae）的细菌群，通称红色非硫细菌。这一类 PSB 不仅能在厌氧光照下以低级脂肪酸、多种二羧酸、醇类、糖类、芳香族化合物等低分子有机物作为电子供体，进行光能异养生长，而且能在好氧黑暗条件下以有机物为呼吸基质，进行好气异养生长。因此，这类 PSB 既不象好氧的活性污泥菌胶团细菌那样受污水中溶解氧浓度的限制，它可以利用光能进行高效的能量代谢，即使是微弱的光照也能利用。它又不象严格厌氧的甲烷细菌等对氧的存在非常敏感，恰恰相反，它可在有氧条件下分解有机物，通过氧化磷酸化取得能量。

PSB 适合于高浓度有机污水处理还有一个重要原因，这就是许多高浓度有机污水中的 BOD 物质在生物降解的第一阶段，常有大量低级脂肪酸产生，其中浓度较高的乙酸、丙酸对许多好氧微生物有抑制作用，而红螺菌科中的许多属种，如 *Rhodobacter sphaeroides*（原称 *Rhodopseudomonas sphaeroides*，球形红假单胞菌）却能在高浓度的乙酸与丙酸以 5 比 1 共存时，具有最大的增殖速率。

PSB 法正是基于上述原理而建立的一个高浓度有机废水处理的人工生态系统。在这系统中各类微生物在不同的阶段最有效地发

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* 参加本试验的尚有同兴袜厂污水组全体同志。

挥着作用，从而使高浓度有机废水能不加稀释而高效率地得到净化。

三、试验材料与方法

1. 废水来源

试验用废水取自上海南市豆制品厂豆制品加工工艺产生的黄浊水，经分析水质如下：

COD_{cr}：22863 mg/L（17,107 ～ 32,340 mg/L）；

BOD_5：13868 mg/L（10,560 ～ 15,653 mg/L）；

总氮：766 mg/L（平均）；

氨氮：68 mg/L（平均）。

2. 试验装置为 A、B 两级串联的上流式接触氧化塔模型试验器。A、B 塔有效容积均为 17L。塔内装有软性纤维填料，塔底部设有曝气管。在盛有可溶化豆制品废水的塔内，以 PSB 及活性污泥混合液接种，闷曝一天后按设定流量进水，经 7—10 d 即挂膜于填料上。

3. 黄浊水经 20 h 曝气可溶化及 4 h 静止沉淀后，取上清液作为进水，流量由计量泵控制 17 L/d，即 A 塔水力停留时间为 24 h，A、B 串联为 48 h。

4. 每天测定原废水、可溶化水及 A、B 塔出水的 COD_{cr}、BOD_5、TVA、T-N、NH_3-N，观察 A、B 塔悬液及填料上 PSB 污泥的生物相。

5. 处理系统中 PSB 优势度检测：PSB 的数量检测采用 MPN（最大可能数）3 管法，异养细菌的检测计数采用标准平板法。

6. COD_{Mn} 的测定：取废水接种少量污泥，连续曝气 30 d，测定起始时及 30 d 后水样的 COD_{cr} 值。

7. 在 B 塔后连接一活性污泥曝气槽模型，容积 6 L，采用批式工艺运行，换水量 12 L/d。

PSB 接触氧化工艺的试验流程见图 1。

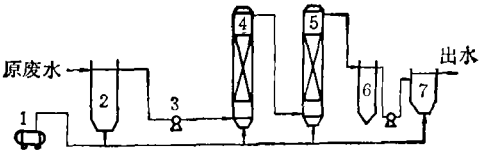

图 1　PSB 接触氧化工艺试验流程

1. 空压机　2. 可溶化槽　3. 水泵　4、5. PSB 接触氧化塔 A、B　6. 沉淀槽　7. 批式活性污泥槽

四、结果与讨论

1. PSB 接触氧化反应器对豆制品废水中的 COD、BOD 有很高的去除效果（见表 1，图 2）。

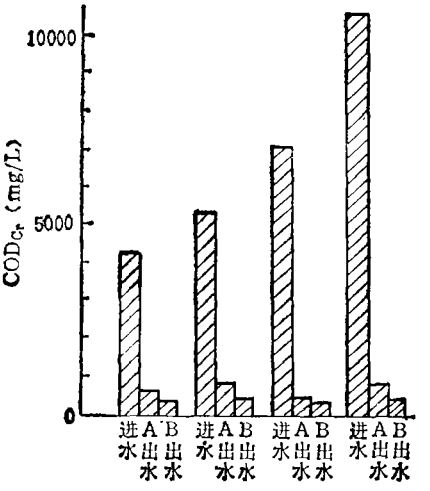

图 2　不同浓度的进水在 PSB 接触氧化反应器中的处理效果

当进水 COD_{cr} 为 10500 mg/L（BOD_5 6000 mg/L）时，A 塔容积负荷为 10.48 kg $COD_{cr}/m^3 \cdot d$（6kg $BOD_5/m^3 \cdot d$），A 塔出水 COD_{cr} 836 mg/L，（BOD_5 148 mg/L），A 塔 COD_{cr} 去除率为 92%（BOD_5 去除率 97.5%）；A + B 塔的容积负荷为 5.24 kg $COD_{cr}/m^3 \cdot d$（3 kg $BOD_5/m^3 \cdot d$），A + B 塔出水为 COD_{cr} 395 mg/L，BOD_5 38.7 mg/L，A + B 塔 COD_{cr} 去除率为 96.2%，BOD_5 去除率为 99.4%。与悬浮污泥 PSB 法相比，不仅容积负荷高，而且处理效果更好。

2. 在试验所做的范围内，COD_{cr} 去除率

表 1 PSB 接触氧化反应器对豆制品废水 COD BOD 的去除效果

	原废水 (mg/L)	可溶化水 (mg/L)	稀释倍数	进水浓度 (mg/L)	A塔出水 (mg/L)	去除率 (%)	A + B塔出水 (mg/L)	去除率 (%)
COD_{cr} 去除效果	22,863	20950	5	4,190	579.1	86.2	335	95
			4	5,237.5	806.6	84.6	411.8	92.1
			3	6,984	417.6	94	306.1	95.6
			2	10,476.5	836	92	395	96.2
BOD_5 去除效果	13,868	12009.4	3	4,003.1	73.8	98.2	30	99.3
			2	6,004.7	148	97.5	38.7	99.4

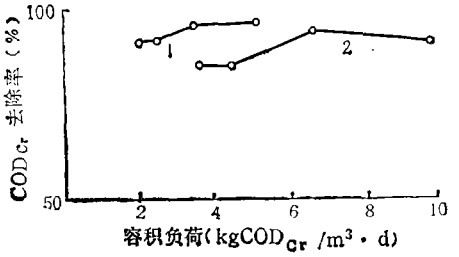

图 3 容积负荷与 COD_{cr} 去除率的关系

1. A + B 塔 2. A 塔

随负荷增加而上升，并保持在高水平（见图 3）。

当 A + B 塔的容积负荷从 2.10 kg $COD_{cr}/m^3 \cdot d$ 增加到 5.24 kg $COD_{cr}/m^3 \cdot d$ 时，COD_{cr} 去除率由 92% 提高到 96.2%。就 A 塔来看，容积负荷为 6.98 kg $COD_{cr}/m^3 \cdot d$ 时 COD_{cr} 去除率高达 94%，当负荷上升到 10.48 kg $COD_{cr}/m^3 \cdot d$ 时，COD_{cr} 去除率仍有 92%。显示了 PSB 法适合于高负荷处理的特点。

3. PSB 在处理系统中的数量与优势度。

当进水浓度为 COD_{cr} 10,500 mg/L (BOD_5, 6,000 mg/L) 时，PSB 接触氧化反应器中 PSB 及异养细菌的数量分布如表 2 所示。

结果表明，原废水及可溶化水中 PSB 数量很少，甚至少到检测不出的程度，而异养细菌数量均达 10^8 个/g MLSS; A、B 两塔中 PSB 数量多，A 塔中的 PSB 数量又明显地多于 B 塔。A 塔悬液中的 PSB 数达 8.2×10^8 个/g MLSS，为 B 塔悬液中 PSB 数量的 55 倍。若从 PSB 与异养细菌的数量比来看，A 塔悬液中为 1/21，B 塔悬液仅 1/1027。生物膜上的 PSB 数，无论是上层、中层或下层，也是 A 塔多于 B 塔，大体上前者比后者高一个数量级。PSB 在反应器中的数量分布显然与系统中有机物浓度由高到低的变化相对应。PSB 在 A 塔中的明显优势，正是 A 塔中高负荷、高效率地去除 BOD 的必要条件。

表 2 PSB 接触氧化反应器中细菌数量的分析

样品	异养细菌数(平板法)[个/g MLSS (生物膜)]	光合细菌数(MPN法)[个/g MLSS (生物膜)]
原废水	4.8×10^5	(未检出)
可溶化水	16.3×10^8	(未检出)
A 塔悬液	17.5×10^9	8.2×10^8
A 塔上层膜	5.5×10^9	6.2×10^7
A 塔中层膜	9.2×10^9	3.0×10^9
A 塔下层膜	10.2×10^8	18.8×10^8
B 塔悬液	15.2×10^7	14.8×10^6
B 塔上层膜	8.2×10^9	6.0×10^9
B 塔中、下层膜	2.6×10^9	14.5×10^7

4. 集 PSB 法悬浮污泥工艺和普通生物膜法接触氧化工艺的优点于一体的“PSB 接触氧化工艺”，可望在以下几方面显示其优越性：

(1) 接触氧化填料提供了有利于光合细菌等各类微生物生长的吸附和附着的表面，从而大大增加了反应器中的生物量和生长活性。

(3) 在反应器的不同层次、不同部位，能

有效地富集适合于该微环境的微生物群，形成与高浓度有机废水降解过程相应的微生物生态演替系列，以使生物降解更高效率地进行。

(3) 已知亚硝化细菌和硝化细菌都是高度好氧的化能自养细菌，它们的比增殖速度很小，在活性污泥中较易流失，而在生物膜法中这类硝化细菌常能得到良好的发育。在 PSB 接触氧化反应器的进水端，由于 BOD 高、溶氧水平低，往往不具备硝化细菌发育的条件，但在两塔的出水端 BOD 已降得很低，溶氧水平也大大提高。因此，在反应器的近出口端，氨态氮完全可能被进一步氧化而生成相当数量的硝酸态氮。加之生物膜内部存在缺氧或厌氧的微环境，具有反硝化脱氮活性的 PSB 将能充分地发挥其脱氮能力，而使处理系统有更显著的除氮效果。

(4) 塔形的接触氧化反应器，将使氧的利用率有所提高。

(5) 处理装置将更紧凑，占地更少。

5. COD_{cr} 为 22,816 mg/L 的原废水测得的 COD_{cr} 为 727 mg/L，去除率约 96.8%。这一结果表明，尽管豆制品废水的可生化性相当好，但因有机物浓度高，其中难以生物降解的部分 (COD_{NB}) 之绝对值却不可低估。为此，我们进一步分析了处理过程中各阶段废水的 BOD_5 与 COD_{cr} 之比 (见表 3)。数据表明，黄泔水在生物处理过程中，随着废水浓度的降低，废水中难以生物降解的有机物比例逐渐增加。B 塔出水 (COD_{cr} 400—500 mg/L) 经后继的好氧活性污泥工艺处理，COD_{cr} 去除率仅 12% 左右。

表 3　PSB 处理过程中 BOD 与 COD 比值变化

	BOD_5/COD_{cr}
黄泔水	0.607
可溶化水	0.573
A 塔出水	0.177
A + B 塔出水	0.098

从以上分析可知，要使最终出水 COD_{cr} 达到 100 mg/L 以下的排放标准，必须设法提高 PSB 出水中可生化部分的比例。一个比较简便的措施就是把厂内的淡有机废水 (COD_{cr} 一般为 400—500 mg/L，水量约为浓废水的 4 倍以上)与 PSB 出水相混和，一起进行好氧处理，最终出水可达排放标准。这样，把浓废水先进行 PSB 处理，后加入淡废水作一般好氧处理，比一开始就浓淡混和处理要少占地、省投资、省成本，而且效果好、效率高。若出水可纳入城市下水道或纳入如上海的污水外排管道系统，则 PSB 段的出水一般都可符合接管要求，不必再作进一步处理。如能这样，PSB 法的效益将更显著。

本试验主要考察了 PSB 接触氧化工艺对高浓度有机废水的 BOD、COD 去除效果，以及 PSB 在系统中的优势度，并就 PSB 出水 COD_{cr} 达标的方法及原理作了探讨。有关其他诸因素对该工艺处理效果的影响等问题有待进一步研究阐明。

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Abstracts

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Research on Transport and Transformation of Contaminants in the Unsaturated Vadose Water Zone

Nie Yongfeng, Liu Zhaochang and Li Yadong (Dept. of Environmental Engineering, Tsinghua University, Beijing)

The potential impact of contaminants on groundwater through transporting in unsaturated vadose zone was studied in this paper. By means of theoretical analysis, the methematical functions of convection, dispersion and adsorption-desorption processes of pollutants were touched. The main attention was paid to the permeability of tilling layer, plough pan and lower aeration zone. The plough pan was refered to the controlling layer of water permeation in terms of the measurement results of samples. The soil-water characteristic curves of three typical soils (fine silt, silt and very fine sand) were made out. The parameters for unsaturated hydraulic conductivity of loam was obtained through curve fitting. Compared with that of foreign scholars. The results were considered practicable. Furthermore, the transport and transformation of pollutants presented by tritium (tritiated water) were researched in an unsaturated column. (See pp. 2—6).

Cytogenetic Toxicity of Mercuric Chloride on Human Lymphocytes and Preventive Effect of Selenite

Meng Ziqiang and Zhang Lianzhen (Dept. of Environmental Sciences, Shanxi University, Taiyuan)

The protective effects of sodium selenite (Na_2SeO_3) against the cytogenetic toxicity of mercuric chloride ($HgCl_2$) were investigated on human whole-blood cultures in relation to induction of sister-chromatid exchanges (SCE) and delay of cell cycle. Mercuric chloride caused a dose-dependent increase in SCE and delay of cell cycle. It strongly affected the ability of human lymphocytes to divide in vitro, the number of cells dividing 3 times within 72 hours in culture was strongly decreased. Sodium selenite also induced SCE, but had only a smaller effects at the low concentration (3×10^{-6} mol/L) than mercuric chloride. SCE frequency increased significantly in culture only containing mercuric chloride of 1×10^{-5}mol/L and cell toxicity appeared in culture only at the concentration of sodium selenite of 1×10^{-5}mol/L. Beyond the limits, cell growth stopped. However, when selenite (3×10^{-7}—1×10^{-5}mol/L) was added simultaneously to cell cultures containing mercuric chloride (1×10^{-5} mol/L), induction of SCE was prevented and the cell cycle was delayed. There existed a clear doserelated manner. When selenite and mercuric chloride were simultaneously added at a molar ratio of Na_2SeO_3: $HgCl_2$ = 1:1, cells in treated cultures showed no increase in the SCE frequency and no delay in cell cycle time. These results indicate that selenite and mercury mutually antagonize the ability to cause DNA damage leading to the formation of SCE and the delay of cell cycle. (See pp. 7—9)

A Preliminary Study on the Characteristics of Bioparticles in Anaerobic Attached Film Expanded Bed (AAFEB) Reactor

Xu Xianyang, Zheng Ping, Feng Xiaoshan (Environmental Science Department, Zhejing Agricultural University, Hangshou)

The characteristics of bioparticles in AAFEB reactor with continuous steady state operation has been studied in this paper. The biological mechanism for high efficiency operating performances of AAFEB reactor with steady state from these respects as follow: sludge retention time (SRT), microbial compositions (methanogens) in biofilm, change and distribution features of acid producing activity, methane producing activity and coenzyme F_{420} contents of bioparticle, which obtained from various sampling spots of AAFEB reactor during operation. Meanwhile, it is also showed that substrate transfer resistance exists in bioparticles or biofilm, and becomes of significance at low substrate concentration and in thick biofilm. (See pp. 10—15)

A Study on Photosynthetic Bacteria (PSB) Contact-Oxydation Process

Shi Jialiang and Xu Yatong (Department of Environmental Science, East China Normal University, Shanghai); *Sun Zhendi* (Tong Xing Hosiery Manufactory, Shanghai)

Treating bean-food wastewater by using PSB contact-oxydation process has been made in order to purify high concentration organic wastewater under the conditions of limited space. Upflow contact oxidation reactor with two stages has been adopted. Under the following conditions: influence COD_{Cr} reaches 10500mg/L(BOD_5 6000mg/L), container A volume load 10.48kg $COD_{Cr}/M^3\cdot$day (6kg $BOD_5/M^3\cdot$day), container A effluent-COD_{Cr} reaches 830mg/L(BOD_5 148mg/L), percentage of COD_{Cr} removal 92%(BOD_5 removal percentage 97.5%). Under the conditions: container A + B volume load reaches 5.24kg $COD_{Cr}/M^3\cdot$day (3kg $BOD_5/M^3\cdot$day), effluent container A + B reaches 395mg/L(BOD_5, 38.7mg/L), percentage of COD_{Cr} removal 96.2%(BOD_5 removal percentage 99.4%).

The quantity of PSB measured and the ratio of PSB/heterotrophic bacteria in container A, which bears high load, is larger than that in container B. This illustrates

that PSB is suitable to high load treatment. In this investigation, the principle and method for treating effluence of PSB stage has been considered. (See pp. 16—19).

Major Bacterial Populations and Their Function in Printing-Dyeing Wastewater Treatment System

Zhang E and Sheng Lingling (Yunnan Institute of Microbiology, Kunming)

This paper deals with an investigation of the bacteria populations which were isolated from activated sludge from wastewater of the Yunnan Printing-Dyeing Mill and had the function of purifying wastewater. 75 strains of bacteria, 5 strains of actinomyces and 2 strains of fungi were isolated, and identified to genus, 14 genera in total, among which some strains of *Pseudomonas, Zoogloca* and *Flavobacterium* were predominent. C_{28} (*Proteus* sp.) has strongly decolorizing effect on the wastewater containing azo dyes, when it is used simultaneously with activated sludge, decolorizing rate can reach above 90%.
(See pp. 20—24)

Effects of Simulated Acid Rain on Growth of Tomato (*Lycopersicon esculentum*)

Chen Yugu et al. (Chengdu Institute of Biology, Academia Sinica, Chengdu, Sichuan Province)

Results of the experiment showed that growth of tomato (*Lycopersicum esculentum*) could be affected by simulated acid rain in two soils (fluviogonic soil and acid yellow soil). The pH values of the simulated acid rain were 4.5, 3.5, 2.5 and 5.6 (ck) respectively. There appeared visible injurious symptoms (chlorosis and necroses) on the leaves of tomato after the simulated rain of pH 2.5 was sprayed. However, at pH 4.5, the symptoms were slight. Owing to increases of acidity of 4.5, 3.5 and 2.5, the fresh of tomato fruit weighed decreasingly by 13.8% 34% and 38.2% in fluviogonic soil respectively and 3.5% (pH 4.5) and 28.8% (pH 2.5) in acid yellow soil.
(See pp. 24—28)

Accumulation and Depletion of the Pesticide *Fenitrothion* in Fish Sampled from Paddy Field

Lou Genlin, Zhang Zhongjun et al. (Institute of Plant Protection, Sichuan Academy of Agiculture, Chengdu)

The behavior of *fenitrothion* in the aquatic ecosystem of paddy field was presented in this paper. Field experiment was performed during 1986—1987 near Chengdu City. The results showed that the pesticide was absorbed moderately by fish in 24 hours and decreased rapidly after one day. Half-life (HF_{50}) of it was about two days. Residue of *fenitrothion* in fish viscera was more than in fish meat. The pesticide residue in fish will thus be depleted as the polluted fish is short-termly cultured in clean water. (See pp. 28—33)

A Research on the Discharge Standard of Maximum Permissible Concentration of Cadmium in Shanghai Sewerage System

Chen Boqi (Shanghai Municipal Centre of Environmental Monitoring, Shanghai)

By simulated tests of activated sludge process with toxicant cadmium (Cd) in the laboratory, the results showed that to a certain concentration of Cd, biological treatment of wastewater was gradually depressed as its concentrations increased. Cd residue in effluent increased as its concentretion in influent got high, and decreased as sustained time of sludge increased. Cd concentration in mixed liquid hadnot a tangible impact on sludge in second sedimentation tank. Based on the results, the author offered a proposal for reviewing the discharge standard of maximum permissible concentration of Cd in Shanghai sewerage system (See pp. 33—37)

Studies on Treatment of *Beiyin* Smelter Process Effluent and Its Utilization

Ni Dong (Beijing Design-Research Institute of Nonferrous Metallurgy, Beijing)

Beiyin Smelter is a large-scale copper smelter built in early 1950s. The metallurgical gas from the Smelter is utilized to produce sulphuric acid and other products. The waste process effluents contain a lot of acid, arsenic, copper bismuth, lead, selenium and mercury etc, which are mainly concentrated in the effluents obtained from scrubbing of acidmaking gas. The acidic effluent with a high content of arsenic and copper is not only very harmful to the lower reaches of the river, but also causes big loss of valuable material.

It is showed through studies that the sulphide agent (sodium sulfhydrate and sodium sulphide solution of S^{2+}-containing waste solution), in the presence of acid, can be directly added to precipitate mercury, copper and arsenic in the form of sulfides for recovery, also the impurities, such as lead and dust etc in the acidic effluents are settled down efficiently, so that the acidic effluents after treated, can be utilized too, for instance, for making phosphate fertilizer.

It is indicated that by use of the multi-stage sulfidization process, copper and arsenic etc could be seperated from the precipitate for recovery or storage. By adoption of a new equipment for sulfidizing and mixing reaction