厌氧颗粒污泥对五氯苯酚的吸附、解吸和生物降解研究*

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摘要　在以氯苯酚驯化污泥接种的上流式厌氧反应器中可形成降解PCP的厌氧颗粒污泥。在HRT20—22 h、PCP负荷率200—220 mg/(L·d)时，该反应器可有效地处理含PCP170— 180 mg/L的废水，PCP去除率大于99.5%。PCP在厌氧颗粒污泥上的吸附和解吸均符合Freundlich等温方程，吸附是部分不可逆的，该方程可较好地描述厌氧反应器内颗粒污泥对PCP的吸附量的变化规律。试验表明厌氧颗粒污泥去除PCP的主要机制是生物降解，而非吸附和挥发作用。

关键词　五氯苯酚，生物降解，生物吸附，解吸，挥发，厌氧，颗粒污泥。

以往有关氯苯酚生物降解的研究大多是在长期的、密闭的、低生物量和低浓度目标化合物为唯一碳源的血清瓶内进行的，对生物吸附在降低水相中目标化合物的作用方面考虑甚少[1—3]。而在废水生物处理系统中，因生物量大，生物吸附很可能在影响这些化合物的归趋方面有重要作用[4—6]，针对现有些研究虽已注意到了生物吸附作用，但无法把生物吸附和生物降解区分开来，本研究选择了以五氯苯酚(PCP)为研究对象，在成功培养出降解PCP的厌氧颗粒污泥基础上，研究了PCP在厌氧颗粒污泥上的吸附、解吸动力学及上流式厌氧消化反应器(UAD)处理含PCP废水的效能。

1　实验材料和方法

1.1　氯酚的来源

PCP由青浦新产品研究所生产，含量98.5%；对氯酚(4-CP)由上海化学试剂三厂生产，含量96.0%；间氯酚(3-CP)来自Fluka AG. Chem. Fabrik CH-9470 Buchs，含量96.0%；邻氯酚(2-CP)由上海来泽精细化学品研究所出品，含量95%—98%。

1.2　厌氧污泥来源

取自浙江杭州柠檬酸厂废水厌氧消化处理站的污泥。在实验室内分别经PCP、4-CP、3-CP、2-CP驯化6个月后作为试验反应器的接种污泥(驯化方法及效果见另文)；另取未驯化的上述污泥接种反应器作为对照。

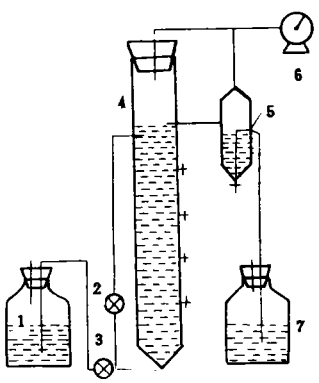

图1　试验装置和工艺流程示意图

1. 进水贮瓶　2. 回流泵　3. 进水泵　4. UAD反应器　5. 三相分离器　6. 气体流量计　7. 出水贮瓶

1.3　仪器、装置和供试废水水质

(1) 仪器　Waters高效液相色谱仪，回转

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式摇床，Finnigan Mat. 4510色质联用分析仪。

(2) 试验反应器及接种　图1为本试验所采用的上流式厌氧消化反应器(UAD)及其工艺流程示意图，反应器置于28±1℃的定温室内，容积及接种污泥组成和接种量见表1。

表1　试验反应器容积及接种污泥组成[1)]

反应器	总容积 (ml)	有效容积 (ml)	接种量 (g·TVS)
1	1140	866	20.1
2	1120	865	20.1

1)　1号反应器为经 PCP 驯化6个月的柠檬酸厂厌氧污泥
2号为分别经 PCP、4-CP、3-CP、2-CP 驯化6个月的柠檬酸厂厌氧污泥以1∶1∶1∶1混合

(3) 供试废水水质　为稳定进水，试验采用模拟废水，其组成见表2，PCP 配成10 g/L 的母液，在使用时按需要稀释。

1.4　试验反应器的起动和运行

由于厌氧絮状污泥经驯化后，均呈悬浮状态，沉降性极差，故本试验先进行分批进料并全封闭式回流循环运行，待基质去除率达80%以上，污泥沉降性明显改善时，开始小流量连续进入废水，并根据出水 PCP 和 COD 浓度及产气情况，及时地递增水力负荷、有机质负荷和 PCP 负荷，缩短 HRT，以加速反应器的起动和降解 PCP 的厌氧颗粒污泥的形成进程。

1.5　供试非降解 PCP 厌氧颗粒污泥的培养

表2　模拟废水的组分及其含量

组分	蔗糖	酵母膏	NH_4Cl	KH_2PO_4	$K_2HPO_4·3H_2O$	$NaHCO_3$
含量(g/L)	27.5	0.3	7.3	2.5	1.3	33.0

以杭州柠檬酸厂废水处理站的厌氧污泥为种泥，以不含 PCP 的模拟废水及生活污水为进水，采用和试验反应器基本相同的方式起动反应器，培养非降解 PCP 的厌氧颗粒污泥供对照试验用。

1.6　厌氧颗粒污泥对 PCP 的吸附、解吸试验

(1) 分批试验方法　取第1组压力管，在每支管内加入0.5 g 经3000 r/min 离心30 min 的湿颗粒污泥和10.0 ml 不含蔗糖和 PCP 的模拟废水(释释5倍后)，充氮后塞上异丁烯橡胶塞，分别用注射器加入相应的 PCP 贮备液，使管内的 PCP 浓度分别为5，10，20，40，80 mg/L(以 HPLC 实测为准)；另取第2组、第3组压力管(不加厌氧污泥)作为对照。在第1、2组压力管内用注射器加入0.1 ml 1% Na_2S 溶液还原介质，在第3组压力管内不加 Na_2S，混匀后，立即从第2、3组压力管的各管内取样1.0 ml，用于 HPLC 分析 PCP 的起始浓度，然后把所有3组压力管均在28±1℃下振荡培养(150 r/min)。14 h 后从每组压力管内取样1.0 ml 用于 HPLC 分析 PCP，其中第2、3组管中的取样分析主要用于检验在培养过程中的 PCP 浓度变化情况。离心分离第1组压力管中的污泥和液体，取1.0 ml 液样后，弃去上清液，并用少量蒸馏水迅速清洗3次，再用吸水纸吸干残液，重新注入2.0 ml 不含蔗糖和 PCP 的模拟废水，在28±1℃下振荡培养6 h，以解吸已吸附的 PCP。培养结束后，离心分离，取1.0 ml 上清液供 HPLC 分析 PCP。每次试验重复做3次。

(2) 厌氧颗粒污泥对 PCP 的吸附量测定　分别取各试验反应器上、中、下3层污泥，放入离心管中，3000 r/min 离心30 min，弃去上清液，用蒸馏水小心清洗3次，再离心后，弃去蒸馏水，称取湿污泥2.0 g，加入1 mol/L 的 NaOH 溶液2.0 ml，乙腈0.5 ml，振荡10 min 后再离心，取上清液经微滤膜过滤后供 HPLC 分析，同时测定污泥浓度。

1.7　COD_{Cr}、TS、TVS、pH 及气体组分的测定

参见文献[10]。

1.8　PCP 的取样分析测定

(1) 反应器出水中的 PCP 分析　取出水样2.0 ml 于离心管中，加入0.5 ml 乙腈，混匀，3000 r/min 离心30 min，上清液经微滤膜过滤后供 HPLC 分析。分析测定条件为：流动相是

2% HAc/CH_3OH (15/85)、流量1.0 ml/min，波长300 nm，保留时间3.2 min。

(2) 吸附、解吸试验时的水相 PCP 分析 将每管中所有试液分别倒入离心管中，3000 r/min 离心30 min，取上清液2.0 ml，加乙腈0.5 ml，经微滤膜过滤后供 HPLC 分析，分析测定条件同(1)。

2 结果与讨论

2.1 厌氧颗粒污泥降解 PCP 活性

结果见表3。从表3可知，经氯酚驯化半年后的污泥接种反应器所培养出的厌氧颗粒污泥具有较快的脱氯降解 PCP 活性，可称为降解 PCP 的厌氧颗粒污泥，而以未驯化污泥接种反应器所培养的厌氧颗粒污泥则几乎没有降解 PCP 的活性，为非降解 PCP 的厌氧颗粒污泥。鉴于此，人们无法用降解 PCP 的厌氧颗粒污泥来得到一种有关 PCP 的精确的吸附或解吸等温线，而必须选用非降解 PCP 的厌氧颗粒污泥来替代，考察其对 PCP 的吸附、解吸特性，以确定厌氧反应器内因污泥的理化作用所引起的溶液中 PCP 浓度减少的可能性。

表3 厌氧颗粒污泥降解 PCP 的活性

反应器	厌氧颗粒污泥层(mg/g·TVS·d)		
	上层	中层	下层
1	2.20	4.10	9.95
2	1.66	3.21	9.78
对照	ND	ND	0.07

2.2 厌氧颗粒污泥对 PCP 的吸附、解吸

PCP 作为一种弱有机酸，它在固液二相间的分配受 pH、有机溶剂和离子强度的影响[7]。为使结果与反应器内的情况有可比性，本试验选用与模拟废水相同的溶液作为吸附、解吸介质，结果见图2。结果表明，PCP 的生物吸附和解吸完全符合 Freundlich 等温方程。吸附等温线：$X/M=0.567C_e^{1.113}$，　$r=0.9619$

解吸等温线：$X/M=0.282\ C_e^{0.965}$　$r=0.9996$

由上述方程可知，吸附等温线的 Freundlich 常数分别为 $K=0.567$ mg/(g·TVS) 和 $1/n=1.113$；而解吸等温线 $K=0.282$ mg/(g·TVS)，$1/n=0.965$。说明 PCP 在厌氧颗粒污泥上的吸附量较小，吸附量与解吸量之间的差异表明 PCP 在厌氧颗粒污泥上的吸附是部分不可逆的，因为未驯化的厌氧污泥不可能在短时间内(14 h)完全降解 PCP(HPLC 检测没有发现其它氯酚的产生)。

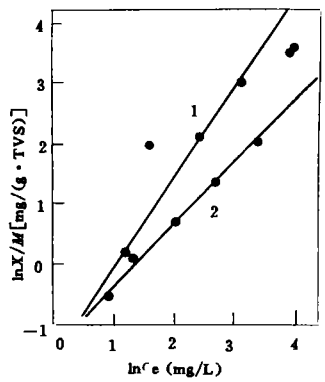

图2 厌氧颗粒污泥对 PCP 的吸附、解吸等温线

1. 吸附等温线 2. 解吸等温线

2.3 UAD 反应器的运作效能试验

表4为试验 UAD 在处理含 PCP 废水时的运行结果。可见，随着降解 PCP 的厌氧颗粒污泥的形成，2个试验反应器可稳定地处理含 PCP170—181 mg/L 的废水，相应的处理 PCP 负荷为200—220 mg/(L·d)，其中以 PCP 驯化污泥接种的1号反应器的效能稍优于以 PCP、4-CP、3-CP、2-CP 驯化污泥等量混合接种的2号反应器。

2.4 PCP 生物吸附动力学的应用

为考察吸附动力学在 UAD 反应器处理含 PCP 废水时的代表性和预测性，笔者在 UAD 反应器运行过程中，对不同出水 PCP 浓度时反应器内厌氧颗粒污泥上的 PCP 吸附量进行了实测，实测值和预测值的比较列于表5。表5表明，尽管在实际反应器中，由于厌氧颗粒污泥对 PCP 的降解作用，不可能使反应器内固液二相之间达到真正的平衡，但利用相似条件下培养的非降解 PCP 的厌氧颗粒污泥所建立的 Freundlich 模型仍可较好地预测反应器内污泥对 PCP 的吸附情况。

表4　UAD 反应器的运行结果

反应器号	运行期(d)	进水 COD_{Cr} (mg/L)	COD_{Cr}去除率 (%)	进水 PCP (mg/L)	出水 PCP (mg/L)	PCP 去除率 (%)	HRT (d)	备注
1	10—30	3000—3080	72.5—96.2	2—4	0—0.216	89.2—100	3.8—1.2	活性恢复
	35—75	4600—6250	97.0—97.8	7.50—66.04	0—0.264	99.6—100	1.1—0.9	颗粒污泥形成
	103—118	5570	97.4—97.5	181.0	未检出	100	0.9	稳定运行
2	10—30	3000—3080	78.5—95.2	2—4	0—0.200	90—100	4.6—1.1	活性恢复
	35—75	4600—6250	95.8—97.6	7.50—66.01	0—0.195	97.4—100	1.0—0.85	颗粒污泥形成
	91—98	5740	90.5—89.8	137—170.1	未检出	100	0.90—0.88	稳定运行

表5　UAD 反应器内颗粒污泥吸附 PCP 量的预测值和实测值

反应器号	1				2			
PCP 平衡浓度(出水浓度, mg/L)	0.04	0.20	0.493	4.0	0.10	0.357	1.474	4.0
实测吸附总量 X_T(mg)	0.618	2.81	7.73		1.037	4.51	24.67	
预测吸附总量(mg)	0.487	2.903	79.0	80.44	1.21	4.95	23.84	72.17
误差(%)	21.2	3.3	2.1		16.4	9.7	3.4	

比较表4和5结果可知，在反应器正常运行时，出水 PCP 浓度很低，颗粒污泥对 PCP 的吸附并不是厌氧反应器去除 PCP 的主要机制；但当进水 PCP 浓度过高，反应器运行不正常时，出水 PCP 浓度陡增，吸附作用可能在受抑制初期(1—2 d)对 PCP 的去除有较大作用。

与好氧污泥对 PCP 的吸附作用相比，本试验的吸附量较小(表6)，这种差异除了与试验条件及污泥种类不同有关外，可能还与厌氧微生物细胞脂类组分有关。一般好氧与厌氧微生物的膜脂总量相差不多，但这二类微生物的膜脂本质却有差别。不同的脂类有不同的吸附性。

表6　PCP 的吸附试验条件和 Freundlich 参数

吸附剂		温度 (℃)	参数 K	参数 $1/n$	文献
无根酒曲菌					
(*Rhizopus arrhizus*)	(活)	20	32.1	0.56	[7]
	(死)	20	28.8	0.90	[7]
好氧活性污泥	(活)	20	85.1	0.60	[7]
	(死)	20	10.1	0.80	[7]
厌氧颗粒污泥	(活)	28	1.15	0.47	[8]
	(活)	28	0.567	1.113	本试验

2.5　PCP 在厌氧反应器内的挥发作用

在密闭的厌氧反应器内，气体和液体之间是基本平衡的，尤其在上流式反应器内 PCP 浓度随高度而逐渐降低，因此挥发的驱动力就可能趋近于0。本试验经过6 d 的沼气吸收试验，吸收液(0.06 mol/L 的 NaOH)中未测到 PCP，这一结果表明反应器内 PCP 以挥发而得以去除的可能性不大。

3　结论

(1) 利用 UAD 处理含 PCP 废水是可能的；UAD 内 PCP 的主要去除机制是生物降解作用，而非吸附和挥发作用。

(2) 厌氧颗粒污泥对 PCP 的吸附量较小，吸附符合 Freundlich 等温方程，吸附是部分不可逆的，该方程可较好地描述 UAD 内颗粒污泥对 PCP 吸附量的变化规律。

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A Study on the Biodegradation of Organic Substances by ATP Test. Sun Lixin et al. (Dept. of Environ. Eng., Tsinghua Univ., Beijing 100084): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 1—4

In this paper, the aerobic biodegradation of organic substances is characterized by the determination of the energy change, ATP content in microbial cells during the biodegradation. A satisfactory result was obtained under the following conditions: the initial concentration of the tested substance is 100 mg/L (as DOC), the amount of the inoculum in the biological medium is 500 mg/L (as MLSS), and the duration of test time is 14 days. The evaluating system (peak time, peak height index and IA index) is proposed to assess the biodegradability of 40 organic substances and 7 wastewater.

Key words: biodegradation, ATP, ATP test, IA index.

Effect of Salinity and Water Pressure on Adsorption of Toxic Organic Chemicals on Separated Submarine Sediment. Quan Xie et al. (Dalian Univ. of Technology, Dalian 116012): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 5—9

The organic and inorganic components of the submarine sediment from Dalian Bay were separated with a sequential chemical separation procedure. The adsorption of several toxic organic chemicals (TOCs) on the separated sediment samples and the effect of salinity and water pressure on the adsorptions were investigated. The conclusions were made as follows: (1) The adsorption capacity of organic components on the sediment increased as the salinity of water increased, but reduced for inorganic components. The relationships could be described with linear equations. (2) The adsorption capacity of both organic and inorganic components increased as the water pressure increased. The relationships could be described with exponential equations.

Key words: salinity, water pressure, submarine sediment, toxic organic chemicals.

The Influence of Diffusive Processes on Overlying Waters at the Sediment-water Interface of Lake Lugu. Wu Fengchang and Wan Guojiang (State Key Lab. of Environ. Geochem., Chinese Academy of Sciences, Guiyang 550002): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 10—12

Through the study on Ca^{2+}、K^+、Na^+、HCO_3^- and pH profiles of water column and porewater of Lake Lugu, Yunnan, a half-close and deep lake, it was found that Ca^{2+}、K^+、Na^+ and HCO_3^- in the sediments could diffuse to overlying water and their diffusive flux and their influence extent on overlying water could be quantitatively estimated. At also indicates that the interreactions between sediment and water play a significant role in controlling basic chemical composition of some lakes.

Key words: diffusive processes, sediment-water interface, Lake Lugu.

The Experimental Study on Decolorization of Dye Wastewater with Pulse Corona Discharge. Li Shengli et al. (Environment Center of Science and Technology, HUST 430074): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 13—15

A new method to decolor dye wastewater with pulse corona discharge has been developed. Nonequilibrium plasma produced by high voltage pulse discharge contacts with dye wastewater and decolorization of dye wastewater can be achieved quickly. The results showed that the decolorization rate can be reached more than 95% by treating wastewater for 40 s at pulse peak voltage of 38 kV and there is influence, of pH value on decolorization rate. When pulse peak voltage is lower, the influences of pH value on decolorization rate are appeared. The decolorization rate of neutral dye wastewater is only reached about 40%—50% after treating for 40 s. However, the decolorization rate can be reached more than 80% at pH<4 or >7. The experimental results of adding NaCl or Na_2SO_4 into dye wastewater have showed that Cl^- is able to decrease decolorization and SO_4^{2-} just opposite.

Key words: dye wastewater, decolorization, pulse corona discharge, pulse peak voltage.

Study on the Leaching Experiments of Minor and Trace Elements in Coal and Its Burnt Products. Wang Yunquan et al. (Beijing Graduate School, China Univer. of Mining and Technology, Beijing 100083): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 16—18

The comparative leaching experiments of coal (C), ashing ash (AA), fly ash (FA) and bottom ash (BA) have been carried out under different pH conditions. The leaching behaviour of As, Zn, Pb, Ni and Sr have been investigated in detail. The results have shown that the pH values of solution, leaching time, and particularly, the properties and species of the elements existed have heavily influenced on the leaching behaviour of elements. Among the 5 elements analysed, the leaching ability of Sr is strong, Pb and As strong to middle, Ni middle and Zn weak.

Key words: coal and its burnt products, minor and trace elements, leaching experiments.

A Study on Adsorption, Desorption and Biodegradation of Pentachlorophenol by Anaerobic Granular Sludge. Shen Dongsheng et al. (Dept. of Environ. Science, Zhejiang Agricultural Univ., Hangzhou, 310029): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 20—23

PCP degrading anaerobic sludge granules may be developed in upflow anaerobic digestion reactors (UAD) seeded with sludges acclimated to chlorophenols, the reactors are able to remove more than 99.5% of PCP in a synthetic wastewater at the concentration of 170 to 180 mg/L, volumetric loading rate up to 200 to 220 mg/(L·d), and hydraulic retention time of 20 to 22 hours. Biosorption and desorption isotherms of pentachlorophenol were determined, and the data were fitted to Freundlich equation. However, it was found that the biosorption of PCP was partly irreversible, and the Freundlich models with empirical constants determined from this study can quite well describe the partition behavior of pentachlorophenol in anaerobic upflow digestion reactor. It was demonstrated

that PCP removal by granular sludge in UAD reactors was due to biodegradation rather than adsorption and volatilizaiton.

Key words: pentachloropenol, biosorption, de-sorption, biodegradation, anaerobic.

Photocatalytic Oxidation of Benzene Hexachloride and Pentachlorophenol in Aqueous Solution. Li Tian and Qiu Yanling (School of Environ. Eng., Tongji Univ., Shanghai 200092): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 24—26

Photocatalytic oxidation of low concentration of benzene hexachloride (BHC) and pentachlorophenol (PCP) in aqueous solution is studied with a high pressure mercury lamp as radiation resource and TiO_2 as a catalyst. BHC can be oxidized easily, half life periods of the 4 isomers of BHC are all around 20 minutes. Oxidation rate of γ-BHC is higher under neutral condition. Chlorinated medium products formed in the photocatalytic oxidation of BHC can be gradually removed by further reaction. For PCP reaction rate of photocatalytic oxidation is much higher than that of photolysis. Dechlorination of PCP can be completed within 30 minutes. As the reaction process continues, PCP will be oxidized into simple small molecules and finally mineralized completely. It is predicable that photocatalytic oxidation has bright prospect in advanced treatment of drinking water.

Key words: photocatalytic oxidation, benzene hexachloride, pentachlorophenol, aqueous solution.

The Dissipation and Residue of Quinclorac in Rice Field Water, Soil and Rice Plant. Wang Yiru et al. (Institute of Agro-environmental Protection, Tianjin 300191): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 27—30

Quinclorac is a new herbicide with high efficiency and low toxicity. The field experiments were carried out both in Tianjin and Jilin Province in 1993 and 1994, respectively. It has been found that the herbicide dissipated rapidly from water and leaves. Its half life values in the water was 0.8 days in Tianjin and 2 days in Jilin, and the half life in rice leaves was less than 1 day. The residure in sediment remained quite low during 6 days of half life. No metabolite was detected in soil. Applied to rice field as a 50% WP formulation at the recommended rates of 412.5 g—525 g/hm^2, one application, preharvest interval 96—105 days, the residue remaining in unpolished rice was less than 0.005 mg/kg, far below MRL, and was safe to humanbeing.

Key words: Quinclorac, metabolite, dissipation, final residue, water, rice, soil.

Wet Air Oxidation Treatment of H-acid Production Waste Liquor. Wang Yongyi et al. (Dept. of Environ. Eng., Tsinghua Univ., Beijing 100084): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 31—33

Under the condition of reaction temperatures of 200—250℃, initial oxygen partial pressures of 1—3 MPa, the wet air oxidation (WAO) of H-acid has 2-step process, including rapid reaction step, in which during the first 10 minutes after the beginning of the reaction COD is decreased rapidly, and UV/Vis. absorbance is increased drastically at first and then reduced rapidly, and slow reaction step, in which, both COD and UV/Vis. absorbance are decreased slowly during about 20 minutes. WAO treatment can improve biodegradability of H-acid significantly. After 1 hour reaction carried out at 160℃ and 3 MPa initial oxygen pressure, COD was decreased by 50%, and the BOD_5/COD ratio of 10 g/L H-acid solution was increased from 3.4% to 33.3%. The offgas from the WAO treatment of H-acid contains undetectable amount of SO_2 and nitrogen oxides.

Key words: wet air oxidation, H-acid, biodegradability.

Emission Factors of Trace OCS from Crop Residues Burning and Estimation Its Amount in China. Cao Meiqiu and Zhuang Yahui (Research Center for Eco-Environmental Sciences, CAS, Beijing 100085): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 34—36

A method of sampling and analysis for trace carbonyl sulfide has been described. The sample is trapped and concentrated at temperature of liquid N_2 and liberated directly into a gas chromatographic column. The concentration of OCS in compressed air as determined as 2.94×10^{-3} μg/L. The method accuracy expressed in term of standard deviation coefficient is ±0.72%. The emission factors of carbonyl sulfide, which were measured during the combustion of rice straws, maize stalks and wheat stalks in an enclosed combustion system, are 1.80, 2.75 and 2.05 g/t for rice straws, maize stalks, and wheat stalks, individual. Standard deviation coefficient are ±6.67%, ±8.36%, and 9.27% for rice straws, maize stalks, and wheat stalks, respectively. Distribution of the amount of crop residues burned in China is presented with a resolution 1° latitude × 1° longitude. The amount of trace OCS could be calculated with their emission factors.

Key words: carbonyl sulfide, biomass buring, emission factor.

The Study of Trace Elements in Human Hair from the Area of Endemic Arsenism. Jiang Ling et al. (Institute of Environ. Medicine, Tongji Medical Univ., Wuhan 430030): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 37—39

217 hair samples and environmental samples from endemic arsenism in Linhe, Inner Mongolia were analyzed. The results showed that the levels of As, Cu and K in hair in studied area were higher than that in control area, but Zn and Se was opposite. The relationship between the typical symptoms of arsenism and the levels of As, Cu, K and Se in hair were found. There were rank correlations between the concentration of Se, Zn, Cu in hair and As in hair (the coefficient = −0.988, −0.794, 0.783, respectively).

Key words: endemic arsenism, trace elements, hair.

Research for the Problem about the Environmental Discount Rate. Wang Yonghang and Fu Guowei (Dept. of Environ. Eng., Tsinghua University, Beijing 100084): *Chin. J. Environ. Sci.*, **17**(1), 1996, pp. 40—43

This paper presents a new formula, which describes the relation between private rate or return and social rate of return. The formula includes two environmental parameters, λ, the fraction of national income spent on environmental investment, and η, the elasticity of environmental improvement with respect to environmental spending. From the formula it can be seen that social rate of return or environmental discount rate should decline systematically over time from the point of view of environmental