

凤眼莲净化印染废水过程中根系微生物生态系统的作用*

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摘要 当用凤眼莲净化印染废水,且停留时间为4天时,根部灭菌的凤眼莲的氧化缸和无凤眼莲的氧化缸对COD的去除分别为13%、15%。相比之下,未灭菌的凤眼莲氧化缸靠其根部微生物生态系统的协同净化作用,对COD的去除率可达35%,当废水停留时间为8天时,此项去除率达46%。三者对PVA、表面活性剂、印染废水中常见的几种染料的去除率也与上述情况相似。不能为凤眼莲直接吸收的有机物,特别是易凝聚的污染物首先被粘附、吸着、固定到根部,然后由根系微生物生态系统的强大净化作用降解。

凤眼莲(*Eichhorina Crassipes*)俗称水葫芦(Water Hyacinths),为多年生漂浮性水生草本植物,根系发达,生长、繁殖速率极快。在水污染控制、水域净化和废水处理等领域得到广泛应用^[1-6]。

国内应用凤眼莲处理针织印染废水试验虽已得到较好的效果。然而,印染废水种类繁多,成份复杂,凤眼莲能否广泛地应用于纺织印染废水的处理尚不清楚。凤眼莲净化废水中的重金属和酚曾有报道^[7-9],本文对凤眼莲净化印染废水的根系微生物生态系统的作用,进行了研究。

一、材料和方法

1. 凤眼莲根系吸附作用试验

参考实际印染废水中几种常见污染物质的浓度,分别配制数种单一成份的废水各54L(分散黄 30mg/l、活性蓝 5mg/l、PVA 50mg/l、十二烷基苯磺酸钠 100mg/l 左右),置于长58cm,宽30cm,高40cm的聚氯乙烯塑料缸内。加入适量植物生长所需营养盐($\text{NaH}_2\text{PO}_4 \cdot 12\text{H}_2\text{O}$ 0.005g/l、 $(\text{NH}_4)_2\text{SO}_4$ 0.05g/l、 K_2SO_4 0.025g/l)。在气温25—35℃、日照为10h/d、水体pH为6.0—7.5、水温20—27℃的条件下,从上海西郊天然水域中生长的凤眼莲挑选株体均匀健壮

者,放入试验缸,每缸生物量为0.7kg,对照缸不植凤眼莲,并用黑纸覆盖2/3,模拟凤眼莲对水面的覆盖。每天定时定点取多点水样混合,测定上述四种成份的浓度。取样前2小时加入一定量清水,并轻轻搅拌混合,以补充前一天蒸发的水量。

2. 根系微生物生态系统作用试验

在气温、日照、试验缸等与前试验相同的条件下,用综合印染厂工业废水,测定凤眼莲对COD的去除,凤眼莲放置量0.7kg。然后采用同前试验的单一污染物的配制废水,同时进行三组试验,每组(缸)凤眼莲的放置量为0.3kg,1号为不灭菌组,将水葫芦根系用自来水冲洗干净,放入缸内,接种10ml生化出水;2号为灭菌组,将根系冲洗干净的凤眼莲在浓度为0.1%漂白粉溶液中浸泡5分钟,废水用新鲜蒸馏水配制,试验开始时缸内基本无菌;3号为不灭菌空白对照组。每天在贴近凤眼莲根部的位置定时、定点取多点水样混合,测定污染成份的浓度和细菌浓度,同时作镜检观察生物相的变化。

3. 测定方法

染料浓度——751G分光光度计比色;

PVA——751G分光光度计比色;

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十二烷基苯磺酸钠——单一成份, 以 COD_{Cr} 来表示;

COD_{Cr} ——标准方法;

细菌浓度——平板计数;

生物相——显微镜镜检。

二、结果与讨论

凤眼莲庞大的根系是净化污染物的关键场所, 其根部细胞壁属生物半透膜, 分子量较大的、非离子的化合物或胶体是无法透过而进入植物体内的。下列实验结果揭示了凤眼莲根部在去除印染废水中常见的几种污染物质时的吸附作用。

1. 单一污染物质的去除

(1) 分散黄染料的去除 分散黄染料在废水中呈不溶性胶体状态, 废水在凤眼莲净化缸中停留 4 天后, 对分散黄的去除率达 70%, 如图 1。镜检发现分散黄染料呈团粒

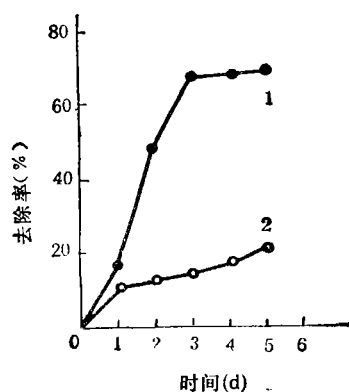


图1 分散黄去除率
1. 有凤眼莲 2. 空白

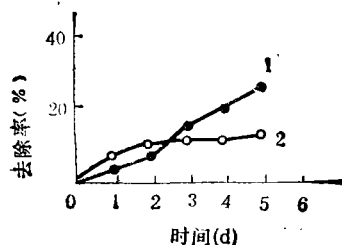


图2 PVA的去除率
1. 有凤眼莲 2. 空白

状被粘附在凤眼莲的根上。由此可见, 凤眼莲对不溶性胶体的去除, 主要是靠其根部的粘附和吸附固定。

(2) PVA的去除 PVA是亲水性的有机高分子物质, 不可能穿过根表面的细胞壁而被凤眼莲所利用, 然而图2表明5天的处理去除率仍达到26%, 这是因为PVA在水中可以通过架桥絮凝等作用, 粘附到凤眼莲的根部而被去除。

(3) 活性蓝的去除 活性蓝属水溶性极好的染料, 在废水中呈分子状态, 凤眼莲对它的去除率很低(结果见图3), 显然, 凤眼莲根部对水溶性小分子的吸附和粘附性能不如对胶体和大分子好。

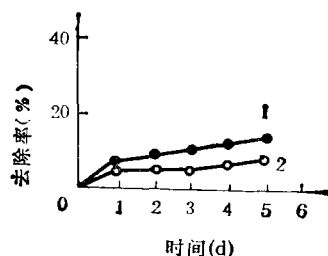


图3 活性蓝的去除率
1. 有凤眼莲 2. 空白

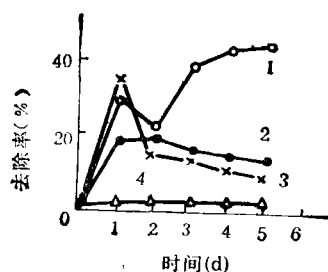


图4 表面活性剂的去除率
1. 100ppm 2. 200ppm 3. 300ppm 4. 空白

(4) 表面活性剂的去除 已知表面活性剂对生物的代谢有一定的抑制作用, 本研究证实了这一点。当表面活性剂浓度大于100ppm时, 凤眼莲生长受到了明显的抑制, 出现黄叶、枯萎现象。但有趣的是, 当浓度达到200ppm, 甚至300ppm时, 实验结果仍显示

出凤眼莲对表面活性剂有一定的去除率,见图4。无疑,这样的去除仍是凤眼莲庞大根系的吸附能力所致。

比较上述四类不同物质的去除效果,可以看出,凤眼莲对不溶性胶体、大分子、或表面活性剂等物质,能够有效地去除;而对水溶性好的物质的去除能力较差。产生这种差别的原因是凤眼莲根部表面进行着离子平衡过程,该过程对水中悬浮、分散和部分溶解的固体物质起着凝聚和吸附作用^[7],使较易凝聚成絮凝物质,如胶体、高分子等,很快地从污水中凝聚沉淀下来从而达到较高的去除率;但对难凝聚的溶解性良好的物质只能得到少量去除。

2. 凤眼莲根系、根系微生态系统在净化过程中的作用

印染废水中,胶体、悬浮颗粒和高分子污染物构成了 COD 的主要部份,利用凤眼莲净化这些污染物比较适宜。但是,由于这些物质不能为凤眼莲直接吸收利用,而是被吸附在根部,这样就会产生吸附饱和问题。即当凤眼莲根系与废水接触达到一定的程度,便不能再起净化作用了。然而由图5的曲线可见,新鲜凤眼莲与废水接触的第四、五天,对污染物仍有去除作用。只是去除率的增加变缓。由此可以推断,被吸附的污染物能被逐渐降解而使凤眼莲根系继续保持净化的功能。

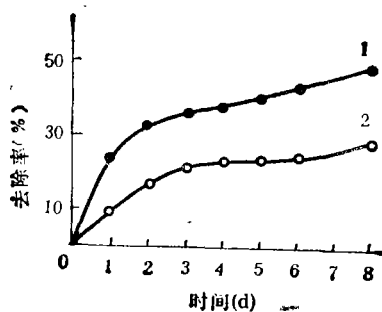


图5 印染废水 COD 的去除率
1. 有凤眼莲 2. 空白

3. 凤眼莲根系生态系统的建立和微生物在净化过程中的重要作用。从图6可知,灭菌凤眼莲氧化缸内微生物数量、种属逐步变化和增长的过程,以及不灭菌凤眼莲氧化缸内细菌浓度的变化和相应的 COD 去除率。

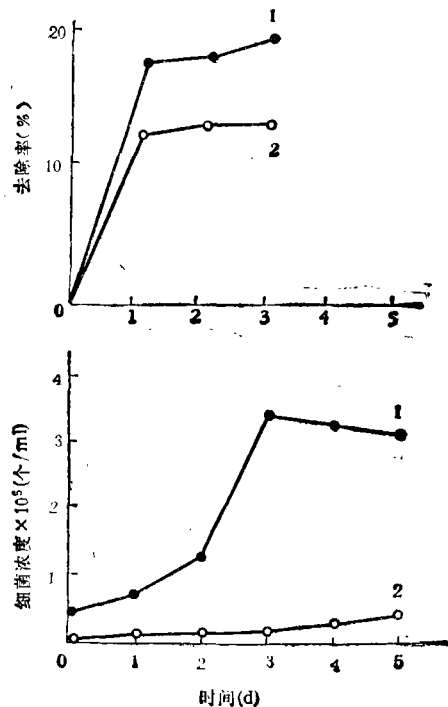


图6 凤眼莲根系微生物的变化过程和相应 COD 去除率

1. 未灭菌凤眼莲 2. 灭菌凤眼莲

2号灭菌缸内,刚放置凤眼莲时,近根处溶液中只有少量细菌。经过一天,出现少量肾形虫;第二天末,细菌数从原110个/ml猛增到6038个/ml,同时出现变形虫和大量漫游虫。到了第三天末,细菌数略有增加,原生动物种类和数量却出现惊人增长,纤毛虫类的漫游虫、草履虫、钟虫、累枝虫等数量大增,非常活跃。到了第四天、第五天,又逐渐出现轮虫和少量线虫等后生动物;近根处溶液中的细菌浓度达到40000个/ml。表1的结果表明,远离根部的溶液中的细菌浓度仅为1100个/ml,多次镜检未发现原虫动物和后生动物,由此可见,细菌等微生物主要集中在

凤眼莲的根部。凤眼莲根系是微生物栖息的理想场所^[10],其根部分泌物可供微生物生长必要的有机营养和无机元素。某些物质可能是微生物生长的促进剂,促使多种微生物种属和群落的生长发育;而微生物的代谢产物,如含 N、P、K 的无机盐,则是凤眼莲生长的必要养分。两者互相依赖,互相促进,构成了极其重要的根系微生态系统。

表 1 第五天不同条件凤眼莲氧化缸内细菌数量比较

缸号	细菌浓度(个数/ml)	
1#	有菌近根	303000
	有菌远根	10000
2#	灭菌近根	40000
	灭菌远根	1100

另一方面,从图 6 和表 1 可见,到了试验第 5 天,未灭菌的 1 号缸内,凤眼莲根部的细菌浓度高达 30 万个/ml,远离根部溶液中每

毫升细菌数 1 万个,两者相差 30 倍。相应地,该缸对 COD 的去除率要比灭菌的 2 号缸高出近 50%。因此,根系微生物在净化过程中起着举足轻重的作用。

表 2 是凤眼莲根部洗净后接种少量生化出水和根部灭菌两种情况下,处理印染废水几种典型的污染物的试验,同时进行不放养凤眼莲,但也不灭菌的空白试验。结果显示接种少量生化出水的凤眼莲氧化缸无论对哪种污染物的去除率都是最高的;灭菌的凤眼莲氧化缸主要靠根系吸附作用而居其次;空白缸仅靠溶液中细菌的自然净化作用,相当于普通氧化塘,去除率最低。由此可见,建立于凤眼莲根部的微生态系统在净化废水过程中显示出一种“协同”作用,单纯的凤眼莲根系和单纯的细菌(空白对照缸)都不具备这样的作用,而且这种协同作用在净化 PVA 时表现得特别明显。这就提示,如果用凤眼莲氧化塘去除难降解印染废水的 PVA 成份比较有利。

表 2 单一成分污染物的去除率和相应的细菌浓度

污染物	缸样	洗净凤眼莲+10ml 生化出水				灭菌凤眼莲				不灭菌空白对照			
	接触时间(d)	0	1	2	3	0	1	2	3	0	1	2	3
分散黄染料	细菌浓度 ($\times 10^4$ 个/ml)	0.6	2.3	2.4	2.6	0	0.3	0.2	0.3	0.2	0.5	0.8	0.8
	去除率(%)	0	19.4	28.1	36.5	0	16.2	19.7	28.9	0	10.2	11.9	18.3
活性蓝染料	细菌浓度 ($\times 10^4$ 个/ml)	0.1	0.4	3.0	5.6	0	0.1	0.15	0.20	0	0.2	0.3	0.7
	去除率(%)	0	5.9	4.8	12.2	0	3.8	4.2	4.5	0	1.9	1.4	2.3
PVA	细菌浓度 ($\times 10^4$ 个/ml)	0.1	1.6	5.8	13.0	0	0.2	3.3	12.2	0	1.1	2.4	2.3
	去除率(%)	0	11.7	18.1	27.4	0	2.2	3.9	9.1	0	0.7	1.2	5.3
表面活性剂	细菌浓度 ($\times 10^4$ 个/ml)	5.3	16.1	21.5	19.0	0	1.8	2.5	2.0	2.0	4.5	6.8	9.5
	去除率(%)	0	8.7	9.0	11.5	0	6.2	6.4	7.0	0	2.1	2.9	3.5

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$$K_1^0(T) = K_1^0(20^\circ\text{C})1.025^{T-20} \quad (7)$$

式中, v 为河流流速 (m/s)

L 为河流平均深度 (m)

(2) 水的气相传质系数

设水的蒸发量为 $N^W(\text{mol} \cdot \text{cm}^{-2} \cdot \text{h}^{-1})$, 根据 Fick 定律得:

$$N^W = k_g^W(p_s^W - p^W)/RT \quad (8)$$

式中, p_s^W 和 p^W 为温度 T 时水的饱和蒸气压和实际分压 (atm)

由测得的蒸发量和相对湿度就可计算出水的气相传质系数 k_g^W , 结果见表 2.

(3) 亨利常数

亨利常数可以根据分子的蒸气压和水中的溶解度来估算^[3,8]:

$$H_c = \frac{16.04 p^0 M}{TS} \quad (9)$$

式中, p^0 为纯有机物的蒸气压 (atm)

M 为有机物的分子量;

T 为绝对温度 (K);

S 为有机物的溶解度 (mg/L).

(4) 气相和液相扩散系数

气相和液相扩散系数可由分子量 (M) 来估算(结果见表 1):

(上接第 27 页)

三、结 论

1. 凤眼莲根系是微生物理想的栖息场所, 微生物在凤眼莲净化废水过程中起着重要的降解有机物的作用, 吸附在凤眼莲根部的污染物通过根系微生态系统巨大的净化能力得到降解, 从而使凤眼莲根系保持一定的吸附能力.

2. 不能为凤眼莲根系直接吸收的较大分子有机化合物, 如分散染料等, 通过根系的粘附、吸着、固定使废水得到净化.

3. 难生物降解的但较易凝聚的污染物主要通过凤眼莲根系的吸附而被去除, 但吸附有一定的容量. 溶解性的小分子污染物, 较难被凤眼莲根系吸附, 因而去除效果不理想.

$$D_g = 1.9 \text{M}^{-2/3} \quad (10)$$

$$D_l = 2.2 \times 10^{-4} \text{M}^{-2/3} \quad (11)$$

三、结 论

1. 模拟实验测定了 37 种有机物的挥发速率, 得出有机物的挥发为一级动力学过程.

2. 可以用双膜理论预测有机物的挥发速率常数.

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Reclamation Treatment of the Scraps of Chrome Leather —Animal Test of the Feed Protein Powder. Jiang Tingda, Zhang Chunping (Research Center for Eco-Environmental Sciences, Academia Sinica, Beijing): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.2—6

The proteins extracted from scraps of chrome leather were mixed with bran and used as feed protein powder. The feeding test for mice showed that the animals grew faster by using the feed additive protein powder, compared with fishpowder after six weeks. No abnormal variations were observed in organs of the mice. The feeding test with the feed additive protein powder for chickens and muddling hens showed that growth of the animals was accelerated in comparison with the group fed with fishpowder after 27 and 17 days respectively. The rate of layeggs in the initial stage was 40% higher than that of feeding fishpowder group. No abnormal variations were observed in organs, and chrome had not been detected out in muscle, liver and egg at ppm level.

Study on Copper Pollution from Fertilizing the Soil with Sludge. Wang Hongkang, Yan Shoucang (Beijing Agricultural University): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.6—11

The pot and plot experiments have been conducted for studying the effect of copper pollution on wheat and rice in calcareous soil fertilized with sludge containing copper. The results demonstrated that high concentrations of copper in soil affected on the growth of the crops and their yields. Rice was more susceptible to it than wheat, and reduced the yield about 10% when the soil had been treated with copper by 100 ppm. The order of absorption and accumulation of copper within the organs was as follows: root >> stem > leaf > grain. The copper content in grains of wheat and rice both were not higher than 20 ppm. In the soil fertilized with the sludge, the variation of available copper, its cation speciation and soil capacity were also studied in the paper. It is suggested that 130 ppm of copper as a critical value, and 800 ppm as a maximum permissible limit in sludge as it is fertilized to calcareous soil.

Structural Influence of Fulvic Acid in Rat Bone Formation. Yang Chunlin et al. (Research Center for Eco-Environmental Sciences, Academia Sinica, Beijing): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.11—15

The influence of fulvic acid from Beijing weathered coal on the structure of rat bone has been studied. Emphasis was put on the fluorescent spectrum, ultra-violet spectrum and gel chromatographic properties of water extract of the rat bone injected with fulvic acid. The results showed that the evidence incorporating of fulvic

acid into rat bone and the pathogenic significance of this incorporation in causing Chinese Kaschin-beck disease was evaluated.

Weathering of Copper Mine Waste Rock and Characteristics of Acid Wastewater. Dai Zhaohua, Wang Zhihai (Research Center for EcoEnvironmental Sciences, Academia Sinica, Beijing): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.15—19

In this paper the characteristics of acid mine water generated from weathering of copper mine waste rock have been described according to the survey in situ. The acidity and concentration of some elements in the acid water were higher. Except that the content of some elements released from the rock weathering affected by seasons, it was affected by rainfall, even if in a season. According to the relationship between elements and the molar ratio between sulfur and iron in the acid water, it was considered that some secondary minerals were formed during generation and transportation of the acid water and controlled the chemical equilibria and acidity of the acid water. Tetraivalent sulfur might be an important intermediate product during the process of acid generation from pyrite weathering on the basis of sulfur speciation analysed, and it was rapidly oxidized to sexavalent sulfur during transportation of acid water.

Tolerance and Purification Capacity of Some Species of Trees against Sulfur Dioxide

Li Yichuan, Liu Houtian (Chinese Research Academy of Environmental Sciences, Beijing); Ma Liangqing, Du Shicai (Chongqing Bureau of Forestry, Sichuan Province): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.20—23

In order to determine the threshold doses of acute and chronic injury by SO₂, the saplings fumigated with SO₂ in the open top chamber were conducted. According to the principle that purification capacity of SO₂ by trees is in a function of sulfur intensity accumulated in leaves and its transfer rate out of leaves, the purification capacity of a tree can be estimated in varied sulfur contents in the leaves before and after fumigation. The experimental results show that the trees *Cunninghamia lanceolata*, *Camptotheca acuminata*, *Cinnamomum pilyphylum* possess strong tolerance and higher purification capacity against SO₂, but the capacity of *Robinia pseudacacia* etc are lower. Chongqing is a city with heavier SO₂ pollution, so the said trees can be selected for greening around the urban districts.

The Function of the Root Microecosystem in the Process of Dyeing Wastewater Treatment by the Hyacinth. Sun Tianhua, Liu Zhenghong, Lin Shaoning (China Textile University

Shanghai): *Chin. J. Environ. Sci.*, 11(3), 1990, pp. 24—27

It has been proved that there is a root microecosystem in the process of dyeing wastewater treatment by the hyacinth. With four days' retention, the percentage of COD removal in the oxidation tank, where the hyacinth was planted and its root sterilized with chloride, was 13%. However the percentage of COD removal in ordinary biological oxidation pond without the hyacinth was 15%. In comparison with this, a water hyacinth oxidation tank without sterilization showed higher COD removal percentage of 35% due to existence of a root microecosystem. Similar results were obtained when wastewater containing PVC, detergent and some dyes were treated with the three methods mentioned above. Some organic compounds that could scarcely be absorbed by the hyacinth, for example, those easy to be coagulated or flocules, could be stuck and fixed on the root surface, and then degraded by the root microecosystem.

The Toxicological Effect of Cr (VI) on Chlorophyll and Iron Contents and Activities of Some Enzymes in the Leaves of Pepper (*Capsicum annuum*). Zhou Yiyong, Liu Tongchou, Deng Boer (Dept. of Soil and Agrochemistry, Huazhong Agricultural University, Wuhan): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.28—29

The toxicological effect of Cr(VI) on some biochemical parameters in pepper were studied both in soil culture and in nutrient cultural experiments. The treatments of the heavy metals decreased fresh weight and promoted senescence of the pepper plant by decreasing chlorophyll and activities of superoxide dismutase and catalase as well as increasing iron content and peroxidase activity over control values.

Study on the Pretreatment of Coke-Plant Wastewater by Anaerobic Acidification. Zhao Jianfu, Qian yi, Gu Xiasheng (Dept. of Environmental Engineering, Tsinghua University, Beijing): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.30—34

According to analysis of the constituents and concentrations of organic pollutants in wastewater at Beijing Coke Plant using combined gas chromatography and mass spectrometry (GC/MS), the effect of anaerobic acidification on the bio-treatability of coke-plant wastewater has been studied and the possibility of using anaerobic acidification as pretreatment of aerobic treatment has also been explored. The results described that aerobic biotreatability of coke-plant effluent could obviously increase through 2—6 hours' anaerobic acidification. After 6 hours and 12 hours, anaerobic acidification, COD in the effluent could be removed by 91%, i.e. removal rate increased about

40% more than that without applying anaerobic acidification. As the influent COD of the wastewater was 1780 mg/L, the effluent COD removed to 158 mg/L.

Preparation of Polyaluminum Chloride with Sulfate Ion and Study on Its Properties.

Gao Baoyu et al. (Environmental Science Center, Shandong University, Jinan): *Chin. J. Environ. Sci.*, 11(3), 1990, pp. 34—37

Polyaluminum chloride with sulfate ion (PACS) has been prepared by using aluminum hydroxide, hydrochloric acid, sulfuric acid and sodium carbonate as raw materials, and the properties of PACS have also been studied. The factors affecting the flocculating effect of PACS have been investigated. The experimental results show that the flocculating effect of PACS is influenced by the amount of sulfate ion in PACS, basicity of PACS and pH of water solution. When the molar ratio of Al^{3+} to SO_4^{2-} is in the range of 15 to 17, the flocculating effect of PACS is best.

Problems on Yellow-Colouring of the Wastewater Treated with the Coagulant, Ferrous Salt. Guan Xijun, Wang Fei (Dept. of Environmental Engineering, Qingdao Institute of Architectural Engineering): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.38—40

When ferrous salt is used as a coagulant to treat wastewater, if there exists superfluity in the process of coagulation to sedimentation, purged water will be clear. However, When the purged water is laid aside, it becomes turbid and turns to yellow-colouring. The reason is that oxygen in the air has dissolved in it as time goes on. The authors have proposed a measure to control the phenomenon that a higher pH or an optimal quantity of the mixed coagulant paralleled with tests can avoid color changing.

Application of Inductest in Research of Environmental Mutagens. Ruan Cuicai et al. (Guangxi Cancer Institute, Nanning): *Chin. J. Environ. Sci.*, 11(3), 1990, pp.41—43

The possible mutagenic activity of 35 different chemicals has been tested with inductest, in which S_9 mixture was used as a metabolizing system. The results showed that 13(37%) chemicals had mutagenic activity, 10 of these chemicals gave positive reaction in inductest in the presence of S_9 mixture, three chemicals gave positive reaction in inductest in the presence of S_9 mixture or without it. Some of the chemicals are known as potent mutagens and carcinogens (aflatoxin B_1) or anticancer drugs (mitomycin C). It is considered that inductest is an effective method in research of environmental mutagens.

A Study on Determination of Formic and Acetic Acids in the Atmosphere. Yu Shaocai,