用人工湿地处理乳制品厂废水的研究*

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摘要　在进水 COD 浓度 400 mg/L—800 mg/L，温度 15℃-23℃时，人工湿地装置处理乳制品加工废水的 COD 去除率达 97%—98%，面积负荷率达 23.3 g/(m²·d)—28.2 g/(m²·d)，BOD_5 的去除率达 97%—99%，BOD_5 的面积负荷率为 12.6 g/(m²·d)—17.2 g/(m²·d)，几乎 70%—90% COD 和 BOD_5 去除率发生在进水沟段. 如果没有 pH 冲击负荷，处理装置的出水水质会稳定地保持在很高的水平.

关键词　人工湿地，地下潜流，芦苇床，控制床.

自 1974 年第一个用于废水处理的人工湿地在西德建成以来，由于该工艺具有投资小，能耗低，管理简单的特点，在世界范围内得到了迅速发展[1, 2]. 但将人工湿地用于处理乳制品厂废水，国内还未见报道.

1　实验设计

实验所采用的人工湿地是已种植芦苇达 4 年之久的芦苇床(图 1)，实验的目的是决定根区处理系统是否适用于乳制品厂废水处理，并考察实验装置去除污染物的效率.

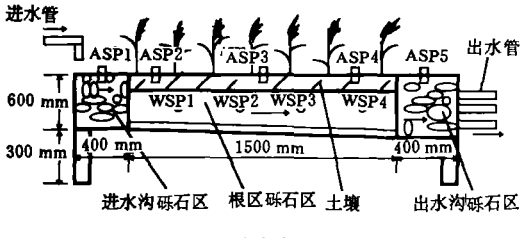

图 1　芦苇床实验装置示意图
(ASP 为空气取样管，WSP 为水样取样管)

芦苇床沿长度方向由 3 个部分组成，即进水沟，根区及出水沟. 进水沟和出水沟各长 400 mm，根区长 1500 mm. 全长 2300 mm，床宽 1200 mm，床底略有坡度，进水端深 600 mm，出水端深 660 mm，其平均深度为 630 mm. 作为背景比较，在靠近芦苇床的边上又建造了一个尺寸较小的不种芦苇的控制床(780 mm×400 mm×600 mm). 控制床的深度和芦苇床相仿，长度和宽度以 1∶3 的比例缩小. 控制床的其他结构都和芦苇床相似，控制床和芦苇床在相同的实验条件下运行.

2　系统运行

图 2 是实验的流程图. 废水直接采自犹他州 Logan 当地的一家乳酪加工厂的污水检查井. 由于乳酪生产是一种批量生产方式，废水的性质随时间变化. 实验中废水的 pH 3—12，COD200—5000 mg/L. 为能在稳定状态下进行实验，用 3 个桶(200 L/只)作废水储存和均质. 利用氢氧化钠和浓硫酸将 pH 调节到 5.5—9. 对于特别浓的废水则用河水稀释使进实验装置

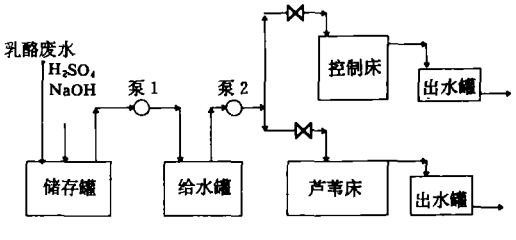

图 2　实验工艺流程图

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的废水浓度控制在 COD 400 mg/L—800 mg/L.

在经历了适应阶段后，实验一共进行了 4 个阶段. 表 1 列出了 4 个实验阶段的日程和相应的实验环境状况. 在第 2 阶段和第 3 阶段，芦苇床和控制床的土壤表层都用玻璃纤维和塑料薄膜覆盖，只让芦苇植株露出床外. 当然，没有植株的控制床要比芦苇床的密封效果好得多.

表 1　实验环境状况

实验阶段	实验时间/d	实验日程/月-日	温度/℃	表层土壤状况
1	35-36	02-22～03-14	15	自然状况
2	90-110	04-17～05-07	15	土壤表面与大气隔离
3	114-131	05-11～05-28	23	土壤表面与大气隔离
4	155-187	06-21～07-23	23	自然状况

3　实验结果

3.1　COD 的去除率

芦苇床 COD 去除率在各阶段均保持在 97%以上(见图 3). 而控制床的 COD 去除率除了在第 1 阶段为 60%之外，在其他各阶段也能达到 93%左右.

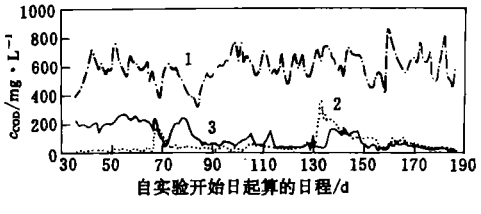

图 3　芦苇床和控制床进水和出水 COD 浓度变化

1. 进水　2. 芦苇床出水　3. 控制床出水

(1) 土壤表面状态的影响　在实验开始阶段，曾设想若污染物去除主要靠好氧微生物作用，那么当土壤表面用塑料薄膜和玻璃纤维与大气隔离后(第 2，3 阶段)，COD 的去除率会下降. 然而实验结果表明，芦苇床和控制床在第 2，3 阶段的去除率都没有下降. 此外，控制床在第 2，3 阶段的空气样品中发现含有甲烷，浓度最高时可达 3%.

实验结果表明，微生物能够很快适应缺氧环境. 可是当实验从第 3 阶段转入第 4 阶段时，两床的土壤表面重新暴露在大气中，COD 去除率都立即下降，这个不稳定时间持续了约 20 d. 表明微生物需要时间来适应好氧条件，且具有适应不同环境的能力.

(2) 床体温度的影响　当床温升到 23℃时，芦苇床的水分蒸发量从第 1 阶段时占进水量的 41.2%上升到第四阶段的 77.5%. 由于在这 4 个阶段中进水流量基本维持不变，因而高蒸发量导致芦苇床的出水水量减少；另外有一些不可生物降解的物质被浓缩在出水中，导致出水的 COD 浓度上升. 芦苇床出水的 COD 从第一阶段的 14 mg/L 上升到第四阶段的 46 mg/L. 对于控制床来说温度上升时水分蒸发量只略为提高了一点，对出水的 COD 无大影响.

(3) COD 在进水沟中的去除情况　在本实验中，大部分 COD 去除发生在进水沟区域. 图 4 列出了 4 个实验阶段中沿着芦苇床长度方向 COD 浓度变化情况. 在本实验中，进水沟原来的设计主要是用来分配进水，然而在废水流经的区域，可以看到在进水沟的卵石表面生长着很厚的灰色生物膜. 生物镜检中可以看到大量活跃的细菌，原生和后生动物. 实验中总 COD 去除率对于芦苇床是 23.3 g/(m^2·d)—28.2 g/(m^2·d)，其中 64%—84%的 COD 是在进水沟中去除的. 废水在进水沟中的停留时间约为 1 d.

假设进水沟中卵石比表面积大约为 45 m^2/m^3，可以计算出近似的负荷率为 2.3 g/(m^2·d)—3.3 g/(m^2·d). 这个数值是典型的低负荷生物滤池的负荷率[3]. 如不包括在进水沟中去除的 COD 量，那么在芦苇床种植区内的 COD 负荷率是 4.0 g/(m^2·d)—9.5 g/(m^2·d).

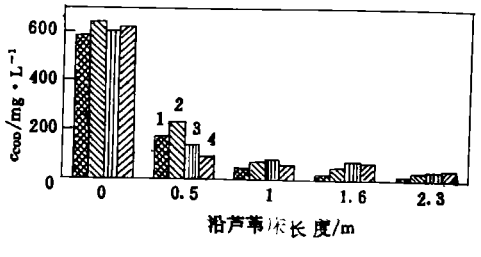

图 4　稳定运行状态时 COD 浓度沿芦苇床长度方向变化情况

1. 第 1 阶段　2. 第 2 阶段　3. 第 3 阶段　4. 第 4 阶段

表2列出芦苇床和控制床中进水沟和床身的负荷率.

根据观察，实验期间芦苇根系在进水沟中发育的情况要好于在床体的部位. 说明进水沟后面接上芦苇床就如2个生物反应器串联在一起，有利于COD的去除.

表2 芦苇床和控制床中进水沟和床身种植区的负荷/g·(m²·d)⁻¹

实验阶段	芦苇床			控制床		
	进水沟	种植区域	总 和	进水沟	种植区域	总 和
1	16.5	6.8	23.3	15.0	2.7	17.7
2	18.4	9.5	27.9	26.4	4.1	30.5
3	22.0	6.2	28.2	24.7	4.7	29.4
4	23.4	4.0	27.4	28.5	3.0	31.5

(4) COD冲击负荷的影响 图3显示进水的COD变化范围很大，约在400 mg/L—800 mg/L，但是出水的COD浓度很稳定，表明短时间的乳酪废水COD冲击负荷对处理工艺没有重大影响.

3.2 BOD_5的去除率

实验中芦苇床和控制床的BOD_5运行数据见图5. 4个阶段的实验数据表明芦苇床对BOD_5的去除率很高，介于96%—99%之间，与土壤表面状况无关，这与COD的去除情况相仿. 实验期间芦苇床的出水BOD_5浓度始终小于30 mg/L(美国二级处理排放标准). 对于控制床来说，BOD_5去除率略低，约为90%—93%. 统计数据分析表明芦苇床的运行数据要比控制床稍好一些，这与COD去除状况相似. 实际上BOD_5是与COD相关的. 进水的BOD_5：COD之值约为0.51—0.63. 而出水的BOD_5：COD之值也类似进水的比值. 根据测算，BOD_5的面积负荷率为12.6 g/(m²·d)—17.2 g/(m²·d)，大部分BOD_5去除率发生在进水沟段，芦苇种植区的BOD_5面积负荷率为2.4 g/(m²·d)—5.9 g/(m²·d).

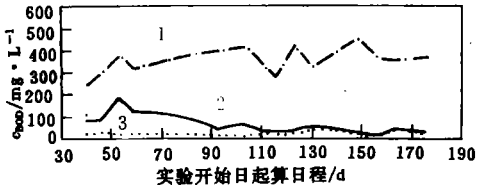

图5 实验中芦苇床和控制床的进水和出水BOD_5运行数据

1. 进水 2. 控制床出水 3. 芦苇床出水

4 结论

(1) 人工湿地是一种很好的处理乳制品废水的工艺. COD和BOD_5的去除能达到很高的去除率. 在处理机理中好氧过程和厌氧过程同时起作用.

(2) 芦苇床系统能承受COD超过平均浓度1.5倍的冲击负荷.

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The experiment was conducted in a vertical reactor with a total length of 3.5 m and cross section of 150 mm×150 mm to simulate flue gas desulfurization with lime and carbide lime slurry injection in the duct. Effects on So_2 removal were found, of such as the approach to adiabatic temperature at the exit, molar ratio of Ca to S, flux ratio of atomizing gas and slurry, gas inlet temperature, SO_2 initial concentration and gas residence time. Also, it was showed experimetally that SO_2 removal can achieve 65% at $\Delta T = 18$℃ and Ca/S = 1.5. In addition, a reaction model was developed, i.e., $\eta = 1 - [(T_i - T_{as})/(T_0 - T_{as})]^{-\frac{\alpha\beta}{\beta+R}}$, where α and β as equation parameters were determined by the conjugate gradient optimization method, and model predictions agree well with the experimental values with relative errors lower than 7%.

Key words: duct slurry injection, flue gas desulfurization, atomization.

Design of an Annular Denuder to Measure Atmospheric Ammonia. Tian Honghai et al. (Peking University, Beijing 100871): *Chin. J. Environ. Sci.*, **17**(5), 1996, pp. 20—23

A new trace gases sampler, annular denuder (AD), was developed and evaluated for the first time in China. Theoretical consideration was given and quality tests have been executed for designed AD. Its absorption efficiency for ammonia is over 97% and the detection limit is down to 0.15 $\mu g/m^3$ (10 m^3 sample volume). The intercomparisons of AD with filter pack as well as wet AD methods showed good agreement with one another. In springs of 1985 to 1992, the atmospheric NH_3 concentrations have been measured in Zhong Guancun District in Beijing City. The results range from 4.6 to 40 $\mu g/m^3$ with the average of 17 $\mu g/m^3$.

Key words: annular denuder, ammonia, determination of atmospheric ammonia.

The Evaluation of Economic Loss by the Acid Deposition Pollution in Chongqing. Chen Nian and Yun Qihou (Dept. of Geography, Southwest China Normal University, Chongqing 630715): *Chin. J. Environ, Sci.*, **17**(5), pp. 24—27

Acid deposition pollution in Chongqing is very serious. In order to define its economic losses, to provide a foundation for the decision making of economic and social development and to select a satisfied control plan, based on investigations in human health and damage of agriculture forest pollution, on tests of materials exposed and simulated experiment of acid deposition, using the methods of market-prices, wages costs and input-output comparison between benifits and losses, the author assessed its economic losses. The total economic losses caused by acid deposition in 1990 and 1994 are 504 million yuan and 1188 million yuan respectively, which are 2.47% and 2.0% of the GNP of the same years. The striking difference in the losses between the two years is caused mainly by the price factor.

Key words: acid deposition, economic loss, evaluation.

Fe-Si Sulfur Capture Promotion During Coal Briquet Combustion. Lin Guozhen et al. (Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085): *Chin. J. Environ. Sci.*, **17**(5), 1996, pp. 28—29

In this paper, A new Fe-Si promoter for sulfur capture was proposed for coal-briquet combustion at high temperature. Characterization of the slag left after combustion has been carried out by means of X-ray powder diffraction. A new phase $CaFe_3(SiO_4)_2OH$ was identified, which is thermally stable. This might explain its stabilizing role in sulfur fixation.

Key words: coal briquet, sulfur capture, XRPD.

COD and BOD_5 Removal Efficiencies in a Pilot Scale Constructed Reed Bed Receiving Cheese-Processing Wastewater. Huichang Zhu (Huan Qiu Environmental Engineering Co. Shanghai 201203), D.K. Stevens (Utah State University, UT84322, USA): *Chin. J. Environ. Sci.*, **17**(5), 1996, pp. 30—32

Under the influent COD concentration between 400—800 mg/L and temperature between 15—23℃, the constructed wetland functioned efficiently for COD removal. COD mass removal efficiencies reached 97 to 98%, and total removal rates reached 23.3 to 28.2 $g/m^2 \cdot d$. BOD_5 mass removal efficiencies reached 97 to 99%, while total removal rates reached 12.6 to17.2 $g/m^2 \cdot d$. The influent trench played an important role in COD and BOD_5 removal. Nearly 70 to 90% of the COD and BOD_5 removal occurred in the influent trench. During the entire experimental period, the reed bed effluent water quality met secondary discharge standards if there was no pH shock loading.

Key words: constructed wetland, subsurface flow, reed bed, control bed.

The Study on Regeneration Efficiency of Ion Exchange Resins to Enhance Nitrate Elimination. Gong Wenli et al. (Institute of Environmental Engineering Technology, Tsinghua University, Beijing 100084): *Chin. J. Environ. Sci.*, **17**(5), 1996, pp. 33—35

The enhanced nitrate elimination from groundwater by modifications of the CARIX process was described. For raw water with relative low hardness and elevated nitrate concentrations, the process was simplified by applying only an anion exchanger. In the service cycle, sulfate and nitrate species were replaced by bicarbonate species. In the regeneration step, the resin was converted into bicarbonate form by carbonic acid and magnesium oxide. Results of experiments in the laboratory scale have demonstrated that regeneration efficiency is improved apparently by adding magnesium oxide during regeneration. The optimum concentration of magnesium oxide was 0.4%. In this case, all of the resins used in the tests gained the average reduction of nitrate above 50%.

Key words: CARIX process, nitrate carbon dioxide, drinking water.