

# 造粒型高效固液分离技术用于电厂废水再生的试验研究\*

王晓昌 袁宏林 谭长鸿 张效智

**提要** 利用造粒型高效固液分离装置进行了西安西郊热电厂冲灰废水处理再生的现场试验研究。在总水力停留时间小于 10 min 的条件下,处理水浊度达到 3NTU 以下,分离污泥在装置内浓缩 1 h 以上,污泥含水率即可降到 85% 以下。装置抗冲击负荷能力强,操作灵活,能满足连续处理和间断处理两种运转的需要。

**关键词** 造粒流化床 固液分离 冲灰废水 无机混凝剂 有机高分子絮凝剂

## 0 前言

造粒流化床高效固液分离法是近年来提出的一种新技术。通过合理控制无机盐和有机高分子两种混凝剂的投加顺序、投量和混合、流化条件,该方法成功地用于高浓度悬浊液<sup>[1]</sup>、高色度悬浊液<sup>[2]</sup>和污水生物处理的固液分离<sup>[3]</sup>。与传统混凝沉淀工艺相比,造粒流化床处理工艺的理论基础在于造成初始颗粒微脱稳的条件实现逐一附着型絮凝操作<sup>[4]</sup>,从而改变絮凝体的分形构造,生成团粒型絮凝体<sup>[5]</sup>,大幅度提高固液分离效率。根据这一原理和工艺的要求,我们设计了适用于高浓度悬浊液分离的高效固液分离设备<sup>[6]</sup>,在西安西郊热电厂进行了冲灰废水处理再生的试验研究。

## 1 试验概要

### 1.1 废水性质和回用要求

西安西郊热电厂的冲灰废水产生于水力冲灰过程,主要成分是悬浮物,SS 浓度通常为数千 mg/L,最高可达上万 mg/L。原有的处理设施为一澄清池,由于废水量大幅度超过原设计能力,加之废水中既有比重大于 1 的渣粒,又有比重接近于 1 的细小灰粉,澄清处理效果很差。处理水回水池中仍为 SS 浓度近千 mg/L 的悬浊液,往往不符合回用的要求,只能部分直接外排,而注入大量的自来水补充水量。鉴于这种情况和限制排污的要求,该厂需要采用新的处理措施,最大限度地对冲灰废水进行再生利用。回用系统对处理水的水质要求是 SS 浓度小于

10 mg/L。

试验用原水取自原有澄清池的上部,SS 浓度在 1 000 mg/L 左右,用浊度仪测定的值为 280~700 NTU,原水中悬浮颗粒的粒径分布范围在 3~100 μm 之间,属于粗分散体系,但平均密度低于 2.0 g/cm<sup>3</sup>,这是澄清效果差的主要原因。颗粒 ζ 电位在 -30 mV 左右。

### 1.2 造粒型高效固液分离装置

图 1 为造粒型高效固液分离装置主体设备示意图。设备内部可分为四个主要功能区:内筒 A 为造粒流化床(造粒凝聚区);外筒 B 为环状存泥区;中部 C 为缓冲区;上部 D 为强化分离区。A 区底部为进水口,内部设有搅拌叶片,通过中心轴由安装于设备顶部的搅拌电机驱动,在稳定操作条件下,A 区内形成高浓度的流化态团粒悬浮层,悬浮层增长高出堰口后,团粒在扩散和重力作用下越过堰口落入 B 区得以分离。沉速小于上升流速的细微颗粒则越过 C 区进入 D 区得到强化分离。处理水通过顶部集水管和出水管流出。

试验装置处理能力为 2 m<sup>3</sup>/h,A 区上升流速为 18 m/h,装置总水力停留时间约为 9 min。

### 1.3 处理流程

现场试验的处理流程如图 2 所示。从原有澄清池上部抽取的废水首先进入调节水箱,经水泵和压水管进入造粒型高效固液分离装置底部。在水泵吸水管一端通过定量投药泵加入无机混凝剂(本试验采用聚合氯化铝 PAC),经水泵混合后在压水管中完成微絮凝,管内停留时间约为 30 s。在高效固液分离装置的入口处通过定量药泵加入少量的有机高

\* 教育部留学回国人员基金(1999),陕西省教委重点科研计划(99JK164)资助项目。

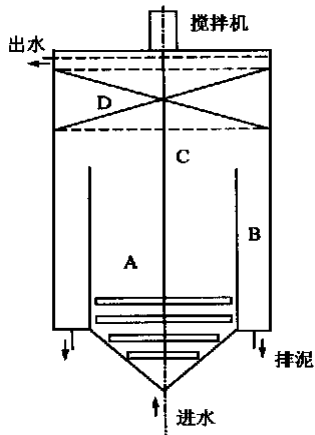


图1 高效固液分离主体设备示意

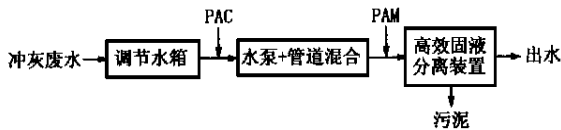


图2 处理流程示意

分子絮凝剂(本试验采用聚丙烯酰胺 PAM), 通过入口的射流扩散得到混合, 然后在装置中完成 1.2 中所述的造粒、分离过程。处理水从装置的顶部流出。分离的污泥定时从装置 B 底部的污泥排放口排出。

## 2 试验结果

### 2.1 处理水浊度

在 PAC 投量为 20~40 mg/L, PAM 投量为 1~3 mg/L 的条件下进行了废水的连续处理试验, 稳定运行条件下的处理效果如表 1 所示。

表 1 废水连续处理试验结果

项目	处理效果					
	280~700	280~700	280~700	280~700	280~700	280~700
原水浊度/NTU	280~700	280~700	280~700	280~700	280~700	280~700
处理水量/ $m^3/h$	2.0	2.0	2.0	2.0	2.0	2.0
PAC 投量/mg/L	20	30	40		30	
PAM 投量/mg/L		2		1	2	3
出水浊度/NTU	1.8~2.5	1.4~1.9	0.9~1.2	1.7~2.6	1.4~1.9	1.1~1.8

### 2.2 污泥含水率

在稳定运行条件下, 对装置存泥区(B区)中的污泥在不同存泥时间的含水率用重量法进行了测定, 结果如表 2 所示。

### 2.3 启动、间歇运转和抗冲击负荷情况

如图 3 所示, 现场试验中在装置初次启动(或放空后再启动)时, 流化态团粒悬浮层成长和稳定需要

一段时间, 因此初期会出现出水浊度较高的情况。但运行 1.5~2 h 后, 出水浊度即达到正常水平。但停机不放空, 保持装置 A 区底部有泥渣的情况下, 流化态团粒悬浮层很快就得到恢复, 不出现初期出水浊度偏高的情况, 因此, 装置在间歇运转的条件下也能正常工作。

表 2 污泥含水率

项目	数据				
存泥时间/h	0.5	1.0	2.0	3.0	4.0
污泥含水率/%	88	85	83	82	81

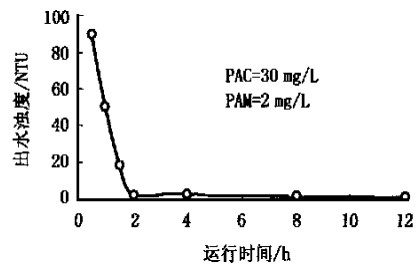


图 3 装置启动初期出水浊度情况

装置也具有抗冲击负荷的能力, 如图 4 所示。在超过额定负荷 25% ( $2.5 m^3/h$ ) 的情况下, 装置运行基本上不受影响, 出水浊度仅从 1 NTU 左右升高到 4 NTU 左右, 在超过额定负荷 50% ( $3.0 m^3/h$ ) 时, 装置运行仍能维持, 但出水浊度超过了 10 NTU。

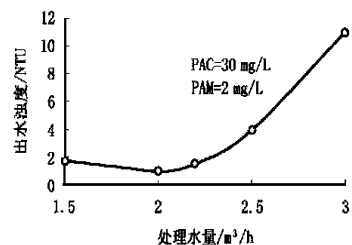


图 4 装置抗冲击负荷情况

## 3 讨论

### 3.1 造粒型高效固液分离处理的佳投药量控制

在造粒型高效固液分离操作中, 无机混凝剂和有机高分子絮凝剂投量的合理控制非常重要。无机混凝剂的投加应满足水中初始粒子微脱稳的要求, 通常可通过颗粒  $\zeta$  电位测定来确定最佳投量范围。图 5 为本试验实测的 PAC 投量与颗粒  $\zeta$  电位之间的关系。如图 5 所示, 对应于 PAC 投量为 20~40

mg/L, 颗粒  $\zeta$  电位在  $-15 \sim -20$  mV 的范围内。这一范围是以往从试验和理论分析两方面证实的造粒流化床操作最佳微脱稳条件<sup>[1,5]</sup>, 本试验结果进一步说明了该条件的合理性。与此对应, 造粒型高效固液分离操作所需的 PAM 系列有机高分子絮凝剂投量(以干量计)一般应为铝盐絮凝剂投量(以铝离子浓度计)的  $1/2$ <sup>[1,5]</sup>。本试验使用的 PAC 混凝剂的  $Al_2O_3$  含量为 20% 左右, 按铝离子计约为 13.7%。以此为基准的投量则为 2.7~5.5 mg。因此, 适宜的 PAM 投量应为 1.4~2.8 mg/L, 本试验采用的 PAM 投量基本上与此相符。

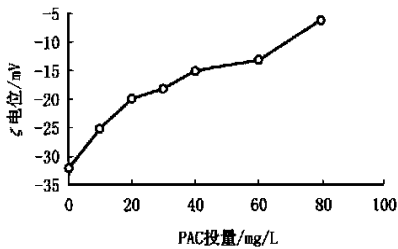


图5 PAC投量与  $\zeta$  电位的关系

### 3.2 造粒型高效固液分离技术的优越性

从本试验研究结果可以看到, 运用造粒型高效固液分离技术处理高悬浮物浓度工业废水在以下几个方面优于传统处理工艺:

(1) 处理效率高, 效果好。高效固液分离装置主体设备的水力停留时间为 9 min 左右, 加上前面水泵和管道混合, 总水力停留时间在 10 min 以内, 远比传统处理工艺所需的停留时间短。经这样短的处理时间, 装置出水浊度已满足工业回用水质要求。且需要的无机混凝剂投量低于传统混凝沉淀工艺(常规处理要求的脱稳程度为  $|\zeta| < 10$  mV<sup>[5]</sup>, 由图 5 可知, 所需投量远比本试验高), 配用的高分子絮凝剂投量也在很低的水平。

(2) 分离污泥含水率低, 无须专门浓缩处理。高效固液分离装置的分离污泥脱水性能非常好, 在存泥区停留 1 h 以上, 污泥含水率就降到 85% 以下, 无须专门浓缩即可进行最终污泥处理。

(3) 操作灵活性强, 能满足不同处理需要, 高效固液分离装置不仅能进行废水连续处理, 也能进行间歇处理, 且抗冲击负荷能力强, 在超过额定负荷 50% 的情况下也基本上能保证处理水质。

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收稿日期: 2001-1-27

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## ABSTRACTS

**On Advanced Treatment of High Quality Drinking Water** ..... *Chen Xiangming et al* ( 1 )

**Abstract:** Nanofiltration has been adopted to treat slightly organics polluted water in a city water distribution network. By this way the hazard substances are removed and the favorable elements reserved. The output water is good enough to meet the requirement of high quality drinking water.

**On the Elevated Road Rainwater Drainage Facility in Shanghai** ..... *Wang Ronghe et al* ( 5 )

**Abstract:** Under the research and investigation on the inner ring elevated road of Shanghai, this paper begins with the infections of the road slope to the storm catchment's distance. It presents the relationship of catchment's distance, time and rainstorm intensity. It also presents the relationship of road slope, rainfall and rainwater depth of the road and the relationship of gully, rainfall and the gully overflow. This paper presents an idea that we should separate the drainage system into 4 parts to compute. It concludes that the type and size of gully, short drainpipe and suspended drainpipe are the main infectors for the storm drainage system of the elevated road.

**On Purification of Slightly Polluted Raw Water by Coagulant and microfiltration Process** ..... *Mo Li et al* ( 12 )

**Abstract:** By an improved jar test the suitable dosage of coagulant PAC for a combination process of coagulation and microfiltration (MF) was determined as 2~3 mg/L. Under this dosage condition, a laboratory test of coagulation-MF process was continuously conducted to treat slightly polluted raw water. It was found that the removal ratios were 85%~95%, 37%~52% and 58%~81% for turbidity, OC and UV<sub>254</sub> respectively. These were 24% and 26% higher for OC and UV<sub>254</sub> respectively than those of the direct membrane filtration process without coagulation. In the continuous operation, the characteristics of MF fell down fast at beginning and then decreased slowly and went stable. At the stable period, MF characteristics of the coagulation-MF process were found to be lower than that of the membrane filtration without coagulation. The mechanism needs to be studied further.

**Sludge Dewatering Operation in Urban Wastewater Treatment Plant** ..... *Zhao Fuxin et al* ( 16 )

**Abstract:** The operating and management of sludge dewatering facility serving for A<sup>2</sup>/O process in the urban WTP in Baoding City are presented. Factors, which influence the sludge dewatering, are discussed and an optimized manipulation for this unit operation has been obtained. By this way the sludge is dewatered duly and the water content of the sludge cake is in the range of 75% to 80%. The expense for chemical dosage decreases because the consumption of cation coagulant polyacrylamide (PAM) is reduced. The management of sludge dewatering operation is also reviewed in this paper.

**Study on Computational Method for On-Line Nodal Demand Forecasting in Microcosmic Model of Water Supply Network** ..... *Tao Jianke et al* ( 25 )

**Abstract:** In this article collating hour system water demand data, forecasting hour system demand and making patterns of water consumption and calculating nodal water demand forecasting value researched area are elaborated. On this basis a microcosmic mathematical model of water supply network had been established for on-line computing of nodal water demand. This method has been verified in practice.

**Process Design of Artificial Wetland System Water Purification** ..... *Liu Quanzhong* ( 35 )

**Abstract:** The utilization of nature water resource will be improved because the water could be purified through the biological function of microbes living around the root system of plants and the multi-layer filtration of soil in the wetland circumstance. In this paper the mechanism, process and feature of wetland purification are presented emphatically. The design of artificial wetland system is also described with a practical wastewater treatment project with capacity of 1000 m<sup>3</sup> per day.

**Water Dechlorination by KDF55 Filtration** ..... *Zhang Shoukai et al* ( 37 )

**Abstract:** The residual chlorine in water could be changed into Cl<sup>-</sup> anion by electro-chemical reaction (oxidation reduction) on KDF55 filtration medium, which is made of high pure Cu/Zn alloy. The mechanism and experiment are introduced and the chlorine removal comparison test by KDF55 and granulated activated carbon is listed with two practical examples.

**Treatment of Ash-Washing Wastewater by a High Efficiency Solid/Liquid Separator Using Fluidized Pellet Bed Technique** ..... *Wang Xiaochang et al* ( 39 )

**Abstract:** A high efficiency solid/liquid separator was developed using fluidized pellet bed technique and used for the

treatment of ash-washing suspension in Xi'an Xijiao Thermal Power Plant. Within a hydraulic retention time of 10 min, the high concentration suspension was efficiently purified to turbidity lower than 3 NTU. After thickening for 1 h, the separated sludge could reach moisture content as low as 85%. The separator is able to resist sudden increase in flow rate and can meet the needs of continuous and intermittent operation.

**On Circulating and Reuse of Intermediate Wastewater in Paper Making** ..... *Wu Yingjuan et al* (42)

**Abstract:** Industrial experiment on composed process of two-stage aerated filtration and floatation-rapid filtration was conducted to treat intermediate wastewater in paper making plant. In this experiment the characteristics of mixed filtration media composed of rare-earth sandstone, quartz sand and stone coal were researched. The results have shown that this process with fair effect is feasible.

**Design of Wastewater Treatment and Drainage System for Quanchai Co.** ..... *Yu Guosheng et al* (45)

**Abstract:** There is a combined sewer system in Quanchai Diesel Engine Company Ltd. The combined wastewater is treated by oil-separation, air-floatation, biological contact oxidation and filtration to meet the requirement of wastewater discharge standard. The pipeline of the sewer system was reconstructed to avoid water logging inside the plant area.

**Application of Carrousel Ditch to Treat Straw Pulp Making Wastewater** ..... *Tian Xuzhong et al* (48)

**Abstract:** A wastewater treatment plant treating the intermediate wastewater of straw pulp preparation with capacity of 500 thousand cubic meters per day was constructed and put into operation in Yinhe Paper Making Group Co. in Shandong Province. The design considerations and operating status of this WTP with Carrousel oxidation ditches as major procedure of secondary biological treatment are presented in this paper. Fair performance has been obtained with COD removal of 80% and certain decreasing of non-degradable AOX (adsorptive organic substances) under conditions of MLSS 5~ 6 g/L in Carrousel process.

**Discussion on Design and Operation of Tannery Wastewater Treatment** ..... *Wei Jiatai* (52)

**Abstract:** The characteristics of tannery wastewater are researched and the experiences in process design and problems arisen in operation of a practical facility treating tannery wastewater are summarized. The author thinks that the enhanced pre-treatment, reduced loading of biological process and just selection of sludge disposal might be key-points to improve the entire treatment process.

**Design of Circulating Water System for Recreation Pools in Biguiyuan Amusement Park** ..... *Li Yunfang et al* (55)

**Abstract:** The Recreation Pool in Biguiyuan Amusement Park in Shunde City, Guangdong Province was designed in June 2000 and the construction was completed in January 2001. In this paper the design of a small capacity water circulating system which serves for wave pool, circulating canal, water game pool and other recreation units in the park is presented. Also some constitutional structures of auxiliary facilities are given.

**Problems on Fire Water System of Residential Building** ..... *Wang Dongqing* (63)

**Abstract:** Always it is confused by a series of uncertain problems when a fire water system design is done according to the currently available Design Norm of Building Fire System. Among these problems the indefinite stands of temporary high pressure, pneumatic tank and outdoor high pressure water system, the un-oriented principal relationship of automatic sprinkling system and the indoor hydrant system, the indisposed coordination of start up and control of fire pumps with the fire duration and the numbers of outlets of outdoor hydrants are included. The author of this paper thinks that these problems need to be taken into consideration in revision of the design norm.

**On Application of Sludge Dewatering Facility for the Exhaust Quench Water of Converter** ..... *Zhu Zhenglin* (82)

**Abstract:** Four kinds of sludge dewatering equipment applied in the treatment of exhaust quench water of converter in a steel works namely frame filter-press, belt filter-press, horizontal belt vacuum filter and rolling drum filter-press are discussed for their application and operation. The performance, effectiveness, investment and operating expenses of these facilities are compared.

**Diagnostic Expert System for WTP** ..... *Shi Hanchang et al* (88)

**Abstract:** A diagnostic expert system using qualitative reasoning has been developed for wastewater treatment plant operation. A diagnosis module to detect the fault in the activated sludge process is presented. The combined strategy of using both forward chaining and backward chaining within the expert system allows the number of questions asked to an operator to be minimized. Fault trees were used to represent the knowledge for fault diagnosis. The expert system was continuously being tested, not only in the laboratory, but also in a full-scale treatment plant with the capacity of 40 000 cubic meters per day. And a successful experience was achieved.