

# 一种新颖的高温高压静电除尘技术

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**摘要:** 电子发射式高温高压静电除尘技术是一种新颖的烟气净化方法。通过动态试验, 对各种条件下阴极的热电子发射性能及其中毒特性进行了探讨, 分析讨论了电子发射式高温高压静电除尘器的除尘性能及其实用价值。此外, 还对该项技术在各种领域的应用前景进行了讨论。

**关键词:** 电子发射; 静电除尘; 烟气; 高温高压

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## 1 引言

高温高压烟气除尘是煤的洁净利用和发电技术领域的国际难题, 它关系到 PFBC 和 IGCC 能否实现工业应用, 因而是近几十年来能源工程界倍受瞩目的一项课题。迄今为止, 有关高温高压烟气除尘的报道很多, 诸如静电除尘, 陶瓷过滤器和颗粒层过滤器等。由于在高温高压环境下, 有许多技术问题没有根本解决, 例如普通电晕式静电除尘器的电绝缘、操作稳定性、运行费用等问题; 陶瓷过滤器的材料很脆易碎, 安装和维护要求高, 易受污染, 清灰困难等, 这些都严重制约了它们在高温高压条件下的实际运用。电子发射式高温高压静电除尘技术是一种新颖的高温高压烟气净化方法, 与传统的电晕式静电除尘技术不同, 它是以某种特殊复合材料制成的阴极在高温下发射电子的方法, 使烟气中的粉尘荷电, 然后依靠电场力的作用将其捕集并除去。研究结果表明, 该项技术特别适用于高温烟气的除尘, 有广泛的应用前景。

## 2 荷电特性

在高温高压烟气环境中, 所开发的复合阴极材料能否长期、稳定地发射出足够的电子, 是该技术能否实际运用的关键。为此, 在一座自行设计、制造的动态试验台上进行了阴极热电子发射特性研究。结

果表明, 即使在较高的压力(0.6 MPa)下, 温度为 700 °C 时, 只需在荷电区施加 2 500 V 电压, 设备运行初期, 荷电区的电流密度仍可高达  $14 \text{ mA/m}^2$ , 比传统的电晕式静电除尘器高两个数量级以上。这在一定程度上说明, 电子发射式静电除尘器比电晕式静电除尘器更适用于高温(高压)烟气的除尘。具体来讲, 在不减少除尘效率的条件下, 与后者相比, 前者荷电区的长度可大大减少, 因而缩小了设备的体积, 减少了成本。换句话说, 若设备的体积不变, 前者对尘粒尤其是微细尘粒的捕集效率可大大提高。

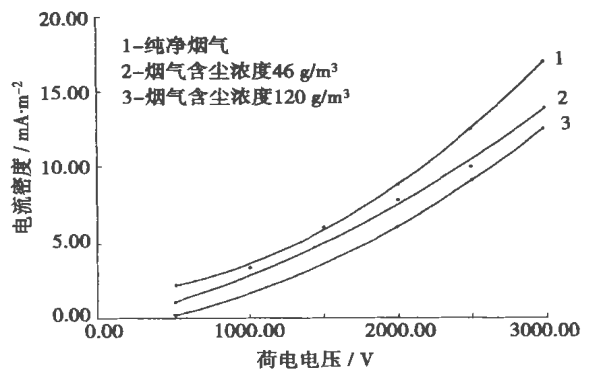


图 1 含尘浓度对荷电区电流密度的影响

对于电晕式静电除尘器(目前所有的商用静电除尘器均属此类), 当所处理的气流含尘浓度大到一定数值时(一般为  $50 \text{ g/m}^3$  以上), 电晕现象消失, 尘粒在电场中根本得不到电荷, 电晕电流减少到零, 失去除尘作用, 这种现象我们称之为“电晕闭塞”。由图 1 可见, 对于电子发射式静电除尘器, 在一个较宽的含尘浓度范围(0 ~  $120 \text{ g/m}^3$ )内, 虽然含尘量对荷电性能有一定的影响, 但荷电区的电流密度仍然保持在较高的水平且比较稳定, 没有出现突然减少或急剧增大等异常情况, 说明没有发生类似于“电晕闭塞”的“发射屏蔽”现象, 以及“电流短路”现象, 这两

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者均会导致除尘器不能正常工作。

在高温(平均温度 750 °C左右)烟气环境下, 荷电区电流密度随时间的衰减情况见图 2。由此图可见, 高温烟气对阴极有一定的毒化作用。这是因为烟气中含有一定数量的 SO<sub>2</sub>、CO<sub>2</sub>、CO、NO<sub>2</sub> 和 H<sub>2</sub>O (气)等气体杂质, 在高温条件下, 它们对阴极材料具有不同程度的腐蚀作用, 造成阴极热电子发射能力的下降, 有关阴极的中毒机理有待进一步的理论与实验研究。尽管如此, 在高温烟气环境下累计运行 2 000 h 以后, 荷电区的电流密度仍高达 12 mA/m<sup>2</sup> (远远高于电晕式静电除尘器), 且趋于稳定, 说明电子发射式静电除尘器可在高温烟气环境下, 长期有效地工作。

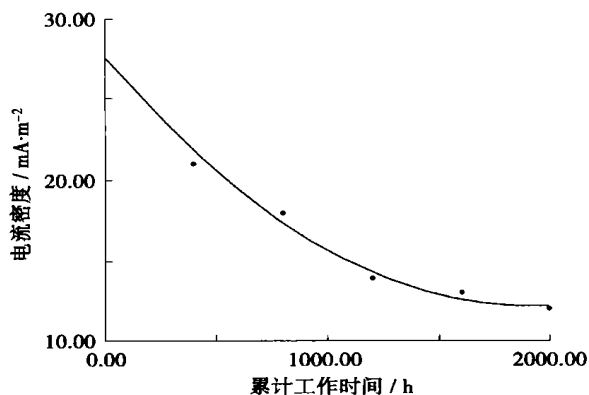


图 2 在高温常压烟气环境中荷电区电流密度的衰减曲线

### 3 除尘性能

图 3 为在不同压力条件下, 荷电电压和收尘电压分别为 2 500 V 和 6 000 V, 流速和入口含尘浓度分别是 2 m/s 和 8 g/m<sup>3</sup> 时, 除尘效率随温度的变化规律。由此可以发现:

除尘效率随温度的升高而增加, 这是由于阴极热电子发射密度随温度的升高而增大, 而对于所选用的粉尘试样(南京下关电厂飞灰), 在试验温度范围内, 烟气粘度和尘粒比电阻的变化对除尘效率的影响不是很显著。

图 4 给出了温度 720 °C, 荷电电压 2 500 V(其它参数值同图 3)时, 在不同的压力工况下用下关电厂飞灰进行试验时除尘效率随收尘电压的变化规律。

由此可见, 电子发射式静电除尘器的除尘效率随收尘电压的增加而提高, 这与电晕式静电除尘器的规律完全一致, 原因是收尘区电场强度增加, 尘粒

驱进速度会相应增大。另外从图 3 和图 4 还可以发现, 与常压工况相比, 尽管高压时除尘效率有所下降, 但只要收尘电压达到 6 000 V, 荷电电压达到 2 500 V, 在温度 720 °C, 压力 0.6 MPa 的烟气环境下工作时, 电子发射式静电除尘器的除尘效率仍可高达 92%以上, 这进一步说明该除尘方式适用于高温高压烟气的除尘。

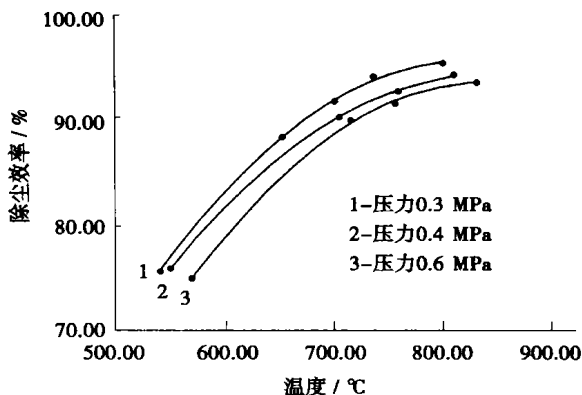


图 3 不同压力工况下, 除尘效率与温度关系

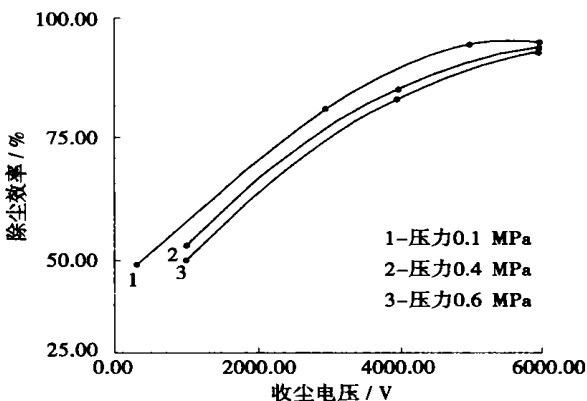


图 4 收尘电压对除尘效率的影响

### 4 推广应用前景展望

如前所述, 电子发射式静电除尘器(EEESP)在高温(高压)环境下具有良好的除尘性能。基于其基本原理, 这一新颖的技术能够推广应用到许多领域。

(1) 如果对荷电区作适当的改进, 比如采用自加热式阴极板, 即可应用于常温或较低温度环境下的除尘。

(2) 对于高温高压烟气的除尘, 美国曾经使用陶瓷过滤器进行过成功的试验, 但由于诸多原因其除尘效率不高(对电厂飞灰仅为 90%左右)。如果

我们在陶瓷过滤器之前,加设一个类似于 EEESP 荷电区的荷电段,形成一个电子发射式过滤器,这样,荷电尘粒在流经陶瓷过滤器时,由于静电力的作用,也许更容易被捕捉,尤其是对于那些细小的尘粒,效果可望更佳。

(3) 在汽车工业,柴油车排气中含有大量的粒子状物质,为了减少对环境的污染,有人曾采用旋风式除尘器将其分离。如果我们将电子发射式电除尘器与普通的旋风式除尘器结合起来,将阴极制成某种形状(比如圆柱形),以高温尾气作热源,以汽车的 12 V 蓄电池作电源,利用油浸感应线圈产生荷电电压,形成电子发射式静电旋风除尘器。姆莱纽克斯曾经以氯化铵( $d_p < 1 \mu\text{m}$ )作粉尘进行过试验,发现这些粉尘用普通的旋风式除尘器几乎不能分离掉,但在静电旋风除尘器中却可以几乎 100%地捕集。由此可见,运用电子发射式静电旋风除尘器,不仅可以有效地利用汽车排气中的废热,而且有可能显著地提高对尾气中粒相物质,尤其是那些细小微粒的捕捉效率。

总之,电子发射式高温高压静电除尘器是一种崭新的电除尘技术,它具有广泛的应用前景,值得进一步深入的探索和研究。

## 5 结 论

(1) 电子发射式静电除尘器在高温高压烟气环境下具有良好的荷电性能,与传统的电晕式静电除尘器相比,它似乎更适用于高温(高压)条件下的除尘。

(2) 尽管高温(高压)烟气对发射极有一定的毒化作用,但电子发射式静电除尘器仍然可以在高温(高压)烟气环境下长期有效地工作,表明它具有较高的实用性。

(3) 与电晕式静电除尘器不同,电子发射式静电除尘器可以在较宽的含尘浓度范围内正常工作,因此在处理高含尘气流时,可以省去预除尘装置,使设备大为简化。

(4) 与电晕式静电除尘器一样,提高收尘电压,可使电子发射式静电除尘器的除尘效率显著提高。然而,与前者不同,提高温度可以大大改善后者的除尘性能,这正是由两者荷电方式的本质区别所决定的。

(5) 电子发射式高温(高压)静电除尘技术具有良好的应用前景,如果作适当的改进也可推广应用到其它领域。

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( 辉 编辑 )

## 启 事

印刷厂在装订过程中出现疏漏,将 2002 年第 4 期 423~440 页个别册重复装订,给读者阅读带来不便,特向读者致歉。

感谢邵维文教授指出这一疏漏。

——编辑部

optimum range of variable offset functions being eventually identified. **Key words:** marine main boiler, variable offset, double-crisscross amplitude limit, control system

椭圆封头旋压控制参数确定的研究 = **An Investigation Concerning the Determination of Spinning Control Parameters for an Elliptical Boiler Head** [刊, 汉] / LIU Xing-jia, WANG Zuo-min, SUN Ming-qi, et al (Thermal Energy Engineering Department, Harbin University of Science & Technology, Harbin, China, Post Code: 150080) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 187—189

The technical difficulty of a profile spinning method for making elliptical boiler heads consists in the determination of relevant technological control parameters. On the basis of analyzing the forming mechanism of elliptical-head profile spinning a locus equation for the spinning process has been worked out. Then, proposed in a relatively systematic way is a method for the determination of the following: the parameters of the involute profile form-plate for the control of a boiler head spinning, and the spacing and sequence of the spinning process. This was followed by a successful technological test. The above information can serve as a guide during the determination of profile (or numerical control) spinning control parameters for other similar rotating bodies. **Key words:** boiler head, spinning, control parameters, profile form plate

柴油机注汽涡轮增压系统 = **Steam-injected Turbocharged System of a Diesel Engine** [刊, 汉] / WEN Xue-you, LU Ben, XIA Jun-hong (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 190—193

During the low load operation of a turbocharged diesel engine there may emerge a series of inherent characteristics, such as insufficient supercharged pressure, a small excess air factor for combustion and high exhaust-gas temperature, etc. To deal with the above deficiencies, a new method has been proposed. It involves the use of exhaust waste heat of a supercharger to produce water steam, which is to be injected into a turbine to enhance the pressure ratio and airflow rate of the supercharger. This will result in an improved matching of the turbocharger and diesel and a better diesel performance. **Key words:** turbocharging, steam injection

废旧含氯塑料热解及其能源利用研究 = **A Study of the Pyrolysis of Chlorine-containing Scrap Plastics and Their Waste Energy Utilization** [刊, 汉] / XIAO Rui, JIN Bao-sheng, ZHANG Ming-yao (Education Ministry Key Lab on Clean Coal Combustion and Power Generation under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 194—196

Chlorine-containing plastics (polyvinyl chloride) in municipal waste are a major source of corrosion and secondary pollution in municipal solid-waste incinerators. With the use of a thermogravimetric-differential analyzer the pyrolytic characteristics are studied of PVC (polyvinyl chloride) and HDPE (high density polyethylene) both with a chlorine content of 53.8%, and CPE (chlorinated polyethylene) with a chlorine content varying from 10% to 46%. Based on the test results of the graded pyrolysis of chlorine-containing plastics the authors have proposed a technological process for the pyrolysis of the chlorine-containing plastics and the combustion of their residue. Furthermore, the performance of a power plant based on the above-cited process is calculated and analyzed. **Key words:** chlorine-containing plastics waste, pyrolysis, combustion, waste-energy recovery

一种新颖的高温高压静电除尘技术 = **An Innovative Technology of High-temperature and High-pressure Electrostatic Precipitation** [刊, 汉] / GU Zhong-zhu (College of Power Engineering under the Nanjing Normal University, Nanjing, China, Post Code: 210092), CAI Song, WEI Qi-dong (Research Institute of Thermal Energy Engineering under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 197—199

Electron-emission type of high-temperature and high-pressure electrostatic precipitation represents an innovative technology for purifying flue gases. Through dynamic tests the performance of thermal electron emission at a cathode and its poisoning characteristics under various conditions are explored. The dust removal performance of and practical benefits attainable from an electron emission-based high-temperature and high-pressure electrostatic precipitator are analyzed and discussed. Furthermore, the usage prospects of the above technology in various industrial sectors are also discussed. **Key words:** electron emission, electrostatic precipitation, flue gas, high-temperature and high-pressure

深圳西部电厂 4 号机组海水脱硫系统监测分析 = **Monitoring and Analysis of a Seawater Desulfurization System for Plant No. 4 of Shenzhen West Power Station** [刊, 汉] / WU Lai-gui (Shenzhen West Electric Power Co. Ltd., Shenzhen, China, Post Code: 518052) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 200—202

The technological design of a seawater desulfurization system for plant No. 4 of Shenzhen West Power Station is described in detail. The flue gas parameters ( $\text{SO}_2$  content, temperature) and water quality parameters ( $\text{SO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ , pH, DO and COD, etc.) under various operating conditions as well as before and after desulfurization were monitored and investigated along with an analysis of their variation mechanism. Furthermore, the variation of the contents of deleterious substances, such as heavy metals in seawater, were also monitored and analyzed both prior to and after desulfurization. **Key words:** seawater desulfurization, absorption, desulfurization efficiency, water quality restoration, heavy metal

湿式烟气脱硫除尘系统工艺的研究 = **A Study of the Wet-process Flue-gas Desulfurization and Dust Removal Technology** [刊, 汉] / WANG Zhu-liang, CHEN Jin-yu, WEN Jing-ping, et al (College of Energy and Power Engineering under the Jiangsu University, Zhenjiang, China, Post Code: 212013) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 203—204, 205

An exploratory study was conducted of the problems existing in a flue-gas desulfurization system. On the basis of the current usage situation overseas proposed is a flue-gas desulfurization and dust removal system suited for coal-fired boilers operating in China. Some specific cases of usage are cited to illustrate the technological merits of the recommended desulfurization system. **Key words:** desulfurization, flue gas, system technology, boiler

燃气轮机小管径自然循环余热锅炉 = **Gas-turbine Natural-circulation Heat Recovery Boiler with Tubes of Small Diameter** [刊, 汉] / CHEN Ming, Ma Yun-xiang, WANG Yan-bin, et al (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 205—207

国外船用大中型齿轮传动形式的发展现状 = **Recent Advances in the Development of Marine large and Medium-sized Gear Transmission Modes Worldwide** [刊, 汉] / FAN Wei, BI Xiao-xu, JI Gui-ming (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(2). 208—211

The status quo of technical development of marine large and medium-sized gear transmission modes worldwide is described. Listed are the construction features of a variety of power transmission schemes employed for GT (gas turbine), CODOG (combined diesel or gas), COGAG (combined gas and gas), COGAS (combined gas and steam) units as well as triple power distribution transmission systems of air-cushion landing craft. It is noted that techniques involving power superimposition, power distribution, transverse crisscross connections, automatic synchronizing clutches, and astern running through the use of a hydraulic coupling, etc all represent the development and application trends of the power transmission systems of geared drive units. **Key words:** marine power transmission device, gear transmission, power transmission mode