

# 煤粉浓缩预热调节燃烧系统在 150 t/h 煤粉炉上的应用

张建胜, 吕俊复, 张 海, 岳光溪

(清华大学 热能工程系, 北京 100084)

**摘 要:**介绍了清华大学新研制的一次煤粉浓缩加一次风预热自动控制装置组成的燃烧系统。该系统利用一次风管弯头来进行煤粉的浓淡分离, 具有结构简单分离效果好的特点; 通过温度的测量来控制预热调节门的开度实现对卷吸热烟气量的控制, 能够适应不同煤种稳定着火的要求。利用该燃烧系统对丹东化纤股份有限公司热电厂的一台 150 t/h 的煤粉炉进行了改造并进行了 10 个工况的运行实验, 结果表明, 该燃烧系统具有良好的煤种适应性和负荷调节性, 在各种工况下可以保持燃烧稳定, 并且燃烧效率高。

**关 键 词:**煤粉炉; 浓缩; 预热; 燃烧系统

中图分类号: TK229.6 文献标识码: B

## 1 引 言

目前国内很多电站锅炉不仅燃用煤种和设计煤种不同, 而且煤种也不稳定。同时随着电力事业的发展, 电厂发电量峰谷差日益加大, 锅炉负荷变动频繁, 这些因素要求锅炉的燃烧系统和燃烧器有良好的调节能力和变工况性能, 在煤种和负荷变化时能够保证稳定经济地运行。

辽宁省丹东化纤股份有限公司热电厂的 3 号炉是 WGZ-150/54-I 型次高压煤粉锅炉, 锅炉呈 II 型室内布置, 单锅筒, 固态排渣, 配备两套中速钢球磨煤机, 中间储仓热风混乏气送粉系统, 四角偏侧墙布置直流燃烧器。为满足公司生产发展的需要, 热电厂于 1994 年对锅炉进行了增容改造, 改造后锅炉的主要参数见表 1。

表 1 3 号炉扩容改造后的主要参数

	数 据
过热蒸汽压力/MPa	5.2
过热蒸汽温度/℃	450
产汽能力/t·h <sup>-1</sup>	150
低负荷能力/%	70

为使锅炉更好地适应煤炭市场的变化及机组调峰运行的需要, 提高机组运行的经济性和安全性, 热电厂决定采用清华大学新研制的一次风浓缩加装一次风预热自动控制装置组成的燃烧系统对 3 号锅炉的下一风燃烧器进行改造。

## 2 浓缩预热调节燃烧系统原理

锅炉燃烧的煤粉由一次风携带送入炉膛, 煤粉气流在刚进入炉膛时, 如果能够及时着火, 则对稳定燃烧、缩短燃烧进程和提高燃烧效率至关重要<sup>[1]</sup>。要使煤粉及时着火, 必须向煤粉气流提供足够的热量, 使之达到着火温度, 这部分热量即为所需的着火热<sup>[2]</sup>。如果着火区域能够提供的热量为一定数, 则当煤粉气流的着火热高时, 着火推迟; 着火热低时, 着火提前。煤粉浓缩预热调节燃烧系统很好地解决了降低风粉着火热和提供风粉着火所需热量这两个方面的问题。

首先通过煤粉浓淡分离将煤粉浓度浓缩到一个最佳值来降低风粉着火热。本系统利用一次风进入喷口前的一次风管弯头来进行浓淡分离, 以此提高煤粉浓度, 如图 1 所示。大量的研究和运行实践表明, 在一定范围内, 随着煤粉浓度的提高, 着火温度大幅度下降<sup>[3~4]</sup>。而进入炉膛的一次风因煤粉浓度高而使单位重量的煤粉在单位时间内可以获得的热量提高, 升温速度快, 加速了煤粉挥发分的析出, 所以煤粉着火时间短。这对低负荷时迅速着火和稳定燃烧是极为有利的。

其次利用热烟气回流进行风粉预加热。一次风浓相进入炉膛后, 能自己卷吸炉膛中的热烟气回来, 加速对浓相的加热, 即一次风在出喷口前就已经被预加热, 如图 2 所示。而且这种烟气回流可以通过温度的测量来自动调节, 图 2 中的煤粉预热调整门

的开度来进行控制。在高负荷时,可使烟气不回流或少回流,而低负荷时则加大烟气回流量;在煤种发生变化时,对易着火和易结焦的燃料,可使烟气不回流或少回流,对不易着火的燃料,则可加大烟气回流量。

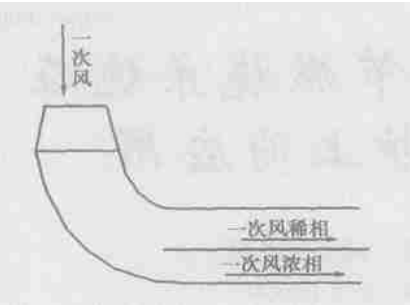


图 1 浓缩部分示意图

烧器的主要设计参数见表 3, 其布置见图 4。

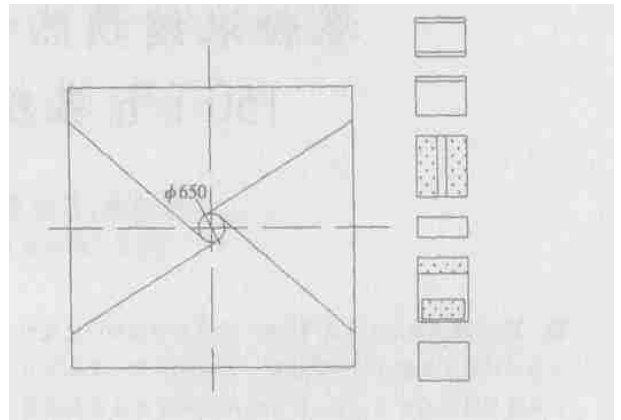


图 4 改造后燃烧器 布置示意图

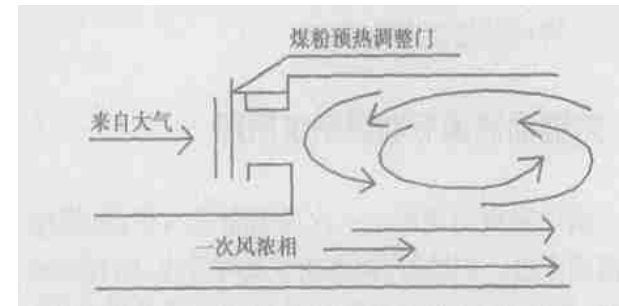


图 2 喷口部分示意图

表 2 改造前后的 燃料全分析

	改造前	改造后
$V_{daf}/\%$	23.00	13~30
$Q_{net.ar}/\text{kJ}\cdot\text{kg}^{-1}$	17 074	23 000~20 000

表 3 新燃烧器主要设计参数

	风率/ $\%$	风速/ $\text{m}\cdot\text{s}^{-1}$	风温/ $^{\circ}\text{C}$
一次风	25	24	138
二次风	62.2	44.7	330
三次风	12.8	48.4	138

### 3 燃烧系统简介

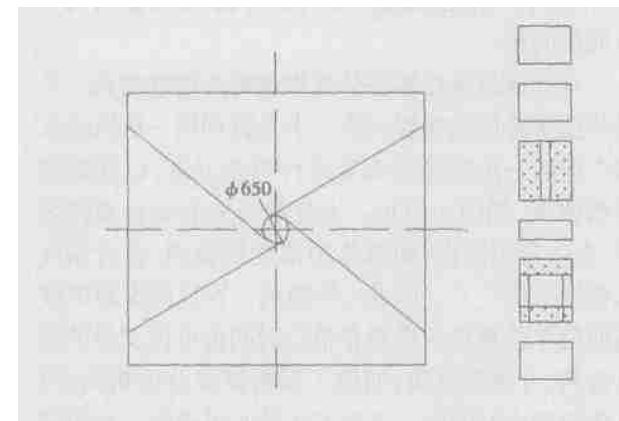


图 3 原燃烧器 布置示意图

3 号炉的燃烧器四角偏侧墙布置, 向炉膛内射流, 形成同向逆时针旋转的切圆, 假想切圆直径为  $\Phi 650\text{ mm}$ , 见图 3。本次燃烧系统改造前使用的燃料为混煤, 改造后要求燃料的适应范围增加, 如表 2 所示, 改造后的锅炉可以使用的燃料挥发分含量和热值范围都比原来有了明显的提高。系统改造后新燃

锅炉改造完成后, 对一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统进行了性能考核, 主要考察燃用广谱煤种的适应性及锅炉燃烧的经济性和安全性及机组低负荷能力。燃烧器改造完成后, 先完成冷态空气动力场试验。在冷态空气动力场试验数据的基础上, 进行锅炉燃烧调整及热态试验。

这次改造采用的燃烧系统, 具有对广谱煤种较好的适应能力, 无须在炉内设置卫燃带, 这样就会使热电厂在燃煤选择方面具有更大的空间, 对过去不能用的丹东和本溪地区的低挥发份贫煤, 可以大量直接燃用, 同时也可根据煤炭市场行情, 采用其它地区更为经济的煤种, 以降低燃料采购成本, 提高热电厂的经济效益。总之采用一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统后, 为电厂的安全和经济运行创造了有利条件。

由于实验时间是夏季, 没有太大热负荷, 150 t/h 锅炉单台运行足可满足需要, 而且还有剩余负荷。

试验在不影响丹东化纤股份有限公司正常生产的前提下进行, 视生产需用负荷情况适时进行各种负荷试验, 因此最大负荷只做到了 138 t/h, 最低负荷在挥发份为 26% 时做到了 80 t/h 不投油稳燃, 在挥发份为 13% 时做到了 106 t/h 不投油稳燃。在各试验工况下, 锅炉燃烧稳定, 相应参数调整灵敏, 机组运

行正常。

各种试验工况下进行了取样分析和热效率试验, 试验煤质和试验工况及结果见表 4; 实际运行不同燃料(主要指挥发份含量)对飞灰含碳量的影响见图 5; 实际运行不同燃料对锅炉效率的影响见图 6。

表 4 改造后热效率试验汇算表

	工况 1	工况 2	工况 3	工况 4	工况 5	工况 6	工况 7	工况 8	工况 9	工况 10
锅炉负荷 $D/t \cdot h^{-1}$	130	90	120	138	80	103	116	106	130	106
煤种	混煤	混煤	小窑煤	小窑煤	小窑煤	小窑煤	混 1	混 1	混 2	混 2
全水份 $M_t/\%$	9.21	6.846	8.76	4.82	6.74	6.74	4.69	4.69	6.67	6.67
收到基灰份 $A_{ar}/\%$	27.44	37.66	28.11	34.31	28	28	28.04	28.04	26.32	26.32
干燥无灰基挥发份 $V_{daf}/\%$	24.24	26.63	21.37	23.14	20.77	20.77	15.20	15.20	13.03	13.03
应用基低位发热量 $Q_{net,ar}/\%$	20 636	17 514	20 315	19 736	21 961	21 961	22 935	22 935	22 489	22 489
排烟温度 $\vartheta_{py}/^{\circ}C$	160	164	165	167	155.5	160	161	162	160	161
锅炉热效率 $\eta/\%$	89.15	87.47	88.09	87.13	88.05	88.68	87.51	86.17	86.86	86.14
燃烧效率 $\eta_b/\%$	97	96.08	96.38	95.23	96.79	97.03	95.31	94.45	94.80	94.60

注: 混 1=无烟煤 67%+老营煤 33%; 混 2=无烟煤 75%+老营煤 25%

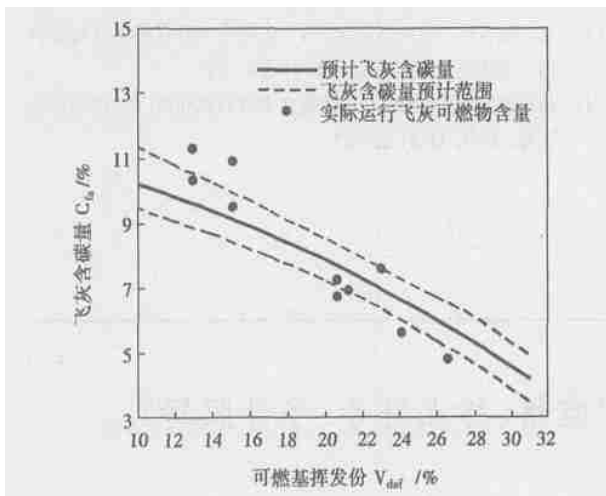


图 5 飞灰含碳量预测值和实际运行结果

由图 5 和图 6 可知, 实际运行结果与采用数值计算方法得到的预测结果基本吻合。

从表 4 可以看出, 锅炉经过一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统改造后, 锅炉热效率和不同煤质条件下的低负荷稳燃特性都达到了预期的设计效果, 具有较好的经济性和对煤种变化的适应性。

当燃用挥发份在 20% 以上, 热值大于 20 000 kJ/kg 的煤种时, 从 53% 额定负荷到 90% 额定负荷的范围内, 锅炉热效率都在 88% 以上, 灰渣含碳量较改前实际运行的数值有较大幅度降低, 锅炉燃烧效率达 95%~97%。

当燃用 1/3 老营子煤与 2/3 当地无烟煤的混煤(此时  $V_{daf}=15.20\%$ ,  $A_{ar}=28.04\%$ ,  $Q_{net,ar}=22 935$  kJ/kg)时, 80% 额定负荷下的锅炉热效率为 87.51%, 70% 额定负荷下的锅炉热效率为 86.17%。

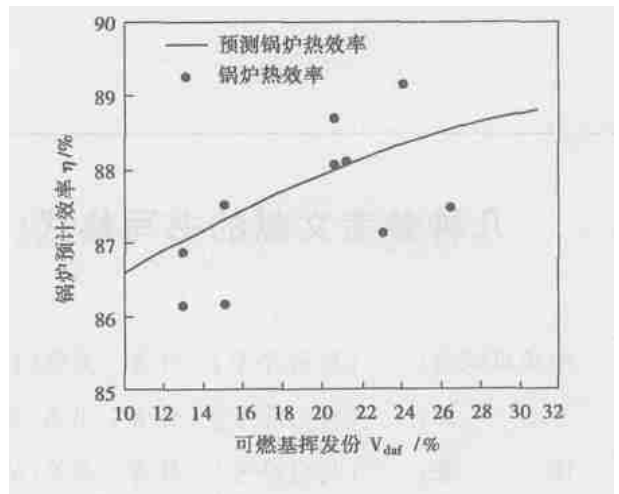


图 6 锅炉效率预测值和实际运行结果

当燃用试验煤种  $V_{daf}=13.03\%$ ,  $A_{ar}=26.32$ ,  $Q_{net,ar}=22 489$  kJ/kg (此试验煤种由 3 份当地无烟煤与一份老营子煤混合而成)时, 锅炉热效率可达到 90% 左右, 90% 负荷时为 86.86%, 70% 额定负荷时为 86.14%。

低负荷稳燃试验工况即工况 5、工况 8 和工况 10。工况 5 为挥发份 20% 试验工况, 其最低负荷达 53% 额定负荷; 工况 8 为挥发份 15% 试验工况, 其最

低负荷值为 70.6% 额定负荷; 工况 10 为挥发份 13% 试验工况, 其最低负荷值为 70.6% 额定负荷。在这 3 种不同煤的低负荷试验工况下, 由于一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统的浓缩与预热功能, 使得锅炉低负荷运行时燃烧稳定无需投油稳燃, 达到了预期的设计效果。

通过燃煤挥发份由高到低变化的 10 个运行工况的试验表明, 煤粉预热调整门开度变化与一次风预热自动控制系统的工作正常准确, 调整门的开度随燃用煤种挥发份的升高而开大, 反之关小, 而开大和关小是由一次风预热自动控制系统来实现的, 自动温控装置根据设定的温度值通过自动控制调整门开度来实现一次风预热温度自动控制, 这样既保证了锅炉燃烧的稳定性又避免了燃烧器因超温而损坏。

## 4 结 论

(1) 一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统能使煤粉在出喷口之前得到适度的预热, 且预热程度可根据不同的煤质和负荷进行

无级自动调节, 煤粉在出喷口约 200 ~ 250 mm 处就能及时着火。煤粉着火早, 其相对燃烬时间长, 燃烧效率得到提高。

(2) 锅炉采用一次风浓缩加装一次风预热自动控制装置所组成的燃烧系统改造后进行了 10 个运行工况的热态试验和燃烧调整, 所有工况燃烧稳定, 表现出这种燃烧系统对煤种变化具有较强的适应性, 而且具有较高的燃烧效率。

(3) 改造后, 当  $V_{daf} > 20\%$  时, 可实现 50% 额定负荷不投油稳定燃烧; 当  $13\% \leq V_{daf} \leq 20\%$  时, 可实现 70% 额定负荷不投油稳定燃烧, 说明该燃烧系统具有较强的稳燃性能。

## 参考文献:

- [1] 何佩葵, 赵仲琥, 秦裕琨. 煤粉燃烧器设计及运行[M]. 北京: 机械工业出版社, 1987.
- [2] 郭晓宁. 煤粉空气化合物着火温度与浓度关系的理论分析及计算[J]. 动力工程, 1998, 18(4), 63-67.
- [3] 王 磊, 孙 悦, 李争起, 等. 浓度分布对煤粉燃烧的影响[J]. 燃料化学学报, 2000, 28(4): 324-327.
- [4] 傅维镛. 对煤粉浓淡分离燃烧技术的利弊分析[J]. 电站系统工程, 1995 11(2): 22-27.

## 几种参考文献的书写格式(其中空格、标点符号、字母照写)

- 连续出版物: [标引序号] 作者. 文题[J]. 刊名, 年, 卷(期): 起始页码—终止页码.
- 专 著: [标引序号] 作者. 书名[M]. 出版地: 出版者, 出版年.
- 译 著: [标引序号] 作者. 书名[M]. 译者. 出版地: 出版者, 出版年.
- 论 文 集: [标引序号] 作者. 文题[A]. 编者. 文集[C]. 出版地: 出版者, 出版年. 起始—终止页码.
- 学位论文: [标引序号] 作者. 文题[D]. 所在城市: 保存单位, 年份.
- 专 利: [标引序号] 申请者. 专利名[P]. 国名: 专利号, 发布日期.
- 技术标准: [标引序号] 技术标准代号, 技术标准名称[S].
- 技术报告: [标引序号] 作者. 文题[R]. 报告代码及编号, 地名: 责任单位, 年份.

ing conditions the impact of the flow rate and temperature of steam injected into a turbocharger turbine on the performance of the turbocharger and turbo-charged diesel was identified along with an analysis of the results. The effectiveness of the steam-injected turbo-charged diesel in improving its part load performance has been verified. **Key words:** turbo-charged diesel, steam-injected turbocharger

再析 N-11220-1 型凝汽器热力特性与改造措施 = **A Renewed Analysis of the Thermodynamic Characteristics and Measures Taken at the Retrofitting of a N-11220-1 Condenser** [刊, 汉] / WANG Guo-shan, MAO Xing-qing (College of Mechanical and Power Engineering under the Jiaotong University, Shanghai, China, Post Code: 200030) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 80~84

By using the latest edition of self-developed software PPOC3.0 designed for the numerical simulation of condensers a renewed numerical calculation and analysis was conducted of the thermodynamic characteristics of a power-plant Chinese-made condenser (Model N-11220-1) at its designed operating condition. Numerous numerical simulation tests aimed at addressing the problem of a relatively great steam flow resistance in this type of condenser indicate that the relatively great steam flow resistance at the condenser shell-side was mainly caused by a irrational layout of the steam passage of the condenser. Further numerical calculations and analyses have shown that for such condensers already put into operation there exist two methods of retrofitting to improve their operating performance. They are either an increase in steam passage dimensions around the condenser tube bundles or a replacement of the old tube bundles by new and more advanced ones. **Key words:** power plant condenser, thermodynamic characteristics, numerical analysis, retrofitting

湿法烟气脱硫吸收塔循环氧化槽的改进 = **An Improvement on the Circulation Oxidation Tank of an Absorption Tower for Wet Flue-gas Desulfurization** [刊, 汉] / DU Qian, WU Shao-hua, LIU Hui, et al (College of Energy Science & Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 85~88

After the three towers of a wet flue-gas desulfurization system was grouped into one, there emerged the problem of a decrease in desulfurization efficiency and gypsum quality. To cope with this problem, an improved scheme was put forward, which consists in dividing the circulation oxidation tank at the bottom of the absorption tower into an oxidation tank and a material-feed tank. Moreover, tests were conducted on a parallel-flow falling-film wet desulfurization plant before and after the implementation of the improved scheme. The results of the tests indicate that the improved desulfurization plant has alleviated the contradiction between the desulfurization efficiency and the gypsum quality. The high pH value of the material-feed tank makes it possible to maintain a high desulfurization efficiency in the tower, while the low pH value of the oxidation tank is favorable to the dissolution of limestone and the oxidation of SIV, thereby enhancing the quality of gypsum. **Key words:** wet flue-gas desulfurization, oxidation tank, material-feed tank, gypsum

煤粉浓缩预热调节燃烧系统在 150 t/h 煤粉炉上的应用 = **The Application of a Combustion System of Pulverized Coal Concentration and Preheating Regulation on a 150 t/h Pulverized Coal-fired Boiler** [刊, 汉] / ZHANG Jian-sheng, LU Jun-fu, ZHANG Hai, et al (Department of Thermal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 89~92

A description is given of a combustion system newly developed by Tsinghua University, which comprises an automatic control unit for concentrating primary pulverized coal and preheating primary air. The combustion system utilizes a primary-air pipe bend to carry out dense/lean separation of the pulverized coal, and features a simple construction and good separation efficiency. Through temperature measurements it is possible to control the opening degree of a preheat-regulat-

ing valve, thus controlling the entrainment quantity of hot flue gases and achieving a stable ignition by adapting to various ranks of coal. By using the combustion system under discussion the retrofitting of a 150 t/h pulverized coal-fired boiler at the Thermal Power Plant of Dandong Chemical Fiber Co. Ltd. was implemented and operating tests at 10 different working conditions performed. Test results indicate that the combustion system can adapt well to various ranks of coal and to load variations. Under various operating conditions a stable combustion and high combustion efficiency can be attained.

**Key words:** concentration, preheating, combustion system

船用增压锅炉热力计算方法有关问题分析 = **A Study of Some Issues Related to the Thermodynamic Calculation of a Supercharged Marine Boiler** [刊, 汉] / LI Yan-jun, JIANG Ren-qiu, SUN Bao-zhi (College of Power and Nuclear Energy Engineering under the Harbin Engineering University, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 93~96

Concerning some key issues encountered in the thermodynamic calculation of supercharged marine boilers an in-depth theoretical study was carried out, and some calculation formulas and methods presented. This has in a certain sense offered a theoretical basis for the final establishment of a thermodynamic calculation method for supercharged marine boilers. By making use of the research results thermodynamic calculations of supercharged marine boilers made in the former Soviet Union were conducted and the results of calculation can relatively well meet boiler performance requirements. **Key words:** supercharged boiler, thermal balance, supercharged combustion, thermodynamic calculation

错动炉排套管式节能热水锅炉(2.8 MW)的研制 = **Research and Development of an Energy-saving Hot Water Boiler (2.8 MW) Equipped with Staggered Grates and Casing Pipes** [刊, 汉] / DING Li-qun, WANG Wen-yu (College of Municipal Environmental Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 97~98

The development process and experience of a 2.8 MW hot-water boiler equipped with staggered grates is described along with the presentation of two items of patented technology, namely staggered grates and casing-pipe convection heating surfaces. A new product among small-sized heating boilers, the recommended boiler features a packaged construction. The casing-pipe type convection heating surfaces can bring about a 1/3 economy in space requirements. A safe and reliable operation of the boiler is secured by the use of natural circulation-based radiation heating surfaces. The boiler with a high thermal efficiency and full steam output can operate on lean coal of low calorific value, formed coal and shell-like refuse. **Key words:** boiler, staggered grate, casing pipe, energy saving

国产 600 MW 超临界机组直流锅炉启动系统 = **Start-up System of a Chinese-made 600 MW Supercritical Once-through Boiler** [刊, 汉] / DUAN Yong-cheng (Taicanggang Environment-protection Power Generation Co. Ltd., Taicang, Jiangsu Province, China, Post Code: 215433) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 99~100

Shanghai Boiler Co. Ltd. in China has for the first time imported the manufacturing technology of 600 MW supercritical once-through boilers from Alstom Co. of USA. A major difference exists between the start-up process of a supercritical boiler and that of a subcritical one. There are few supercritical boilers presently in operation in China and in the majority of cases external steam-water separators are used. Through a brief account of the construction features of a once-through boiler start-up system the author has analyzed the adjustment principle of drainage employed in the boiler start-up system. This can serve as a guide and resource of useful information for other analogous units. **Key words:** supercritical parameter, once-through boiler, start-up system