文章编号: 1001-2060(2004)01-0073-04

高温空气发生器冷态实验研究

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摘 要: 概述了发展生物质高温空气气化(HTAG)系统的必要性, 为进行生物质高温空气气化的研究, 研制了关键部件—高温空气发生器实验装置, 并在此装置上进行了冷态实验, 结果表明: 冷态实验条件下, 高温空气发生器可以正常稳定运行, 并可以进行下一步热态实验研究; 通过冷端调节可以实现高温空气的分流, 并且分流出口的流量和压力随鼓风机开度的增大和排烟机开度的减小逐渐增大; 进入燃烧室的高温空气量及其流速与鼓风机开度无关, 是随排烟机开度的增大而增大。

关 键 词: 高温空气发生器; 冷态实验; 生物质能; 高温空气气化

中图分类号: TK16 文献标识码: A

1 概 述

近年来, 燃料利用和能源供应领域内提出了一种高温空气气化技术(High Temperature Air Gasification, 简称 HTAG), 它采用 1 000 ℃以上的高温空气对生物质进行气化[1~3], 获得的燃气具有热值较高、焦油和酚类的含量极低、对外界的污染很小等特点[4~5]。日、美、欧等发达国家相继开展了这方面的工作, 并取得了初步的研究结果, 如美国已研制开发出生物质高温气化联合动力装置发电系统, 并证明应用生物质高温空气气化的 IGCC 电厂其系统综合热效率可达 40%以上, 合成燃气热值可达 5.86 MJ/m^3[2]。我国在这方面的研究工作刚刚起步, 一方面对生物质高温空气气化过程本身缺乏足够的研究, 另一方面还没有一个较完善的可用于生物质高温空气气化研究的实验系统; 为提高我国生物质高温空气气化技术的研究水平, 早日形成我国自主的知识产权, 有必要着手建立相关实验台架并开展有关研究工作。高温空气发生器是该系统极其关键的部件之一, 因此, 研制与开发高温空气发生器, 并对其性能的实现和特征进行研究和分析, 对生物质高温空气气化的研究和发展具有决定性的意义。

为确保高温空气发生器热态实验的正常进行及提供实验依据, 并为了对高温空气发生器分流出口流量、压力及用来燃烧的空气流速的特性等进行探索和研究, 开发研制了高温空气发生器实验装置, 并在此装置上进行了冷态实验, 结果表明: 实验装置各部分可以正常稳定地进行运行, 控制电路可以实现对实验装置的调控, 说明该实验装置可以进行下一步的热态实验研究; 通过冷端调节可以实现空气的分流, 鼓风机和排烟机的开度对分流出口的流量及压力具有显著影响, 即随鼓风机开度的增大和排烟机开度的减少, 分流出口的流量和压力逐渐增大; 同时, 进入高温低氧燃烧室的空气量及流速与鼓风机开度无关, 是随排烟机开度的增大而增大, 并且通过调节鼓风机和排烟机开度在燃烧室可以实现空气的高速流动的目的; 实验结果为热态实验和以后的研究工作奠定了重要的基础。

2 高温空气发生器工作原理及实验

2.1 工作原理

高温空气发生器主要由燃烧室、燃烧器、蓄热室、四通阀、鼓风机及排烟机等组成, 其中燃烧室、燃烧器、蓄热室各两个呈左右对称布置; 工作原理示意图如图 1 所示[6], 高温空气发生器工作时, 燃料在 A 侧燃烧室内燃烧, 产生 1 300 ℃左右的高温烟气, 高温烟气通过蓄热室时与蜂窝陶瓷蓄热体进行热交换, 蓄热体被加热, 烟气则被冷却到 120 ℃左右经四通阀排入大气中, 与此同时, 常温空气经四通阀后进入 B 侧的蓄热室, 吸收蓄热室中高温蓄热体中的热量, 迅速升温到 1 000 ℃以上, 加热后的高温空气

收稿日期: 2003-04-08; 修订日期: 2003-09-04
基金项目: 国家高技术研究发展计划基金资助项目(2001AA514013)
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分成两部分，其中一大部分输入到卵石床气化器中用作气化剂，另一部分用于 A 侧燃烧室清洁燃气的燃烧。经过一段时间后进行切换，B 侧燃烧，A 侧产生高温空气，切换周期为 15～30 s；为使高温烟气的温度得到控制，一般向燃烧侧供以常温空气。

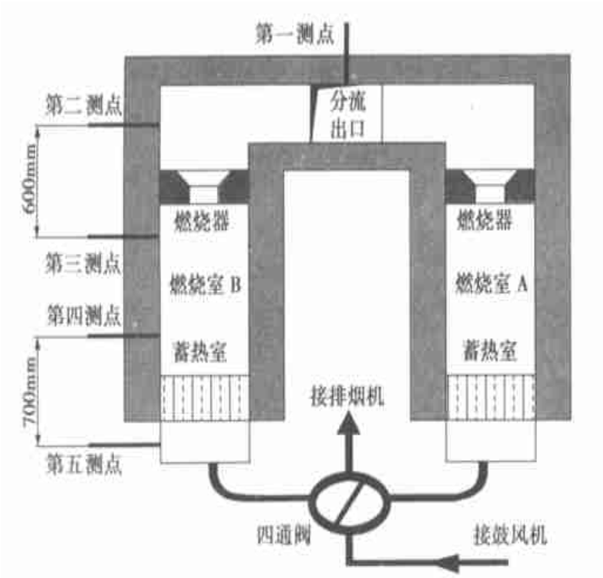

图 1　工作原理及冷态实验测点布局图

高温空气发生器冷态实验主要目的如下：

（1）检验高温空气发生器装置能否正常运行，控制电路能否稳定进行控制和切换；

（2）在高温空气发生器正常运行情况下，研究通过冷端调节鼓风机和排烟机来达到分流目的的特性；

（3）在不同的鼓风机和排烟机开度下，了解用来燃烧的空气流速规律；

（4）在不同的鼓风机和排烟机开度下，研究分流处的压力和流量的变化规律。

2.2　实验说明

冷态实验测点布局如图 1 所示[6]，在分流出口的内壁面安排第一测点，用以测量分流出口的动静压力，在烧嘴砖上方 260 mm 处安排第二测点，在烧嘴砖下方 200 mm 处设置第三测点，在蓄热体上方 250 mm 处安排第四测点，在蓄热体下方 250 mm 处设置第五测点；并且在排烟机出口设置第六测点用来测量出口流量和压力，在鼓风机出口设置第七测点用以测量鼓风机出口流量和压力，在各测点处采用具有密封性能较好的高温粘结剂密封。为模拟分流出口的压力变化，实验前首先在高温空气发生器分流出口处设计一个挡板。

实验步骤：（1）确定一定分流挡板开度；（2）从小到大改变鼓风机的开度，并在不同排烟机开度下记录对应的所需数据，即各处的压力和流量；（3）对于不同分流挡板开度下的实验可以再重复（2）步。

3　实验数据处理及分析

实验过程中，首先是确定装置是否可以正常运行，控制电路是否可以正常工作，再是主要通过调节高温空气发生器中鼓风机和排烟机开度来改变其分流出口的流量及压力，其中流量与压力是紧密相关的。实验结果表明：实验装置可以正常稳定地运行，并且控制电路可以协调工作，该装置可以进行相关的研究工作，并且实验过程中记录了大量的实验数据，通过对实验数据的精心整理，从中发现了一些关于高温空气发生器的基本规律或特征，现将实验数据整理说明如下。

3.1　分流出口流量与其影响因素的关系

在分流挡板全开时，实验测得鼓风机出口流量与鼓风机开度、排烟机开度的关系如表 1 所示[6]，从表 1 可以看出：高温空气发生器中鼓风机出口流量与排烟机的开度无关，只与鼓风机的开度有关，随鼓风机开度的增加而增加；实验测得排烟机出口流量与鼓风机开度、排烟机开度的关系如表 2 所示[6]，从表 2 可以发现：排烟机出口流量与鼓风机的开度无关，只与排烟机的开度有关，随排烟机开度的增加而增加。由于分流出口流量为鼓风量与排烟量之差，故在分流挡板全开下，分析鼓风机出口流量和排烟机流量表可以发现：对于确定的排烟机开度，可以调节鼓风机的开度来改变分流出口的流量；同样，对于确定的鼓风机开度，可以调节排烟机的开度来改变分流出口的流量。依据表 1 和表 2，可以得到在分流挡板全开下高温空气发生器分流出口流量的等流量线图，如图 2 所示[6]。改变分流出口挡板的开度，重复上述实验，得到分流出口流量的变化趋势是不变的，并由各实验得到分流出口的分流量总范围为 −0.012～0.102 m^3/s。

表 1　分流挡板开度为全开时，鼓风机出口流量表（m^3/s）

		鼓风机开度			
		30°	50°	70°	90°
排烟机开度	30°	0.04	0.044	0.079	0.127
	45°	0.04	0.044	0.079	0.127
	60°	0.04	0.044	0.079	0.127
	75°	0.04	0.044	0.079	0.127
	90°	0.04	0.044	0.079	0.127

表 2　分流挡板开度为全开时, 排烟机出口流量表(m^3/s)

		鼓风机开度			
		30°	50°	70°	90°
排烟机开度	30°	0.025	0.025	0.025	0.025
	45°	0.037	0.037	0.037	0.037
	60°	0.046	0.046	0.046	0.046
	75°	0.050	0.050	0.050	0.050
	90°	0.052	0.052	0.052	0.052

表 3　分流挡板开度为全开时, 分流出口压力表　(Pa)

		鼓风机开度			
		30°	50°	70°	90°
排烟机开度	30°	20	50	150	160
	45°	20	40	130	140
	60°	－20	－30	120	130
	75°	－30	－30	110	130
	90°	－30	－30	110	120

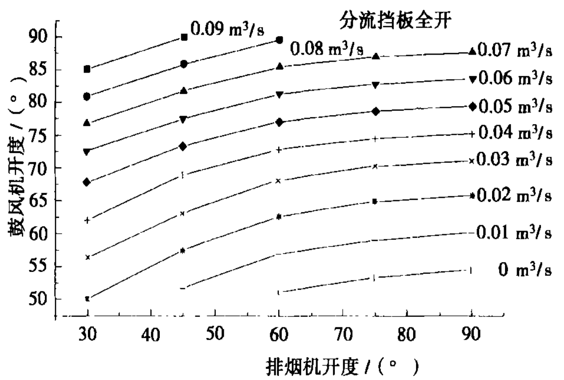

图 2　分流挡板开度为全开时,
分流出口流量的等流量线

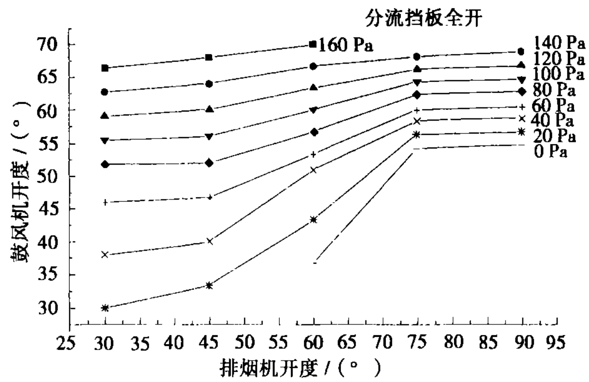

图 3　分流挡板开度为全开时,
分流出口压力的等压力线

3.2　用于燃烧的空气流速与其影响因素的关系

对于流入燃烧室用于燃烧的空气流速而言, 烧嘴砖的截面积已确定, 其流速只与流入燃烧室的空气流量有关, 即随排烟机流量的增大而增大。根据经验资料可以知道, 为达到高温低氧燃烧流入燃烧室的空气流速必须在 40 m/s 以上, 故在实际运行过程中, 根据不同分流挡板开度下的分流出口等流量线图、鼓风机出口流量数据表、经验流速值及燃烧情况等相关实验数据, 就可以确定不同分流挡板开度下排烟机和鼓风机的最优开度。

3.3　分流出口压力与其影响因素的关系

在分流挡板全开的情况下, 由实验得到分流出口压力与鼓风机开度、排烟机开度如表 3 所示[6], 从表 3 可以发现: 高温空气发生器中分流出口压力随排烟机的开度增加而减少, 随鼓风机开度的增加而增大; 故在实际运行当中对于确定的排烟机开度, 可以调节鼓风机的开度来改变分流出口的压力; 同样, 对于确定的鼓风机开度, 可以调节排烟机的开度来改变分流出口的压力。根据表 3 可以得到在分流挡板全开的情况下分流出口的等压力线, 如图 3 所示[6]。改变分流出口挡板的开度, 重复上述实验, 可以发现分流出口压力的变化趋势是不变的, 并由各实验可以得到分流出口压力总范围为－50 ~ 210 Pa。

4　实验结论

高温空气发生器实验装置冷态实验的结果表明:

(1) 在冷态实验条件下, 高温空气发生器实验装置中各部分能协调正常运行, 说明装置设计是合理的, 并且控制电路和电磁阀能够稳定进行控制和切换, 可以进行热态实验和实际运行;

(2) 通过在冷端调节鼓风机和排烟机开度可以实现高温空气的分流目的, 分流出口的流量随鼓风机开度的增大和排烟机开度的减小逐渐增大, 并且其流量总范围为－0.012 ~ 0.102 m^3/s;

(3) 在不同分流挡板开度下, 高温空气发生器中分流出口压力随排烟机的开度增加而减少, 随鼓风机开度的增加而增大, 其调节总范围为－50 ~ 210 Pa;

(4) 热态实验和实际运行过程中, 可以根据冷态实验所得的分流挡板不同开度下的等流量线图、等压力线图、等流速线图及实验数据可以确定和优化鼓风机、排烟机开度;

(5) 由于生物质高温空气气化系统正常运行时分流出口压力为大气压, 并且分流出口截面积不变, 故在系统实际运行中, 分流挡板开度为全开时, 所得

的等流量线图、等压力线图及相关实验数据具有重要的实际应用价值。

由于在鼓风机和电磁阀到蓄热体之间的管道阻力损失较大,本次实验是在蓄热体前入口压力不高的情况下测得的,为提高出口压力更好地适应热态实验和实际运行的要求,需要适当地增大电磁阀的通径,增加管道的直径。

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(何静芳　编辑)

中压错油门套筒与滑阀修理工艺

1. 错油门滑阀外圆柱面研磨

选择硬度低于滑阀且较耐磨、组织均匀和变形小的灰铸铁材料,加工一副研磨套筒,其内径较滑阀外径尺寸大 0.03~0.05 mm,长度应大于滑阀长度的 1.5 倍。其中 1 只研磨套内柱面挑以 3 头螺旋槽,用以贮藏被挤出的多余研料,另 1 只为光柱面孔研磨套,供精研和抛光之用。

在研磨套和滑阀表面分别涂以用汽轮机油稀释调匀的微粉研磨剂,将滑阀装入研磨套内,做正反两个方向的转动和轴向往复运动。研磨操作时,防止滑阀和研磨套晃动,切忌滑阀露出研磨套以外,为避免在滑阀两端产生锥度,隔时将滑阀调头进行研磨。

为了提高工效,减少研磨时间,可采用车床和手工配合研磨的方法:将滑阀卡在车床上,另一端用车床顶针顶稳,不得晃动。车床转速控制在 50 r/min 左右。研磨方法与前手工研磨方法相同,不断添加研磨剂,并检查研磨质量。若出现锥度,可控制研磨套筒,在直径较大的部位,增加研磨时间或将工件或研磨套筒调头研磨。

滑阀经过一定时间研磨后,将其清洗干净,检测质量,达到初步要求以后,换用光孔柱面研磨套,涂以稀释调匀的抛光用微粉研磨膏进一步精研磨抛光。为得到错油门配偶件的工作高灵敏度,最终将滑阀和光孔柱面研磨套用煤油清洗干净,以确保得到满意的工作效果。

2. 错油门套筒内圆柱面研磨

与前述同理,加工一副研磨棒,其中 1 只带多头螺旋槽的研磨棒用于初阶段的研磨,另 1 只表面光洁度(R_a0.2~0.6 μm)极高的光柱面精研磨棒表面涂以用汽轮机油稀释调匀的微粉研磨膏或干净的汽轮机油,用作对工件(套筒)进行精研磨或抛光之用,以提高被研磨配偶件的工作质量。

研磨错油门套筒时,应控制研磨棒与套筒的间隙:间隙小,孔柱面易拉毛;间隙大,孔柱面又易成椭圆。一般以用手推动时不费很大力量为宜,此时研磨棒与套筒的间隙约为 0.03~0.05 mm。研磨操作时切忌研磨棒一端伸出套筒过长,而另一端进入套筒内部太深,避免晃动或受力不均,使孔口扩大或两端内径不等。为了保证套筒的圆柱度,先将研磨棒两端用砂纸磨削小一些,约 0.005~0.01 mm,或者采用竖研的方法,研磨棒上下移动且需缓慢回转。

车床与手工配合进行研磨,省时省力,工效高,研磨棒由车床卡紧顶稳,涂以用清洁的汽轮机油稀释的研磨材料,装上错油门套筒,以 30~50 r/min 的速度拖动研磨棒旋转,手持错油门套筒,沿轴向缓慢往复加周向转动,以克服套筒自重或工作者握持力可能引起的偏磨。

以上错油门滑阀和套筒的研磨,简便可行。但应注意的是:欲得到精确的表面尺寸、形状及良好的表面光洁度,必须首先保证磨具的精度。研磨工作全过程必须十分细心,更换磨料时,需将研磨工具和被研磨的工件用煤油清洗干净,然后精心选择和使用粒度合适的研磨剂,稀释后薄薄一层施与研具或工件表面,操作方法须得当,否则会影响研磨质量。

(王金明　供稿)

The operating principle and causes of damage of a honeycomb ceramic regenerator during high-temperature air combustion are described. By using an algebraic Reynolds-stress model and a revised speed-pressure coupled algorithm SIMPLEC a coupling of fluid flow and heat exchange process in the regenerator was implemented. With the help of a finite-element analysis method a numerical study of the stress variation law at the cellular-hole wall-surface of the honeycomb ceramic regenerator was performed. On the basis of calculation results operating parameters were improved on. It has been found that a very frequent switching-over of the process of heat accumulation and release will subject the cellular-hole wall-surface alternately to tension and extrusion stresses. The greater the fluid flow speed, the greater will be the variation of stresses. The shorter the direction-change time, the greater will be the influence of the stress alternating effect. A proper lowering of the load of burner nozzles and a prolongation of the direction-change time of a four-way valve will be conducive to increasing the service life of the regenerator. The calculation results can serve as a basis for the structural design of the regenerator and the optimization of the operating parameters. **Key words**: high-temperature air combustion, honeycomb ceramic regenerator, stress, fatigue failure, finite element

等离子发生器燃烧流场的数值模拟＝**Numerical Simulation of the Combustion Flow Field in a Plasma Generator** [刊,汉] / ZHANG Ming-chang, LIU Min, CHEN Xiao-hong, et al (Harbin No.703 Research Institute, Harbin, China, Post Code: 150036) //Journal of Engineering for Thermal Energy &Power. — 2004, 19(1). —66~68, 80

The numerical simulation of a combustion flow field in a plasma generator was performed with the use of an eddy-breakage combustion model, a $k-\varepsilon$ two-equation turbulence model and a SIMPLEC algorithm. As a result, a diagram was obtained, which shows the distribution of temperature fields, pressure fields and such parameters as turbulence pulsation kinetic-energy and its average dissipation rate, etc. **Key words**: plasma generator, numerical simulation, combustion, turbulence model, flow field

磁稳流化床除尘装置的设计与验证＝**Design and Experimental Verification of a Dust Removal Device for a Magnetically Stabilized Fluidized Bed** [刊,汉] / WANG Ying-hui, GUI Ke-ting, SHI Ming-heng (Education Ministry Key Laboratory of Clean Coal Power Generation and Combustion Technology under the Southeastern University, Nanjing, China, Post Code: 210096) //Journal of Engineering for Thermal Energy &Power. — 2004, 19(1). —69~72

The design method of a dust removal device for a magnetically stabilized fluidized bed is presented with a focus on the description of key component design. Meanwhile, an experimental verification was conducted of the major factors having an impact on the dust removal efficiency. The results of the experiments indicate that keeping the dust removal device in a magnetically stabilized state is a key factor for achieving high dust-removal efficiency. Other factors, such as bed layer thickness, gas apparent flow-speed ratio, etc also exert some influence on the dust removal efficiency. **Key words**: magnetically stabilized fluidized bed, dust removal, particle regeneration, dust removal efficiency

高温空气发生器冷态实验研究＝**Cold-state Experimental Research of a High-temperature Air Generator** [刊,汉] / CAO Xiao-ling, WENG Yi-wu, LIU Yong-wen (Institute of Mechanical &Power Engineering under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030), JIANG Shao-jian (Institute of Energy &Power Engineering under the Zhongnan University, Changsha, China, Post Code: 410083) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(1). —73~76

The necessity for developing a high-temperature air gasification system for biomass is expounded. For the research of high-temperature air gasification from biomass the authors have developed a key component, a high-temperature air generator experimental device, on which cold-state experiments were carried out. The results of the experiments indicate that the generator is capable of a normal and stable operation under cold-state experimental conditions. It is also possible to conduct further a hot-state experimental study. Through a cold-end regulation a divided flow of the high-temperature air can be realized. The flow rate and pressure at the outlet of the divided flow will gradually increase with an increase in the opening degree of a forced draft fan and a decrease in the opening degree of a fume exhaust fan. The quantity of high-

temperature air entering a combustion furnace and its flow speed is in no way related to the opening degree of the forced draft fan, but they will increase with an increase in the opening degree of the fume exhaust fan. **Key words**: high-temperature air generator, cold-state experiment, biomass energy, high-temperature air gasification

孔隙结构对石灰石脱硫性能的影响＝**The Influence of Pore Structure on the Desulfurization Performance of Limestone** [刊, 汉] / LIU Xian-zhou, ZHAO Chang-sui, QIAN Xiao-dong, et al (Shandong Provincial Consulting Institution of Electric Power Engineering, Shandong Ludian Environmental Protection Co., Jinan, China, Post Code: 250100) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(1). —77～80

After undergoing flashing and expansion on a solid-particle pore diameter expansion device limestone particles were investigated for their desulfurization performance on a gas-flow reactor. The results of the investigation indicate that after expansion of the limestone pore diameter there was a relatively great improvement of the transport properties of reaction gases due to an enhancement in the cross-linking quality among the pores, thus decreasing the influence of sintering in the pyrolysis process. As a result, the desulfurization activity in the pore inner surface has increased. Hence, under identical test conditions after the expansion of the pore diameter there will be a significant increase in the desulfurization efficiency of the limestone. **Key words**: flashing, limestone, hole structure, desulfurization

汽轮机最有利真空循环水泵变频驱动控制系统＝**A Variable-frequency Drive Control System of a Circulating Water Pump for Allowing a Steam Turbine Unit to Operate at an Optimum Vacuum** [刊, 汉] / ZHANG Cheng-hui, CHENG Jin, XIA Dong-wei (Institute of Control Science & Engineering under the Shandong University, Jinan, China, Post Code: 250061) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(1). —81～84

Currently, thermal power plants adopt in most cases a throttle-governing mode for regulating the flow rate of circulating water. Such a regulating method suffers from poor control effectiveness and is incapable of ensuring that a steam condenser operates at a most favorable vacuum. Moreover, it also results in a high power consumption of circulating water pumps. In view of the above, the authors have developed a variable-frequency speed-governing system, using a programmable logic controller (PLC) to design a rational control logic. This makes it possible to realize a stable start-up, shutdown and the switching-over of the circulating water pumps, thus providing a steam turbine unit with an optimum vacuum for its economic operation. The economic operating modes of the steam turbine unit are analyzed and a method for calculating optimum vacuum values is given along with a detailed description of the system control theory, hardware configuration and PLC program design. Furthermore, some fruitful application results are presented. **Key words**: thermal power plant, optimum vacuum, programmable logic controller, variable frequency governing, proportional-integral-differential control

基于遗传算法的燃煤电站锅炉整体燃烧优化方法研究＝**Genetic Algorithm-based Integrated Optimization of a Combustion Process for a Coal-fired Utility Boiler** [刊, 汉] / SUN Qiao-ling, SHEN Jiong, LI Yi-guo (Power Engineering Department, Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2004, 19(1). —85～88

Concerning the combustion efficiency and pollutant emissions of utility boilers a concept is proposed concerning the integrated optimization of a combustion process. In combination with a genetic algorithm and the techniques of an artificial neural-network an investigation was performed of the method of integrated optimization for a combustion process. The results of a simulation indicate that the system of optimized combustion control proposed by the authors can lead not only to sizable energy savings but also to a decrease in nitrogen oxide emissions by flue gases, contributing to a reduction in environmental pollution. Because of the foregoing the proposed system has a great potential for engineering applications. **Key words**: utility boiler, integrated optimization of combustion, BP neural network, genetic algorithm

简单循环船用燃气轮机间冷回热改造方案探讨＝**Exploratory Study of a Modification Scheme Incorporating Intercooling and Regeneration for a Simple-cycle Marine Gas turbine** [刊, 汉] / XIAO Dong-ming, WEN Xue-you