第 19 卷第 5 期
2004 年 9 月
热 能 动 力 工 程
JOURNAL OF ENGINEERING FOR THERMAL ENERGY AND POWER
Vol. 19, No. 5
Sep., 2004

技术交流

文章编号: 1001－2060(2004)05－0534－03

余热锅炉补燃装置的研究

于朝阳[1], 王建志[2], 贺 年[3]
(1. 哈尔滨锅炉厂有限责任公司, 黑龙江 哈尔滨 150046; 2. 哈尔滨第七〇三研究所, 黑龙江 哈尔滨 150036;
3. 黑龙江省完达山乳业股份有限公司, 黑龙江 哈尔滨 150090)

摘 要: 介绍了燃一蒸联合循环余热锅炉补燃装置的分类及布置形式, 分析了燃用气体燃料的内置式补燃装置的设计及结构特点, 给出了补燃装置重要参数的计算方法及补燃系统的构成, 提出了理论氧气消耗量的计算修正公式, 指出了影响最大补燃量的主要因素, 给出了最大补燃燃料量的计算方法和计算公式, 对余热锅炉补燃装置设计、选型及余热锅炉设计具有指导意义。

关 键 词: 补燃; 补燃装置; 联合循环; 余热锅炉

中图分类号: TM611. 31 文献标识码: B

1 前 言

蒸汽一燃气联合循环发电技术已经在当今发电领域占有了相当的比例, 随着"西气东输"工程的建设及对节能、环保指标的追求, 燃气轮机联合循环发电技术必将获得更大的应用。燃气轮机联合循环发电具有建设周期短、污染少、设备启停迅速等特点, 特别适用于调峰电厂或热电联供电厂。余热锅炉是蒸一燃联合循环系统中的重要设备之一。余热锅炉按照有无外加燃烧设备可以划分为无补燃余热锅炉和带补燃余热锅炉两种, 无补燃余热锅炉应用的较多[1]。当燃机排气温度较低, 而蒸汽温度要求较高的时候, 采用带补燃余热锅炉就成为了很好的解决途径。通过补燃可以增加余热锅炉产量、提高蒸汽参数, 在一些对蒸汽需求量较大, 蒸汽温度要求较高的燃机电厂有一定的作用。如何研制出既高效, 又便于操作使用的补燃装置是重要的研究课题。

2 补燃系统工作原理及布置形式

余热锅炉补燃系统可以分为外补燃和内补燃两种(见图 1)。补燃燃料可以采用燃油或天然气。所谓外补燃系统即在锅炉系统外部设有专用的燃烧室, 燃烧室中布置有受热面, 补燃用空气由补燃风机提供, 燃料与补燃空气混合后在补燃燃烧室内燃烧, 热烟气进入烟道中与燃机排气混合, 将燃机排气加热到预定温度后进入余热锅炉。在提高烟气温度的同时, 又产生了部分蒸汽。其优点是补燃量可以设计得较大, 当燃机停止运行时, 也可以利用外补燃装置的燃烧维持锅炉运行。但缺点是投资较高, 运行维护不便, 特别是燃烧室水冷壁与其它受热面的匹配及调控问题使得锅炉结构变得较为复杂。

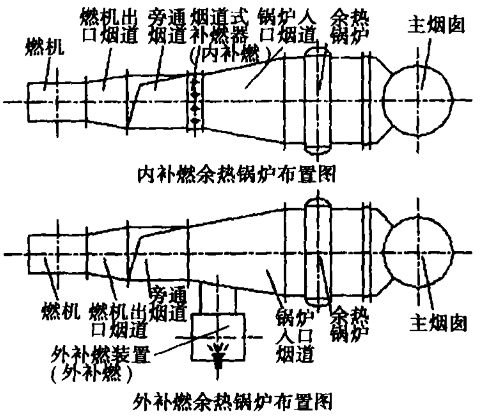

图 1 带补燃余热锅炉 布置图

内补燃装置一般安装于锅炉入口烟道中, 燃料直接喷入烟道中与燃机排气混合燃烧, 利用燃机排烟中的过余氧气作为燃料的氧化剂, 利用锅炉入口烟道的内部空间作为补燃燃烧室, 不必另设燃烧室和燃烧风机。内补燃装置系统简单, 设备投资少, 易于调控, 运行维护方便。在所需补燃量较小的余热锅炉中较为适用。

收稿日期: 2004－03－15
作者简介: 于朝阳(1970－), 女, 黑龙江哈尔滨人, 哈尔滨锅炉厂有限责任公司工程师.

本文重点介绍一种由 703 研究所研制的以天然气为燃料的内补燃装置的设计及特点。该装置已经成功应用于多台联合循环装置中。

补燃系统由补燃器本体、炉前燃料系统及其调控系统构成，补燃器本体安装于锅炉入口烟道前方，监控系统与余热锅炉控制系统相联送入 DCS。补燃器后面设置锅炉入口烟道，同时用做补燃燃烧室，由于工作温度较高，所以在该烟道的设计中，要采用特殊的耐热保温结构，这也是带补燃余热锅炉与普通余热锅炉的区别之一。

3　补燃装置参数计算

3.1　氧气消耗量计算

对于内补燃系统，由于燃烧用氧气来源于燃机排气中的残氧，与直接应用空气燃烧的计算方法有所不同。在常用的热力计算公式中[2]，关于氧的消耗都是针对空气的，如果直接应用，计算出来的是理论空气量，而不是纯氧气的消耗量，因此，须将原公式修正为理论氧气消耗量计算公式：

$$V'_{O_2}=0.01(0.5CO+0.5H_2+1.5H_2S+\Sigma(m+0.25n)C_mH_n) \tag{1}$$

式中：V'_{O_2}—燃烧 1 m^3 气体燃料所需的氧气量，m^3/m^3；

CO，…—燃料中各种组分的含量，m^3/m^3。

对于燃烧产物三原子气体及水蒸气的理论生成量仍可采用下述公式：

$$V_{RO_2}=0.01(CO_2+CO+H_2S+\Sigma mC_mH_n)\quad m^3/m^3 \tag{2}$$

$$V_{H_2O}=0.01(H_2S+H_2+\Sigma 0.5nC_mH_n)\quad m^3/m^3 \tag{3}$$

在补燃后烟气成分计算中要将氧气的消耗及三原子气体和水蒸气的生成量考虑进去，计算出补燃后的烟气焓温表，用于锅炉热力计算。

3.2　最大补燃量的确定

在补燃装置的设计中，最大补燃量是一项重要指标，必须先确定后，才能进行补燃器本体及其系统的设计。最大补燃量主要受以下几个因素的制约：第一，补燃后的最大产汽量。该指标是用户最关心的，蒸汽量的大小受到用汽设备的制约，产汽量过大，可能无法消耗。同时，追求过高的产汽量使得补燃燃料消耗量过大，余热锅炉的经济性受到影响。在选择蒸汽量时要考虑到燃机不同负荷时对蒸汽参数的需求。确定合理的最大需求量。第二，补燃后最高烟气温度的限制。补燃后烟温过高，将直接影响到烟道的结构、保温、热损失和使用寿命等指标，一般情况下该温度最好不超过 700 ℃。第三、氧气总量的限制。由于内补燃装置没有外部供风，燃烧用的氧气完全来自于燃机排气中的残氧，因此，最大燃料量就受到燃气中含氧量的限制。对于一般的燃气锅炉，为了使燃料充分燃烧，要保证实际供氧量超过理论所需要的氧气量，即取一个大于 1 的过量空气系数，这样，在利用燃气中残氧作为氧化剂燃烧时，同样要考虑到一个“过量氧气系数”，该系数应不小于 1.1。因此，烟气中可供燃烧的氧气量可用下式计算：

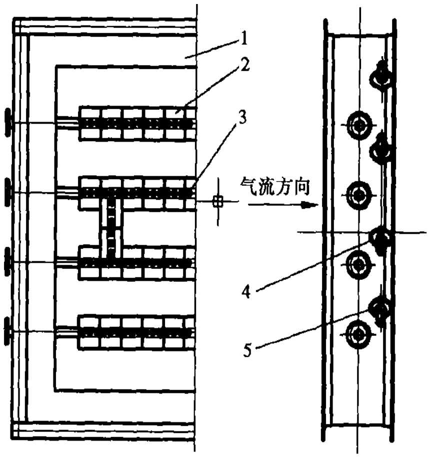

图 2　补燃器本体

$$V_{O_2}=r_{O_2}\cdot V/\alpha \tag{4}$$

式中：V_{O_2}—可供燃烧的氧气量，m^3/h；

V—流经补燃器的烟气量，m^3/h；

r_{O_2}—烟气中氧气的含量，

α—过量氧气系数。

在计算出 V_{O_2} 之后，可以计算出在没有外加空气的情况下最大可能的燃料消耗量：

$$B_3=V_{O_2}/V'_{O_2}\quad m^3/h \tag{5}$$

根据前面 3 种情况分别计算出各自情况下的燃料最大值以后，即可以选取一个合适的最大补燃量作为补燃装置的最大补燃量设定值。

$$B=\min(B_1,B_2,B_3),\quad m^3/h \tag{6}$$

式中：B —最大补燃量，m^3/h；

B_1—受最大产汽量限制的补燃量，m^3/h；

B_2—受最高燃气温度限制的补燃量，m^3/h；

B_3—受燃气含氧量限制的补燃量，m^3/h；

3.3　最小补燃量的确定

最小补燃量直接影响着系统的结构设计和调控系统设计。当补燃器喷嘴结构确定之后，相应的燃料调节比就已基本确定，因此，对于每个喷嘴都存在着保证稳定燃烧的最小燃料量。如果在结构上不能保证装置在该范围内稳定燃烧时，则必须在系统上来解决这一问题。

4　补燃装置的结构

内置烟道式补燃器安装于燃机排气烟道中，利用补燃器后部的烟道内空间作为燃烧和混合空间。带补燃装置的烟道布置及结构应该满足来流均匀、混合充分和耐热保温等要求。

补燃装置做成一体快装式，在通流截面上均匀布置有燃烧喷嘴和相应的配风导向器，各喷嘴的布置考虑了相互引燃和联焰，保证稳定燃烧。由于燃气在烟道中的流速较高，气体燃料的密度较小，如果配风导向器设置得不好，极容易点不着火或燃烧不稳定，因此在该装置设计中，采用了特殊的旋流配风结构，既保证了燃料与氧气很好的混合，同时又保证了稳燃。

5　补燃系统的构成

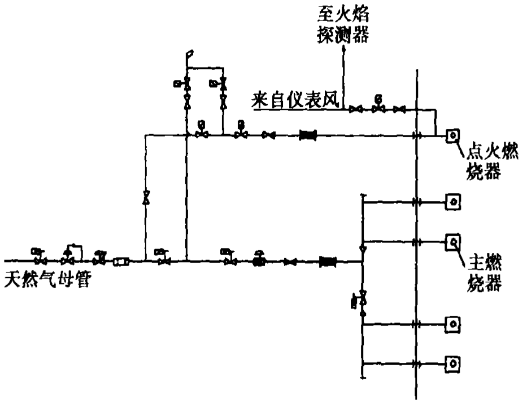

图3　补燃系统图

补燃系统由补燃器本体、主燃气管道、点火管道、排放管道和阀门仪表等组成，在管道中设有自立式压力调节阀、气动关断阀、流量调节阀和阻火器。

主燃气管道在进入补燃器本体前分为两路，并设有控制阀门，使得补燃燃料量可调范围增加一倍。当需要的补燃量较大时，所有喷嘴都投入工作，而当所需补燃量较小时，为避免燃料流量小造成燃烧不稳定，装置可以自动关断部分喷嘴，保证工作喷嘴的稳定工作。

装置设有电点火式点火燃烧器，点火用空气来源于点火风机或仪表风，点火燃烧器燃料量较少，设为长明灯式，保证主燃烧器燃烧可靠。管道上还设有排放管，当装置停止工作时，可以将管道中的余气放掉，保证设备工作安全可靠。

6　结　论

该补燃装置已经成功运行多年，从制造、安装、及运行结果来看，该型补燃装置主要具有如下特点：

（1）结构简单，模块化出厂，现场安装周期短。补燃装置本体模块化出厂，并集成有自动点火器和火焰监视器，安装使用方便。

（2）操作简便，工作安全可靠。在燃烧系统中设有自动调压装置、自动火焰检测、熄火保护和漏气检测装置等一系列安全保护措施，可以实现全自动运行，减轻了操作人员的劳动强度。

（3）机动性强，启动速度快。这对于启停频繁的燃气轮机电站余热锅炉尤为重要。

（4）运行费用省。补燃装置运行利用了燃机排气中的过余氧气，没有另设鼓风机，节省了运行电耗和初始设备投资。

随着联合循环发电技术的广泛应用，余热锅炉技术也在日益成熟和完善，在余热锅炉蒸汽产量或温度无法达到使用要求时，采用带补燃余热锅炉是解决问题的行之有效的手段。经实践检验，内补燃装置以其结构简单、操作方便及投资较省等优点是补燃型余热锅炉的首选。

参考文献：

[1]　于朝阳，王建志．带补燃余热锅炉的研制[J]．锅炉制造，2004(1)：28－30.

[2]　全苏热工研究所，中央锅炉透平研究所．锅炉机组热力计算——标准方法[M]．(1973年版)．上海：工业锅炉研究所，2001.

Key words: boiling tube, CFX, throttling element

转子蜂窝密封封严特性的试验研究＝**Experimental Investigation of the Sealing Characteristics of a Rotor Honeycomb Seal** [刊, 汉] / WANG Xu, ZHANG Wen-ping (Nuclear and Power Engineering Institute under the Harbin Engineering University, Harbin, China, Post Code: 150001), MA Sheng-yuan (Harbin No.703 Research Institute, Harbin, China, Post Code: 150036) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —521～525

To study the sealing characteristics of a rotor honeycomb seal, five kinds of stator test piece for honeycomb seals and five kinds of rotor test piece were designed and fabricated. Tests were carried out on a rotor seal test rig to identify the impact on sealing characteristics of such factors as honeycomb core lattice size, seal clearance, rotor speed, honeycomb depth, and seal pressure ratio. Contrast tests were also conducted of the sealing characteristics of a seal structure composed of a honeycomb stator, labyrinth disc and smooth disc. Finally, the conclusions of the experimental study were presented.
Key words: rotor, honeycomb seal, labyrinth seal, sealing characteristics

五孔探针实验数据处理的线性插值法＝**Linear Interpolation Method for Processing the Test Data of Five-hole Probes** [刊, 汉] / YUE Guo-qiang, Han Wan-jin, Lu Wen-cai, et al (Institute of Energy Science & Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —526～529

During the calibration of data by using five-hole probes a spline interpolation and least square fit are generally employed. For the calibration of curves by the use of identical probes the results of interpolation obtained by employing respectively the above-mentioned two methods may be quite different. Through a theoretical analysis of these two methods the authors have come up with a linear interpolation method, which is more practical for general use. For probes with good characteristics the recommended method can attain a precision close to that of the spline interpolation. As for probes with relatively poor characteristics the above method is capable of ensuring interpolation precision without the change of the probe characteristics, and relative to the spline interpolation and least square fit it enjoys a higher degree of adaptability. **Key words**: five-hole probe, linear interpolation, spline interpolation, least square method

循环流化床的物料平衡和运行中的物理现象＝**Mass Balance of a Circulating Fluidized Bed and Physical Phenomena Encountered in the Latter's Operation** [刊, 汉] / MA Su-xia, WANG Ming-min, YUE Guang-xi (Department of Thermal Engineering, Tsinghua University, Beijing, China, Post Code: 100084) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —530～533

Mass balance in a fluidized bed constitutes the core and basis of the combustion process in a circulating fluidized bed and is of utmost importance to the operation of the fluidized bed. A mass balance model is presented for a circulating fluidized bed in its steady state along with a discussion of various factors liable to influence the mass balance. The mass balance model was used to calculate the circulating mass flow rate, residue mass flow rate and fly ash flow rate (including its particle distribution) of a 75t/h circulating fluidized bed boiler. An analysis was conducted of the intrinsic causes of the physical phenomena and problems encountered in the operation of the fluidized bed boiler under the influence of the mass balance. Such phenomena include "bed quality" and the characteristics of the separator used for the circulating bed, etc. Some existing problems currently attracting the attention of a circle of theoretical and industrial workers are quantitatively explained. **Key words**: circulating fluidized bed, mass balance, model, physical phenomena

余热锅炉补燃装置的研究＝**A Study of the Supplementary-firing Burner Unit for a Heat Recovery Steam Generator** [刊, 汉] / YU Zhao-yang (Harbin Boiler Co. Ltd., Harbin, China, Post Code: 150046), WANG Jian-zhi (Harbin No.703 Reseach Institute, Harbin, China, Post Code: 150036), HE Nian (Equipment Engineering Depart-

ment, Wondersun Milk Products Industrial Co. Ltd., Harbin, China, Post Code: 150090) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —534~536

The classification and layout schemes of supplementary-firing burner units for gas-steam combined cycle heat-recovery boilers are described, and the design and construction features of an in-built supplementary-firing burner unit operating on gas fuel analyzed. A method for calculating the major parameters of the above-mentioned unit and the composition of a supplementary firing system are given. In addition, a correction formula for calculating the theoretical consumption of oxygen is proposed and the main factors affecting maximum supplementary-firing fuel consumption are indicated. Also given is the calculation method and formula for determining the maximum supplementary-firing fuel consumption. The information given above may serve as a guide during the design and type selection of supplementary-firing burner units as well as the design of heat recovery boilers. **Key words**: supplementary firing, supplementary-firing burner unit, combined cycle, heat recovery boiler

300 MW 机组排污膨胀器的事故分析及改造=**Failure Analysis and Modification of the Blow-down Flash Tank of a** 300 **MW Unit** [刊, 汉] / JIN Chun-nan, HE fu-dong, et al (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036), MAN Guo-dong (Shuangyashan Electric Power Plant, Shuangyashan, China, Post Code: 155136) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —537~538

The periodic blow-down flash tank of a 300MW unit suffered serious overpressure and serious carry-over of water at an steam exhaust port during its operation. Through calculations and a structural analysis the causes of the failure were identified as irrational structure and insufficient volume of the flash tank as well as an excessively small section area of the steam exhaust port. In light of the results of failure analysis it was decided to change the flash tank dimensions and structure. Three years of stable operation after completion of the flash tank modification indicate that the implemented changes have brought about excellent results, showing promise of its prospective wide application in other analogous units. **Key words**: expansion tank, critical speed, flashing, small hole injection

热流量计量分析与应用=**Analysis and Application of Heat Energy Flux Metering** [刊, 汉] / FENG Dian-yi (Liaoning Engineering Institute, Jinzhou, China, Post Code: 121001), XU Bo (Power Engineering College under the Shanghai University of Science & Technology, Shanghai, China, Post Code: 200093) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —539~541

The principle and method of heat energy flux metering is expounded for a closed steam circulation system. Within a certain range a mathematical model was set up for calculating the heat energy flux of superheated steam and condensate. Calculation formulas and a metering method are presented for the actually consumed heat energy by end-users in a closed circulation system, making the metering of heat energy flux tend to be more rational. The application of this heat-energy metering method will promote the rational consumption and considerable savings of energy in industrial enterprises. **Key words**: heat energy flux, calculation formula, mathematical model, closed circulation system

浅析吹风气余热回收锅炉的运行=**Brief Commentary on the Operation of a Heat Recovery Boiler by Utilizing Blown-in High-temperature Air** [刊, 汉] / CHEN Tian-shui, SUI Guang-ke, JIAN Yu-fen (Thermal Power Plant Affiliated to Lunan Chemical Fertilizer Factory, Tengzhou, Shandong Province, China, Post Code: 277527) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(5). —542~543

The basic structure of a Q75/900-25-3.82/450 heat recovery boiler is presented, which operates by utilizing blown-in high-temperature air. Some problems in operation are analyzed along with a description of load adjustment and economic benefits being achieved. **Key words**: blown-in air, waste heat recovery, vibration