文章编号: 1001－2060(2002)06－0635-03

高水分燃料的沸腾层烟气热平衡方程

黄怡珉, 于洪彬

(哈尔滨工业大学 能源科学与工程学院, 黑龙江 哈尔滨　150001)

摘　要: 以树皮、褐煤、Ⅰ类烟煤为例, 分析了沸腾层内未燃烧燃料中的水分蒸发吸热对埋管吸热份额和沸腾层温度的影响, 得到了高水分燃料的沸腾层烟气热平衡方程。计算和分析表明, 对高水分燃料, 沸腾层内未燃烧燃料中的水分蒸发吸热所需热量较大, 在沸腾层烟气热平衡方程中应予考虑。

关　键　词: 高水分燃料; 热平衡方程; 流化床锅炉

中图分类号: TK229. 6^{+}6　　文献标识码: B

1　引　言

沸腾层烟气侧热平衡方程是沸腾层传热计算所依据的基本方程之一, 其形式为[1]:

$$Q_m = \varphi B_j\left(Q_r\frac{\delta(100-q_3-q_4)-q_{6ft}}{100-q_4}+\alpha_{ft}I_k^0-\frac{100-q_{4ft}}{100-q_4}I_{ft}''\right) \quad (1)$$

式中: Q_m— 埋管吸热量, kJ/kg;

φ— 保热系数;

B_j— 计算燃料消耗量, kg/s;

Q_r— 锅炉输入热量, kJ/kg;

δ— 沸腾层燃烧份额;

q_3— 气体未完全燃烧热损失, %;

q_4— 固体未完全燃烧热损失, %;

q_{3ft}— 沸腾层气体未完全燃烧热损失, %;

q_{4ft}— 沸腾层固体未完全燃烧热损失, %;

q_{6ft}— 沸腾层灰渣显热损失, %;

α_{ft}— 沸腾层出口名义过量空气系数;

I_k^0— 空气焓, kJ/kg;

I_{ft}''— 沸腾层出口烟气焓, kJ/kg;

在该方程的推导过程中, 未考虑沸腾层未燃尽燃料所含水分的蒸发热和焓值, 由于沸腾层温度较高, 进入沸腾层的燃料短时间内就可完成干燥过程[2], 因此, 即使在沸腾层中未燃烧的燃料, 也会析出水分, 水分吸热汽化所需要的热量要由沸腾层提供。燃料水分较高时, 汽化所需热量较大, 在热平衡计算时必须考虑, 本文将分析这一问题。

2　高水分燃料的沸腾层烟气热平衡方程

在沸腾层中未燃烧的燃料, 汽化水分所需要的热量为:

$$Q_s = (B_j - B_j^*)[C_h\vartheta_{ft}(1-M_{ar}/100)+(I_{H_2O}^{ft}+r)\cdot M_{ar}/100] \quad (2)$$

式中: B_j^* — 沸腾层计算燃料消耗量, kg/s;

C_h— 灰的比热, kJ/(kg·℃);

ϑ_{ft}— 沸腾层温度, ℃;

M_{ar}— 燃料收到基水分, %;

$I_{H_2O}^{ft}$ 沸腾层出口理论水蒸气焓, kJ/kg;

r— 水的汽化潜热, kJ/kg;

将该项热量计入沸腾层的输出热量中, 得沸腾层埋管吸热量为:

$$Q_m = \varphi B_j[Q_r\frac{\delta(100-q_3-q_4)-q_{6ft}}{100-q_4}+\alpha_{ft}I_k^0-A+\frac{100-q_{4ft}}{100-q_4}(A-I_{ft}'')] \quad (3)$$

$$A = C_h\vartheta_{ft}(1-M_{ar}/100)+(I_{H_2O}^{ft}+r)\times M_{ar}/100 \quad (4)$$

由　$$Q_{yx} = \varphi B(Q_r\frac{(100-q_3-q_4-q_6}{100}-\frac{(I_{py}-\alpha_{py}I_{lk}^0)(100-q_4)}{100}) \quad (5)$$

得　$\beta = Q_m/Q_{yx}$

$= \{Q_r[\delta(100-q_3-q_4)-q_{6ft}]+(100-$

收稿日期: 2001-11-15

作者简介: 黄怡珉(1963－), 女, 四川成都人, 哈尔滨工业大学工程师.

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

$q_4)(\alpha_{ft}I^0_k - A + (100 - q_{4ft})(A - I''_{ft})\}/$
$[Q_r(100 - q_3 - q_4 - q_6) - (I_{py} - \alpha_{py}I^0_{lk})\times$
$(100 - q_4)]$ (6)

式中：β— 埋管吸热量占锅炉有效利用热量的份额；

Q_{yx}— 锅炉有效利用热量，kW；

q_6— 灰渣显热损失，%；

I_{py}— 排烟焓，kJ/kg；

I^0_{lk}— 冷空气焓，kJ/kg；

α_{py}— 排烟处过量空气系数；

沸腾层内未燃烧燃料中的水分蒸发吸热所需热量占锅炉中燃料燃烧放热量的百分数为

$$k = \frac{100Q_s}{B_j Q_r} = \frac{100(q_{4ft} - q_4)A}{(100 - q_4)Q_r} \quad (7)$$

3 计算结果及分析

以水分较高的树皮、中等水分的褐煤和水分较低的Ⅰ类烟煤为例进行计算，燃料特性见表 1。计算时，取排烟处过量空气系数为 1.6，排烟温度为 180 ℃，热空气温度为 150 ℃，其它参数取文献[3] 推荐数据中的平均值。计算结果见图 1～图 5。

图 1 和图 2 为埋管吸热份额与沸腾层温度和沸腾层燃烧份额的关系，每种燃料的下面一条曲线为考虑沸腾层内未燃烧燃料水分蒸发吸热的情况。由图可见，燃烧份额相同时，沸腾层温度增加，埋管吸热份额减少；而沸腾层温度一定时，燃烧份额增加，埋管吸热份额增加。在相同条件下，由于水分蒸发吸热，使考虑沸腾层内未燃烧燃料水分蒸发吸热时的埋管吸热份额比不考虑该项热量时要低，燃料水分越高，差别越大；但随着燃烧份额的增加，水分蒸发吸热的影响越来越小，燃烧份额为 1 时，所有燃料在沸腾层中燃烧，水分蒸发所需的热量已计入烟气焓中，图中曲线交于一点。

表 1 燃料特性(收到基) (%)

	碳	氢	氧	氮	硫	水分	灰分	低位发热值/kJ·kg^{-1}
树皮	18.85	2.29	14.8	0.14	0.14	62.00	1.78	6 196.4
褐煤	34.65	2.34	10.48	0.57	0.31	34.63	17.02	12 288.3
Ⅰ类烟煤	38.46	2.16	4.65	0.52	0.61	10.50	43.10	13 535.9

由图 1、图 2 还可看出，当燃烧份额较低时，如果仍要维持较高的沸腾层温度，埋管吸热份额出现了负值，该情况在实际中并不会出现，它说明了燃料热值较低时，在沸腾层中应布置较少的受热面或不布置受热面。

图 3 为沸腾层温度与燃烧份额的关系，图 4 和图 5 为沸腾层内未燃烧燃料中的水分蒸发吸热所需热量占燃料在锅炉中燃烧放热量的百分数与沸腾层温度和燃烧份额的关系，由图可更直观地看出水分的影响。燃料水分越高，燃烧份额越低，水分对沸腾层热平衡的影响越大。

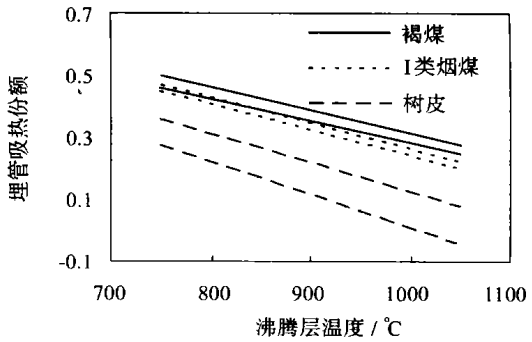

图 1 埋管吸热份额与沸腾层温度的关系 (δ=0.8)

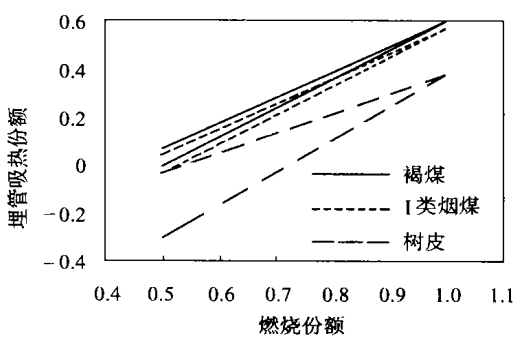

图 2 埋管吸热份额与燃烧份额的关系 (ϑ_{ft}=850 ℃)

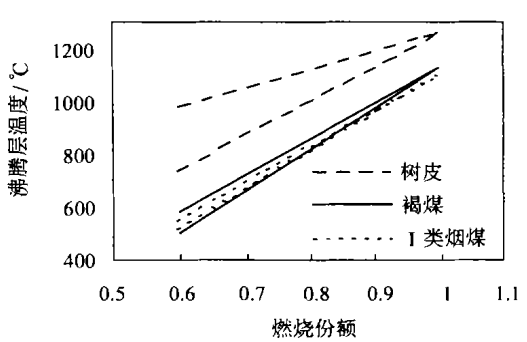

图 3 沸腾层温度与燃烧份额的关系 (树皮 β=0，褐煤 β=0.4)

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

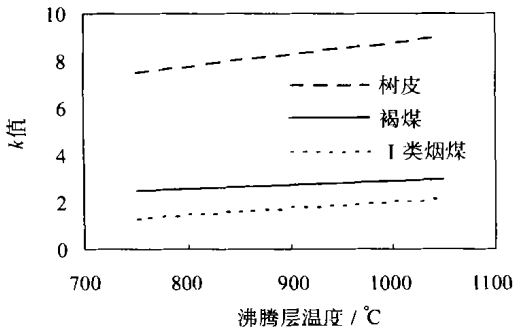

图 4　k 值与沸腾层温度的关系($\beta=0.8$)

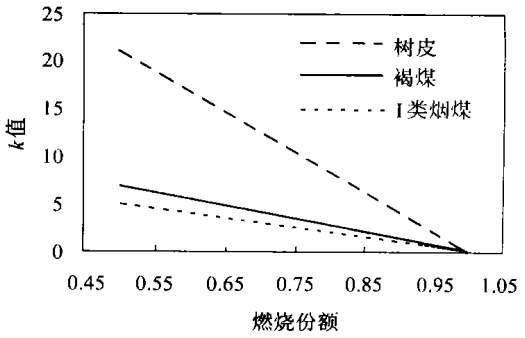

图 5　k 值与燃烧份额的关系($\vartheta_{ft}=850$ ℃)

4　结论

对高水分燃料, 沸腾层内未燃烧燃料中的水分蒸发吸热所需热量较大, 在烟气热平衡方程中应予考虑, 此时的沸腾层烟气热平衡方程为文中式(3)。

参考文献:

[1] 赵明泉. 锅炉结构与设计[M]. 哈尔滨: 哈尔滨工业大学出版社, 1992.

[2] 田子平. 沸腾燃烧的理论与实践[M]. 北京: 煤炭工业出版社, 1985.

[3] JB/DQ 1060—82. 层状燃烧及沸腾燃烧工业锅炉热力计算方法[S].

(何静芳　编辑)

新技术

下一代燃气轮机计划

据《Gas Turbine World》2001 年 5~6 月号报道, DOE(美国能源部)新计划的研究表明, CHAT 装置在 30~150 MW 功率范围的性能(输出功率和效率)将优于联合循环, 而其价格却与简单循环相当。

在"先进涡轮系统"计划下, DOE 把其注意力转移到"下一代燃气轮机"计划, 为 30~150 MW 功率应用提供高效的设计。

CHAT—"Cascaded Humidified Advanced Turbine(级联加湿先进涡轮)"使燃气轮机和工业部件的设计相结合, 其特点是利用中间冷却、热量回收、加湿和再热。下面列出三型 CHAT 装置设计的性能。

基于 Rolls—Royce Avon 核心发动机, CHAT 装置额定功率为 37.0 MW, 效率为 45.0%, 对应的 Avon 燃机的功率为 14.6 MW, 效率为 28.2%。

基于 GE Fr6B 核心发动机, CHAT 装置额定功率为 94.3 MW, 效率为 52.3%, 对应的 PG6581B 燃机的功率为 42.1 MW, 效率为 32%。

基于 GE Fr6FA 核心发动机, CHAT 装置额定功率为 143.5MW, 效率为 54.9%, 对应的 PG6101FA 燃机的功率为 70.1MW, 效率为 34.2%。

(思娟　供稿)

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

bines system identification with a numerical simulation, the results of fitting were simplified, thereby obtaining a simplified model, which complies with experimental results. **Key words**: Lawrence algorithm, system identification, transfer function fitting

基于OPC规范的火电厂监控信息系统研究=**A Study of the Supervisory information System for a Thermal Power Plant Based on an OPC (Object-linking-and-embedding for Process Control) Specification** [刊, 汉] / QUAN Xin-jian, LIN Zhong-da (Power Engineering Department, Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —625~628

The study mainly focuses on a plant-level supervisory information system for a thermal power plant by adopting the design conception of a modularized program based on COM/DCOM technology. A standard OPC (object-linking-and-embedding for process control) interface (OPC client program and OPC server program) in compliance with OPC specification has been adopted to serve as the communication interface of the supervisory information system. This gives full play to the identity and opening characteristics of the OPC interface, thereby providing a new realistic approach for organizing an open and flexible plant-level supervisory information system for thermal power plants. **Key words**: thermal power plant, supervisory information system, design

饱和蒸汽减温在燃机余热锅炉的应用=**The Application of Saturated Steam Attemperation in Gas-turbine Heat Recovery Boilers** [刊, 汉] / ZHANG Yong, YAO Dong, WEI Shao-jie (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036), ZHAI Zuo-wu (Harbin No. 3 Power Generation Co. Ltd., Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —629~631

Described is a method of superheated steam regulation for the heat recovery boiler of a gas-steam combined cycle power plant, the so-called boiler-drum saturated steam attemperation. The design of such a saturated-steam attemperating system is analyzed with some problems worthy of close attention in practical use being pinpointed. **Key words**: gas-steam combined cycle power plant, heat recovery boiler, saturated steam attemperation

百叶窗式水平浓淡煤粉燃烧器在燃贫煤300MW机组的应用=**The Use of a Horizontal and Louver-type Concentrated-diluted Pulverized Coal Burner in a 300 MW Lean Coal-fired Power Plant** [刊, 汉] / WANG Ji-hong (Boiler Repair Shop at Anyang Power Plant, Anyang, Henan Province, China, Post Code: 455004) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —632~634

The steady combustion and low NOx emission mechanism of a horizontal and Louver-type concentrated-diluted pulverized coal burner was analyzed from the perspective of its construction features. After a modification of the burners installed on boilers No. 9 and 10 of Anyang Power Plant test results indicate that an optimum performance has been attained in respect of both NOx emissions and combustion stability. This has a certain reference value for similar type of boiler units. **Key words**: 300MW power plant, horizontal and Louver-type concentrated-diluted pulverized coal burner, modification, test, combustion stability

高水分燃料的沸腾层烟气热平衡方程=**A Thermal Energy Balance Equation Obtained for the Flue Gases of a Fluidized Bed When High-moisture Fuels Were Fired** [刊, 汉] / HUANG Yi-min, YU Hong-bin (Power Engineering Department, Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —635~637

A thermal energy balance equation has been obtained for the flue gases of a fluidized bed operating on high-moisture fuels. With bark, lignite and bituminous coal of grade 1 serving as fuels analyzed was the effect of heat absorption during the water evaporation of unburned fuel in the fluidized bed on two factors. The latter are the quantity of heat absorbed by a submerged tube and the temperature of the fluidized bed. The results of calculation and analysis indicate that when

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

high-moisture fuels are burned, the heat quantity needed for water evaporation-related heat absorption is relatively great. In view of this, the latter should be taken into account in the thermal energy balance for the flue gases of a fluidized bed. **Key words**: high moisture fuel, thermal energy balance equation, fluidized bed boiler

通道形面对PSR性能影响的分析＝**An Analysis of the Effect of Plate Corrugation on the Performance of a Primary Surface Recuperator (PSR)** [刊, 汉] / ZHANG Zhi-jun, CHENG Hui-er (Power Engineering Institute under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030), WEN Xue-you, XIAO Dong-ming (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —638 ~640

With respect to an innovative type of compact heat exchanger, the so-called primary surface recuperator (PSR), newly emerging in the international arena, analyzed is the effect of plate corrugation formed respectively by elliptic, sinusoid and parabola curves on exchanger core performance. In connection with the design of a PSR sample unit used as the recuperator of a gas turbine the authors have given the main performance of three types of PSR core, based on three plate corrugation configurations. The superior performance of the PSR core can be demonstrated through its comparison with the core performance of plate-fin heat exchangers. **Key words**: primary surface recuperator, plate corrugation, core performance

国产UP直流炉水冷壁改造方案分析＝**An Analysis of the Water Wall Modification Scheme for a Chinese-made Once-through Boiler** [刊, 汉] / TANG Ren-hu, HU Zhi-hong, CHEN Ting-kuan, et al (National Key Laboratory of Multi-phase Flows under the Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —641 ~643

A hydrodynamic analysis was conducted in connection with the modification scheme of a 300MW once-through boiler at Yaomeng Power Plant. On the basis of a comparison of the boiler water-wall negative and positive flow-rate response characteristics existing prior to and after the modification the authors noted the poor hydrodynamic characteristics of the furnace water-wall composed of vertical tube coils. An excessively high water-wall temperature and the big difference in metal and inter-tube fluid temperatures leading to tube explosion can mainly be attributed to the high mass flow speed and the resulting negative flow rate response characteristics. The above discovery may provide a helpful guide during the modification of analogous boilers. **Key words**: boiler water wall, negative-flow response characteristics, hydrodynamic calculation, mass flow rate, once-through boiler

40 t/h燃气锅炉过热器爆管原因分析＝**An Analysis of the Cause of a Superheater Tube Explosion Occurring in a 40 t/h Gas-fired Boiler** [刊, 汉] / FAN Wei-dong, ZHANG Ming-chuan (School of Mechanical &Power Engineeirng under the Shanghai Jiaotong University, Shanghia, China, Post Code: 200240), HONG Mei (Shanghai Boiler Co. Ltd., Shanghai, China, Post Code: 200240) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —644 ~647

The tube explosion occurring in a low-temperature stage superheater of a gas-fired industrial boiler was analyzed from various aspects, such as boiler design, superheater structure and layout, etc. With the cause of explosion being identified some effective measures were proposed to solve the problem. **Key words**: industrial boiler, superheater, tube explosion

锅炉多管除尘器改进＝**The Improvement of a Multi-tube Dust Separator for a Boiler** [刊, 汉] / LIU Bao-jun, WANG Tie-yan (Harbin Hongqi Boiler Works, Harbin, China, Post Code: 150080) // Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —647 ~649

A high-efficiency multi-tube dust separator is described. After a modification its use on 1 - 75 t/h boilers for space heating during the winter has played a significant role in the protection of environment. **Key words**: multi-tube dust separator, cyclone, flow resistance, role of negative pressure

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net