旋流燃烧器壁温计算数学模型

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[摘要]　对旋流燃烧器轴向壁温分布数学模型做了介绍。用此模型可计算出燃烧器出口壁温与炉温的关系,并通过试验验证了该数学模型的合理性。

关键词　燃烧器　壁温　辐射　数学模型

中图分类法　TK223.23

符号表

A	面积, m^2
F	角系数
K	对流换热系数, $W/(m^2\cdot ℃)$
q	热负荷, W/m^2
G	入射辐射, W/m^2
J	有效辐射, W/m^2
T	温度, K
u	气体流速, m/s
D	直径, m
l	燃烧器计算长度, m
c_p	定压比热, $J/(kg\cdot ℃)$
W	壁厚, m
e	辐射常数
p	密度, kg/m^3
λ	导热系数, $W/(m^2\cdot ℃)$
X	黑度

上标

′	一次风道
″	二次风道

下标

c	导热
d	对流
n	内表面
w	外表面,外壁
g	气体
jk	进口
ck	出口

1　引言

燃烧器影响锅炉内烟气的流场、煤粉的燃烧等。电厂在低负荷下运行时,为保证一定的风速和煤粉浓度,部分燃烧器要停用,这些燃烧器因受到烟气的辐射而导致出口变形或烧坏,从而影响炉内的空气动力场,降低锅炉的效率。为了保证燃烧器在运行中的安全性,在其设计、安装时,燃烧器出口段壁温是一个重要参数。本文通过一些合理的假设,建立了计算旋流燃烧器壁温的数学模型,并通过试验进行了验证。

2　基本假设和基本方程

实际燃烧器的传热关系比较复杂,对此问题作一些假设:所有壁面为漫射灰体;每个风道径向壁温均匀;无水冷壁环绕的燃烧器外壁绝热;冷却风对辐射透明;炉内烟气与燃烧器出口壁面的对流传热略去不计。根据这些假设,对燃烧器各风道壁面的微元体进行热平衡分析,计算模型如图 1所示。

2.1　中心风道壁面热平衡方程(热量均折算到其内外表面平均表面积上):

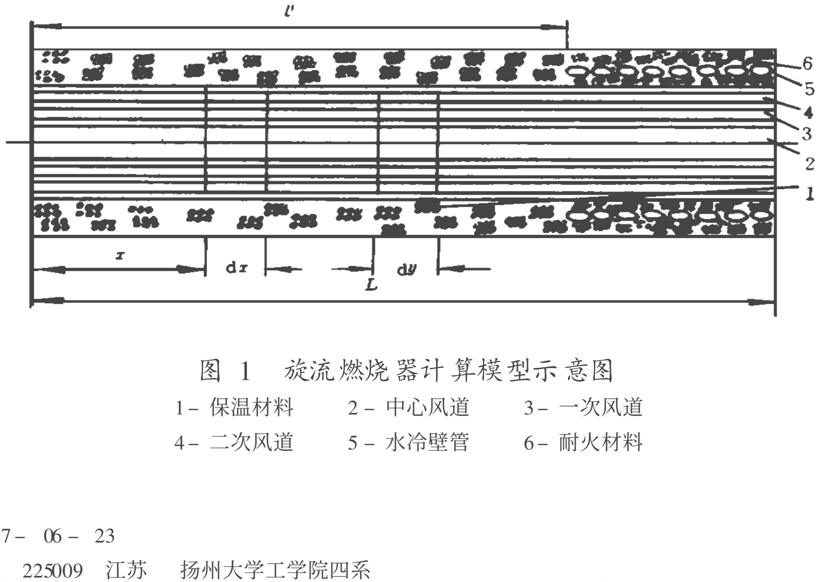

图 1　旋流燃烧器计算模型示意图

1-保温材料　2-中心风道　3-一次风道
4-二次风道　5-水冷壁管　6-耐火材料

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$$G''_w(x) = J''_w(x) + q''_c(x) + q''_d(x) \quad (1)$$

2.1.1 离开微元体的热量

表面本身的有效辐射热:

$$J''_w(x) = 2XeT''^4_w(x) + (1-X)G''_w(x) \quad (2)$$

沿轴向导出的热量:

$$q''_c(x) = -\lambda W'' \frac{d^2 T''_w(x)}{dx^2} \quad (3)$$

冷却风带走的热量:

$$q''_d(x) = \frac{2[K''_n D''_n(T''_w(x) - T''_g(x)) + K''_w D''_w(T''_w(x) - T'_g(x))]}{D''_w + D''_n} \quad (4)$$

2.1.2 进入微元体的热量 $G''_w(x)$

$$G''_w(x) = \frac{2}{dA''_{xn} + dA''_{xw}}[eT^4_{jk}F''_{xn,jk}dA''_{xn} + eT^4_{ck}F''_{xn,ck}dA''_{xn} + eT^4_{jk}F''_{xw,jk}dA''_{xw} + eF^4_{ck}F''_{xw,ck}dA''_{xw} + dA''_{xn}\int_0^L J''_{wn}(y'')dF''_{xn,y''}(|x-y''|) + dA''_{xw}\int_0^L J'_{wn}(y')dF''_{xw,y}(|x-y'|)] = 0 \quad (5)$$

由方程(1)~ (5)得:

$$J''_w(x) = 2eT''^4_w(x) + \frac{1-X}{X}[\frac{K''_n D''_n}{D''_n + W''}(T''_w(x) - T''_g(x)) + \frac{K''_w D''_w}{D''_w + W''}(T''_w(x) - T'_g(x)) - \lambda W''\frac{d^2 T''_w(x)}{dx^2} \quad (6)$$

$$J''_w(x) - \lambda W''\frac{d^2 T''_w(x)}{dx^2} + \frac{K''_n D''_n[T''_w(x) - T''_g(x)]}{D''_n + W''} + \frac{K''_w D''_w[T''_w(x) - T'_g(x)]}{D''_n + W''} - \frac{2}{dA''_{xn} + dA''_{xw}} \times [eF^4_{jk}F''_{xn,jk}dA''_{xn} + eF^4_{ck}F''_{xn,ck}dA''_{xn} + eT^4_{jk}F''_{xw,jk}dA''_{xw} + eT^4_{ck}F''_{xw,ck}dA''_{xw} + dA''_{xn}\int_0^L J''_{wn}(y'')dF''_{xn,y''}(|x-y''|) + dA''_{xw}\int_0^L J'_{wn}(y')dF''_{xw,y'}(|x-y'|)] = 0 \quad (7)$$

中心风道微元体内气体的热平衡:

$$\frac{dT''_g(x)}{dx} = \frac{4K''_n}{dc_pD''_nu''}(T''_w(x) - T''_g(x)) \quad (8)$$

2.2 一次风道外壁和二次风道外壁的热平衡方程:

$$J'_w(x) - \lambda W'\frac{d^2 T'_w(x)}{dx^2} + \frac{2K'_n D'_n}{D'_w + D'_n}(T'_w(x) - T'_g(x)) - \frac{2}{dA'_{xn} + dA'_{xw}}[eT^4_{jk}F'_{xn,jk}dA'_{xn} + eF^4_{jk}F'_{xw,jk}dA'_{xw} + eF^4_{ck}F'_{xw,ck}dA_{xw} + dA'_{xn}\int_0^L J'_{wn}(y')dF'_{xn,y'}(|x-y'|)dA_{xw}\int_o^l J_{wn}(y)dF'_{xw,y}(|x-y|) + dA'_{xn}\int_o^l J''_{ww}(y'')dF'_{xn,y''}(|x-y''|) + eF^4_{ck}F'_{xn,ck}dA'_{xn}] + \frac{2K'_n D'_w}{D'_w + D'_n}(T'_w(x) - T_g(x)) = 0 \quad (9)$$

$$J'_w(x) = 2eT'^4_w(x) + \frac{1-X}{X}\left[\frac{K'_n D'_n}{D'_n + W'}(T'_w(x) - T'_g(x)) + \frac{K'_w D'_w}{D'_n + W'}(T'_w(x) - T_g(x)) - \lambda W'\frac{d^2 T'_w(x)}{dx^2}\right] \quad (10)$$

$$\frac{dT'_g(x)}{dx} = \frac{4}{du'c_p(D'^2_n - D''^2_w)}[K''_w D''_w(T''_w(x) - T'_g(x)) + K'_n D'_n(T'_w(x) - T'_g(x))] \quad (11)$$

$$J_w(x) - \frac{\lambda(D^2_w - D^2_n)}{4D_n}\frac{d^2 T_w(x)}{dx^2} + K_n(T_w(x) - T_g(x)) - [eT^4_{jk}F_{xn,jk} + eT^4_{ck}F_{xn,ck} + \int_0^L J_w(y)dF_{xn,y}(|x-y|) + \int_0^L J'_{ww}(y')dF_{xn,y'}(|x-y'|)] + q(x) = 0 \quad (12)$$

$$J_w(x) = eT^4_w(x) + \frac{1-X}{X}\left[K_n(T_w(x) - T_g(x)) - \frac{\lambda(D^2_w - D^2_n)}{4D_n}\frac{d^2 T_w(x)}{dx^2} + q(x)\right] \quad (13)$$

$$\frac{dT_g(x)}{dx} = \frac{4}{du\,c_pD_n}\left[K_n(T_w(x) - T_g(x)) + \frac{K'_w D'_w}{D_n}(T'_w(x) - T_g(x))\right] \quad (14)$$

2 计算结果和实验研究

由方程(6)~ (14)组成的方程组封闭。以华能南京电厂(300 MW)旋流燃烧器的结构尺寸为例进行计算,计算结果($u = 25$ m/s, $u' = 20$ m/s, $u'' = 10$ m/s,烟气黑度 取为 1,一、二次冷却风温为 366℃)见图 2图 3(此文中炉温皆指燃烧器区域的炉温)。在计算过程中,对辐射、对流和导热对壁温的影响分别进行了计算。其中导热在传热中所占比例不到 1%,可略去不计;辐射传热是影响燃烧器壁温的主要因素。由于一、二次冷却风温相对于炉温较低,因而对燃烧器出口壁温影响不大;炉温是影响燃烧器出口

壁温的决定因素,燃烧器出口壁温与炉温呈线性关系 (图 3)

为了检验上述模型和计算结果的可靠性,通过实验进行了验证: 用 EU－ 2热电偶测量了华能南京电厂旋流燃烧器出口壁温,实验测量结果见表 1(冷却风温在 350℃ 左右)。电厂 225 MW负荷时,燃烧器区域的炉温为 1450℃ 左右。计算燃烧器出口壁温与实测平均壁温相近,从而说明了前面的假设是合理的。

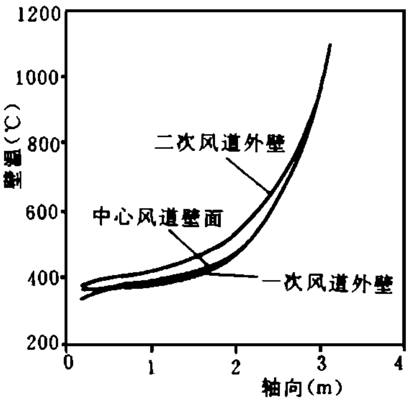

图 2　燃烧器轴向温度分布 (炉温 1500℃)

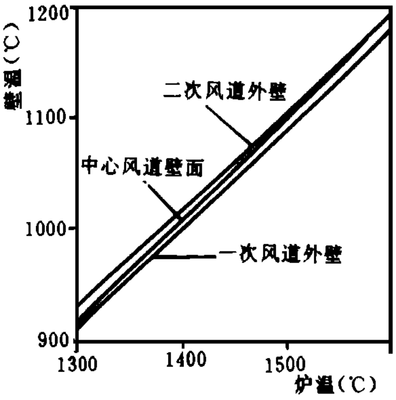

图 3　燃烧器出口壁温与炉温的关系

表 1　燃烧器各喷嘴出口实测平均壁温 (℃)

状态	1	4	9	12	13	16
250 MW	926	868	983	1005	975	1084
200 MW	865	830	904	912	893	954

4　结论

(1) 用本文给出的数学模型可以计算出燃烧器的轴向温度分布,可用于指导燃烧器材料的选择,并可指导燃烧器的安装,且有足够的精度。

(2) 在电厂正常运行范围内停用的燃烧器如不采取任何保护措施,其出口温度一般在 1000℃ 以上。

(3) 燃烧器出口壁温和燃烧器区域炉温成线性关系。

(4)进行燃烧器壁温数值计算时,可忽略壁面导热的影响。

参考文献

1　卞伯绘 编著.辐射换热的分析与计算.清华大学出版社, 1988
2　郭宽良等 编著.计算传热学.中国科技技术大学出版社, 1988
3　Robert Siegel John R. Howell. Thermal radiation heat transfer. Hemisphere Publishing Corporation, 1992

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4　结束语

自由度是为表征热力系统数学模型数值计算特性而引进的参量,是对热力系统进行系统分析的有力工具,通过自由度分析,可以为决策变量的选择提供具体指导,能够有效地避免数据冗余或者因数据采集不当造成的流程模拟计算无解,这种方法已经在热耗的在线计算以及汽轮机相对内效率的监测计算等软件的研究和开发中得到了广泛的应用。因篇幅所限,其应用部分拟在另文叙述。

参考文献

1　杨冀宏,麻德贤.过程系统工程导论.烃加工出版社, 1989. 9
2　周宇阳,胡念苏.热力系统流程模拟计算的模块序贯及动态收敛技术.热力发电 (修改定稿待发表)
3　Kwauk M. A System for counting variable in separation processes, AIChE J., 1956(2): 240
4　吴季兰.汽轮机试验技术.水利电力出版社. 1994. 10

(渠　源　编辑)

流化床锅炉水冷绞龙冷渣器的试验研究= **Experimental Study of a Water-cooled Spiral Conveyance Type Ash Slag Cooler for a Fluidized Bed Boiler** [刊,中]/Chen Hanping, Lu Jidong (Central China University of Science& Engineering) //Journal of Engineering for Thermal Energy& Power. - 1998, 13(4). - 264~266

On the basis of the industrial operation and testing of a water-cooled spiral conveyance type ash slag cooler an analysis is conducted of the movement pattern of ash slag particles in the water-cooled spiral conveyer, and a formula for calculating the ash slag transport quantity given along with a heat transfer factor. Moreover, an analytical exploratory study of the ash slag transport and heat transfer characteristics has brought forth a number of useful conclusions and provided a major basis for the research and development, design improvement and wide application of such ash slag coolers. Key words: water-cooled spiral conveyer, particle movement, ash slag transport, heat transfer characteristics

流化床气固传热特性的实验研究= **Experimental Study of a Fluidized Bed Gas/Solid Heat Transfer Characteristics** [刊,中]/Ai Yuanfang, et al (Southern China Polytechnical University) //Journal of Engineering for Thermal Energy& Power. - 1998, 13(4). - 267~270

An effective heat transfer factor has been derived through a simple analysis of fluidized bed gas/solid heat transfer characteristics and on the basis of the gas temperature profile of a steady-state operating condition active region. The experimental results are in good agreement with traditional empirical values. This justifies the rationality of the gas/solid heat transfer characteristics analysis and the feasibility of calculating a fluidized bed gas/solid effective heat transfer factor, thus providing helpful guidance for the study of fluidized bed gas/solid heat transfer characteristics. Key words: fluidized bed, temperature profile, gas/solid heat transfer characteristics, effective heat transfer factor

PG9171E燃机余热锅炉的改造设计= **Modification Design of a Heat Recovery Boiler for PG9171E Gas Turbine**[刊,中]/Ye Jianfei, Zhang Xiaohong (Shenzhen Nanshan Cogeneration Power Co. Ltd.) //Journal of Engineering for Thermal Energy& Power. - 1998, 13(4). - 271~273

This paper describes the modification design of a heat recovery boiler for a large-sized gas turbine. The design features low weight, small physical size, fine cost effectiveness, low cost and innovative technology. Derived from engineering practices these design approaches can serve as a guide during the design of heat recovery boilers for use on gas turbines. Key words: gas turbine, heat recovery boiler, modification design

热力系统数学模型自由度分析= **Degree of Freedom Analysis of a Mathematical Model for a Thermodynamic System** [刊,中]/Zhou Yuyang, Hu Niansu, Fan Tianjing (Wuhan University of Water Resources and Electrical Power) //Journal of Engineering for Thermal Energy& Power. - 1998, 13(4). - 274~276, 279

By utilizing the conception of the degree of freedom the authors have performed a systemic analysis for a thermal power plant thermodynamic system, presenting a method for evaluating the degree of freedom of a physical stream unit model and structure model as well as for determining decision variables. The above-cited method can be employed for the numerical characteristics analysis of on-line flow sheet analog calculation. Key words: thermodynamic system, degree of freedom, flow sheet simulation

旋流燃烧器壁温计算数学模型= **A Mathematical Model for Calculating the Wall Temperature of a Swirl Burner** [刊,中]/Sun Zhigao, Zhang Yongfu (Southeastern University) //Journal of Engineering for Thermal Energy& Power. - 1998, 13(4). - 277~279

A brief description is given of a mathematical model for the axial wall temperature profile of a swirl burner. The use of this model allows one to evaluate the relationship between the burner outlet wall temperature and furnace temperature. The rationality of the mathematical model has been verified through a number of tests. Key words: burner, wall temperature, radiation, mathematical model