炉内冷态流场数值模拟算法讨论及验证

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[摘要]　文中对用 SIMPLER方法模拟炉内流场时所采用的一些促进收敛的方法及 QUICKE格式的特点进行了研究,并用多孔度和分布阻力相结合的方法来处理炉内受热面。并结合冷模试验验证了结果。计算结果与实测值吻合较好。

关键词　模拟流场　QUICKE格式　多孔度
中图法分类号　O242

0　引言

随着工业的飞速发展,电站锅炉的容量正在朝着大型化方向发展,在锅炉上直接进行热态试验是基本不可能的。因而数值模拟的方法以其准确的模拟结果,节省费用及对工程极具指导意义等优点,而倍受瞩目[1]。

目前,国内锅炉炉内的数值模拟,研究结果发表很多,但是仍有很多的不足之处: 尤其是流场的模拟,由于方程数目多,易发散: 而且炉内由于屏或过热器的布置,更加给流场的模拟带来了很大的困难。本文的主要工作就是探讨这些问题的解决办法。

1　数学模型

电站锅炉的炉内流动是复杂的三维湍流流动,本文仍采用经典的 $K-X$模型,通用的控制方程形式:

$$\frac{\partial(\rho \overline{u_j H})}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\Gamma_H \frac{\partial H}{\partial x_j}\right) + S_H \qquad (1)$$

其中: 变量 H,扩散系数 Γ_H,源项 S_H的含义见下表:

方　　程	∅	$\Gamma_{\varnothing}$	$S_{\varnothing}$
连续性方程	1	0	0
x轴向动量	u	$\_{eff}$	$-\frac{\partial P}{\partial x}+\frac{\partial}{\partial x}(\_{eff}\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\_{eff}\frac{\partial v}{\partial x})+\frac{\partial}{\partial z}(\_{eff}\frac{\partial w}{\partial x})$
y轴向动量	V	$\_{eff}$	$-\frac{\partial P}{\partial y}+\frac{\partial}{\partial x}(\_{eff}\frac{\partial u}{\partial y})+\frac{\partial}{\partial y}(\_{eff}\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\_{eff}\frac{\partial w}{\partial y})$
z轴向动量	W	$\_{eff}$	$-\frac{\partial P}{\partial z}+\frac{\partial}{\partial x}(\_{eff}\frac{\partial u}{\partial z})+\frac{\partial}{\partial y}(\_{eff}\frac{\partial v}{\partial z})+\frac{\partial}{\partial z}(\_{eff}\frac{\partial w}{\partial z})$
湍流脉动动能	K	$\frac{\_{eff}}{e_k}$	$G_K - dX$
湍流动能耗散率	X	$\frac{\_{eff}}{e_S}$	$C_1 G_k \frac{X}{k'} - C_2 d\frac{X^2}{k}$

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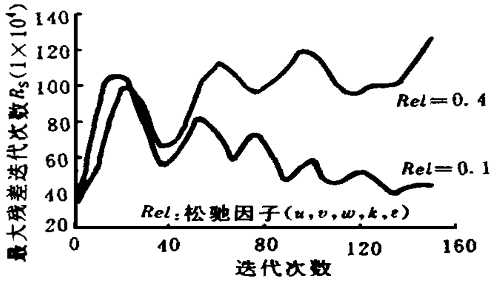

$(R_S = |\sum_{i,j,k} A_E\Phi_E + A_W\Phi_W + A_N\Phi_N + A_S\Phi_S + A_T\Phi_T + A_B\Phi_B - A_P\Phi_P|)$

图 1 QUICKE格式的不稳定性

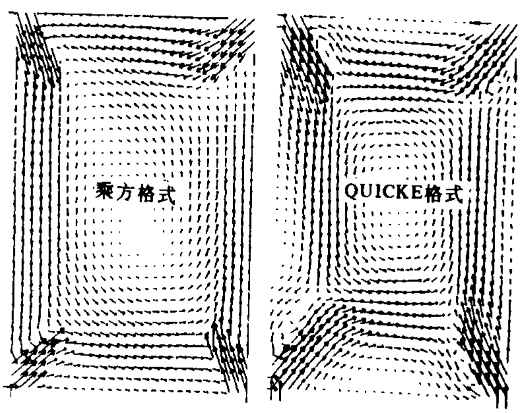

图 2 QUICKE格式与乘方格式的对比
(炉膛某一次风截面)

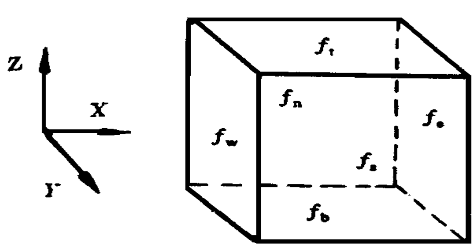

图 3 控制体 P 上的各面通流系数

其中 $\mu_{eff} = \mu + \mu_t$, $\mu_t = C_\mu \rho K^2/\varepsilon$

$$G_k = \mu_t\{2[(\frac{\partial u}{\partial x})^2 + (\frac{\partial v}{\partial y})^2 + (\frac{\partial w}{\partial z})^2] + (\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x})^2 + (\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x})^2 + (\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y})^2\}$$

方程的离散是本文的特点之一:

$$A_P\Phi_P = A_E\Phi_e + A_W\Phi_W + A_N\Phi_N + A_S\Phi_S + A_T\Phi_T + A_B\Phi_B + S \quad (2)$$

$$S = S_C^{REST} + S_P^{REST}\Phi_P \quad (3)$$

这里,S_C^{REST}和 S_P^{REST}是包括压力梯度等在内的源项。我们知道当方程接近收敛时对于任意一个控制体 P 其各方向(角标:东:e,西:w,南:s,北:n,上:t,下:b)的通流量的代数和应接近零:

$$F_e - F_w + F_n - F_s + F_t - F_b = 0 \quad (4)$$

但是在未收敛的时候这个通流量的代数和不为零。为了加速收敛速度,加上一项,作为连续性的反馈:

$$A_P\Phi_P = A_E\Phi_e + A_W\Phi_W + A_N\Phi_N + A_S\Phi_S + A_T\Phi_T + A_B\Phi_B + S + \max|(F_e - F_w + F_n - F_s + F_t - F_b),0|\Phi_P^{OLD} - \max|(F_e - F_w + F_n - F_s + F_t - F_b),0|\Phi_P \quad (5)$$

这样有:

$$S_C = \max|(F_e - F_w + F_n - F_s + F_t - F_b),0|\Phi_P^{OLD} + S_C^{REST} \quad (6)$$

$$S_P = \max|(F_e - F_w + F_n - F_s + F_t - F_b),0| + S_P^{REST} \quad (7)$$

取绝对值是为了防止源项出现负值。事实证明,由于引入了流量的连续性的反馈,取得了较快的收敛速度。

2 QUICKE格式

本文的计算对象之一是某厂 HG670/140-HM9型锅炉,其尺寸为:炉高37.65 m,长13.66 m,宽11.2 m。计算采用 SIMPLER方法,网格为32×44×94。由于含灰气流射入炉膛的角度与网格体系夹角 α或β大约为25°~35°,此时常用的乘方格式等伪扩散较严重[2]。为了解决这个问题,本文采用QUICKE格式[3],图1为 QUICKE格式因松

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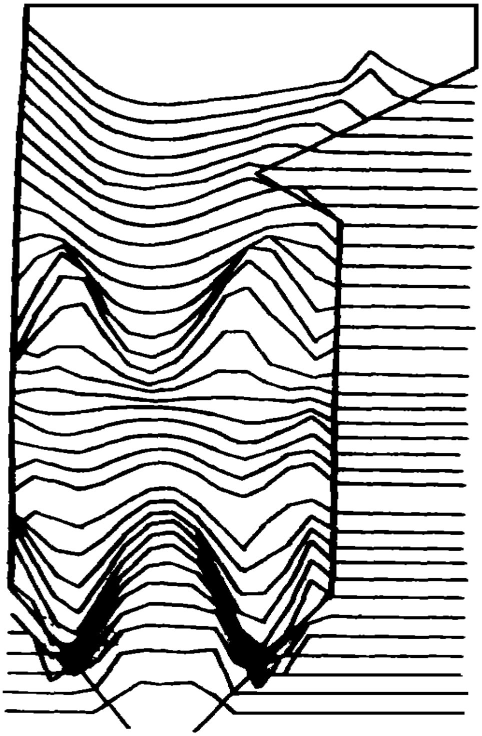

图 4　炉膛中心纵截面 Z 方向速度线图

驰因子选取的不同而呈现的不稳定性,图 2为 QUICKE格式与乘方格式的对比。可见 QUICKE格式能够较好地抑制假扩散,但却是不稳定的格式,计算过程发现,它不仅较大地依赖松驰因子,而且对初值也较敏感。本文用混合格式进行初算,把得出的大致流场作为 QUICKE格式的初值。松驰因子在开始时选用小值,尤其对于 K,X,本文的经验是 0.1 ~ 0.25;之后可以适当增大以提高收敛速度。

3　多孔度方法

为了较好地模拟炉内的屏区和尾部过热器,本文引入多孔度的方法结合分布阻力和壁面函数法。

3.1　多孔度

对于任意一个单元控制体 P把它想象成一个多孔性质的物体,其六个面上都存在面通流系数(面通流系数 = 通流面积 /总面积),同样存在体通流系数(体通流系数 = 通流体积 /总体积)[4],这样可以对 P内的实际流体写其控制方程。

以 X方向的动量方程为例(其余方向略):

$$\frac{\partial(\rho uuf_x)}{\partial x}+\frac{\partial(\rho vuf_y)}{\partial y}+\frac{\partial(\rho wuf_z)}{\partial z}=\frac{\partial}{\partial x}\left(f_x\Gamma_u\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left(f_y\Gamma_u\frac{\partial u}{\partial y}\right)+\frac{\partial}{\partial z}\left(f_z\Gamma_u\frac{\partial u}{\partial z}\right)-f_v\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}\left[\mu_{eff}\frac{\partial(uf_x)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mu_{eff}\frac{\partial(vf_y)}{\partial x}\right]+\frac{\partial}{\partial z}\left[\mu_{eff}\frac{\partial(wf_z)}{\partial x}\right] \tag{8}$$

这里的 f_v 是体通流系数。其中,f_x(西: f_w,东: f_e);f_y(南: f_s,北: f_n);f_z(下: f_b,上: f_t)为面通流系数,在离散时按所在面不同而不同,如图 3所示。

3.2　分布阻力

对于某屏或对流过热器,进出口处压力分别为 P_3 P_1,网格数为 N。每个网络上的压降为 $P = (P_2 - P_1)/N$。然后代入相应方向的动量方程的压力梯度项中,压力降由炉膛阻力计算算得。

由多孔度和分布阻力算得的结果如图 4,由于屏的存在,出现了折烟角处的小的烟气走廊,可见收到了一定的预期效果。

4　结论

以某厂 CE公司 600 MW机组锅炉的模化试验与计算结果进行比较。其炉膛尺寸为 19.558 m× 16.4325 m,燃烧器十五排。冷模为原炉的 15:1的完全缩小的几何相似体,采用电烟花系统来进行燃烧示踪,并辅以炉

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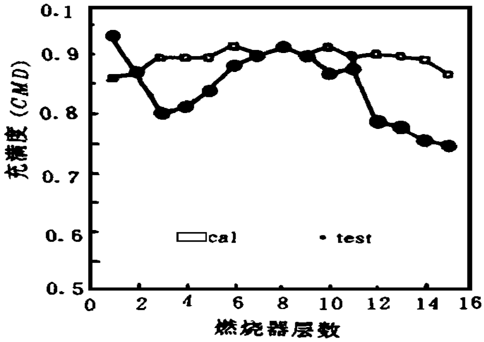
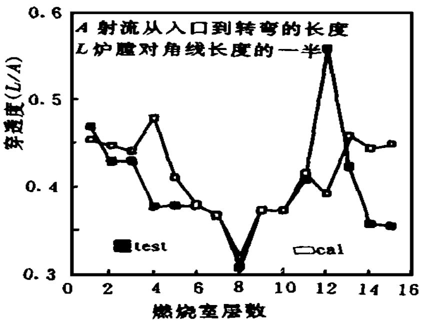
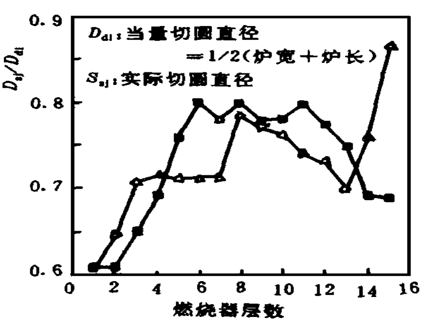


(1)炉膛充满度沿炉膛高度的变化



(2)炉膛穿透度沿炉膛高度的变化



(3)实际切圆当量,直径沿炉膛高度的变化

图 5　计算结果与模化试验结果对比

顶摄影进行显示,用四孔、五孔探针及自制的热电风速计对炉内三维气流的流量进行定量测量。计算网格为 32× 42× 94。对比的结果见图 5,图 5中 (1), (2), (3)分别为炉膛充满度沿炉膛高度的变化、炉膛穿透度沿炉膛高度的变化、实际切圆当量直径沿炉膛高度的变化。

可见,冷模试验与数值模拟在一定程度上符合得较好。因此,以本文的离散格式,引入 QUICKE格式,以多孔度和分布阻力结合处理屏及尾部过热器的方法可以取得较好的模拟效果。

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discusses the design philosophy of the modification scheme and proposes a new type of high-temperature boiler flue gas tube construction. **Key words** high-temperature boiler flue gas tube, failure analysis, structural design

模糊自组织神经网络在汽轮机转子故障诊断中的应用=(**Application of Fuzzy Self-organizing Neural Networks in a Steam Turbine Rotor Fault Diagnosis**)[刊,中]/Wang Jian, Jiang Dongxiang, Ni Weidou (Qinghua University)// Journal of Engineering for Thermal Energy & Power. -1998, 13(1). -43~45

In the light of the problems involved in a steam turbine rotor fault diagnosis proposed in this paper is a new diagnostic method based on a fuzzy self-organizing neural network. The proposed method features a simple structural algorithm, supervision-free self-study and lateral thought association, etc. This highly effective method for turbine rotor failure classification has been verified in the course of its practical use. **Key words** steamt urbine totor, failure diagnosis, fuzzy mathematics, neural network

能源及化工过程中的事故仿真=(**Failure Simulation in Energy Sources and Chemical Engineering Processes**)[刊,中]/Xiao Lichuan, Xue Guoxin (Jiangsu Petrochemical Institute)// Journal of Engineering for Thermal Energy & Power. -1998, 13(1). -46~48

After a discussion of the universal method for failure setting in energy sources and chemical engineering processes the authors come up with a transitional general function for the interface of failure status and normal operating condition. A generally applicable form of failure occurrence and an exit from ascertainment criteria are also given. Furthermore, other details concerning the failure entering form and its succession have been taken into account. **Key words** failure, simulation, transitional general function, failure ascertainment, failure succession

炉内冷态流场数值模拟算法讨论及验证=(**A Discussion and Verification of the Numerical Simulation of a Cold-state Flow Field in a Boiler**)[刊,中]/Sun Ping, Fan Jianren, Cen Kefa (Zhejiang University), Xie Hailong (Northeast Electrical Power Institute)// Journal of Engineering for Thermal Energy & Power. -1998, 13(1) -49~52

Studied in this paper are some convergence promotion methods for the simulation of flow fields in a boiler furnace by the use of a Simpler method and the specific features of Quicke scheme. Heating surfaces in the furnace are treated through the use of multi-hole rate in conjunction with resistance distribution. The calculated results agree well with experimental ones. **Key words** simulation of flow field, Quicke scheme, multi-hole rate

旋转机械振动故障的模糊诊断=(**Fuzzy Diagnosis of Rotating Machinery Vibration Faults**)[刊,中]/Ruan Yue, Xu Shichang (Harbin Institute of Technology)// Journal of Engineering for Thermal Energy & Power. 01998, 13(1). -53~56

After making an analysis of the existing difficulties in the failure analysis of rotating machinery vibration failures this papr presents a mathematical model for conducting failure mechanism study and failure diagnosis. On the basis of symptoms asserting a positive and negative trend of the vibration failures proposed is a fuzzy recognition matrix of fault diagnosis with the realization of a complex failure diagnosis. **Key words** vibration failure, fuzzy diagnosis, mathematical model, rotating machinery

自然循环蒸发系统运行特性分析模型=(**A Model for Analysing the Operating Characteristics of a Natural Circulation Boiling System**)[刊中]/Wang Guangjun, Li Hongyuan (Northeast Electrical Power Engineering Institute)// Journal of Engineering for Thermal Energy & Power-1998, 13(1). -57~60

Proceeding from a basic physical equation a distribution parameter model of natural circulation boiling system was established and a numerical calculation method based on a fluid microelement tracing philosophy also proposed. By using this model it is possible to not only conduct the static-state calculation of the boiling system

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