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增压流化床燃烧煤水混合物管内输送阻力特性研究

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摘 要: 在假定煤水混合物这类液固两相流体为广义的非牛顿流体和其管内流动存在滑移(负滑移)现象特性的基础上, 导出了表征煤水混合物这类液固两相非牛顿流体流动状态的相似准则, 并为工程上确定煤水混合物管内输送阻力特性提出了一种新的简便方法。

关 键 词: 增压流化床; 煤水混合物; 广义雷诺数

中图分类号: TK229; TQ534 文献标识码: A

1 引言

随着增压流化床洁净煤燃烧技术的发展, 煤水混合物的泵送湿法加料技术的研究, 近年来引起了世界各国能源界的高度重视。由于所输送高固体浓度的煤水混合物常表现为复杂的非牛顿流体的性质且其管内流动存在滑移(负滑移)现象的特性, 因此要完全从理论上去计算煤水混合物的管内阻力是困难的[1]。本文采用理论分析和实验研究相结合的方法, 导出了表征煤水混合物这类液固两相非牛顿流体流动状态的相似准则数——广义雷诺数。为工程上确定煤水混合物管内输送阻力特性提出了一种新的计算方法。

2 广义雷诺数 Re_g 及其分析

2.1 广义雷诺数 Re_g 的提出

假设高浓度煤水混合物在水平圆管内作定常层流流动, 其本构关系为广义宾汉体 Herschel Bulkey 方程[2]

$$\tau = \tau_y + K\gamma^n \tag{1}$$

当管内流动存在滑移流动时, $u_s > 0$, 煤水混合物浆在管内壁面处产生的"滑移层"内的浓度很低, 且厚度很薄, 故可将滑移层内的流动看作为沿管内壁面作层流的"牛顿流体"的流动, 并认为在该薄层内任意处的切应力 $\tau = \tau_w$, 如图 1 所示。

依据上述假设, 可得作为广义宾汉体的煤水混合物管内流动的广义雷诺数

$$Re_g = \frac{\rho \upsilon D[a^{n-1}(1-a)]^{1/n}}{K^{1/n}\tau_y^{1-1/n}(1-u_s/\upsilon)} f(a) \tag{2}$$

式(2)中, $a = \tau_y/\tau_w = r_b/R$ 称核流比

$$f(a) = \frac{4n}{3n+1} - \frac{4na}{(2n+1)(3n+1)} - \frac{8n^2a^2}{(2n+1)(3n+1)(n+1)} - \frac{8n^3a^3}{(2n+1)(3n+1)(n+1)} \tag{3}$$

则水煤膏管内流动的摩擦阻力系数

$$\lambda = 64/Re_g \tag{4}$$

2.2 广义雷诺数 Re_g 的分析

2.2.1 滑移对 Re_g 的影响

由式(2)知, 要确定广义雷诺数, 必须首先确定管内"滑移层"外边界的速度 u_s, 据文献[3,4]知:

$$u_s = \beta_c\tau_w/R \tag{5}$$

$$Q_s = \pi R\beta_c\tau_w \tag{6}$$

式中滑移修正系数 β_c 是 τ_w 函数, 它与 R 无关, 为实验确定的参数。

由上述关于滑移现象的研究可知: 对于存在滑移现象的流动, 即滑移现象修正系数 $\beta_c > 0$, $u_s > 0$; 由广义雷诺数表达式(2)分析知, 在同样条件下, 考虑滑移的存在使广义雷诺数 Re_g 值较不考虑滑移时增大, 即相应的管内沿程阻力损失系数 λ 值减小, 滑移的存在使流动性增强。反之, 当管内流动存在负滑移时, 即 $\beta_c < 0$, $u_s < 0$, 则广义雷诺数 Re_g 值减小, 其相应的管内沿程阻力损失系数 λ 值增大, 即负滑移的存在使流动性减弱。

2.2.2 Re_g 的通用性

对低浓度时常具有宾汉体性确质的煤水混合物, $n = 1$, $\tau_y = \tau_b$, $K = \eta$, 则式(2)简化为

$$Re_g = \frac{\rho\upsilon D(1-a)}{\eta(1-u_s/\upsilon)} f(a) = \frac{\rho\upsilon D(1-4a/3+a^4/3)}{\eta(1-u_s/\upsilon)} \tag{7}$$

若无滑移存在, 即 $u_s = 0$, $\upsilon = \upsilon_c$, 则式(7)简化为

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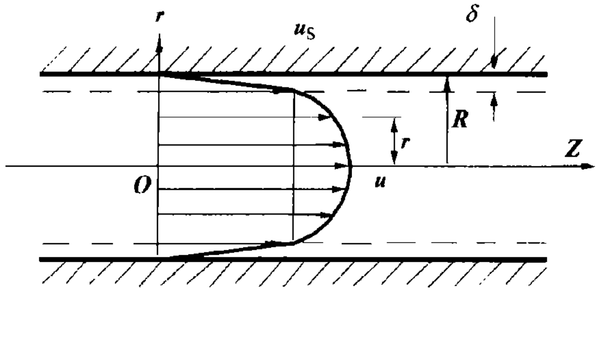


图 1 煤水混合物管内流动示意图

$$Re''_g = Re_b/(1+\frac{\tau_b D}{6\eta\upsilon}) = Re_b/(1+\frac{He_b}{6Re_b}) \quad (8)$$

式中 $He_b = \rho\tau_b D^2/\eta^2$ 称宾汉赫氏数, 式(8) 即文献[5,6] 中常见的无滑移条件下宾汉体的综合雷诺数, 它是式(2) 在一定条件下的特殊形式。

同样可以证明: 对幂律流体的无滑移流动, 式(2) 可简化为

$$Re_g = \frac{\rho\upsilon^{2-n}D^n}{K8^{n-1}}(\frac{4n}{3n+1})^n = \frac{\rho\upsilon^{2-n}D^n}{K'8^{n-1}} \quad (9)$$

式中 $K' = K[(3n+1)/4n]^n$, 式(9) 即为幂律流体无滑移条件下广义雷诺数的形式, 这同文献[6,7] 中采用的形式是一致的。

对牛顿流体的管内流动, 式(2) 简化为牛顿流体的雷诺数。

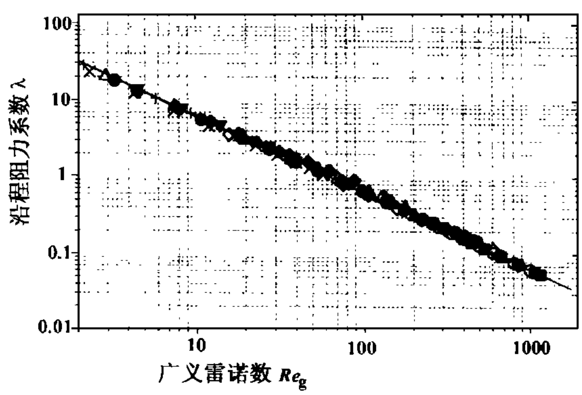
上述分析表明, 由式(2) 表示的雷诺数, 是一般粘塑性流体雷诺数的通用形式, 可称其为广义雷诺数。对于一般粘塑性流体的管内定常层流流动, 只要其雷诺数按广义雷诺数, 即按式(2) 计算, 则它们的沿程能量损失系数的计算式与牛顿流体的计算式具有相同的形式, 即式(4)。

3 实验结果

为了验证上述分析, 对三种不同粗细粉配比($PB_1 = 75:15$, $PB_2 = 60:40$, $PB_3 = 85:15$) 所配制的各种不同水份含量的煤水混合物($W_t = 24.2\% \sim 28.8\%$) 在两种管径(D 为 20mm 和 32 mm) 管道内进行了沿程阻力测量。实验中管内的实际流量 Q 由电磁流量计测定, 相应水平管段的沿程压降 ΔP 由带有隔膜装置的电子差压计测量。实测沿程能量损失系数由下式给出

$$\lambda = 4R\Delta P/\rho L\upsilon^2 \quad (10)$$

实验结果表明, 在 $Re_g = 2 \sim 1000$ 的实验范围内, λ 的实测值与式(4) 的计算值之间的相对误差一般在 5% 以内, 误差最大值不超过 10%。实验结果见图 2。



▲$PB = 75:25$, $D = 32$ mm, $W_t = 28.8\%$; ◇$PB = 75:25$, $D = 20$ mm, $W_t = 25.74\%$; ○$PB = 75:25$, $D = 20$ mm, $W_t = 28.8\%$; △$PB = 75:25$, $D = 32$ mm, $W_t = 25.74\%$; ■$PB = 60:40$, $D = 20$ mm, $Wt = 28.53\%$; ● $PB = 60:40$, $D = 20$ mm, $W_t = 25.48\%$; ◆$PB = 60:40$, $D = 32$ mm, $W_t = 28.53\%$; ▼$PB = 85:15$, $D = 20$ mm, $W_t = 27.1\%$; + $PB = 85:15$, $D = 32$ mm, $W_t = 27.1\%$; × $PB = 85:15$, $D = 32$ mm, $W_t = 25.64\%$

图 2 沿程阻力系数 λ 与广义雷诺数 Re_g 关系曲线

4 结论

(1) 本文提出了一个适用于煤水混合物这类液固两相非牛顿流体的包含“滑移” 因素在内的管内定常层流流动的广义雷诺数, 它对无滑移存在($u_s = 0$) 的这类非牛顿流体和牛顿流体同样适用。

(2) 采用式(2)定义的广义雷诺数, 复杂的非牛顿流体管内定常层流流动的沿程能量损失系数的计算式(4)与简单的牛顿流体具有同样的形式, 且计算精度令人满意。

(3) 相同流量下, 有滑移存在的煤水混合物管内流动的广义雷诺数较不考虑滑移时大, 而沿程能量损失系数较不考虑滑移时小, 而当存在负滑移流动时, 其广义雷诺数较不考虑滑移时小, 而沿程能量损失系数较不考虑滑移时大。即滑移流动使管内流动增强, 而负滑移流动使管内流动减弱。

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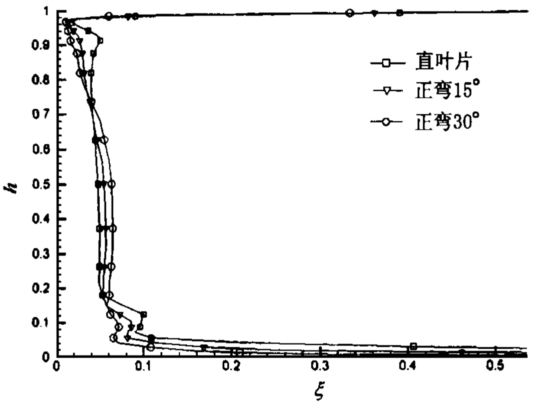
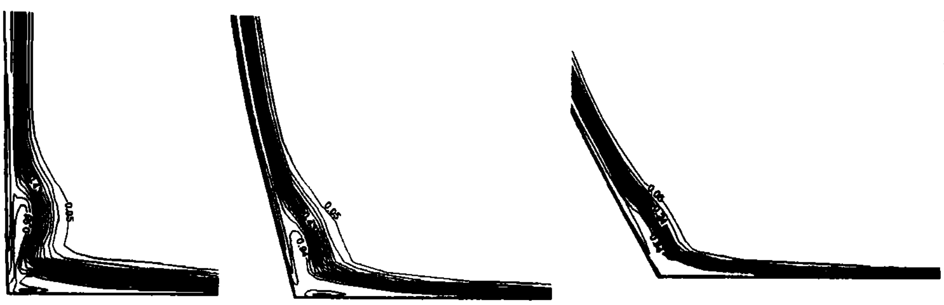


图6 出口截面节距平均能量损失系数沿叶高的分布



a 直叶片　　c 正弯15 叶片　　b 正弯30 叶片

图7 出口截面吸力面侧能量损失系数等值线

5 结论

本文对由常规叶片组成的直叶栅及不同弯角下弯叶栅的跨音速流场进行了数值模拟,分析了叶片弯曲后对流场气动参数及典型旋涡生成位置的影响。

(1)叶片正弯后,将使马蹄涡起始分离点的位置向前、向流道中间偏移,从而使通道涡提早发生,随着弯角的增大这种改变也就愈大。

(2)改变通道涡的空间位置。通道涡将被抬起,随着弯角的增大这种改变也就愈大。

(3)在吸力面将建立起"C"型压力分布,随着弯角的增大这种趋势则更加明显。因此在大弯角下,附面层向中部迁移的程度将有所提高,这会有效地减少端部二次流损失,但此时中部损失将有所增加。

(4)叶片正弯后,将降低端部压力梯度,削弱横向二次流动,随着弯角的增大这种趋势则更加明显。这表明弯叶片可以有效地降低横向压力梯度,从而控制二次流的发展。叶片正弯后,会提高中径处的出口马赫数,相应的会增加中部附近的叶型损失,对于出口有激波的流场,会使激波损失增大。

(5)弯叶片可以显著的降低端部损失但却使中部损失有所提升,因此采用何种弯曲规律以便得到最大的收益,要视流场的具体情况而定。

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换热器网络优化研究进展＝**Recent Developments Concerning the Optimization Study of Heat Exchanger Networks** [刊, 汉] / Zhang Junhua, Ying Qijia, Huang Weimin (Power Engineering College under the Shanghai University of Science & Technology, Shanghai, China, Post Code 200093) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —201～204

This paper presents the most recent developments both at home and abroad in the study of heat exchanger networks (HEN). Two different methods for the study of heat exchanger networks are compared in detail and a brief description is given of the study of HEN dynamic characteristics. The authors hold that the use of a pinch theory and a mixed integer nonlinear optimization program to other power systems, such as refrigerating and air conditioning systems, can also be conducive to the energy-savings of these systems. In conclusion, the proper orientation of research and development of the HEN has been indicated. **Key words**: heat exchanger networks, pinch theory, mixed integer nonlinear optimization

燃气轮机叶片轮盘振动特性分析＝**An Analysis of the Vibration Characteristics of a Gas Turbine Bladed Disc** [刊, 汉] / Zhou Chuanyue. Zou Jingxiang (Department of Aerospatial Engineering and Mechanics, Harbin Institute of Technology, Harbin, China, Post Code 150001), Wen Xueyou, *et al* (Harbin No. 703 Research Institute, Harbin, China, Post Code 150036) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —205～209

A brief survey is given of the current status concerning the research at home and abroad of the vibration characteristics of a bladed disc, the key component of a gas turbine. The vibration characteristics studied in this paper pertain to the following elements and components, a single blade, a turbine disc, a blade-disc coupled system and shrouded blades. Also studied are the resonance and flutter occurring in the above-cited elements. In the meantime, a specific example for the calculation and analysis of the relevant vibration characteristics has been presented of the blade and blade-disc coupled system. **Key words**: gas turbine, blade, disc, vibration characteristics, resonance, flutter

垂直浓淡煤粉燃烧方式下炉内拟序结构研究＝**A Study of the In-furnace Coherent Structure under a Vertical Bias Pulverized-coal Combustion Mode** [刊, 汉] / Wang Chungang, Zhu Qinyi, Yin Xiangmei, *et al* (College of Energy Science and Engineering under the Harbin Instiute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —210～215, 225

With the help of a particle dynamic analyzer (PDA) system an experimental and analytical study of the turbulent flow characteristics has been conducted of the in-furnace coherent structure in a tangentially fired furnace under a vertical bias pulverized-coal combustion mode. The in-furnace coherent structure can have an effect on the mixing of the primary air with a main flow field. The results of the above study show that the interaction of the primary air jet flow and the transverse jet flow at the upper stream results in the formation of a wake eddy and a shear eddy respectively at the back-of-flame side and at the flame-facing side. In this regard, there exists in the wake eddy and shear eddy a relatively high turbulent kinetic energy and shear stress, which may play a major role in controlling the diffusion of particles in the furnace. Based on a theoretical analysis the authors conclude that the vertical bias pulverized-coal combustion mode can give rise to certain conditions, unfavorable for the burn-up of pulverized coal particles, thus triggering the formation of slags on boiler water walls. **Key words**: coherent structure, particle dynamic analyzer, vertical bias combustion

增压流化床燃烧煤水混合物管内输送阻力特性研究＝**A Study on the Characteristics of In-tube Transmission Resistance of Coal-water Mixture Burned in a Supercharged Fluidized Bed Furnace** [刊, 汉] / Meng Lingjie, Zhang Mingyao (Thermal Energy Engineering Institute under the Southeastern University, Nanjing, Jiangsu, China, Post Code 210096) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —213～214, 242

Coal-water mixture can be assumed as pertaining to a generalized non-Newton fluid of two-phase solid-liquid flow and its in-tube flow is characterized by a slip (negative slip) flow phenomenon. On this basis deduced in this paper is a similitude criterion, featuring the flow state of the above-cited coal-water mixture in pipes. Furthermore, a new and simple method has been proposed for determining the in-tube resistance properties of such a coal-water mixture from an engineering perspective. **Key words**: supercharged fluidized bed, coal-water mixture, generalized Reynolds number

GT25000燃机试验工艺基架动态特性研究＝**A Study of the Dynamic Characteristics of a Technological Base-frame for GT25000 Gas Turbine Test** [刊, 汉] / You Guoying (Wuxi Division of Harbin No. 703 Research Institute, Wuxi, Jiangsu, China, Post Code 214151) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3).