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煤粉锅炉液化气点火装置的理论与实践

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摘　要: 阐述了煤粉锅炉液化气点火装置的喷嘴、引射器及烧嘴的设计计算与稳定火焰的方法, 通过应用, 得出了该点火装置具有火焰温度高、适应性强、使用方便等优点, 在电站锅炉无油、少油点火方面有着广阔的应用前景。

关　键　词: 煤粉锅炉; 液化气; 强制预混; 点火装置

中图分类号: TK223.2

为了达到节约能源、经济实用的目的, 作者设计了液化气点火装置, 本装置采用强制预混式燃烧方式, 先在预燃室中点燃煤粉－空气流并使之稳定燃烧, 再由喷出煤粉火炬去加热炉膛并最终点燃锅炉的主煤粉流, 这样用煤粉预燃室代替了油枪, 从而达到了节油目的。由于本装置采用液化气来作为点火源, 燃气热值高, 调节方便, 只需 1～2kg 液化气在几分钟内就能将预燃室点燃, 并在很小的消耗下长期伴烧。通过实验及技术经济分析表明, 本设计安全可靠、操作方便、投资小、经济效益高等优点, 这也正是本设计所具有的独创之处。

1　设计所依据的主要技术参数

本装置适用于容量为 130 t/h 的煤粉锅炉, 引燃煤种为无烟煤, 所选用的液化气流量为 2.4 m^3/h, 额定出口压力的 10 kPa, 一定空气消耗系数为 0.95, 空燃比为 $L = 30\ m^3/m^3$, 液化气是由丙烷、丁烷为主要组分的 C_3H_6 占 30%, C_4H_{10} 占 70%(体积比), 燃烧传播速度 $V_T = 41$cm/s。本设计采用强制预混式燃烧完全, 热效率较高, 其原理是用液化气引射一定量的空气, 保证在过剩空气系数近 1 的条件下实现完全燃烧, 由于液化气的压力低, 引射的空气量不足, 因此需加装风机, 增大空气量, 以实现强制预混燃烧。液化气的性质及着火性能见表 1。

表 1　液化气的性质及着火性能

密度	$Q_{net,or}$	在空气中的着火温度	在空气中的着火极限	
(kg/m^3)	(kJ/m^3)	℃	下限	上限
2.003 7	91 086	476	2.1	10.1

2　燃烧器的设计计算

2.1　喷嘴的设计计算

喷嘴的设计是燃烧器的关键部分, 尤其是喷嘴直径的选择更为重要。喷嘴的计算是基于气体动量方程和气体流动的基本方程。由于液化气的额定出口压力为 10 kPa, 所以按压缩性低压气体计算。

液化气喷嘴出口流速可由式(1)算出。

$$V = \sqrt{\frac{2T_oP_r}{\rho_{or}T_rP_o}} \cdot \Delta P_r \qquad (1)$$

式中 T_o－空气温度, K; T_r－燃气温度, K; ρ_{or}－液化气密度, kg/m^3; P_o－空气绝对压力, kPa; P_r 液化气绝对压力, kPa; ΔP_r－燃气喷嘴前相对压力, kPa; V－液化气出口流速, m/s; 喷嘴直径可由式(2)算出。

$$d_r = \sqrt{\frac{q\times10^6}{0.785V}} \cdot \sqrt{\frac{1}{K}} \qquad (2)$$

式中 d_r－喷嘴直径, mm; q－液化气的流量, m^3/h; K－喷嘴修正系数, 取 0.75 喷嘴长度可由式(3)算出。

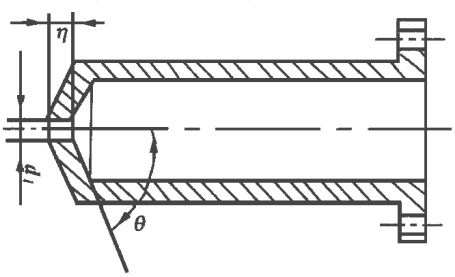

图 1　喷嘴的结构

$$L_r = 2d_r \qquad (3)$$

式中 L_r－喷嘴的长度, mm

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喷嘴的结构见图 1，喷嘴的尺寸见表 2。

2.2 引射器的设计计算

引射器的计算是以动量定理、连续性方程及能量守恒定律为基础，同时又考虑了燃气和空气在混合管内所产生撞击及摩擦损失，而撞击损失又属于完全非弹性体的阻力性质，因此使计算十分复杂，在这里简要概述之。

混合管 f_c 与液化气喷嘴 f_r 的最佳面积比 F_1 可用式(4) 求出。

$$F_1 = f_c / f_r = A[Bmn - C(m-1)(n-1)] \tag{4}$$

式中 A — 修正系数，取 $A=1$；B — 引射器内空气、液化气混合气的沿程流动阻力，其值可由式(5) 求得；C — 引射器内空气沿程流动阻力，其值可由式(6) 求得；m — 体积喷射比、即混合气的体积与液化气体积之比，其值可由式(7) 求得。

n — 重量喷射比，即混合气的重量与液化气的重量之比，其值可由式(8) 求得

$$B = 1 + \Sigma\xi_C \tag{5}$$

$$C = 1 - \Sigma\xi_B \tag{6}$$

$$m = 1 + \alpha_1 L \frac{T_0}{T_r}\left(\frac{P_0}{P_r}\right)^{-0.23} \tag{7}$$

$$n = 1 + \alpha_1 L \frac{\rho_o}{\rho_{or}} \tag{8}$$

在式(5)、(6)、(7)、(8) 中：$\Sigma\xi_C$ — 引射器内空气、液化气混合物的沿程流动阻力；$\Sigma\xi_B$ — 引射器内空气沿程总阻力；α_1 — 引射器内过剩空气系数；L — 空燃密度，m^3/m^3；ρ_o — 空气密度，kg/m^3。因此混合管直径 d_c、长度 L_C，扩张管长度 L_A，入口管长度 L_k，扩张管的最粗直径 d_A，入口管收缩前的直径 d_k，可分别由式(9)、(10)、(11)、(12)、(13) 求得，收缩入口管角度 β_k 取 40°，扩张管张角 β_A 取 8°。引射器的结构见图 2。

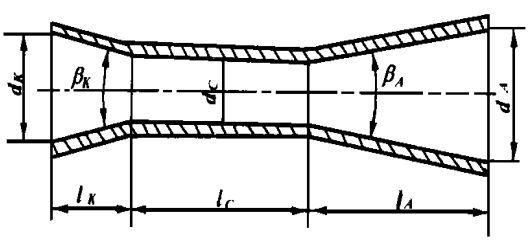


图 2 引射器的结构

$$d_c = d_r \sqrt{F_1} \tag{9}$$

$$L_c = L_A = 4.5 d_c \tag{10}$$

$$L_A = 1.2 d_c \tag{11}$$

$$d_A = d_c + 2L_A \tan\frac{\beta_A}{2} \tag{12}$$

$$d_k = d_c + 2L_k \tan\frac{\beta_K}{2} \tag{13}$$

2.3 燃烧器烧嘴的计算

燃烧器烧嘴的截面积 $f_{h,r}$ 与混合管截面积 f_c 的最佳面积 F_2 可由式(14) 求出。

$$F_2 = f_{h,r}/f_c = \sqrt{\frac{mn(1+\xi_{h,r})\Delta P_C}{F_1(\Delta P_C - \Delta P_{炉})}} \tag{14}$$

式中：ξ —— 烧嘴喷头阻力系数，取 0.2；ΔP_c —— 烧嘴内混合气体压力的增高值，Pa，其值可由式(15) 确定；$\Delta P_{炉}$ — 预燃室内煤粉—空气混合物压力的升高值，Pa，其值可由式(16) 确定。

$$\Delta P_c = \varphi^2 \frac{P_r}{F_1} \tag{15}$$

$$\Delta P_{炉} = \rho_0 \frac{V_1^2}{2} \tag{16}$$

式中：φ —— 修正系数，取 0.85；V_1 —— 预燃室内混合物的流速，m/s。

因此烧嘴喷口直径，$d_{h,r}$，烧嘴长度 $L_{h,r}$，可燃混合物喷口喷出的速度 $V_{h,r}$，可分别由式(17)、(18)、(19) 求得。烧嘴的结构见图 3。

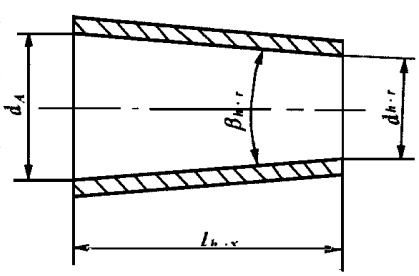


图 3 烧嘴的结构

$$d_{h,r} = d_c \sqrt{F_2} \tag{17}$$

$$L_{h,r} = (d_A - d_{h,r})/2\tan\frac{\beta_{h,r}}{2} \tag{18}$$

$$V_{h,r} = \frac{q(1+\alpha_1 L)T_{cm} \times 10^6}{0.785 d_{h,r}^2 T_0} \tag{19}$$

在式(17)、(18)、(19) 中：

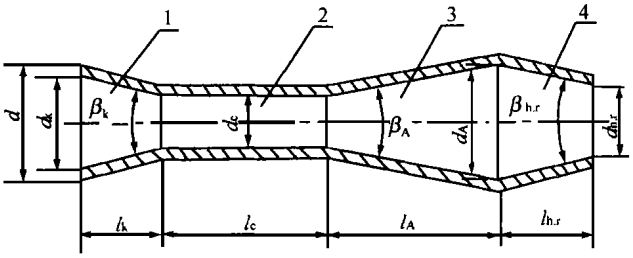
$\beta_{h,r}$ —— 烧嘴的收缩角，取 14°；

T_{cm} —— 可燃混合物温度，K。

因此燃烧器的各部分设计的尺寸见表 2，结构见图 4。

表 2 燃烧器各部分设计尺寸

设计参数	d_r (mm)	L_r (mm)	θ	F_1	d_c (mm)	L_k (mm)	L_A (mm)	L_k (mm)
设计尺寸	3.5	6.5	60°	444	69	312	312	83
设计参数	β_k	β_A	d_k (mm)	d_A (mm)	F_2	$d_{h,r}$ (mm)	$\beta_{h,r}$	$L_{h,r}$ (mm)
设计尺寸	40°	8°	130	113	1.32	80	14°	136



1— 缩管　2— 混合管　3— 扩张管　4— 烧嘴

图 4　燃烧器的结构

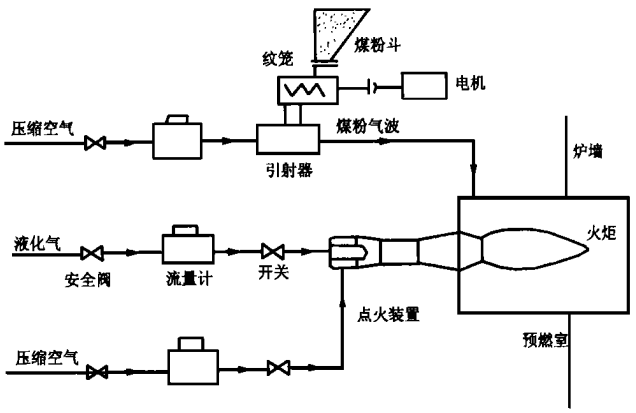


图 5　液化气点火系统示意图

2.4　稳定火焰的方法

由于本设计采用强制鼓风预混式燃烧。气流速度和 *Re* 数都较大，易产生脱火现象，为此需在燃烧器喷头上加装用锌白铜制作的多孔挡火板，预混的可燃气体流过多孔板时，在相邻两孔之间形成回流区，防止脱火的发生。在一定燃料及混合比相同条件下，临界状态的吹熄速度 ω 与气流压力 p 及回火尺寸成正比，即气流压力增大，吹熄速度也增大，一定气流压力下回流尺寸越大，火焰越不易被吹熄，同时又考虑到点火热负荷，因此挡火板上孔和板的面积比应为 1 ∶1。

3　气体点火装置在电站锅炉点火中的应用

作者设计的液化气点火装置首次应用在 DG 130/ 39/ 450—M 电站锅炉上两支出力为 0. 18 kg/ s 煤粉预燃室点火中，并获得了点火上的成功。液化气点火系统见图 5，所得结果列于表 3。

表 3　液化气点火装置在 DG 130/ 39/ 450— M 电站锅炉上应用结果

指标	实验次数						
	1	2	3	4	5	6	7
液化气流量(m^3/ s)	2. 22× 10^{-4}	3. 33× 10^{-4}	5. 05× 10^{-4}	6. 11× 10^{-4}	6. 67× 10^{-4}	7. 78× 10^{-4}	8. 89× 10^{-4}
空气流量(m^3/ s)	6. 33× 10^{-3}	9. 49× 10^{-3}	1. 43× 10^{-2}	1. 74× 10^{-2}	1. 90× 10^{-2}	2. 21× 10^{-2}	2. 54× 10^{-2}
空燃比(m^3/ m^3)	30	30	30	30	30	30	30
火焰温度(℃)	1450	1553	1645	1756	1850	1850	1850
火焰长度(m)	0. 55	0. 68	0. 77	0. 89	1. 10	1. 10	1. 10
煤粉流量(kg/ s)	0. 18	0. 18	0. 18	0. 18	0. 18	0. 18	0. 18
点火时间(s)	1260	840	558	456	420	420	420

4　结论

（1）　本装置在给定设计参数下，火炬长达 1. 10 m，火焰温度高达 1850 ℃，有较强的辐射力，从技术上来讲是可行的，达到了设计的要求，同时也证明了该设计方法的正确性与科学性。

（2）　液化气火焰温度高于城市煤气和天然气等气体燃料温度，这对各类煤种点火的适应性较强。

（3）　该点火装置在 DG130/ 39/ 450— M 电站锅炉的煤粉预燃烧 420s 后，煤粉预燃室完全进入稳定运行状态，点火装置可熄灭。这也就是说该点火装置在短短的几分钟内，只需 1 ~ 2 kg 液化气就可将煤粉预燃室点燃，折合成本 5 元，从经济上看也是合理的。与传统用油点燃一次锅炉需 2 t 柴油（折合人民币 4000 元），时间长达 4 h 相比，此装置更显得优越。

本装置具有点火可靠，操作方便，应急能力强，经济效益高，污染小等优点，在我国电站锅炉上有着广阔的应用前景。

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（渠　源　编辑）

On the basis of the water wall thermodynamic test of a 600 MW boiler unit and through the use of a finite-element analytical method an analysis was conducted of the dynamic variation with heat transfer conditions of membrane water wall tube wall temperature distribution of a low-circulation ratio boiler. The analysis aims at identifying the underlying basic cause of water wall tube wall temperature fluctuations. The results of the analysis show that the basic cause leading to the fluctuations of the water wall tube wall temperature lies in the deterioration of in-tube heat transfer. In the course of a heat transfer deterioration taking place inside the tubes of a single-side heated water wall the temperature difference between the fire-facing tube inner and outer tube wall surface has a relatively small time-dependent fluctuation. However, the water wall peripheral temperature difference suffers a drastic fluctuation triggered by the wall temperature fluctuations of the fire-facing outer wall. **Key words**: water wall, temperature field, finite element

换热器性能的火用经济评价＝**Exergy-economic Evaluation of a Heat Exchanger Performance** [刊, 中] / Wu Shuangying (Chongqing University) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —437～440

Based on the exergy-economic analysis of heat exchanger heat transfer and flow process the author has come up with a heat exchanger performance evaluation index, the so-called η criterion, defined as the total cost per unit quantity of heat transferred. Furthermore, conducted was the exergy-economic analysis and optimization of three types of heat exchangers, i.e., down-flow, cross-flow and counter-flow. The methods employed and results presented in this paper can serve as a guide during the performance evaluation of heat exchangers. **Key words**: heat exchanger, exergy-economic analysis, performance evaluation

三维温度场计算机可视化系统的研制与开发＝**Development and Fabrication of a Computer-based Visual System for Three-dimensional Temperature Fields** [刊, 中] / Zhang Shishuai, Luo Jun, Zhu Maoshu, et al (Central University of Science & Technology) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —441～442

Described in this paper is a computer-based visual system for the visualization treatment of a three-dimensional temperature field encountered in engineering thermophysics by the use of computer graphic and image techniques. The above-cited system includes a variety of modules, which are used for performing such functions as the model building of the three-dimensional temperature field, color mapping, setting-up of a visual model, extraction of a sectional plane, the setting of visual angle, etc. The system is developed and realized on a Windows 95 platform with the help of Visual C. **Key words**: three-dimensional temperature field, visual system, model building

大型亚临界无烟煤电站锅炉的开发设计＝**The Design and Development of a Large-sized Anthracite-fired Subcritical-pressure Utility Boiler with a Tangential firing System** [刊, 中] / Chen Jirong, Gao Feng (Harbin Boiler Co. Ltd.) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —443～446

The present paper describes the technical features and operational achievements of a 300 MW subcritical-pressure, natural-circulation and anthracite-fired boiler developed and designed by Harbin Boiler Co. Ltd (HBC). It focuses on some effective technical measures taken to ensure a good ignition, stable combustion and thorough burn-off, a stable combustion without relying on oil support even at low loads and complete combustion of low volatile coal as well as a slag-free operation and a reduction in NO_x emissions. With respect to the burner design a "self-stabilizing combustion technology incorporating double primary air channel" developed jointly by HBC and Qinghua University has been adopted. This item of technology was awarded a China National Golden Prize for outstanding creative and inventive patents. The marked flame stability at low loads and excellent overall performance provided by the above-cited technology have advanced the design of high-capacity anthracite-fired boilers to a new level. Such boilers with a tangential firing system enjoy the advantages of low steel consumption, low NO_x emission, etc. Their successful development has blazed a new trail for the utilization of low volatile coals, an abundant resource in China. **Key words**: anthracite, sub-critical, natural circulation, boiler design, burner

煤粉锅炉液化气点火装置的理论与实践＝**Theory and Practice of a Liquefied Petroleum Gas-based Ignition**

Device for Pulverized Coal-fired Boilers [刊, 中] / Liu Shengyong, et al (Key Laboratory of Renewable Energy Sources under the Ministry of Agriculture) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —447 ~449

This paper expounds in detail the design and calculation of nozzles, injectors and burner cones of a liquefied petroleum gas-based ignition device for pulverized coal-fired boilers as well as ways and means for flame stabilization. Application results show that such ignition devices feature a high flame temperature, good adaptability in operation and ease of use, etc. They have broad prospects for use in utility boilers that consume no oil or only a limited amount of oil for ignition. **Key words**: pulverized coal-fired boiler, liquefied petroleum gas, forced premixing, ignition device

旋流浓淡煤粉燃烧器出口区域气固两相流动特性的实验研究＝**Experimental Study of Gas-Solid Dual-phase Flow Characteristics at the Outlet Zone of a Dense-dilute Pulverized Coal-fired Swirl Burner** [刊, 中] / Li Zhiqiang, Li Rongxian, et al (Qinghua University) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —450 ~454

With the help of a three-dimensional phase Doppler particle analyzer an experimental study was conducted of the dual-phase flow characteristics at the outlet zone of a dense-dilute swirl burner. As a result, obtained are the distribution relationship of gas-solid dual-phase flow field and concentration field of the said burner under various degrees of openness of swirl blades and at different ratios of swirl secondary air and direct-flow secondary air. In addition, an analysis is also conducted of the above distribution relationship. **Key words**: dense-dilute pulverized coal-fired swirl burner, gas-solid dual-phase flow, three-dimensional Doppler particle analyzer (PDA), swirl blade openness, air flow rate proportioning

浓淡型双调风旋流燃烧器低 NO*x* 特性分析＝**An Analysis of the Low NO*x* Emission Feature of a Dense-dilute Dual-channel Swirl Burner** [刊, 中] / Yu Zhanying, Jiang Hongli, Tan Houzhang, et al (Xi'an Jiaotong University) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —455 ~457

An experimental study is conducted of a dense-dilute dual-channel swirl burner with the help of cold-state isothermal simulation technology. On the basis of the test results the structure and features of such a burner are analyzed and a study is conducted of the characteristics of a stepped air-feed and dense-dilute combustion techniques. In addition, the major role played by a combustion stabilization ring has also been investigated. All the above has led to a better understanding of the mechanism of low NO*x* emission and partial load flame-stabilization of the dual-channel swirl burner. **Key words**: dual-channel swirl burner, low NO*x* emission, flame stabilization, experimental investigation

带纵肋环烟管流动与传热实验研究＝**An Experimental Study on the Flow and Heat Transfer in Annular Flue Gas Pipes with Longitudinal Ribs** [刊, 中] / Wang Huaibin, Du Jun, et al (Harbin Institute of Technology) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —458 ~460

A new type of flue gas pipe fitted with longitudinal internal ribs and featuring an intensified convection heat exchange is proposed by the authors for use on an oil-field heating boiler. An experimental study was performed of its flow and convection heat exchange with a criterion equation of heat exchange being given. **Key words**: longitudinal rib, annular flue gas pipe, convection heat exchange

声波吹灰器的研制＝**Development of a Sonic Soot Blower** [刊, 中] / Li Qiang, Sun Cengrun, Xuan Yimin (Nanjing University of Science & Technology) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —461 ~462

Based on the principle of hydrodynamics and acoustic resonance the authors have developed a sonic soot blower for use on heat exchangers. A relevant experimental test has been performed of its acoustic intensity performance. The experimental test and industrial application results show that the sonic soot blower under discussion can effectively remove soot deposits from heat exchangers. **Key words**: boiler, heat exchanger, sonic wave, sootblowing

一种汽轮机转子的热应力测试系统＝**A Test System for Measuring Thermal Stresses in Turbine Rotors** [刊, 中] / Gao Jingbo, Wu Xinhua, Xia Songbo, et al (Harbin Institute of technology) // Journal of Engineering for Thermal Energy & Power. —1999, 14(6). —463 ~464

This paper focuses on a new system for measuring turbine rotor thermal stresses. The use of a difference measur-