

方形里克和里克 - ZT型脉动燃烧器研究

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[摘要] 对具有 350 mm×350 mm 方形燃烧室的里克和里克 - ZT 型脉动燃烧器进行了试验。结果表明方形燃烧器能够在自然抽风条件下实现里克型脉动燃烧, 但比圆形燃烧器困难; 两者的脉动机理基本一致。声学分析和实验均表明其中传播的是一维平面波。

关键词 脉动燃烧 方形里克型脉动燃烧器 方形里克 - ZT 型脉动燃烧器

中图分类号 TK223.23

1 引言

脉动燃烧器中特有的气流脉动, 强化了燃料和空气之间、冷反应物和热生成物之间的混合、传热、传质过程, 从而大幅度提高燃烧效率和燃烧强度, 降低空气剩余量 (Zimm, B. T. 等人的实验表明, 在实验条件下燃煤里克型脉动燃烧器的空气剩余系数 Γ 可达到约等于 1, 块煤的燃烧效率高达 89% ~ 98.5%)。同时, 气流的压力和速度脉动自发导致了脉动对流传热, 大幅度提高传热强度和传热效率 (June, R. R. 等人的实验研究显示, 在 200 Hz 163 dB 脉动条件下, 平行平板自然对流换热系数最大可增加 22%)。另外, 脉动燃烧带来的高燃烧效率和低空气剩余量, 减少了燃烧产物中未燃成分的含量, 降低了烟尘、CO 和 NO_x 的生成量, 满足洁净燃烧的要求。因此, 脉动燃烧正日益引起专家们的关注, 为研制高效节能、低污染的燃烧器提供了一个新的途径。从国内外的资料中可以看到脉动燃烧的应用潜力, 美国福伯能源工程公司 1984 年试制的用于大型商业大厦和办公大楼采暖的脉动蒸汽锅炉, 总热效率超过了 86%; 1986 年试制的日供应 14 吨开水的脉动锅炉, 其效率高于 90%。

里克型脉动燃烧器是一种自激声振式脉动燃烧器。除了具有脉动燃烧器的共有特点以外, 与强迫型脉动燃烧器相比, 它还具有无需任何运动部件就能实现定型自激脉动, 结构简单, 操作维护方便, 使用

寿命长的特点, 是实现脉动燃烧技术工程实用化的一个理想选择对象。有关里克型脉动燃烧器大型化问题的研究在另一篇文章中介绍, 本文主要集中在里克型脉动燃烧器方形化问题上。

考虑到我国工厂和企事业单位所用的锅炉大多是链条炉, 如果能将里克型脉动燃烧技术与燃煤链条炉结合起来, 就既可提高燃烧、传热效率, 又利用了链条炉的成熟技术。通常链条炉燃烧室是非圆形的 (方形或长方形), 目前国内外报道的里克型燃烧器均是圆形的, 而圆形和方形管道对声波传播而言是不同的。因此, 研究在非圆形燃烧器中实现里克型自激脉动, 扩大里克型脉动燃烧器的适用范围就显得很有意义。

一般来说, 方形 (或矩形) 管比圆形管更容易产生多维声波传播。那么, 管道中多维波的形成是否有一定的条件呢?

2 方形管中平面波的存在条件

根据声波导管理论, 当管道尺寸给定以后, 其截止频率就确定了, 只要声源的工作频率低于截止频率, 该管道中就只能传播 (0, 0) 次波, 即一维平面波。因此, 对里克型脉动燃烧器而言, 只要其脉动频率低于管道 (燃烧器) 的截止频率, 燃烧器内就只能形成一维平面驻波脉动了。

2.1 矩形声波导管的截止频率

在图 (1) 所示的矩形声波导管中, 假设导管在 x 、 y 方向有刚性壁, 长度分别为 l_x 和 l_y , 声波沿 z 轴传播

由波动方程可求得矩形声波导管中的简正频率为:

$$f_{n_x, n_y} = \frac{c_0}{2} \sqrt{\left(\frac{n_x}{l_x}\right)^2 + \left(\frac{n_y}{l_y}\right)^2} \quad (1)$$

因此, 管中产生沿 z 方向传播 (n_x , n_y) 次声波的条件可归结为:

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$$f > f_{n_x, n_y} \quad (2)$$

对于一组不同的 (n_x, n_y) 数值将得到不同的波 $(0, 0)$ 次波就是沿 z 轴方向传播的一维平面波, 其简正频率 $f_{0,0} = 0$

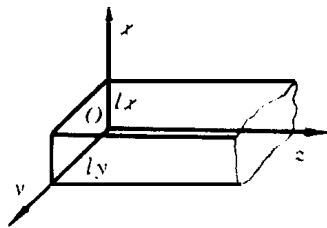


图 1 矩形声波导管示意图

声学上称除零

以外的一个最低简正频率为该声波导管的截止频率 f_c 。根据式 (2) 和截止频率的概念, 容易得到管道中只能传播唯一的 $(0, 0)$ 次波 (平面波) 的条件为:

$$f < f_c \quad (3)$$

对矩形管而言其截止频率计算式为:

$$f_c = \min(f_{1,0}, f_{0,1}) \quad (4)$$

所以, 在方形里克型脉动燃烧器中, 只要实际脉动频率低于燃烧器 (管道) 的截止频率, 那么就只能形成一维平面驻波脉动。

2.2 实验所用燃烧器的管道截止频率

取声速 $\omega = 400 \text{ m/s}$, 得到实验所用方形燃烧器管道的截止频率, 结果列于表 1 实验测得 $350 \text{ mm} \times 350 \text{ mm}$ 方形里克型燃烧器的脉动频率为 63 Hz

表 1 方形实验里克脉动燃烧器管道的截止频率

| 边长 (mm) | $f_{1,0}$ (Hz) | $f_{0,1}$ (Hz) | 截止频率 f_c (Hz) |
|------------------|----------------|----------------|-----------------|
| 350×350 | 571.4 | 571.4 | 571.4 |

比较对应的截止频率和实际脉动频率很容易看出, 实验所用到的方形里克脉动燃烧器的脉动频率远低于燃烧器相应的截止频率, 由此可得, 其中传播的主要声波成分是一维平面波

3 方形里克和里克 - ZT 型脉动燃烧器试验

方形里克脉动燃烧器结构如图 2 所示; 方形里克 - ZT 脉动燃烧器的中段为方形管, 上下两段为圆形管, 其结合部有面积收缩, 如图 3

试验中燃烧块状烟煤, 实验测得方形里克脉动燃烧器的脉动频率 63 Hz , 略低于等长度 $H300 \text{ mm}$ 圆形里克燃烧器的脉动频率值 65 Hz 脉动压力 101 dB (C 声级), 低于等长度 $H300 \text{ mm}$ 圆形里克燃烧器的脉动压力值 110 dB (C 声级)。此外, 若将方形截面面积折合成圆截面面积求得等效直径 D , 则当长径比等于 8 时方形里克燃烧器还能实现自然抽风状态

下的脉动燃烧, 但已非常勉强, 排烟量很大了。

分析试验结果后得到, 方形里克和里克 - ZT 燃烧器的脉动特征和机理与圆形里克燃烧器基本一致。但是, 由于方形燃烧器中炉排四角的燃烧情况不够理想, 同样情况下燃烧器内的平均温度就比圆形燃烧器的低, 各点声速就较低。因此, 脉动强度和频率也就略低于相同情况下圆形燃烧器的值

另外, 由频谱图 4 可以看出, 方形里克 - ZT 脉动燃烧器内高谐波分量很小,

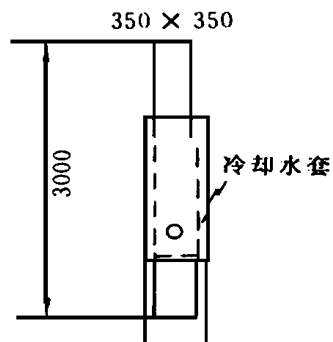


图 2 方形里克脉动燃烧器示意图

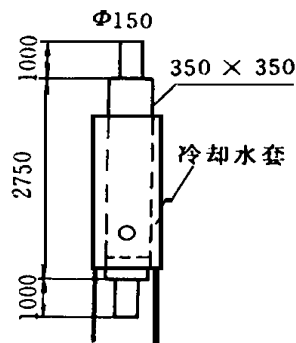


图 3 方形里克 - ZT 脉动燃烧器示意图

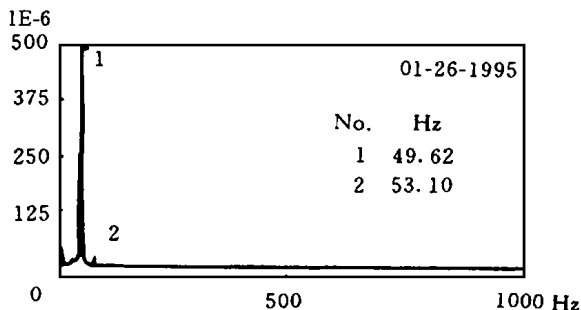


图 4 $350 \text{ mm} \times 350 \text{ mm}$ 方形里克 - ZT 脉动燃烧器频谱图

主要传播的依然是一维基频平面波

4 小结

综合方形里克和里克 - ZT 型脉动燃烧器的实验结果, 可以得到以下结论:

- (1) 能够在方形燃烧室中实现燃煤里克型脉动燃烧
- (2) 方形里克燃烧器与圆形燃烧器的脉动机理基本相同, 只要设计得当, 仍可实现一维基频波自激

内循环流化床锅炉稀相区中试性实验研究

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[摘要] 对一台 1.4 MW 的内循环流化床进行了中试性实验研究,给出了二次风率对颗粒浓度的影响以及传热实验关联式。

关键词 流化床 内循环 二次风率 颗粒浓度
传热系数

中图分类号 TK229.66

1 引言

流化床燃烧技术在节约能源、减少环境污染方面起到了积极作用。内循环流化床燃烧技术是流化床燃烧技术的一种发展和突破^[1~4]。它集中了鼓泡床和循环床的诸多优点,在设备投资及运行维护方面具有较大优势。作者对一台 1.4 MW 的内循环流化床进行了中试性实验研究,对内循环流化床的工程设计和应用具有理论和实践指导意义。

2 实验原理及测试装置

实验锅炉及测试系统如图 1 所示,炉膛上部装有带一定立面角(30°)和切面角(50°)的喷嘴,二次风($W = 30 \text{ m/s}$)由此喷射进入炉膛形成强烈的下旋转流场,使物料进行炉内分离循环。由于炉膛为圆形,传热和浓度测试元件中心对称布置,可认为均处

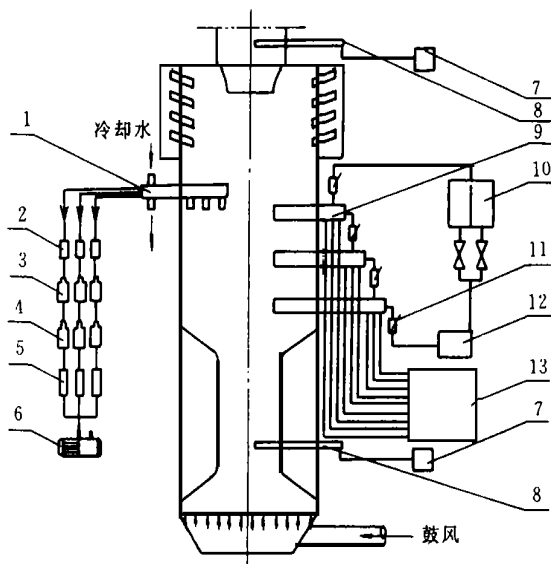


图 1 热态实验台测试系统图

1-浓度测量探头 2-取样器 3-过滤瓶 4-干燥瓶 5-转子流量计
6-真空泵 7-电位差计 8-热电偶 9-壁温测量探头
10-标准水箱 11-玻璃温度计 12-循环水泵 13-巡回检测仪

于相同工况下。

2.1 飞灰浓度测试

稀相区飞灰浓度的分布不仅对含尘气流与管束间的换热规律有重要的影响,而且也是衡量内循环流化床粒子分离效率的重要指标。实验中沿炉膛轴

脉动

(3) 方形里克燃烧器脉动强度比等长度、相同截面积圆形里克燃烧器的低,表现为排烟量较大。

(4) 方形里克燃烧器的脉动频率略低于等长度圆形里克燃烧器的脉动频率。

参考文献

- 1 Chen F L, Shi Z L, Zhong Y J. Rijke-ZT pulse combustion technology for coal. Proceedings of the Int. Conf. on Energy and Enviro., Shang Hai, 1995.
- 2 Shi Z L, Tu J H, Zhong Y J. Investigation of a square Rijke-type pulse combustor for coal. The Third Asian Pacific

Int. Symp. On Comb. and Eng., HongKong, 1996.

- 3 钟英杰. 热声转换和脉动燃烧技术研究现状及其应用. 浙江工业大学学报, 1998, 26(1).
- 4 June R R, Bakre M J. Journal of Heat Transfer., 1963 279.
- 5 Znn B T, Danniell B R, Shani S et al. Investigation of the characteristics of liquid fuel burning, Rijke type, pulse combustors. Final Report for DOE Contract No. DE-AS04-85 A131881(1989).
- 6 Gerald Parkinsin. Pulse combustion sounds off. Chemical Engineering, 1990 28~ 35.
- 7 Keller J O, Hongo I. Pulse combustion the mechanisms of NO_x production. Combustion and Flame, 1990, 80 219~ 237.
- 8 杜功焕,朱哲民,龚秀芬.声学基础.上海科学技术出版社,(上下册),1981.

树皮在复合燃烧锅炉流化床内的燃烧份额 = **The Combustion Share of Bark in a Bark Fluidized Bed-Pulverized Coal Compound Combustion Boiler** [刊, 中] / Zhao Guangbo, Liu Wentie, Huang Yimin, Qin Yukun (Harbin Institute of Technology), Li Han (Boiler & Pressure Vessel Inspection Institute of Harbin Labor Bureau) // Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 325~ 327
By the analysis of a heat balance of fluidized bed in a bark fluidized bed-pulverized coal compound combustion boiler a calculation formula is obtained of the combustion share of bark in the fluidized bed. With a 75t/h bark fluidized bed-pulverized coal compound combustion boiler being taken as an example the authors analyze the effect on bark combustion share of such factors as fluidized bed temperature, fluidized bed outlet nominal excess air factor, hot air temperature, embedded tube heat absorption share and the evaporation heat consumption of water contained in the fluidized bed unburned bark. **Key words** compound combustion boiler, bark, combustion share

一种新型可变导热管传热与控制温度机理分析与实验 = **Experimental Study and Analysis of a New type of Variable Heat Conduction Pipe Heat Transfer and Temperature Control Mechanism** [刊, 中] / Zhao Xiaobao (Nanjing Power Engineering College), Yuan Zhulin, Zhang Mingyao (Southeastern University) // Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 328~ 330

A new type of variable heat conduction pipe heat exchange unit is proposed, which can be used for the cooling and temperature control of ash exhaust pipe in a pressurized fluidized bed power generation system. The results of analysis and tests show that in case of an unstable ash flow in the ash exhaust pipe, i. e. in the presence of a significant change in the outside heating load or cooling conditions, the operating temperature of the heat pipe remains almost unchanged and can be controlled within a required range. The heat pipe working temperature will increase with an increase in gas loading, but the control temperature characteristics will not undergo a marked change. In contrast with conventional heat pipes there is a significant change of steam temperature in the variable heat conduction pipe along a condensing section axial direction. Steam condensation is inhibited and a reduction in heat pipe heat transfer quantity results. **Key words** gas-loaded heat pipe, heat transfer performance, temperature control

燃气轮机余热锅炉三通档板阀的研制 = **Development of a Three-way Diverter Damper for Gas Turbine HRSG** [刊, 中] / Liang Haidong, Yang Jiadong, Wang Jianzhi (Harbin No. 703 Research Institute) // Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 331~ 333

This paper describes the working principle, main construction and technical features of a three-way diverter damper. It is a new product developed and put into operation in China for the first time. Also given in the paper is the approach to be taken for its further improvement and a forecast of future application prospects. **Key words** gas turbine, HRSG, three-way diverter damper

方形里克和里克 - ZT型脉动燃烧器研究 = **A Study of Square-shaped Model Rijke and Rijke ZT Pulsating Combustors** [刊, 中] / Zhong Yingjie, Chen Fulian, Shi Zhuling, et al (Zhejiang Industrial University) // Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 334~ 336

Tests were conducted of model Rijke and Rijke ZT pulsating combustors of a 350× 350 mm square-shaped furnace. The test results show that with the help of the square-shaped combustor a model Rijke pulsating combustion under natural draft conditions can be realized but with a greater difficulty than in the case of a

circular combustor. A basically same pulsation mechanism is involved in both cases. An acoustic analysis and test has shown that one-dimensional plane waves are propagated. Key words pulsating combustion, square-shaped model Rijke ZT pulsating combustor, square-shaped model Rijke ZT pulsating combustor, test

内循环流化床锅炉稀相区中试性实验研究 = The Pilot-plant Test Study of an Internal Circulation Fluidized Bed Boiler Rarefied-phase Region [刊, 中] /Wang Huaibin, Quan Wentao, Du Jun (Harbin Institute of Technology) //Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 336~339

A pilot-plant test study is conducted of a 1.4 MW internal circulating fluidized bed. Presented are the effect of a secondary air feeding rate on particle concentration and also a heat transfer experimental correlation. **Key words** fluidized bed, internal circulation, secondary air feeding rate, particle concentration, heat transfer factor

回流区分级着火旋流煤粉燃烧器的试验研究 = An Experimental Study of Recirculation Zone Staged-ignition Swirl-flow Pulverized Coal Burners [刊, 中] /Chen Changdong, Jin Shiping, Ai Yuanfang, et al //Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 340~342

A cold-state model experimental study is conducted on the basis of an analysis of the working principle of recirculation zone staged-ignition swirl-flow pulverized coal burners. A modification of swirl-flow pulverized coal burners of No. 5 boiler installed at Huangshi Power Plant was undertaken based on the study results. The operational test results show that these novel burners exhibit relatively good stabilized combustion characteristics when burning low-volatile coals. **Key words** swirl-flow pulverized coal burner, recirculation zone staged-ignition, test, development

下降液膜受热流动与换热的实验研究 = An Experimental Study of Falling Liquid Film Heated Flow and Heat Exchange [刊, 中] /Shi Jinsheng, Shi Mingheng (Southeastern University) //Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 343~344

An experimental study is conducted of flow and heat exchange characteristics of the film of a liquid falling from a vertical wall when the liquid film is being heated. The phenomenon of the film break-up was brought under observation. A fitting correlation for film break-up and heat exchange was obtained from the experimental results. **Key words** falling liquid film, break-up, heat exchange

一种新的热力循环性能的估算方法和 HAT 循环的性能估算方式 = A Method for the Evaluation of a New Thermodynamic Cycle Performance and a Formula for HAT Cycle Performance Evaluation [刊, 中] /Wang Yongqing, Yan Jialu (Harbin Institute of Technology), Wen Xueyou (Harbin No. 703 Research Institute) //Journal of Engineering for Thermal Energy & Power. - 1998, 13(5). - 345~347

Based on the fundamental principles of thermodynamics, the authors have come up with a new method for evaluating complicated thermodynamic cycle performance, i. e. a factor correction method. Furthermore, on this basis recommended is a formula for evaluating the performance of a humid air gas turbine cycle. **Key words** thermodynamic cycle, factor correction method, humid air gas turbine, HAT cycle, performance evaluation formula