

煤粉浓缩器阻力特性的试验研究

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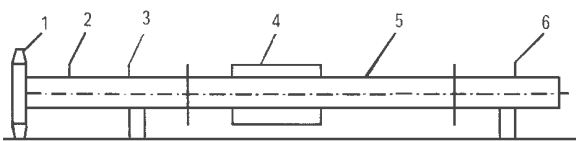
【摘要】 采用近似模化法研究了两种不装导流板的煤粉浓缩器——丘体和百叶窗的阻力随结构参数变化的特性。试验结果表明, 随着丘体斜面长度的增加, 阻力系数增大。对于百叶窗, 阻力系数随着叶片倾角或叶片宽度的增加而增大, 叶片间距比的变化对流体流动影响比较大, 它在2.5~3.0之间变化时, 流动阻力较小。

关键词: 煤粉浓缩器; 丘体; 百叶窗; 阻力特性

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1 引言

对于旋流燃烧器, 可通过装设在一次风煤粉管道上的高浓缩比的煤粉浓缩器使一次风中的煤粉分成浓、淡两股气流, 可见, 实现浓淡燃烧技术的关键是调节浓淡分离的煤粉浓缩器。一次风流过浓缩器时必须克服一定的阻力, 在满足燃烧要求的浓缩比的前提下, 应当使浓缩器的阻力尽可能小。由于煤粉浓缩器的分离过程是一种复杂的流动过程, 并且结构多种多样, 以致目前尚不能从理论上建立起完整的数学模型^[1]。本文采用近似模化的方法, 以黄岛电厂4#炉旋流煤粉燃烧器为模拟结构, 比例为1/3。由于旋流燃烧器的一次风道狭窄, 不宜布置结构复杂的浓缩器, 而传统的浓缩器在其末端与一次风出口处装有导流板, 使浓淡风粉分别走不同的管道。为了简化结构, 降低阻力, 本文试验研究了两种不装导流板的浓缩器——丘体和百叶窗的阻力特性, 为今后的结构设计提供参考依据。



1—送风机 2—流速测点 3—静压测点
4—浓缩器 5—试验段 6—静压测点

图1 试验装置系统图

2 试验系统及测量^[2]

试验装置见图1, 风机提供试验用空气, 经进风管道和均流段后进入试验段。用皮托管测量进风管道入口的流速, 风量利用风机入口挡板进行调节。为了消除漏风对试验结果的影响, 各接头用橡胶片和密封胶带封牢。整个试验段用有机玻璃制造。通过U型管测压计读出试验段进出口静压降差值, 以求浓缩器的阻力。

浓缩器的阻力特性可用阻力系数来评价。试验证明^[3], 在同一管道内, 速度越高, 阻力越大; 而且当速度相当高, 处于湍流状态时, 阻力损失 ΔP 和速度 V 的平方成正比。因此, 阻力系数的定义为:

$$\zeta = \frac{\Delta P}{1/2 \rho V^2} \quad (1)$$

3. 丘体浓缩器的阻力特性

3.1 理论分析

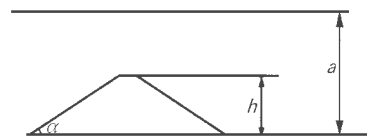


图2 丘体结构图

丘体的结构设计考虑了丘体高度 h 和倾角 a 两个变量, 为了便于分析, 合并成一个变量, 即丘体斜面长度 L ($L = h/\sin a$), 见图2。各种结构的丘体被做成一个组件, 以便更换。试验工况见表1。空气流过丘体, 相当于先经过一个渐缩管, 接着再流过一个渐扩管。当来流流向试验段的最窄截面时, 流线必须弯曲, 流束必定收缩, 流速增加, 流体流过最窄截面以后, 由于流体有惯性, 流体将继续收缩直至最小截面, 而后又逐渐扩大充满整个流通截面^[4]。在流线弯曲、流体加速和减速过程中产生的损失, 称为弯曲损失。流束先渐缩后渐扩的过程中, 流体在管壁、丘体附近

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形成漩涡,漩涡靠主流束带着旋转,主流束把能量传递给漩涡,漩涡又把得到的能量消耗在旋转运动中(变成热而消散),称之为漩涡损失。因此,空气流过丘体时的阻力损失由两部分组成:弯曲损失和漩涡损失。

3.2 试验结果分析

3.2.1 丘体斜面相对长度 L/a 对阻力的影响

从图3可看出,随着 L/a 的增加,阻力系数增大,其值在 0.5~3.0 范围内。丘体高度不变,倾角减小,或者倾角不变,高度增加,都会引起斜面长度增加,增强了对流场的扰动,流线的变形程度增加,漩涡数目增多,损失增加,因此,阻力系数增大。

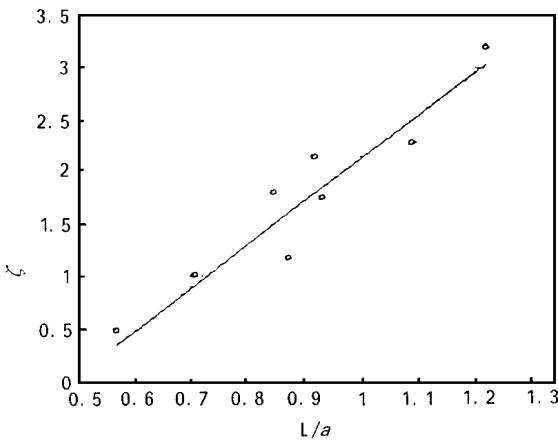


图3 丘体斜面相对长度 L/a 对阻力的影响

用最小二乘法,回归得到的公式为:

$$\zeta = -1.52 + 4.04 \times [(h/a) / \sin(\alpha)] \quad (2)$$

表1 丘体浓缩器的试验工况表

序号	1	2	3	4	5	6	7	8
h/a	0.7	0.7	0.65	0.6	0.6	0.5	0.5	0.4
$\alpha(^{\circ})$	40	35	45	45	40	45	35	45

表2 百叶窗浓缩器的试验工况表

序号	1	2	3	4	5	6	7	8	9	10	11
$W(\text{mm})$	50	50	50	50	50	55	60	65	50	50	50
$\beta(^{\circ})$	20	25	35	40	30	30	30	30	30	30	30
x/x_0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.5	3.5

4 百叶窗浓缩器的阻力特性

4.1 理论分析

百叶窗的结构参数用 ω 、 β 、 x/x_0 、 γ 表示,见图4。 w 表示叶片宽度, β 表示叶片倾角, x/x_0 表示两

相邻叶片的轴向间距比,其中百叶窗倾角 γ ($\gamma = \arctg(x_0/x \cdot \tg\beta)$) 由 x/x_0 、 β 决定。气流流过百叶窗后,静压降低,产生了阻力损失^[3],这个阻力损失由三部分构成:摩擦损失、导流损失和碰撞损失。

现分析如下:流体流过百叶窗浓缩器时,由于粘性作用,靠近叶片表面的流体因受到阻滞而降速,根据附面层理论,叶片表面有一层很薄的附面层,附面层内速度发生剧烈的变化,因此,气流与叶片表面必定存在摩擦损失。当来流经过第一个叶片后,气流的一部分 Q_1 继续向前运动,如图5所示,由于流通截面逐渐缩小,流速不断增大,气流在第二个叶片的导向作用下,流线继续向上弯曲,流束继续向上收缩,气流 Q_1 中只有一部分气流 Q_3 流过第三个叶片的上部,在最后一个叶片的某个位置,流束收缩至最小截面,流速达到最大值,然后流束慢慢扩大,气流速度逐渐减小。在流线的弯曲、收缩、扩张过程中,容易形成一些小漩涡,造成一定的能量损失。我们把叶片以上流体流动过程中带来的损失称为导流损失。气流 Q_2 的流线向下弯曲,流过两个叶片之间的空隙后,继续向前运动,遇到气流 Q_4 后,发生碰撞混合,然后一起向前运动,在浓缩器后面各股气流逐渐掺混,形成一个整体,同时还伴随着产生一些漩涡。把叶片以下流体流动过程中产生的损失称为碰撞损失。

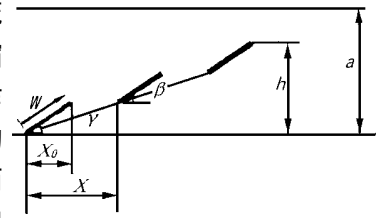


图4 百叶窗结构图

下面讨论百叶窗的结构参数对浓缩器阻力的影响。为了减少阻力损失,叶片出口端加工成圆弧状。试验表明,叶片本身的形状对阻力影响较大,研究单个因素对阻力的影响时,保证其它条件相同。试验工况见表2。

4.2 试验结果分析
4.2.1 百叶窗浓缩器叶片倾角 β 对阻力的影响

4.2.1 百叶窗浓缩器叶片倾角 β 对阻力的影响

由于多相流体流动较单相流动更早地进入自模化状态^[9],因此,单相阻力特性试验的目的在于寻找系统进入第二自模区的临界雷诺数,并以此为根据,

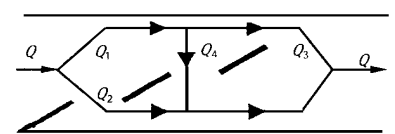


图5 百叶窗浓缩器气流流量分布图

选择模化试验的风量。Eu 准则的物理意义为阻力系数的一半, 因此, 把试验数据整理为 $Eu-Re$ 曲线更能说明问题。

从图 6 可看出, 当 $Re < 2 \times 10^5$ 时, 随着 Re 的增大, Eu 数增大; 当 Re 在 $2 \times 10^5 \sim 2.5 \times 10^5$ 之间时, 阻力系数基本不变, 可认为流动进入了第二自模化区。这时阻力系数与叶片倾角的关系可用下式表示:

$$\zeta = 0.53 + 0.57 \times (\beta / 20) \quad (3)$$

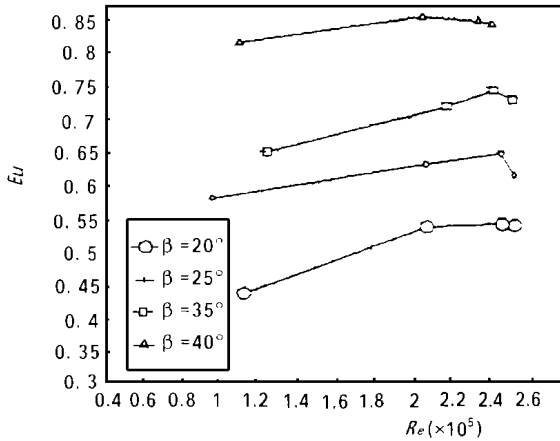


图 6 叶片倾角变化 $Eu-Re$ 曲线

当雷诺数相同时, 随着叶片倾角 β 的增大, 阻力系数增大。当 β 由 20° 增加到 40° 时, 叶片间轴向距离的相对值 $(x-x_0)/a$ 由 0.705 减小到 0.575, 浓缩器高度的相对值 h/a 由 0.386 增加到 0.725。前者使气流流过叶片间隙的流速增大, 气流 Q_2 或 Q_4 的弯曲程度加大, 故碰撞损失增大, 后者使气流 Q_1 或 Q_3 的流通截面变窄, 流速增大, 气流与叶片的碰撞程度增加, 造成导流损失增加。

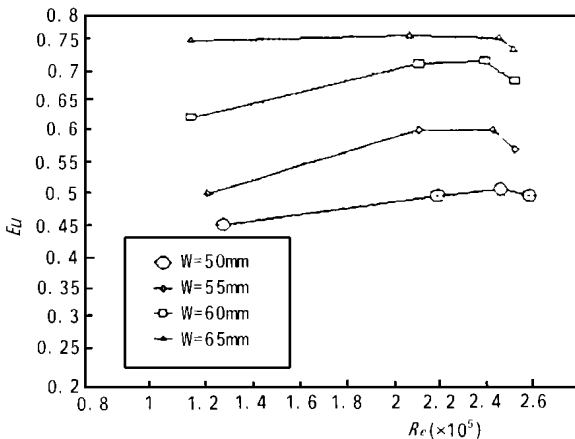


图 7 叶片宽度变化 $Eu-Re$ 曲线

4.2.2 百叶窗浓缩器叶片宽度 W 对阻力的影响

由图 7 可知, 当 Re 在 $2 \times 10^5 \sim 2.5 \times 10^5$ 之间时, 流动进入了第二自模化区。阻力系数与叶片宽度的关系式为:

$$\zeta = -0.70 + 1.74 \times (W/50) \quad (4)$$

叶片宽度由 50 mm 增加到 65 mm 时, 叶片与气流的摩擦损失增加, 浓缩器高度的相对值 h/a 由 0.56 增加到 0.73, 叶片间轴向距离的相对值 $(x-x_0)/a$ 由 0.65 增加到 0.845。前者使导流损失增加, 后者使叶片间隙处的气流流速降低, 气流 Q_2 或 Q_4 的弯曲程度减小, 减小了碰撞损失。试验结果表明, 雷诺数相同时, 随着叶片宽度的增加, 浓缩器的阻力系数是增加的。

4.2.3 百叶窗浓缩器两相邻叶片轴向间距比 x/x_0 对阻力的影响

图 8 说明, 间距比的大小对流体的流动影响比较大。当 $Re < 2.2 \times 10^5$ 时, 间距比从 2.0 变到 3.5, 阻力损失是先下降后上升, 当 $x/x_0 = 2.5$ 时, 阻力损失系数最小。这说明间距比并不是越大越好, 它存在着一个最佳范围, 在该范围内, 阻力损失小而且分离效果好。这可能是由于当间距比从 2.0 增加到 2.5 时, 叶片间轴向距离的相对值由 0.33 增加到 0.49, 气流进入叶片间隙的碰撞损失减小, 使得阻力损失减小。当间距比继续增大时, 浓缩器轴向长度的增加对气流流动造成的影响比较强, 使得阻力损失又增大。当 $Re > 2.2 \times 10^5$ 时, 阻力损失与间距比的关系变得比较复杂, 有待于更深一步研究。

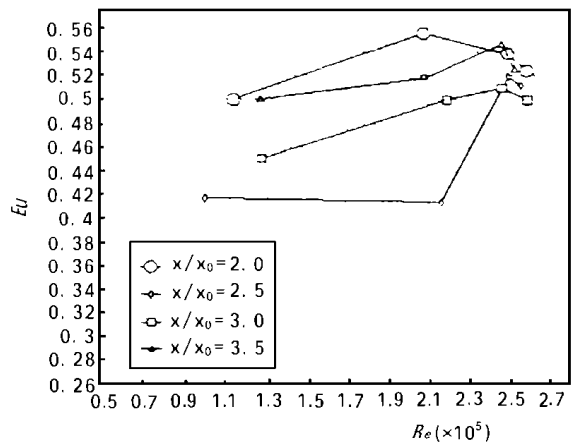


图 8 间距比变化 $Eu-Re$ 曲线

5 结论

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按《蒸汽锅炉安全技术监察规程》进行水压试验。对管板、焊缝、管端进行检查。水压试验合格标准：受压元件金属壁和焊缝上无水珠、水雾；水压试验后，未发现残余变形。

2.2 烟风系统改造

修复原有的调风门，锅炉实现分段送风；清理省煤器堵灰。

2.3 给煤装置改造

取消原有煤闸门，改装正转链条分层给煤装置。原煤经过该装置后，被筛分。粒度大的原煤在煤层底部、而粒度小的原煤落在煤层上面。这种布煤方式对加强燃烧有以下3方面有利因素：

煤粒之间的间隙得到充分保证，煤层通风阻力小，炉排面积热负荷和炉膛温度提高，燃烧速度加快。

整个火床通风均匀，避免炉排上出现火口和踏火现象。

细煤粉在煤层表面，易着火，显著改善着火条件。使锅炉对煤种适应性大大增强。

2.4 炉拱改造

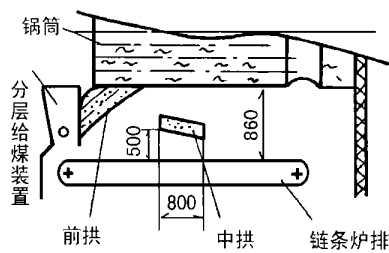


图1

取消原有吊砖结构前拱，浇注耐火混凝土前拱。在炉排中部增加一中拱，中拱倾角为 12° 。如图1所示。增加中拱后，可改变烟气流

流向，加强炉内气体扰动，延长飞灰可燃物在炉内停留时间。与前拱配合，加强对刚进入原煤的热辐射。

3 改造效果

锅炉经过技术改造后，本体可靠性提高，并取得了很好的节能效果。改造后，炉膛温度提高 200°C ~ 260°C ，锅炉热效率为68.4%，灰渣含碳量为13.4%；比改造前热效率提高12.3%，灰渣含碳量下降17.6%，蒸汽单耗由改造前每吨蒸汽耗标煤149 kg下降到124 kg，节煤率达16.8%。该炉经2年多的运行表明：改造方案合理、节能效果好。

(复 编)

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本文研究了两种不装导流板的浓缩器——丘体和百叶窗的阻力特性。试验：

(1)随着丘体斜面长度的增加，丘体的阻力损失增加。

(2)随着百叶窗叶片倾角和叶片宽度的增加，百叶窗浓缩器的阻力损失增加。

(3)百叶窗浓缩器的间距比在2.5~3.0之间变化时，阻力损失小并且分离效果好。

(4)这两种浓缩器结构都比较简单，便于对已投用锅炉的燃烧器进行改造。

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(复 编)

电子束沉积叶片保护层

据'Gas Turbine World' 1998年11-12月号报道, 1998年8月西门子公司在柏林展示了一种新的叶片涂层设备, 用它来给大型工业燃气轮机动叶和静叶喷涂热障涂层(TBC)。

该设备使用电子束物理蒸气沉积过程。使用电子束过程, 陶瓷TBC形成与叶片表面相垂直的杆形柱状结构。这产生了“弹性”涂层, 使叶片十分耐燃气轮机运行过程中产生的热力和化学负荷。

蒸气沉积室装有三支150kW的电子束枪。在该真空室内电子束蒸发陶瓷源材料, 以便产生精确定义的陶瓷蒸气。

西门子公司声称, 在燃气轮机运行过程中当暴露在 1350°C ~ 1500°C 温度下这些涂层的使用寿命至少比惯用的喷雾涂层长一倍。

此方法的另一个优点是更精密的涂层厚度公差和能力, 使之能涂已钻好冷却空气孔的叶片, 而不会冒堵死冷却孔的风险。

(思娟 供稿)

船用增压锅炉技术的新进展 = **New Developments in Marine Supercharged Boilers** [刊, 中] / Liu Changhe (Harbin No. 703 Research Institute) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

A brief description is given of the working principles, construction design, performance parameters of naval supercharged boilers as well as their research and development history and operating experiences. Also proposed is a more advanced overall layout scheme based on an improved boiler design. **Key words:** boiler, supercharged boiler, design, research and development

核态池沸腾中气泡生长和脱离的动力学特征 —— 气泡动力学研究回顾 = **Dynamic Characteristics of Bubble Growth and Detachment in the Course of Nucleate Boiling - Part I: A Review of Bubble Dynamic Study in Nucleate Boiling** [刊, 中] / Yang Chunxin, Wu Yuting, Yuan Xiugan (Beijing Aeronautical and Aerospace University), Ma Chongfang (Beijing Industrial University) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

This paper presents a systematic review and analysis of the research progress of bubble dynamics over the past fifty years. Some deficiencies in the study of bubble growth and detachment have been identified with the orientation of future development conducive to a further in-depth study of the bubble dynamics being pinpointed. **Key words:** nucleate boiling, bubble, detachment diameter, detachment frequency, overview

燃气轮机进气用蒸发式冷却器中的气水分离技术实验研究 = **An Experimental Study of the Gas/Water Separation Technology for a Gas Turbine Inlet Air Evaporative Cooler** [刊, 中] / Lin Feng, Li Weishun, et al (Harbin No. 703 Research Institute) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

Proceeding from the aim of enlarging engineering applications the authors have conducted an experimental study of the characteristics of a novel plant-mesh pad type gas/water separator developed by No. 703 Research Institute on its own. Meanwhile, performance evaluation was made of corrugated-plate inertial-grade gas/water separators commonly used in industries nowadays under certain specific conditions. The results thus obtained are of practical value for facilitating engineering applications. **Key words:** evaporative cooler, gas/water separation, large water droplet separator

燃油喷嘴气液两相流雾化特性研究 = **A Study of the Two-phase Flow Atomizing Characteristics of Oil Spray Nozzles** [刊, 中] / Li Guangjun, Wang Xinjun, Xiang Yu, et al (Xi'an Jiaotong University) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

With air and water serving as working media a detailed experimental study was conducted of the atomizing characteristics of a two-phase flow atomizing nozzle with the help of a Malvern particle size analyzer. During the study measurements were made of the particle size distribution of atomized liquid particles formed after having passed the spray nozzles under different inlet pressure ratio conditions of the gas/liquid two-phase flow. Discussed and analyzed in detail was the influence on the nozzle atomizing effectiveness of the gas/liquid two-phase pressure and the gas and liquid feeding mode. As a result, determined was the variation relationship between the gas/liquid two-phase flow rate and gas/liquid two-phase pressure in the course of nozzle atomizing process as well as the optimum atomizing principles. In addition, the nozzle atomizing mechanism has also been discussed. **Key words:** spray nozzle, gas/liquid two-phase flow, atomizing characteristics, liquid particle size distribution

煤粉浓缩器阻力特性的试验研究 = **An Experimental Investigation of the Resistance Characteristics of Pulverized Coal Concentrators** [刊, 中] / Shi Liming, et al (Qinghua University) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

By the use of an approximation simulation method a study was conducted of two types of pulverized coal concentrator without guide plates with respect to the variation of their mound-body and louver resistance characteristics with the change of structural parameters. The test results show that with the increase in mound-body inclined surface length there is an increase in the resistance factor. The louver resistance factor increases with an increase in the blade inclined angle or blade width. The variation of blade spacing ratio has a fairly significant effect on fluid flow. A relatively small flow resistance is

observed when the blade spacing ratio has a variation interval of 2.5 ~ 3.0. **Key words:** pulverized coal concentrator, mound body, louver, resistance characteristics

火电厂水力输灰系统阻垢防垢研究 = **A Study of Scale Inhibition and Prevention for a Thermal Power Plant Wet-ash Transportation System** [刊, 中] / Chen Yafei, Gao Xiang, Fang Mengxiang, et al (Zhejiang University) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

Discussed in this paper are the scale prevention measures for an ash water transportation system and the scale inhibition mechanism of scale inhibiting agents. An experimental study of scale inhibition and prevention was conducted of a kind of utility boiler-fired coal with ash rich in CaO, addressing such a variety of topics as the scale characteristics and scale inhibition rate when scale inhibitors of various formulas are adopted, and the scale inhibition and prevention effectiveness when steel/rubber combination pipes and ash water precipitation tank are employed. A comparison analysis has also been performed with respect to different kinds of methods used. **Key words:** wet ash transportation, scale, scale inhibition and prevention

各向异性散射介质的辐射传热分析 = **An Analysis of Radiation Heat Transfer in Isotropically and Anisotropically Scattering Media** [刊, 中] / Xing Huawei, Ruan Jian, Zheng Chuguan (Central China University of Science & Technology) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

With the use of a combined Monte-Carlo and Zone method of numerical calculation (called MCZ method for short) an analysis was conducted of the radiation heat transfer in isotropically and anisotropically scattering media. For convenience of comparison an one-dimensional slab system is employed. With the help of specially prepared programs calculated respectively are the hemispherical reflectivity and transmissivity of isotropically scattering absorbing media and linear phase-function anisotropically pure scattering media as well as the radiation heat transfer in flat slabs of linear phase-function anisotropically scattering absorbing media. Fairly satisfactory conclusions were obtained. **Key words:** hemispherical reflectivity, hemispherical transmissivity, MCZ method, isotropical scattering, anisotropical scattering, phase function

用 PIV 测量法研究燃气轮机叶轮与导叶叶轮间的速度场 = **A Study of the Velocity Field Between a Gas Turbine Runner and Guide Vane Wheel with the Use of PIV Measurement Method** [刊, 中] / Zhao Yabin (Jiangsu Petrochemical Institute) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

A test rig for the experimental research of fluid flow condition inside the cavity ahead of a gas turbine first stage blade wheel is described along with the test method and results. Particle imaging technology was employed to measure the velocity field inside the disk cavity. Analyzed is the effect of the magnitude of seal gas flow rate on the flow field at various locations. Also studied is the relationship between the critical parameters of main flow into the cavity and the flow field. **Key words:** gas turbine, experiment, PIV system

分配联箱气液两相流流型对垂直并联管分配特性的影响 = **The Effect of Gas/Liquid Two-phase Flow Pattern in a Distribution Header on the Distribution Characteristics of Vertical U-Junction Pipe System** [刊, 中] / Cheng Zhuoming, Zhou Yunlong (Northeast Power Engineering Institute) // Journal of Engineering for Thermal Energy & Power. -1999, 14 (4). -

A theoretical and experimental study was conducted of the flow distribution characteristics of low-mass flow in a vertical U-junction parallel-connected pipe system. Obtained were the distribution characteristics of gas phase and gas/liquid two-phase mass flow rate as well as the flow pattern record of various branch pipes. Also analyzed is the effect of flow pattern in distribution headers on the flow distribution and the flow pattern in various branch pipes. **Key words:** gas/liquid two-phase flow, parallel pipes, flow distribution

双调风燃烧器锅炉燃烧参数优化的试验研究 = **An Experimental Study on the Optimization of Combustion Parameters of a Dual Air-Register Burner Boiler** [刊, 中] / Hu Jianguo, Huang Yuming, et al (Zhejiang Provincial