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结构及运行参数对内混喷嘴压力的影响研究

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摘 要:在内混式介质雾化喷嘴的设计计算中,通常近似将混合室内压力与雾化介质进口压力之比看作为临界压比[1],这种近似与实验结果有较大差别。实验研究结果表明,内混式喷嘴混合室内压力并不等于雾化介质进口压力与临界压比之积,而与喷嘴的结构特性及运行参数密切相关。本文以压缩空气和变压器油为工质对内混式介质雾化喷嘴混合室内压力特性进行了实验研究,获得了该类喷嘴混合室内压力与结构及运行参数间的实验关系式(1)、式(2),可供工程设计及运行参考。

关 键 词:内混式喷嘴;实验研究;压力特性

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1 引 言

内混式油喷嘴雾化质量高,已在电厂锅炉、工业窑炉的燃烧设备中获得了广泛应用[1~3]。内混式喷嘴的压力特性主要指喷嘴的混合室内压力与运行油压、气压之间的相互影响关系。根据流量计算公式计算内混式介质雾化喷嘴的油流量和气流量时,混合室内压力是必不可少的。只有了解混合室内压力,才能根据相应的算式,预测喷嘴的油、气流量。

内混式喷嘴的实际运行中,有时会遇到"倒汽现象"或"倒油现象",即蒸汽倒流入油管或油倒流入气管中的现象,导致事故停炉[2~3]。究其原因,是喷嘴的结构型式不合理或者运行参数不匹配,导致混合室内压力高于气压(此时出现"倒油现象")或高于油压(此时出现"倒汽现象")。如果能够得到混合室内压力与喷嘴的结构参数和运行参数的关系式,就能够指导这类喷嘴的优化结构设计,并在实际运行中从根本上杜绝此类事故的发生。

目前,国内外对于内混式介质雾化喷嘴混合室内压力特性研究还比较少。在这类喷嘴的设计计算中,通常近似认为混合室内压力等于气体(雾化剂)临界压力比 β_{1j} 与雾化气体在混合室进口压力 P_2 的乘积[1]。然而从我们的实验结果看,混合室内压力并不等于临界压比与雾化气体进口压力的乘积。文献[4~5]对3个不同油孔深度的内混式介质雾化喷嘴混合室内压力进行了研究,获得了这种内混式介质雾化喷嘴混合室内压力变化的计算式及其线图;但由于实验喷嘴较少,获得的实验数据也比较少,对混合室内压力的研究还不够充分。因此进一步研究内混式介质雾化喷嘴混合室内压力特性随结构及运行参数的变化规律,对于这类喷嘴的理论研究及设计应用均有重要意义[5]。

2 实验系统及测试

实验在上海理工大学燃烧实验室的立式燃油冷态雾化性能实验台进行[5]。雾化室为圆柱形,底面直径为1.5 m,高为1.8 m,四周镶有机玻璃,雾化室内设有自动升降平台,可放置液滴捕集器,液滴分散度采集装置等器件;油泵采用额定压力为6.3 MPa的YB1型叶片泵,通过调节阀和旁路阀调节供油压力和流量;雾化介质压缩空气由GA55型阿特拉斯螺杆空压机供给。实验在常温下进行,实验油品为变压器油。

实验时进油压力由标准压力表测定,压缩空气压力由精密压力表测定,压缩空气流量由LZB-50型转子流量计测定;喷油量用称重法测定,由XF-200型电子秤读数。为了使喷入雾化室的油雾尽快散去以便于观察,安装了一个排气系统。排气系统由油气分离器、排风机以及风管组成,它从雾化室底部抽气,经油气分离器分离出的油通过管路重又回到供油罐中继续利用,空气则排到室外。

实验中设计制造的喷嘴共有3个系列15个喷嘴。喷嘴的雾化头采用单油孔、多气孔斜交型结构,

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气孔中心线与油孔成 45°在油孔周围均匀布置。实验用内混式喷嘴结构如图 1 所示，各喷嘴的主要结构尺寸及试验工况数列于表 1。

表 1 实验用喷嘴主要尺寸及工况数

油孔数和直径/mm	气孔数和直径/mm	混合孔数和直径/mm	混合室直径/mm	混合室长度/mm	$P_1 \geqslant P_2$ 工况数	$P_1 \leqslant P_2$ 工况数
1－Φ4.2	6－Φ3.0	8－Φ3.6	Φ48	98	18	0
1－Φ4.6	6－Φ3.3	8－Φ3.6	Φ48	98	18	0
1－Φ5.0	6－Φ3.6	8－Φ3.6	Φ48	98	18	0
1－Φ4.1	6－Φ3.0	8－Φ4.1	Φ48	108	24	16
1－Φ3.0	6－Φ3.0	8－Φ4.1	Φ48	108	24	16
1－Φ2.8	6－Φ2.8	8－Φ4.1	Φ48	108	24	16
1－Φ2.8	6－Φ2.6	8－Φ4.1	Φ48	108	24	17
1－Φ4.1	6－Φ3.0	8－Φ2.9	Φ48	108	24	9
1－Φ3.0	6－Φ3.0	8－Φ2.9	Φ48	108	24	9
1－Φ2.8	6－Φ2.8	8－Φ2.9	Φ48	108	24	10
1－Φ2.8	6－Φ2.6	8－Φ2.9	Φ48	108	24	10
1－Φ4.1	6－Φ3.0	10－Φ2.8	Φ48	108	24	11
1－Φ3.0	6－Φ3.0	10－Φ2.8	Φ48	108	24	10
1－Φ2.8	6－Φ2.8	10－Φ2.8	Φ48	108	24	10
1－Φ2.8	6－Φ2.6	10－Φ2.8	Φ48	108	24	12
15 个喷嘴在两种情况下（$P_1 \geqslant P_2$ 和 $P_1 \leqslant P_2$）的试验工况总数					Σ342	Σ146

为了测量混合室内压力，在喷嘴混合室外壁上钻了一个直径 1 mm 的垂直小孔，并通过焊在小孔外的测压管和 0.4 级的精密压力表连接，如图 1 所示。实验在常温下进行，以变压器油为实验介质。实验用油的粘度为 21.93 mm²/s，油的密度为 880 kg/m³。实验时进油压力和压缩空气压力由精密压力表测定。

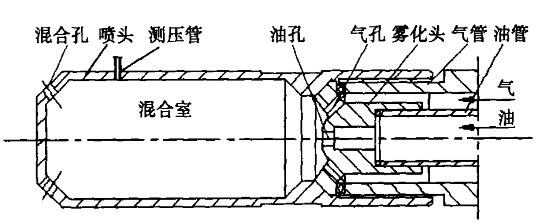

图 1 实验用内混式介质雾化喷嘴示意图

3 数据处理及实验结果

为了获得“最佳”的回归方程，采用逐步回归分析的数据处理方法[6]。这种方法可对多元线性回归进行因子筛选，最后给出一定显著性水平下各因子均为显著的回归方程中的诸回归系数，以及偏回归平方和、复相关系数及 F－检验值、各回归系数的标准偏差、应变量条件期望值的估计值和误差。按照这种方法，分别以内混式介质雾化喷嘴的油孔面积 F_1(mm²)、气孔面积 F_2(mm²)与混合孔面积 F_3(mm²)之比 F_1/F_2、F_1/F_3，以及油压 P_1(MPa)和气压 P_2(MPa)为自变量因子 X(1)、X(2)、X(3)和 X(4)，混合室内压力 P_3(MPa)为应变量 Y，对实验数据进行逐步回归处理。

对于 $P_1 \geqslant P_2$ 的 342 个试验工况下 1710 个结构及运行参数的试验数据，在给定显著性水平 α＝0.01，经逐步回归得到的关系式为：

$$P_3 = -0.9575F_1/F_2 + 1.8365F_1/F_3 + 0.5719P_2 + 0.1183P_1 - 0.0263 \tag{1}$$

该式 F－Y 检验显著。其适用范围为：

$0.1667 < F_1/F_2 < 0.3267$

$0.0583 < F_1/F_3 < 0.250$

$6.154(\mathrm{mm})^2 < F_1 < 19.63(\mathrm{mm})^2$

$0.5\ \mathrm{MPa} \leqslant P_2 \leqslant 0.8\ \mathrm{MPa}$

$0.5\ \mathrm{MPa} \leqslant P_1 \leqslant 1.3\ \mathrm{MPa}$

将实验数据与回归值相比较可得：其中 79％的实验数据与回归值的相对误差在 10％以内。而它的复相关系数达到了 0.938，由此可见，该实验关系

式可信度较高; 回归值与实验数据吻合较好, 基本上能满足工程实际的要求。

对于 $P_1 \leqslant P_2$ 的 146 个试验工况下 730 个结构及运行参数的试验数据, 在给定显著性水平 $\alpha = 0.01$, 经逐步回归得到的试验关系式为:

$$P_3 = -0.9329 F_1/F_2 + 1.9208 F_1/F_3 + 0.4112 P_2 + 0.2444 P_1 - 0.0138 \quad (2)$$

该式 $F-Y$ 检验显著。其适用范围为:

$0.1667 < F_1/F_2 < 0.3267$

$0.0583 < F_1/F_3 < 0.250$

$6.154\,(\mathrm{mm})^2 < F_1 < 19.63\,(\mathrm{mm})^2$

$0.5\ \mathrm{MPa} \leqslant P_2 \leqslant 0.8\ \mathrm{MPa}$

$0.3\ \mathrm{MPa} \leqslant P_1 \leqslant 0.8\ \mathrm{MPa}$

将实验数据与回归值相比较可得: 其中 80% 的实验数据与回归值的相对误差在 10% 以内。而它的复相关系数达到了 0.955, 由此可见, 该实验关系式可信度较高, 是高度显著的; 回归值与实验数据吻合较好, 基本上能满足工程实际的要求。

4　结　论

(1) 实验研究表明, 内混式喷嘴混合室内压力并不等于雾化介质进口压力与临界压比之积, 而与喷嘴的结构特性及运行参数密切相关。对于利用临界压比的算法应按实验结果修正。

(2) 通过实验研究获得了内混式介质雾化喷嘴混合室内压力与结构及运行参数间的实验关系式(1)、式(2), 可供工程设计及运行部门参考。

参考文献:

[1] 赵钦新, 惠世恩. 燃油燃气锅炉[M]. 西安: 西安交通大学出版社, 2000.

[2] 龙　悦, 马其良, 曹丽丽, 等. 化工废液喷嘴冷态雾化性能实验研究[J]. 能源研究与信息, 2003, **19**(3): 154－158.

[3] 曹丽丽, 马其良, 张松寿, 等. Y 型喷嘴运行临界点的冷态实验研究[J]. 工业炉, 2004, **26**(3): 1－3.

[4] MA QI LIANG, LONG YUE, BI ZHENG YI, *et al*. Experimental study on pressure characteristic in the mixing chamber of gas-liquid two-phase internal-mixing-oil-nozzle[A]. 2003 **International Conference on Energy and the Environment Shanghai**[C]. Shanghai: Shanghai Scientific and Technical Publishers, 2003. 952－954.

[5] 马其良, 龙　悦, 毕政益. 气液两相内混式油喷嘴混合室内压力特性的实验研究[J]. 上海理工大学学报, 2004, **26**(1): 24－26.

[6] 汪荣鑫. 数理统计[M]. 西安: 西安交通大学出版社, 2000.

(渠　源　编辑)

技术展望

供 40 MPa 压力用的远景的发电机组

《Теплоэнергетика》2005 年 10 月号刊登了国立伊凡诺夫动力大学 Мошкарин А В 技术科学博士的文章, 文章分析了用于 40 MPa 压力的发电机组的参数和热力系统。

使用超超临界蒸汽参数: 40 MPa, 700/700/700 ℃的发电机组参数和热力系统数值研究的结果。得到的结论如下:

(1) 蒸汽参数从 30 MPa, 600/600/600 ℃过渡到新的更高水准的 40 MPa, 700/700/700 ℃, 允许期望发电机组绝对效率增加 1%～1.5%。

(2) 中间再热器内的最佳压比值随蒸汽初参数的增加移向更小值一侧。

(3) 在热力系统中使用外置式蒸汽冷却器时, 应选择用于它们的抽汽压力, 使得安装在蒸汽冷却器前的加热器内水的加热比具有通常的内装式蒸汽冷却器的加热器内水的加热高 1.4 倍。应用外置式蒸汽冷却器允许使效率提高 0.4%～0.5%。

(吉桂明　供稿)

Through a theoretical analysis of a plane standing-wave sonic field a test rig on acoustic agglomeration and removal characteristics of burned coal inhalable particles has been designed and set up. Under the condition of the inhalable particles of burned coal being subject to the action of a high intensity sonic field studied was the impact of different acoustic intensity and particle retention time in sonic field on the change of particle diameter distribution prior to and after the acoustic agglomeration. On the basis of experiments a numerical calculation was conducted. A comparison of the results of numerical calculation with those of experiments revealed a relatively good agreement. Moreover, by way of a numerical algorithm a forecast was performed of the influence of particle initial concentration and acoustic frequency. The results of experiments and numerical calculation indicate that as for the inhalable particles an increase in acoustic intensity, a lengthening of retention time in sonic fields and an enhancement in initial particle concentration is, without exception, favorable to particle agglomeration. It has been found that an increase in frequency can contribute to the agglomeration of small particles. However, there exists an optimum frequency for attaining integral removal effectiveness. **Key words**: inhalable particle of burned coal, acoustic agglomeration, numerical forecast

混煤煤灰软化温度的实验研究与预测＝**Experimental Research and Forecast of the Softening Temperature of Blended Coal Ash**[刊, 汉] / WU Chang-hong, MA Xiao-qian (College of Electric Power under the South China University of Science & Technology, Guangzhou, China, Post Code: 510640) // Journal of Engineering for Thermal Energy & Power. — 2006, 21(2). —179 ~182

Samples of blended coal ash were taken from the boiler of a power plant 700MW unit. Their softening temperature was measured by a pyramid method on an intelligent ash-melting point measuring device. Experimental results indicate that the softening temperature of blended coal ash and blend/mixture ratio assume a nonlinear relationship. Through the use of a radial-based function neural network (RBFNN) an intelligent forecasting model for the blended-coal softening temperature was set up under MATLAB environment. To verify the forecast effectiveness of the model, with 8 blended coal ash samples under test serving as samples to be examined a forecast of their softening temperature was conducted using the above-mentioned RBFNN-based model. The results of the forecast indicate that the forecast results of the RBFNN model agree well with those of experiments. The maximum relative error between the above two results is 3.79% with the average relative error being 1.56%. The effectiveness of the forecast has been found to be by far superior to that of a linear forecast model. **Key words**: blended coal, softening temperature, forecast, radial-based function neural network, nonlinear

结构及运行参数对内混喷嘴压力的影响研究＝**Experimental Study of the Influence of Structural and Operating Parameters on the Pressure of an Internal-mixing Nozzle**[刊, 汉] / MA Qi-liang, BI Zheng-yi (College of Power Engineering under the Shanghai University of Science & Technology, Shanghai, China, Post Code: 200093) // Journal of Engineering for Thermal Energy & Power. — 2006, 21(2). —183 ~185

In the design calculations of a media-atomization nozzle of internal mixing type it is common practice to regard the ratio between the pressure in a mixing chamber and the inlet pressure of atomization media as approximately a critical pressure ratio. Such an approximation will give rise to a relatively great difference with respect to the results of experiments. The results of an experimental study indicate that the pressure in the mixing chamber of the internal mixing type nozzle is not equal to the product of atomization-media inlet pressure and the critical pressure ratio, but has been closely related to the structural features and operating parameters of the nozzle. With compressed air and transformer oil serving as working media an experimental study was conducted of the pressure characteristics in the mixing chamber of the media-atomization nozzle of an internal mixing type. As a result, an experimental relation was obtained between the pressure in the mixing chamber on one hand and the structural and operating parameters on the other hand for this kind of nozzle. This relation can serve as a reference for design and operation engineers. **Key words**: nozzle of internal mixing type, experimental study, pressure characteristics

混输泵半螺旋形吸入室不同含气率下的速度分析＝**Analysis of the Velocity Flow-field in the Semi-Volute Suction Chamber of a Multiphase Pump for Different Void Fractions**[刊，汉] / MA Xi-jin, QIN Xia, NIU Xian-ming (College of Fluid Dynamics and Control under the Lanzhou University of Science & Technology, Lanzhou, China, Post Code: 730050) // Journal of Engineering for Thermal Energy & Power. — 2006, 21(2). —186～188

By using simulation-analysis software CFD (Computational Fluid Dynamics), STAR-CD, a three-dimensional simulation analysis was conducted of the semi-volute suction chamber of a gas-oil multiphase pump for flow fields at different void fractions. The results of the simulation indicate that the variation of flow field velocity is relatively uniform, showing that it is proper to use this kind of semi-volute suction chamber to serve as the suction chamber of a multi-phase pump. However, at a partition tongue location eddies may occur with the phenomenon of gas stagnation emerging, which is related to the magnitude of flow speed and the void fraction of gas. On the basis of analysis results the circular arc radius at the partition tongue location has been augmented and the thickness of the outlet-end partition tongue decreased. The test of a sample machine indicates that there is a significant enhancement of pump efficiency and void fraction, demonstrating the effectiveness of the measures being taken. **Key words**: gas-oil multiphase pump, semi-volute suction chamber, three-dimensional simulation, velocity flow-field analysis

HAT 循环饱和器工质　计算分析及　效率＝**Exergy Computational Analysis of the Working Medium of a Saturator and the Exergy Efficiency of the Saturator in a HAT Cycle**[刊，汉] / LI Yi-xing, WANG Yu-zhang, WENG Shi-lie, et al (Education Ministry Key Laboratory of Power Machinery & Engineering under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030) // Journal of Engineering for Thermal Energy & Power. — 2006, 21(2). —189～192

A saturator is the key component of a humid air turbine (HAT) cycle. Knowledge about its performance has a direct bearing on the performance analysis of the system as a whole. The authors have calculated the exergy of the saturator working-medium, i.e. humid air and water and analyzed the law governing the influence of temperature and humidity at difference reference points on exergy as well as the variation of physical exergy and chemical diffusion exergy with a change in humid air temperature. Through the establishment of an exergy equilibrium model for the saturator a target-exergy efficiency has been employed to serve as the exergy efficiency of the saturator. From the calculation results the law governing the variation of humid air exergy magnitude with a change in temperature and humidity at reference points has been identified as follows: the exergy of the humid air first decreases until a minimum value of zero is reached, then there is a continuous rise in value, the exergy magnitude being always greater than (or equal to) zero. Moreover, the greater the difference from the reference-point parameters, the greater will be the exergy magnitude. With an increase in humid air temperature the share taken up by the physical exergy decreases, while that taken up by the chemical diffusion exergy