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气流式喷嘴雾化特性试验研究

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摘 要: 一般气流式喷嘴并不能雾化气液混合物, 而压力式喷嘴相比气流式喷嘴, 存在着易磨损, 雾化效果差等问题。为解决上述问题, 我们自行设计了新型的气流式喷嘴, 并进行了雾化特性的试验研究, 对雾化粒滴进行了测量分析。测量结果表明, 该型喷嘴在试验条件下雾化粒度小于 50 μm, 雾化效果优于一般的气流式喷嘴。与此同时我们对影响雾化效果的影响因素进行了分析研究, 对不同气液比的情况进行了测试, 发现当气液比增大时雾滴粒度减小; 同时我们还对空气速度分别为 150 m/s 及 250 m/s 进行了测试, 测试看出气液相对速度越大, 雾滴粒度越小。研究表明, 该型喷嘴能够对气液混合物进行雾化, 并可应用于石化领域中分离塔的碱液分离, 压缩(气)机注水降温中水的雾化等。

关 键 词: 气流式; 喷嘴; 雾化; 试验研究

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引 言

对气液混合物的雾化, 一般情况下应用压力式喷嘴, 其使用条件是气液混合物必须具备一定的压力。它的缺点是存在喷嘴易磨损、使用寿命短、雾化效果差等问题[1]。而一般气流式喷嘴要求气体和液体是分离的, 气体和液体在雾化之前并不掺混, 国内外的雾化气液混合物的气流式喷嘴技术还未见报道, 因此雾化气液混合物只能应用压力式喷嘴。为解决非压力喷嘴雾化前气液混合的问题, 自行设计了一种能够在雾化前进行气液混合的"气流式"喷嘴, 该喷嘴雾化效果好、使用寿命长, 并进行了雾化特性的试验研究, 从而提高了气液混合物的雾化效率, 克服了传统压力式喷嘴效率低的缺点, 同时使得喷嘴的气动阻力减小, 运行能耗明显下降。为了提高在某些应用场合下旋流器的耐磨性, 旋流器采用耐磨材料或对表面进行硬化处理, 形成耐磨层, 延长喷嘴使用寿命。该喷嘴可应用于气液混合物的雾化, 如石化领域中分离塔的碱液分离, 压缩(气)机注水降温中水的雾化等。

1 气流式喷嘴的雾化机理

气流式喷嘴雾化原理是利用高速气流使液膜产生分裂[2~3], 当压缩空气或其它气体以很高的环隙速度(一般在 200 m/s, 有时甚至达到超声速)从喷嘴喷出时, 液体的流速很低, 因此两者存在着很高的相对速度。速度差的存在使气液之间产生摩擦力和剪切力, 液体在瞬间被拉成一条条细长的丝, 这些液丝在较细处很快断裂而形成微小的雾滴。当气液相对速度足够大时, 薄膜不断地膨胀扩大, 然后分裂成极细的雾滴, 薄膜的残余周边则分裂为较大的雾滴。表 1 为一般气流式喷嘴的雾滴尺寸范围。

表 1 一般气流式喷嘴的雾滴尺寸范围

气液比	平均尺寸/μm
＞5:1	5~20
(2.5:1)~(5:1)	20~30
(1.5:1)~(2.5:1)	30~50
(0.5:1)~(1.5:1)	50~200

2 试验设备及试验方法[4~6]

试验系统由供气系统、供水系统、预混段、试验喷嘴和粒度测量等设备组成, 其中供气系统主要由空气压缩机、储气罐、电磁阀、截止阀、流量计和调节阀组成; 预混段由空气稳定段、空气加速段和气水混合段组成, 用来将进入试验喷嘴之前的气体和液体进行预先混合, 模拟实际工作流程中混合工作介质, 如图 1 所示。

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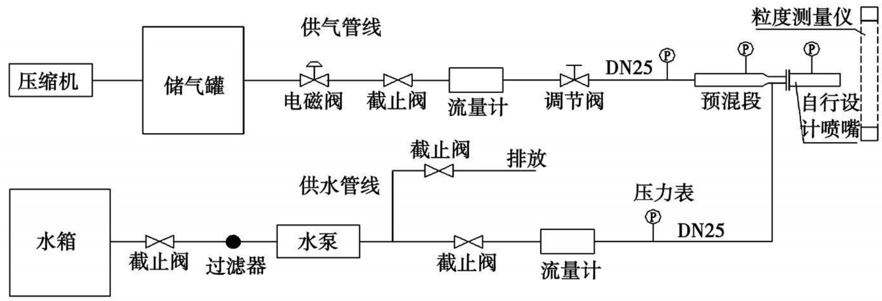

图 1　气流式喷嘴试验系统图

喷嘴组件由法兰、连接主体、旋流器和喷头等构成。试验时, 在喷嘴的入口前和旋流器后设置了压力测点, 用来监测流体经旋流器后产生的压力降。

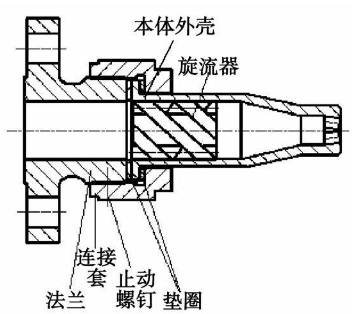

图 2　喷嘴结构示意图

粒度测量设备为 LPI—3 型激光粒径测量仪, 该仪器可测颗粒直径范围为 10～1 000 μm。雾化平均粒径(SMD) 及粒度分布(N)测量结果可以由计算机自动处理。为排除随机脉动的影响, 实验中每个实验点重复测量 20 次, 最后取其算术平均值。

在试验中, 水为城市自来水, 水温为 25 ℃, 喷嘴背压为 1 个大气压, 气体为空气, 温度为 27 ℃。测试位置距喷嘴出口正前方 200 mm。

3　试验测量结果及分析

在空气压力为 0.08～0.15 MPa 时喷嘴的旋流器压降为 0.003～0.01 MPa, 雾化角度为 20°～25°, 喷射距离为 2.9—3.5 m, 雾化锥为实心锥形, 雾化锥外端最大雾团的直径为 0.8 m, 雾化效果如图 3 所示。

图 3　气流式喷嘴雾化效果

3.1　雾化粒度分布分析

图 4 为不同液滴直径的百分比含量图。从粒度仪测量的结果可以看出, 在液滴平均雾化直径在 45～60 μm 附近时, 小于 10 μm 的液滴在数量上占到液滴总数量的 55%, 10～20 μm 的液滴在数量上占到了液滴总数量的 26%, 20 μm～50 μm 的液滴在数量上占到了液滴总数量的 15%, 其余 4%为直径大于 50 μm 的液滴。

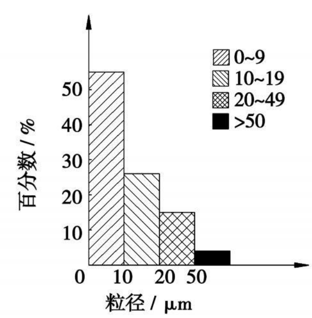

图 4　不同液滴直径的百分比含量图

3.2　气液比对雾化效果的影响

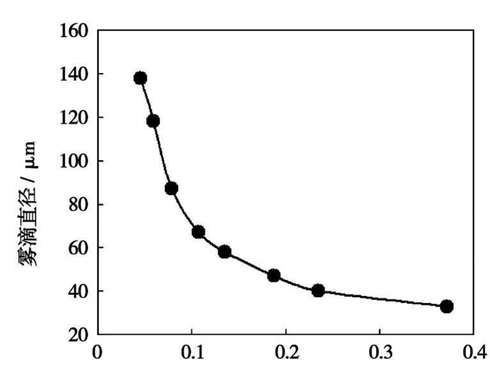

图 5　气液比对雾化效果的影响

图 5 为气液比对雾化效果的影响曲线, 从图中可以看出, 气液比是影响雾滴粒度的一个重要参数, 气液比值增大时液滴平均粒度(SMD)减小。当气液比小于 0.1 时, 即使是很容易雾化的液体, 雾化情况也会很快恶化, 当气液比逐渐增大时, 平均雾滴粒度逐渐接近一个极限值。

3.3 气液相对速度对雾化效果的影响

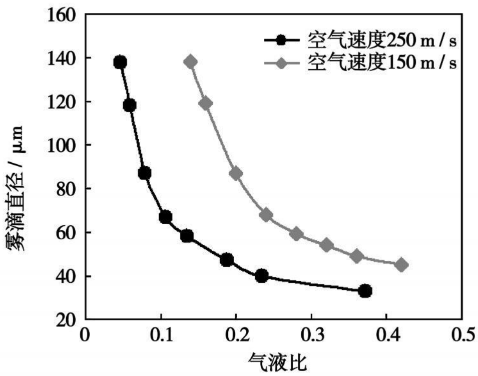

图 6 气液相对速度对雾化效果的影响

图 6 为气液相对速度对雾化效果的影响曲线，由于液体速度较小，气液相对速度可以认为是气体速度。液滴平均直径随着气体的速度增加而减小，因为增大接触点的相对速度就意味着增加了空气动能，让更多的能量用于雾化。实际上，液滴平均直径与空气的速度的 1.14 次方成反比。

试验结果表明，在试验水量接近实际工作条件的水量时，气液质量比在 10%～13%时，喷嘴的液态雾化粒径已经接近或小于 60 μm，而在气液质量比大于 20%时喷嘴的液态雾化状况均小于 50 μm。在实际工作中气液质量比将高于 20%，并且在工作时的温度为 93.5 ℃、压力为 0.55～0.7 MPa，相比于试验条件的温度和压力均更高。表 2 为 30 ℃和 93.5 ℃时空气的粘度、水的粘度和表面张力的对比。

表 2 不同温度下空气和水的物性对比

介质	物性参数	30 ℃	93.5 ℃
空气	粘度 μ/Pa·s(×10^5)	1.86	2.17
水	粘度 μ/Pa·s(×10^5)	80.07	30
	表面张力 σ/N·m^{-1}(×10^3)	72.6	61.2

在压力较低的情况下，气液内混式喷嘴的雾化动力主要来源不是压力差，而是气液两相的速度差，在这种雾化机理条件下，气液两相的物性参数变化将会对雾化效果产生一定的影响；在温度升高时，气体的粘性增大，提高了带动液体或撕裂液体的能力，而温度升高时液体水的粘性和表面张力都减小，即意味着水更容易被撕裂或打散，所以除温度以外在同样的试验条件下，温度高的时候雾化效果将好于温度低的时候，许多试验也证明了这一点[7]。

另一方面，液滴离开喷嘴后在周围的气体介质中运动，会继续分裂成更细小的液滴，这种现象被称为液滴的二次雾化。液滴在气体中运动时主要受两种力作用：一为气动压力，使液滴变得破碎；二为表面张力，使其维持原状。当液滴直径较大、运动较快时，气动压力就可能大于表面张力，使液滴发生变形，继而分裂成更细小的液滴。二次破碎所需的气动力条件可用韦伯数表示：

$$We = \rho w^2 d / \sigma$$

式中：w—相对速度；ρ—气体密度；d—液滴直径；σ—液体的表面张力。

实验结果表明临界韦伯数接近常数，在 10.7～14 之间，当 $We > 22$ 时大液滴均破碎成小液滴，We 数越大，液滴就越细[8]。

4 结 论

(1)气流式喷嘴雾化机理是雾滴分裂成膜状，薄膜不断膨胀和扩大，分裂成极细的雾滴。

(2)气液比对雾化效果影响很大，气液比值增大时雾滴粒度减小。当气液比小于 0.1 时，即使是很容易雾化的液体，雾化情况也会很快恶化，当气液比逐渐增大时，液滴平均粒度逐渐接近一个极限值。对于一般的气流式喷嘴当气液比达到 0.5 时，液滴平均直径为 50～200 μm；相比而言，新型气流式喷嘴当气液比达到 0.5 时，液滴平均直径小于 50 μm，雾化效果优于一般的气流式喷嘴。

(3)气液相对速度也是雾化效果影响因素之一，气液相对速度越大，则有更多的空气动能用于雾化，液滴将越小。

(4)该型喷嘴可对气液混合物进行雾化，能够满足雾化粒度小于 50 μm 的要求，可应用于石化领域中分离塔的碱液分离，压缩(气)机注水降温中水的雾化等。

致谢：对参加试验的杨成毅、海、杨振华以及提供测试的孙瑜民、吴国松工程师等表示感谢！

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method, studied was the influence of the solid—phase particulate mass carrying rate in a two—phase turbulent flow of a flue gas desulfuration tower on the gas—phase flow field. When the particulate Strokes number in the tower is kept in a range from 1 to 100, the gas—solid flow coupling characteristics in the tower was analyzed by gradually increasing the particulate mass carrying rate. As a result, under different particulate mass carrying rates the in—tower gas—solid flow characteristics, the particulate concentration distribution along the axial direction, the gas—phase axial speed radial distribution and the bed layer pressure drop curves have been obtained. It has been found that when the particulate mass carrying rate is not greater than 0.031, the particulate flow exhibits a relatively good follow—up nature and assumes a pneumatic transmission flow state. In such a case, the particulate movement has an extremely small influence on the continuous phase field and can be neglected. When the particulate mass carrying rate is greater than 0.031, the gas—solid flow coupling action in the bed will be enhanced, and the discrete particulate movement will exercise a conspicuous influence on the gas—phase flow field. The gas—solid two—phase flow characteristics are dependent on each other and exhibit an obvious unstable state and non—uniformity. When the particulate mass carrying rate is relatively big, the bed layer pressure drop is closely related to the discrete particulate field distribution. **Key words:** direct simulation Monte Carlo method, gas—solid two—phase flow; coupling characteristics

气液两相流容积含气率的图像检测方法＝**Image processing—based Detection Method for the Measurement of Volumetric Gas Content in a Gas—liquid Two—phase Flow**[刊, 汉] / ZHOU Yun—long, SHANG Qiu—hua, FAN Zhen—ru, HONG Wen—peng (College of Energy Source and Mechanical Engineering, Northeast Dianli University, Jilin, China, Post Code: 132012)// Journal of Engineering for Thermal Energy &Power. — 2008, 23(5). —507~511

A method for the on—line detection of volumetric gas content of a gas—liquid two—phase bubble flow has been studied and developed. The method in question is based on digital image processing technology, employs a high—speed video camera system to conduct a real time camera shooting and image collection of the bubble flow process in vertical risers and makes use of rim detection and image fill—in technology to extract gas bubbles and calculate their sizes, thereby calculating the volumetric gas content. A real time on—line detection and measurement have been made of the volumetric gas content under different operating conditions. Test results show that compared with real values, the detected values have a relative error not exceeding 15%. Having attained a relatively high measurement accuracy, the method under discussion can be used for the on—line detection of parameters in a gas—liquid two—phase flow. **Key words:** gas—liquid two—phase flow, volumetric gas content, image processing, gas bubble

气化炉内撞击区气体浓度与火焰形状分析＝**Gas Concentration and Flame Shape Analysis of the Impinging Zone in a Gasification Furnace**[刊, 汉] / GUO Qing—hua, LIANG Qin—feng, YU Zun—hong, YU Guang—suo (Education Ministry Key Laboratory on Coal Gasification, East China Institute of Technology, Shanghai, China, Post Code: 200237)// Journal of Engineering for Thermal Energy &Power. — 2008, 23(5). —512~515

By using a water—cooled sampling tube and gas purification analytic system, a hot—state experimental study has been conducted of the gas concentration distribution of a nozzle plane in a gasification furnace. Through an image processing, the flame image was divided into three portions along the direction of a gas sampling tube: namely, a flame impinging zone, a transition zone and a flameless zone. Test results show that the gas constituents of the flame impinging plane in the gasification furnace are closely related with the flame shape, and the gas concentration in the transition zone has the greatest changes. The maximum concentration of CO_2 and O_2 appears at the central location of the furnace. In the flameless zone, the measured gas concentration has kept basically unchanged. The ratio of CO and CO_2 recovery rate can serve as an underlying basis for judging the flame shape, or when O_2 concentration decreases to less than 0.03%, it can be regarded as an extinguishment of the flame. **Key words:** impinging flame, gas concentration, gasification, multi—nozzle contraposition

气流式喷嘴雾化特性试验研究＝**Experimental Study of Atomization Characteristics of an Airflow Type Nozzle** [刊, 汉] / REN Lan—xue, MA Sheng—yuan, WANG Yong—feng, PANG Xue—jia (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036)// Journal of Engineering for Thermal Energy &Power. — 2008, 23(5). —516~518

Compared with ordinary pressure type nozzles, airflow type nozzles have such problems as easy to be worn out and a poor atomization effectiveness. However, ordinary airflow type nozzles are incapable of atomizing any gas—liquid mixture. To solve the above problem, a new type of airflow nozzle was designed by the Institute and an experimental study has been conducted of its atomization characteristics. In addition, the atomized particles and droplets were measured and analyzed. The measurement results show that under the test conditions, the particle diameters atomized by the nozzles in question are less than 50 μm and the atomization effectiveness is superior to that of ordinary airflow type nozzles. In the meantime, an analysis and study of the factors influencing atomization effectiveness have been conducted. Measurements were performed at different gas—liquid ratios. When the gas—liquid ratio increases, the atomized droplet particle diameter will decrease. At the same time, measurements were also performed at an air speed of 150 m/s and 250 m/s respectively. The greater the relative speed between the gas and liquid, the smaller the atomized droplet particle diameter. The results of the study show that the type of nozzles under discussion can atomize the gas—liquid mixture and can be applied to the alkaline solution separation in the separation towers of petrochemical industry and the water atomization for temperature reduction through water injection into a compressor. **Key words**: airflow type, nozzle, atomization, experimental study

气流搅拌流场中不同通气结构的CFD模拟＝**CFD (Computational Fluid Dynamics) Simulation of Different Aeration Structures in a Gas—liquid Agitation Flow Field**[刊,汉] / ZHANG Chao—ping, XU Tao, KE Chang—hua (Shandong Shanda Hua—te Environmental Protection Engineering Co. Ltd., Jinan, China, Post Code: 250001), LI Yan—fen (Beijing Strength and Environment Research Institute, Beijing, China, Post Code: 100827)// Journal of Engineering for Thermal Energy & Power. — 2008, 23(5). —519～522

By using a numerical simulation method, studied were the features of a gas—liquid two phase flow field in a same kind of agitation reactor with four types of different oxidation spray gun structures. With a Euler—Euler dual fluid model a flow field was analyzed by adopting RNG $k-\varepsilon$ two—equation turbulent flow model. A mortar agitation zone was processed by using a multiple reference system method. As a result, the air content in the flow field of different oxidation spray gun structures was obtained. It has been found that 90 degree tube—bend finned structure can be used to attain a better agitation effectiveness, a more rational velocity field, a more ideal air bubble trajectory and a higher air content on a typical surface. **Key words**: two—phase flow, agitation, oxidation spray gun

钛管$CaCO_3$污垢特性的实验研究＝**Experimental Study of $CaCO_3$ Fouling Characteristics of Titanium Tubes** [刊,汉] / XU Zhi—ming, QIU Zhen—bo (Postgraduate shool, Northeast Dianli University, Jilin, China, Post Code: 132012), ZHANG Zhong—bin (College of Energy Source and Power Engineering, North China Electric Power University, Baoding, China, Post Code: 071003)// Journal of Engineering for Thermal Energy & Power. — 2008, 23(5). —523～526

An experimental study of titanium tube fouling characteristics was conducted, which were compared with those of stainless steel tubes and copper bare tubes. The results of the study show that the fouling induction period of the titanium tubes will increase with an increase of concentration, and decrease with an increase of flow speed. However, the law governing the change of fouling heat resistance with the concentration and flow speed is rather complicated. Under the same operating conditions, the induction period of titanium tubes is shorter than that of stainless steel tubes but longer than that of copper tubes. The fouling heat resistance asymptotic value of the titanium tubes is smaller than that of copper tubes, but bigger than that of stainless steel tubes. This indicates that the fouling resistant characteristics of titanium tubes, though superior to those of copper tubes, are inferior to those of stainless steel tubes. **Key words**: titanium tube, $CaCO_3$ fouling, fouling characteristics, induction period

两种内翅片管对流换热特性数值模拟＝**Numerical Simulation of Convection Heat Exchange Characteristics of Two Types of Internally—finned Tubes**[刊,汉] / WU Feng, DENG Zhi—an, CHEN Jun—bin, HE Guang—yu (Petroleum and Gas Storage and Transportation Engineering Department, College of Petroleum Engineering, Xi'an Shiyou University, Xi'an, China, Post Code: 710065)//Journal of Engineering for Thermal Energy & Power. — 2008, 23(5). —527～530

With a laminar flow model and a turbulent flow model—based numerical simulation method being adopted and in combi-