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粉煤加压气化小型试验研究

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摘　要: 煤气化技术是燃煤联合循环发电、煤化工、综合利用系统、近零排放系统中的核心技术。干煤粉加压氧气气化技术是煤气化技术发展的一个主流方向。介绍了国电热工研究院的干煤粉加压气化试验系统, 以及干煤粉加压气化试验研究的过程和结果。试验结果达到了预期的目的, 得到干煤粉加压气化过程的规律, 并验证了试验系统在高压下的稳定性。

关　键　词: 煤气化; 气流床; IGCC; 干法进料

中图分类号: TQ546. 2　　　文献标识码: A

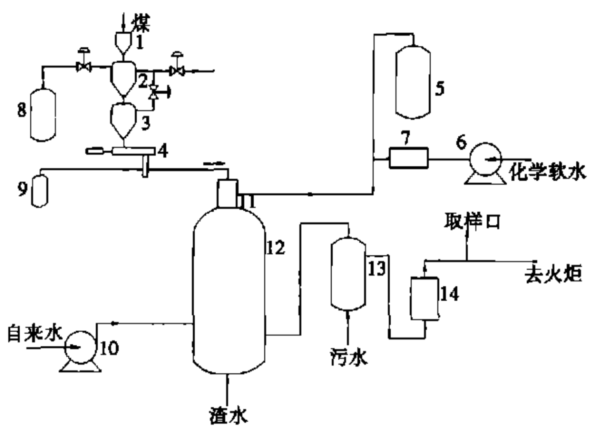
1　引　言

煤气化技术是燃煤联合循环发电、煤化工、煤制油及其它煤基、近零排放系统的核心技术。煤气化方式可分固定床、流化床和气流床 3 种[1]。气流床气化是用极细的粉煤为原料(干煤粉或制成的水煤浆), 被氧气和水蒸气组成的气化剂高速气流携带, 喷入气化炉[2]气化的过程。其中干煤粉加压氧气气化工艺具有煤种的适应性广、冷煤气效率和热煤气效率以及碳的转化率都很高、适于开发单炉容量大的气化炉等特点[3], 是煤气化工艺技术的发展方向。

到了 20 世纪 90 年代后期, 随着 IGCC 洁净煤发电技术的推广应用, 国电热工研究院建立了国内第一套干煤粉加压气化特性试验装置并进行了试验研究。该装置的气化能力为每小时 10～20 kg 煤粉, 压力为 3.0 MPa。研究的目的是积累中国主要动力煤在干粉气化状态下的气化数据库, 形成一套干煤粉加压气化评价方法。

2　干粉加压气化试验流程简介

干粉加压气化试验装置的工艺流程如图 1 所示。



1–煤粉仓; 2–变压仓; 3–加压仓; 4–螺旋输送机; 5–氧气缓冲罐; 6–计量泵; 7–蒸汽发生器; 8–氮气缓冲罐; 9–氮气缓冲罐2; 10–电动往复泵; 11–喷嘴; 12–气化炉; 13–汽液分离器; 14–焦炭过滤器;

图 1　干煤粉加压气化试验装置的工艺流程

含水量低于 1%、粒度 85% 小于 200 目的粉煤储于常压煤粉仓, 靠重力落入变压煤仓, 变压仓用 N_2 充压, 充到与加压仓压力相等或略大时, 粉煤落入加压仓, 由此用螺旋输送机定量送出, 被 N_2 吹送入气化炉。试验用 O_2 经缓冲罐稳压后送往燃烧器外套管。化学软水经计量泵升压, 在电加热器内蒸发成过热蒸汽, 与氧气混合后进入燃烧器外套管。粉煤、氧气、水蒸气在燃烧器出口处着火并进行气流式火焰反应, 生成以 CO 和 H_2 为主的粗合成气, 气化炉燃烧室排出的高温气体和熔渣, 在气化炉内从上向下进入激冷室, 被激冷环喷出的激冷水激冷后, 下降到激冷室的水浴直接与水接触冷却, 熔渣迅速固化, 工艺气被水饱和并由位于激冷室上部的煤气

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口引出，送往煤气净化系统；因为煤气中含有飞灰，经气液分离器用水进一步润湿洗涤，除尘、分离，除去残余的飞灰后将湿煤气分离出来，再经焦炭过滤器干燥、过滤，根据需要送到取样口或排入大气。在激冷室生成的灰渣留在水池中，绝大部分迅速沉淀并定期排出炉外；混在黑水中的细灰在气液分离器经沉降下部，通过液位控制器自动排出界外。自来水用高压水泵升压后送入气化炉急冷室。

在干煤粉加压气化试验装置中，气化炉是关键设备，其结构如图 2 所示。

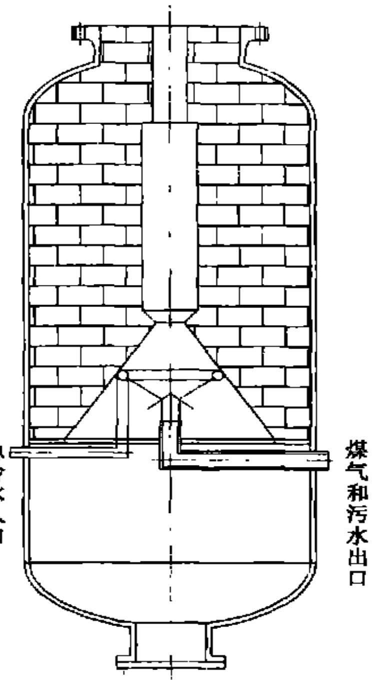

图 2 气化炉结构示意图

气化炉是内衬耐火材料的压力容器，又是气化装置的核心设备。它有一个整体的钢制承压外壳，上部为燃烧室，炉内衬四层耐火材料。这些耐火材料，用以保护气化炉壳体不受燃烧高温反应的影响，向火面耐火材料选用高铬材料，以适应工艺过程对耐火材料的苛刻要求。燃烧室直接与激冷室相连，激冷环置于燃烧室下部，激冷水从激冷环喷出，既激冷了高温介质，也保护了金属部件。激冷室下部充满激冷水，从燃烧室出来的煤气夹带熔渣经过激冷环，被喷出的激冷水淬冷，熔渣凝结成固态渣，沉积在水池中。煤气通过激冷水室，由导气管通往煤气出口。

3 气化试验研究

3.1 气化试验原始参数

3.1.1 气化压力的选定

气化压力选定为 0.5～2.0 MPa，从中选择几个最有代表性的点。压力测点设在气液分离器顶部，该处离反应区最近，最具有代表性（气化反应区不能直接测压）。

3.1.2 试验煤种

本研究选用 3 种煤：甘肃华亭煤、山东兖矿北宿煤和杨庄煤。其中，山东兖矿北宿煤和杨庄煤分别是中国 IGCC 示范电站的设计煤种和校核煤种。

这 3 种煤的煤质分析如表 1 所示。

表 1 3 种煤煤质分析

		煤种		
		华亭煤	北宿煤	杨庄煤
工业分析	收到基全水分 Mar/ %	—	7.30	6.9
	干燥基水分 Mad/ %	5.74	3.74	2.54
	干燥基灰分 Aad/ %	10.69	10.77	13.99
	干燥无灰基挥发分 Vdaf/ %	39.68	44.38	45.25
	低位发热量 Qnet/ kJ·kg^{-1}	24 180	26 680	25 840
元素分析	收到基碳 Car/ %	63.68	67.00	64.08
	收到基氢 Har/ %	4.28	4.39	4.15
	收到基氧 Oar/ %	14.39	6.45	5.74
	收到基氮 Nar/ %	0.70	1.12	1.10
	收到基硫 Sar/ %	0.52	3.38	4.36
灰熔点	变形温度 *DT*/ ℃	1 190	1 080	1 080
	软化温度 *ST*/ ℃	1 270	1 120	1 110
	流动温度 *FT*/ ℃	1 310	1 150	1 170

3.2 气化工艺条件选择

3.2.1 炉温

为保证气化炉顺利排渣和求取较好的气化指标，气化炉应在高于灰熔点的温度下操作。根据国内外气流床气化操作经验，炉内温度应比灰渣流动温度（FT）高，故将这 3 种煤的热态试验的操作温度控制在 1350～1400 ℃。几次热态试验表明，在该炉温下操作可达到顺利排渣和追求较为理想的气化指标。在投煤量、汽煤比基本不变的情况下，调节入炉氧量来控制炉温。

另外，由于本试验采用的气化炉用耐火砖砌成，为保证其使用寿命，操作温度不能设置太高（即超过 1 400 ℃），故在本实验中，将气化炉炉温设置为一个定值来进行试验。

3.2.2 蒸汽煤比

这 3 种煤都是典型的烟煤，在试验中控制汽煤

比为 0.3（重量比）左右。在气化别的煤种时，如为低挥发分烟煤或褐煤时将适应调节这个比例。

3.2.3　入炉煤量

综合供氧能力和气化炉容积等因素，气化炉设计投煤量为 10～20 kg/h。

夹带粉煤的氮气不宜过高，固气比为 8～10 kg/m^3，这与国外大型装置的 15 kg/m^3 还有较大差距，这是由于试验规模太小所决定的。

3.3　数据采集及处理

3.3.1　数据采集

（1）气相

粉煤气化的特点是气流床瞬间反应，一般当点火 1 h 数据就趋稳定，试验中用气相色谱定期分析气体成分（CO_2、O_2、CO、H_2、CH_4、N_2），H_2S 和 COS 未作分析，根据硫平衡（质量守衡）来进行计算。

（2）渣样

停车后称重，测定含水量、渣中含碳量，从而求得炉底渣中含碳量或称碳损失。

（3）污水样

在运行中测量污水流量，取污水样，停车后测定污水含尘（飞灰）量，飞灰含碳量，计算出污水中碳损失。

3.3.2　数据处理

（1）煤气流量根据煤气流量计来确定。

（2）碳转化率根据碳损失计算：

$$碳转化率（\%）= \frac{入炉碳-渣中碳-污水中碳}{入炉碳} \times 100\%$$

3.4　主要试验数据

在压力为 2.0 MPa 下，各种煤气化后的干煤气成分如表 2 所示。

表 2　不同煤种的气化结果

		煤种		
		华亭煤	北宿煤	杨庄煤
煤气成分/%	CO	55.1	52.2	51.8
	H_2	32.5	32.6	31.8
	CO_2	6.2	6.9	7.2
	N_2	6.1	7.3	7.9
	CH_4	0.1	0.1	0.1
碳转化率/%	H_2S+COS	96.9	95.01	94.27
煤气产率/$m^3 \cdot kg^{-1}$（干）		1.98	2.18	2.06
冷煤气效率（LHV）/%		80.1	77.1	74.6
比氧耗/$m^3 \cdot km^{-3}$（CO+H_2）		312	338	351
比煤耗/$kg \cdot km^{-3}$（CO+H_2）		567	541	581

4　结果与讨论

（1）通过试验，得到了干煤粉加压气化过程的规律：在高温、高压下气化，反应比较剧烈，气化反应强度大；液态排渣；干煤气中有效气体成分比较高，冷煤气效率和碳转化率均比水煤浆进料高。

（2）从试验结果可以看出，这 3 种煤均可以作为干煤粉加压气化的原料，煤气有效成分（CO+H_2）、碳转化率和冷煤气效率均为华亭煤较高，这说明华亭煤是比较容易气化的煤种，北宿煤和杨庄煤略差。

（3）煤气产率三者相差不多，北宿煤的最高。这是因为北宿煤中碳元素含量较多。

（4）华亭煤的比氧耗略低，北宿煤的比氧耗略高。这是因为华亭煤中氧元素含量较多。

经过三年研究工作，干煤粉加压气化试验已基本达到了预期目标。在试验工作中，应注意：

（1）干煤粉加压小试气化试验中，输煤系统是关键。要注意煤粉的湿度，如果湿度较大，则容易产生架桥，从而发生断煤现象；同时要注意煤粉的粒度问题，由于输送管较细，如果粒度过粗，则容易发生堵塞现象。如果是中试则估计不会发生输送管堵塞问题。

（2）由于该气化系统气化能力较小，因气化炉较小，而热损失较大，所以气化指标不是很理想。如果在中试试验中，这些问题都可以解决。

（3）试验过程中气化炉运转较平稳，排渣比较流畅。本试验采用渣平衡反推碳转化率和煤气产率，虽有误差，但变化趋势比较稳定。

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Thermal Energy & Power. — 2004, 19(6). —567～571.

The promotive role of a hydration reaction on CaO particle-based desulfurization reaction has been attributed to the activation of the hydration reaction while the promotive role of Fe_2O_3 on the above-cited desulfurization reaction attributed to an increase in active core number of the CaO particles. From the viewpoint of chemical kinetics the above assertion is not sufficiently clear-cut. Through a series of TGA tests the authors have proved that the essential function of hydration activation reaction of CaO and that of Fe_2O_3 in CaO particle-based desulfurization reaction consists in the enhancement of a pre-exponential factor. Moreover, a contrast analysis was conducted of the functioning mechanism of the hydration reaction and Fe_2O_3. **Key words**: desulfurization reaction, hydration reaction, Fe_2O_3, CaO particles, Arrhenius formula, pre-exponential factor

助剂对 CuO/γ-Al_2O_3 烟气脱硫活性影响的初步研究＝**Preliminary Study of the Effect of a Catalytic Promoter on the Activity of CuO/γ-Al_2O_3 for Flue Gas Desulfurization** [刊，汉] / WANG Yan, ZHANG Chao, ZHENG Chuguang (National Key Laboratory on Coal Combustion under the Huazhong University of Science & Technology, Wuhan, China, Post Code: 430074) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(6). —572～574, 578.

Sulfur dioxide and NO_x brought about by combustion processes are a main precursor of acid rain. The use of regenerative CuO/γ-Al_2O_3 as an integrated adsorption catalyst for the removal of sulfur dioxide and NO_x has wide prospects of applications. Through the adding of various metallic salt compounds into a CuO/γ-Al_2O_3 flue-gas desulfuriztion agent to serve as a catalytic promoter the effect of various promoters on desulfurization activation has been preliminarily investigated. In addition, with the help of physical characterization means an analysis was conducted of the internal causes, which enable these promoters to influence the desulfurization activation. **Key words**: flue gas desulfurization, copper oxide, metallic salt compound, catalytic promoter

除雾器 ΔP-v-d_{cr}选型方法研究＝**A Study of the Type Selection of Mist Eliminators with the Help of a ΔP-v-d_{cr} Method** [刊，汉] / LI Sen, ZHOU Qu-lan, XU Tong-mo, HUI Shi-en (College of Energy & Power Engineering under the Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(6). —575～578.

Through a study of the separation characteristics of a mist eliminator in a wet desulfurization system the following two concepts are defined, namely, critical separated droplet diameter of a mist eliminator and critical captured droplet diameter by a cylinder. With respect to a wet desulfuriztion system equipped with a tubular flue-gas reheater the authors have proposed the type selection of mist eliminators by using a ΔP-v-d_{cr} method. This method can be described as follows. A mist eliminator with the lowest flue-gas pressure drop is selected as the optimum type. The selection shall meet two requirements: i.e. the flue-gas pressure drop is less than 200 Pa and the critical separated particle diameter is smaller than the critical captured particle diameter of the flue-gas reheater tube wall. The recommended method features conciseness and clarity. It can serve as a guide during the optimized design, type selection and operating condition analysis of mist eliminators. Moreover, it also provides a standard for a comprehensive evaluation of the separation characteristics of mist eliminators. **Key words**: wet flue-gas desulfurization, mist eliminator, droplet, separation

粉煤加压气化小型试验研究＝**Small-scale Experimental Research of Pulverized-coal Pressurized Gasification** [刊，汉] / REN Yong-qiang (Energy & Power Engineering Institute under the Xi'an Jiaotong University, Xi'an, China, Post Code: 710049), XU Shi-sen, XIA Jun-cang, ZHU Hong-chang (Xi'an Thermal Engineering Institute Co. Ltd., Xi'an, China, Post Code: 710032) //Journal of Engineering for Thermal Energy & Power. — 2004, 19(6). —579～581.

Coal gasification technology is considered a key technology employed in coal-based combined cycle power generation, coal-based chemical industries, energy comprehensive utilization systems and near-zero pollutant emission systems. Pressurized oxygen-blown gasification fed with dry pulverized coal represents a main direction of development for coal gasification technology. The authors briefly describe a test system of pressurized coal gasification fed with dry pulverized coal, which has been set up in a Thermal Engineering Research Institute. The study and test results of the above system are given. With the clarification of the law of pressurized coal gasification fed with dry pulverized coal the tests have attained the anticipated aim. In addition, the operational stability of the test system under high pressures have also been verified. **Key words**: coal gasification, entrained flow, dry feed of pulverized coal

超细煤粉还原 NO_x 的试验研究= **Experimental Investigation of Super Fine Pulverized-coal Reburning Technology for Reducing NO_x emissions** [刊, 汉] / JIN Jing, LI Rui-yang, ZHANG Zhong-xiao (College of Power Engineering under the Shanghai University of Science &Technology, Shanghai, China, Post Code: 200093) //Journal of Engineering for Thermal Energy &Power. — 2004, 19(6). —582~585.

Ultra-fine pulverized coal reburning technology features high-efficiency NO_x reduction, low operating costs and ease of implementation. Through tests the authors have studied the key factors in this reburning technology, which exercise a major influence on NO_x reduction. The results of this study indicate that the finer the reburned fuel particles, the higher the NO_x reduction efficiency. The optimum average particle diameter of the reburned fuel is 20 μm. The optimum ratio of reburned fuel is 20% for lignite of Longkou and 25% for bituminous coal of Shenfu. There exists an optimum injection location for the reburned fuel. In general, the higher the coal rank, the further is the distance from a main fuel nozzle. The residence time of fuel in the optimum reburning zone is 0.63 s for lignite of Longkou and 0.75 s for bituminous coal of Shenfu. **Key words**: super fine pulverized coal, reburning, NO_x, reduction efficiency

一种基于差压波动图的段塞流识别方法= **Slug-flow Identification Method Based on a Differential-pressure Fluctuation Diagram** [刊, 汉] / LIANG Fa-chun, WANG Dong, LIN Zong-hu (National Key Laboratory on Multi-phase Flows in Power Engineering under the Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) //Journal of Engineering for Thermal Energy &Power. — 2004, 19(6). —586~588.

Extensive air-water two-phase flow tests were conducted on a large-sized horizontal test loop of multi-phase flows made of steel pipe of 80 mm inner diameter. The differential-pressure fluctuation signals of stratified, slug and annular flow patterns collected in a certain length of time were displayed as two-dimensional images. Through an analysis of 30 groups of differential-pressure fluctuation data it has been found that the ratio between signal zone area and background zone area has an average value of 0.026 for the slug flow, 0.53 for the stratified flow and 0.35 for the annular flow. The ratio between slug-flow signal zone and the total image area is considerably smaller than that of the other flow patterns. Consequently, this ratio can be taken as a characteristic parameter for slug-flow identification. The method under discussion can be effectively employed for the rapid and automatic detection of slug flow patterns. **Key words**: slug flow, flow pattern identification, differential-pressure fluctuation, image

薄液膜二维表面驻波的流动稳定性研究= **Flow Stability Investigation of Two-dimensional Surface Stationary Waves on a Thin Liquid Film** [刊, 汉] / YE Xue-min, LI Chun-xi, YAN Wei-ping (Department of Power Engineering, North China Electric Power University, Baoding, China, Post Code: 071003) //Journal of Engineering for Thermal Energy &Power. — 2004, 19(6). —589~592.

The flow stability of stationary waves, a kind of surface wave on a thin-liquid film, is subject to the influence of thermal non-equilibrium effect at a vapor-liquid interface. On the basis of boundary layer theory and thermal non-equilibrium effect derived is a spatial stability equation of the two-dimensional surface stationary waves universally applicable on evaporating, isothermal or condensing liquid films draining down along an inclined wall. From a theoretical viewpoint an in-