煤燃烧特征点变化规律的研究

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〔摘要〕 在升温速率为 20℃ /min条件下,采用热天平对 13种煤的燃烧特性进行了试验研究,得到了燃烧特征点的变化规律。

关键词　煤　燃烧　热天平　燃烧特征点
分类号　TQ534

0　前言

煤是多种有机化合物和无机矿物质组成的复杂混合物,多年实践经验表明,仅从煤的常规分析数值 (工业分析和元素分析)来预示煤的燃烧过程有很大的局限性。因此许多研究者从不同角度对煤的燃烧特性进行了大量的理论和试验研究,如文献 [1, 2]。为了较全面地了解煤的整个燃烧过程,国内外目前广泛采用热分析技术。本文采用热天平,对几种典型动力用煤燃烧的一些特征点 (着火温度、最大燃烧速率及最大燃烧速率对应的温度)的变化规律进行了试验研究。

表 1　煤样的工业分析和元素分析

		工业分析 (分析基)					元素分析 (分析基)				
		V_{ad}	FC_{ad}	M_{ad}	A_{ad}	$Q_{gr,ad}$ (kJ/kg)	C_{ad}	H_{ad}	O_{ad}	N_{ad}	S_{ad}
1	秦　岭	15.53	57.22	0.62	26.63	24 276.6	63.24	3.10	3.45	2.02	0.94
2	大　同	27.99	56.68	3.68	11.65	27 811.4	70.26	3.75	8.88	1.0	0.78
3	豆　坝	10.87	54.62	0.34	34.17	21 722.6	56.61	2.31	2.63	0.75	3.19
4	肥　田	7.43	78.61	2.39	11.57	30 442.2	78.92	2.49	1.07	1.22	2.34
5	韶　关	8.17	47.58	0.24	44.01	16 288.2	47.89	1.94	4.2	0.92	0.80
6	镇　海	19.81	41.69	1.80	36.70	20 283.4	49.91	2.59	6.89	1.28	0.83
7	首阳山	26.96	38.23	3.78	31.03	19 051.2	48.96	3.17	10.73	1.63	0.7
8	马　头	15.28	62.15	0.8	21.77	26 777.1	68.03	3.13	4.10	0.98	1.19
9	金竹山	10.08	68.73	0.22	20.97	27 148.0	70.67	2.93	3.63	0.46	1.12
10	织　金	7.24	78.77	1.02	12.97	29 864.4	77.42	2.76	2.88	1.14	1.81
11	芙　蓉	9.65	63.53	0.99	25.83	25 015.3	64.33	2.4	1.36	0.76	4.33
12	合　山	12.58	37.02	1.44	48.96	14 442.8	37.16	1.76	5.09	5.07	0.52
13	陡　河	27.19	42.26	2.7	27.85	21 742.1	55.63	3.35	8.43	1.0	1.04

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1　试验设备及试验条件

试验采用日本产 RIKAGU8150型热天平,气体流动型式如图 1,试样支架为 TG架,坩埚为圆柱形,直径为 1.0 cm,高为 0.3 cm,采用红外加热炉。

试验中,先以 100 ℃/min升温速率升到 105℃,在此温率下恒温一段时间,一般当恒温时间大于 3分钟后,试样不再失重,本文取恒温时间为 5分钟,此时试样重量即为干燥基的试样重量,记为 G_g,试

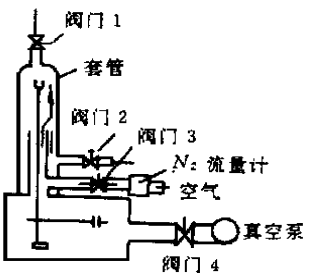

图 1　气体流动型式

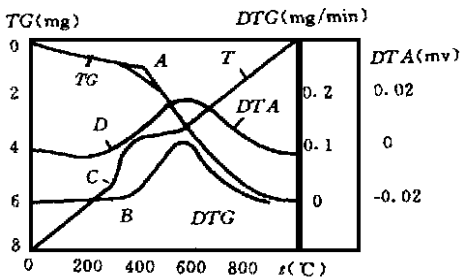

图 2　着火点示意图

验中 G_g为 4~5 mg 而后试样在 20℃/min升温速率下进行燃烧试验,气体为空气,流量为 150 ml/min,常压。本文共对 13种煤的燃烧特征点变化规律进行了试验研究,煤样平均粒径为 80.5μm(相邻两层筛孔尺寸为 71~90μm,取算术平均径)。煤样的工业分析和元素分析见表 1

2　理论分析

2.1　着火温度的确定

采用热天平研究煤粉着火温度时,常用以下几种方法定义着火温度 T_i,如图 2

2.1.1　TG-DTG法

煤粒在着火前,反应速度较低,试样失重比较缓慢,当达到着火温度开始燃烧后,反应速率迅速增加,此时在 TG或 DTG曲线上存在一突变点。如在 TG曲线上作切线,其交点 A定义为着火点,显然切线的作法具有一定的任意性。在 DTG曲线上与 A点对应点处,表现为失重率迅速增加,一些研究者定义当失重率达 0.1 mg/min时的 B点为着火点,有的定义两点间失重率差满足: $(d\omega/d\tau)_i - (d\omega/d\tau)_{i-1} \geqslant 0.1$ mg/min时的点为着火点。试验发现,对高挥发份煤在热解阶段即可达到上述失重率,而对一些低挥发份煤,当达到上述失重率时,煤粒早已着火燃烧。另外,失重率大小与试样量及升温速度有关,试样量越大,升温速度越高,失重率越大,反之越小。

2.1.2　温度曲线突变法

在着火点,由于试样燃烧放热,试样温度会偏离程序线性升温,在温度曲线 T上存在一突变点(如 C点),因此,C点可定义为着火点。但在某些情况下,C点不明显,尤其在氧浓度较低,试样量较少时,C点很难确定。

2.1.3　DTA曲线法

煤粒受热时,首先析出挥发份,此时试样吸热,在 DTA曲线上出现负值,随着温度升高,反应速率加快,在着火点由于放热,DTA曲线变成正值。定义正负值的分界点 D为着火点。采用 DTA方法时,影响因素较多,如参比物量的多少,试样量的多少等,同时存在虚假吸放热现象,如图 3 图 3为采用 DTA支架,在参比物坩埚中放入一定量的 Al_2O_3,试样坩埚中不放试样,在炉子开始升温阶段出现虚假放热现象,这是由于参比物坩埚的升温比炉子的升温要慢,而试样坩埚为空坩埚,热容量小,其升温能与炉子保持同步,因此出现虚假放热。随着温度继续升高,当高于某一温度后,出现虚假吸热,这是由于随着炉子温度升高,进入炉子的冷空气不能与炉子同步升温,空坩埚与周围气体间换热大于参比物坩埚与周围气体间的换热,此时出现虚假吸热。虚假吸放热还与升温速度有关。

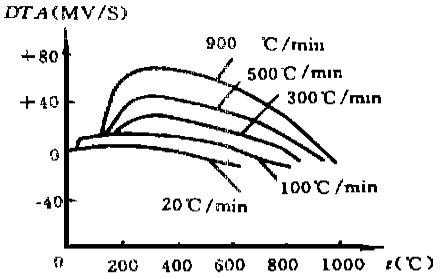

图 3 虚假吸放热曲线

2.1.4 TG曲线分界点法

定义燃烧曲线与热解曲线在 TG曲线上的分界点为着火点(见图 4),同样,试样量越少,此分界点越不明显。

通过分析各种方法的优缺点,本文采用燃烧曲线与热解曲线在 TG曲线上的分界点结合两曲线在 DTG曲线上的分界点定义着火温度 T_i:

$$T_i = (T_{TG,i} + T_{DTG,i})/2$$

试验得,DTG曲线上的分界点在试样量较少时更清晰。

最大燃烧速率 $(dk/df)_{max}$及最大燃烧速率对应的温度 T_{max},如图 4

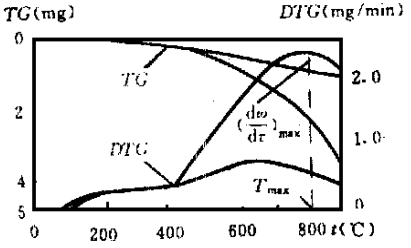

图 4 着火点示意图

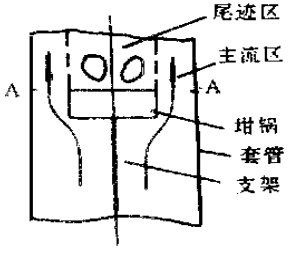

图 5 坩埚周围气体流动

2.2 采用的燃烧模型

如图 5,套管内气体流动分成两个区域,一是坩埚出口附近的尾迹区,一是坩埚周围的主流区。试样燃烧时,氧气经坩埚出口截面 A—A传递到颗粒表面,氧气在试样层中为扩散传质,沿试样层厚度方向上各处氧浓度不同,因此不同层内粒子的燃烧速度不同。一些研究者对试样层内的氧气质扩散系数进行了试验研究,但所得结果相差较大。为了忽略试样层内氧气浓度分布不均对计算带来的困难,文献[3]提出了适合热天平研究煤燃烧特性时的"零维燃烧模型",即当试样厚度 δ_m(cm)与试样平均粒径 d_p(μm)之比 $W_m/d_p \leqslant (1.3 \sim 1.5) \times 10^{-4}$时,可以忽略试样层内氧气浓度分布不均,此时所有粒子燃烧过程均匀一致。经试验验证,该模型的假设是合理的。可见,采用该模型所得的试验结果更能真实地反映煤的燃烧特性。

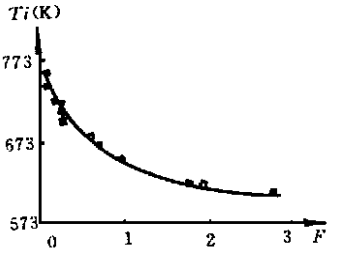

图 6 T_i 与 F_i 关系曲线

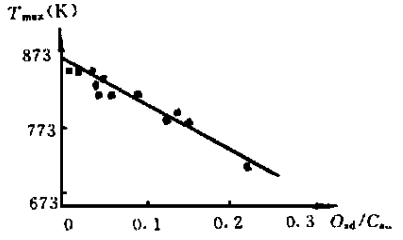

图 7 T_{max} 与 O_{ad}/C_{ad} 关系曲线

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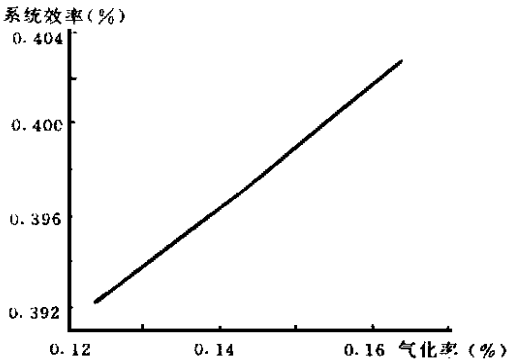

图 3　气化率对系统效率的影响

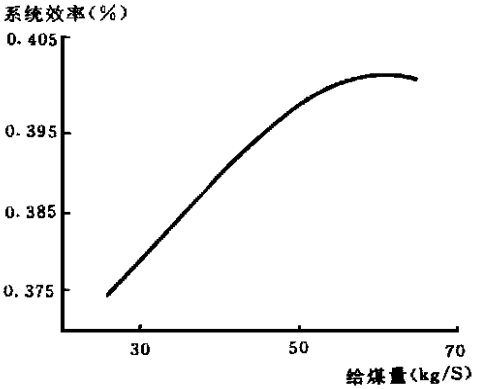

图 4　给煤量对系统效率的影响

3　徐向东,钊 丽,朱为民 . 载热气化燃煤联合循环能研究,热能动力工程 , 1996, 11(3): 337~ 342

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3　燃烧特征点试验结果

在上述试验条件下,得到表 1中各煤样燃烧特征点的试验结果,见图 6~ 8

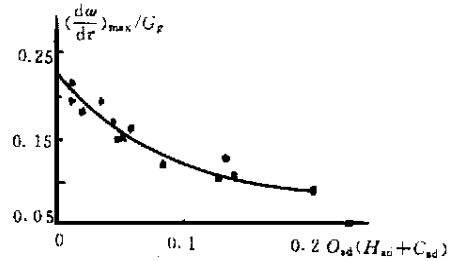

图 8　$(d\omega/d\tau)_{max}/Gg$ 与 $O_{ad}/(C_{ad}+H_{ad})$的关系曲线

在热天平试验条件下,煤粒的着火倾向于非均相着火,颗粒比表面积越大,越有利于着火。显然挥发份越高,在热解期间形成的孔隙越多,比表面积越大;另外,水份析出温度明显低于着火温度,水份析出的结果和挥发份析出的结果一样,均可使颗粒比表面积增加。煤的热值越高,反应时消耗单位质量的可燃物放热量越大,有利于提高颗粒表面温度。这些均有利于煤粒的着火燃烧,引入着火指数 F_i:

$$F_i = (V_{ad} + M_{ad}) \cdot Q_{net,ad} \times 10^{-7}$$

利用 F_i 综合着火温度 T_i,如图 6,可见规律性较好。

一般来讲,煤分子结构中含氧官能团多,煤容易燃烧,最大燃烧速率对应的温度 T_{max}相应减小。图 7为 T_{max}与 O_{ad}/C_{ad}间的关系曲线。

在煤的组成中,碳、氢成分含量越高,煤的发热量越高,相应的燃烧速率增加。图 8为最大燃烧速率 $(d\omega/d\tau)_{max}/Gg$ 与 $O_{ad}/(C_{ad}+H_{ad})$间的关系曲线。

4　结论

本文采用“零维燃烧模型”,在升温速率为 20℃ /min条件下,得到了一些典型动力用煤的燃烧特征点变化规律。

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大型电站锅炉炉内温度场的数值试验研究= **An Experimental Study of the Temperature Field Inside a Large - sized Utility Boiler Furnace by CAT** [刊,中]/Chen Xiaodong, Dong Peng, Cheng Congshu, Qin Yukun (Harbin Institute of Technology)//Journal of Engineering for Thermal Energy & Power. - 1997, 12(5). - 321~ 323

Through the use of a computer aided test method a fundamental research is conducted of the characteristics of the temperature field in a large-sized utility boiler furnace. On the basis of a three-dimensional numerical simulation of the working medium radiation heat transfer in the furnace obtained is a pertinent in-furnace temperature field distribution law. The numerical test results in most cases are in relatively good agreement with those of the on-site tests. **Key words**: boiler, temperature field, computer aided test

垂直布置倒 U型管内气液两相流稳态特性及脉动特性研究= **A Study of the Steam/Liquid Dual-phase Flow Steady-State and Pulsation Characteristics in a Vertically Placed and Inverted-U Shaped Pipe** [刊,中]/Wu Yining, Lin Zonghu (Xi'an Jiaotong University)//Journal of Engineering for Thermal Energy & Power. - 1997, 12(5). - 324~ 326

With Freon- 113 serving as a working medium the steady-state and pulsation curves of steam/liquid dual-phase flow in a vertically placed inverted-U shaped tube is studied from both the experimental and theoretical aspects. The test range can be given as follows: outlet pressure P= 0.2- 0.4 MPa, system heating power output Q= 6.4- 10.4 kW, mass flow speed m= 3- 24 kg/m. For the theroetical study adopted is a one-dimensional uniform-phase model with a difference method used for solving a group of conservation equations. Obtained are the steady-state flow ratedifferential pressure characteristics curves. Moreover, a numerical calculation method has been used to simulate pressure-drop type pulsation curves. **Key words**: dual-phase flow, unstability, pulsation

螺旋槽管凝结换热器的研究与应用= **The Study and Application of Condensation Heat Exchangers Consisting of Spirally Corrugated Tubes** [刊,中]/Wu Huiying, Shuai Zhiming (Southeastern University)//Journal of Engineering for Thermal Energy & Power. - 1997, 12(5). - 327~ 329

An experimental study is made of a condensation heat exchanger with spirally corrugated tubes. Dimensionless correlations are obtained separately for phase transformation-related convective heat transfer in spirally corrugated tubes, tube-outside condensation heat transfer criteria and tube-inside flow resistance. On the basis of the test results the spirally corrugated tubes have been successfully used in power station condensation heat exchangers. **Key words**: spirally corrugated tube, condensation heat exchanger, intensified heat transfer

含温多孔介质内热量迁移的研究= **A Study of Heat Migration in Unsaturated Porous Media** [刊,中]/Jin Feng, Shi Mingheng, Yu Weiping (Southeastern University)//Journal of Engineering for Thermal Energy & Power. - 1997, 12(5). - 330~ 331

An analysis is given of the mechanism of heat migration under the coupled action of heat and moisture in unsaturated porous media. A mathematical model for calculating the heat migration in porous media is proposed. Also discussed is the effect of different boundary conditions on the temperature distribution in porous media. **Key words**: heat transfer, porous media, coupled action, heat/moisture migration

煤燃烧特征点变化规律的研究= **A study of the Variation Law of Coal-combustion Characteristic Points** [刊,中]/Zhu Qunyi, Zhao Guangbo, et al (Harbin Institute of Technology)//Journal of Engineering of Thermal Energy & Power. - 1997, 12(5). - 332~ 334

An experimental study is performed of the combustion characteristics of thirteen kinds of coals by using a

thermobalance and under a temperature rise of 20℃ /min, resulting in the identification of a variation law of coal combustion characteristics points. **Key words**: thermobalance, combustion characteristic points

内循环流化床颗粒功力特性的研究= **A Study of the Dynamic Characteristics of Inner-circulating Fluidized Bed Particles**[刊,中]/Lu Chumei, Xu Yanshong(Shandong University of Technology)//Journal of Engineering for Thermal Energy & Power.- 1997,12(5).- 335~338

This paper presents the results of an experimental study on the dynamic characteristics of particles in a V type inner-circulating fluidized bed, including the kinematic trajectory of the particle inner circulation, the distribution feature of the bed layer inner pressure and fluidization speed, etc. **Key words**: inner circulation fluidized bed, dynamic characteristics, fludization speed

高浓度煤粉燃烧过程中氮氧化物生成的研究= **An Investigation of NOx formation Resulting from the Burning of High-concentration Pulverized Coal**[刊,中]/Qi Hong, Fan Yaoguo, Yuan Jianwei (Huazhong University of Science & Technology)//Journal of Engineering for Thermal Energy & Power.- 1997,12(5).- 339~344

NO*x* emissions were measured during the process of pulverized coal burning with the formation and disassociation of NO*x* undergoing a chemico-dynamics simulation. The simulation results show that the major cause of the significant decrease in NO*x* emissions during the combustion of high-concentration pulverized coal consists in a combustion deviating from the stoichiometric ratio. The disassociation action on NO*x* of a huge amount of CO produced under a uniform phase ignition mode can be explained as the second cause. **Key words**: high-concentration pulverized coal, coal combustion, NO*x*, CO

立式上锅筒实际液位计算方法的探讨= **An Exploratory Investigation of the Method for Evaluating Actual Water Levels in Vertical Steam Drums**[刊,中]/Zou Xiang, Wang Liangyan(Guangzhou Energy Resources Research Institute under the Chinese Academy of Sciences)//Journal of Engineering for Thermal Energy & Power.- 1997,12(5).- 345~347

An analysis and discussion is given of the bubbeing process in the case of underwater admission of steam-water mixture. Two kinds of methods for evaluating average section volumetric quality are compared with a calculation formula given, which facilitates the computation of actual water levels. The difference between an actual water level and a weight water level is dependent on the steam drum steam output and operating pressure. In the case of a medium and low-pressure range and a constant steam output a moderate increase in operating pressure can lead to an increase in actual gravity separation height, thereby enhancing the effectiveness of natural separation. Under certain circumstances the difference between the maximum water level and an average water level should not be taken lightly or disregarded. **Key words**: vertical steam drum, water level, volumetric quality, evaluation

贾汪 PFBL-CC中试电站异形煤仓设计和试验= **Design and Test of an Irregular-shaped Coal Bin for Jiawang PFBC-CC intermediary Test Power Station** [刊,中]/Yang Yaping (Southeastern University)//Journal of Engineering for Thermal Energy & Power.- 1997,12(5).- 348~350

With the help of Jeike's design method of mass flow hopper bins some special issues in the design of hopper bins are analysed with a simplified treatment being proposed. A Study is conducted of the shape selection which can produce a mass flow in an irregular-shaped coal particle hopper bin. In addition, a model test has been conducted to verify the accuracy of the results. **Key words**: coal bin, hopper bin, mass flow, slope, inner flow valley