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我国动力用煤煤质与着火特性试验研究

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摘 要: 煤质特性是影响煤着火特性的重要因素, 通过一维燃烧炉对动力用煤的着火特性进行试验研究, 并对影响煤粉着火过程的煤质特性进行了分析, 利用挥发分、水分、灰分、固定碳含量对着火特性的影响, 建立了着火判别指数 δ。提出了利用煤质分析数据计算着火温度判别指数 δ, 从而判断动力煤的着火特性方法, 并对计算所得着火温度与试验测得的着火温度进行拟合, 二者的相关系数为 0.9571, 表明这种评价煤着火特性的方法比较精确、可靠。

关 键 词: 燃烧; 煤粉; 煤质特性; 着火特性; 一维燃烧炉; 动力用煤

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引 言

煤的着火特性是评价煤燃烧特性的重要指标, 它直接关系到燃煤单位设备运行的经济性和稳定性。目前, 利用热天平、燃烧炉和沉降炉等设备进行试验是判断着火特性的常用方法, 这些方法都要在试验室进行, 需要专门的试验设备, 耗费时间长, 因此在工厂应用有一定困难。本研究根据一维燃烧炉得到的试验数据, 并在对燃烧过程深入分析的基础上, 提出了利用煤质分析数据就可对动力用煤的着火特性进行判别的方法, 建立了着火判别指数 δ。

1 一维燃烧炉试验

1.1 一维燃烧炉

一维燃烧炉是进行煤燃烧试验的常用方法, 它可以在动态条件下实现煤与空气燃烧试验, 可直接得到煤粉燃烧的着火温度, 通过对燃烧产物的分析, 可评价煤的燃烧特性, 煤粉燃烧状况比较接近于实际情况。

研究使用的一维燃烧试验炉系统如图 1所示, 它分为给料系统、预热系统、自动控制系统、反应炉系统、取样系统和烟气处理系统 6部分。

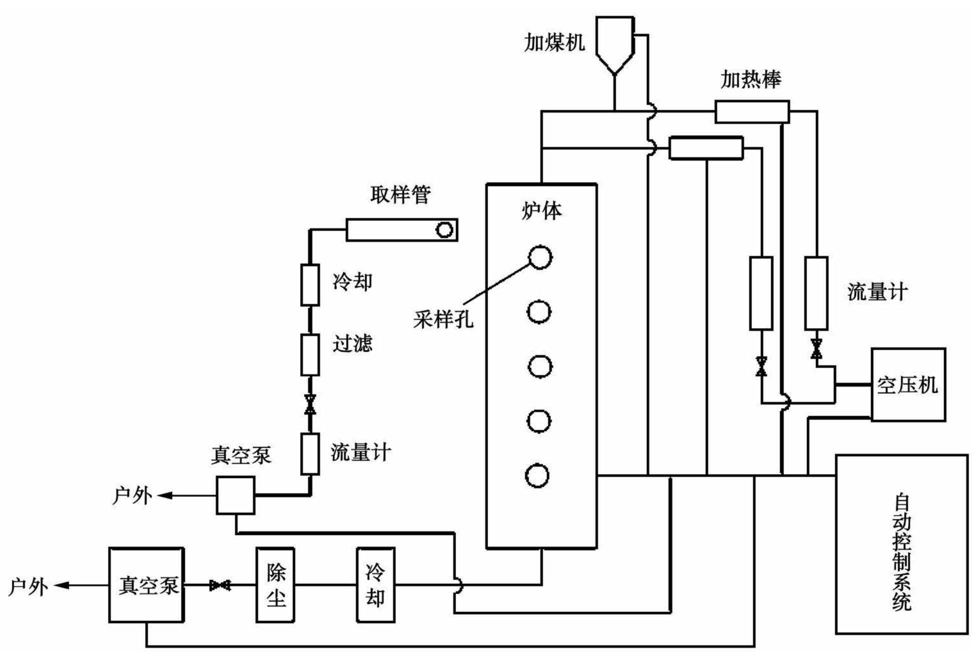

图 1 一维燃烧炉系统流程图

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燃烧反应炉的温度范围为室温到 1 500 ℃,可恒定温度,恒温区长度 1.8 m,适合多种煤的着火条件试验,也可进行多种煤的燃尽试验。恒温区段平均分布 5个取样或观察孔,可以进行取样检验或观察炉内的燃烧状况。空气预热器可以将空气最高加热到 500 ℃,可根据需要任意设定,并可调节流量。给粉机是经过特殊设计的微量给粉装置,可稳定、连续给粉,连续给粉量在 60~600 g/h范围内调节。

1.2 试验方法及条件

气、粉混合物由燃烧试验炉顶部引入。试验时,首先将各级炉体预热至预定温度,随后启动引、送风机,调整一、二次风量及给粉量,投入煤粉。炉体持续升温,煤粉气流在某一断面稳定着火时的温度就是煤粉着火温度,用抽气热偶可测定沿程火焰温度、并可从取样口抽取燃烧后煤样,对取到的焦样进行分析,通过分析结果对燃烧特性进行研究。

一维燃烧炉燃烧试验中,反应炉温度、煤样粒度、加煤速率、空气过剩系数和空气预热温度需要试验前设定,如表 1所示。

表 1 一维燃烧炉着火试验主要参数

	数 值
加煤速率 /g· min⁻¹	5
空气过剩系数	1.2
空气预热温度 /℃	200
煤样粒度 /目	200
炉体预热温度 /℃	300

1.3 燃烧试验结果

利用一维燃烧炉试验系统,选用 24种动力煤煤样进行了着火特性试验,通过试验测得了各煤样的着火温度,并依据式(2)计算得到 δ值,各煤样的煤质分析数据及试验结果列于表 2。

表 2 一维燃烧炉着火特性试验数据

煤种	工业分析 /%					元素分析 /%					T_i/℃	δ
	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	$Q_{net,ad}$ /MJ·kg⁻¹	C_{ad}	H_{ad}	N_{ad}	$S_{t,ad}$	O_{ad}		
1	2.95	31.88	23.95	41.24	20.05	50.77	3.54	0.91	0.62	9.33	590	6.429 8
2	1.51	27.10	23.81	47.59	24.29	60.23	3.53	1.18	0.53	5.93	590	6.286 6
3	4.2	14.43	28.45	52.92	27.05	65.41	4.16	1.04	0.54	10.21	502	9.077 1
4	3.98	20.66	27.50	47.86	23.96	60.49	3.76	1.08	0.61	9.42	546	8.348 3
5	4.98	14.36	27.89	52.79	25.37	66.26	4.03	0.84	0.75	8.79	518	9.028 1
6	4.08	24.58	26.22	45.12	21.26	55.60	3.44	1.01	1.04	10.27	552	7.701 6
7	2.04	22.94	28.71	46.31	25.08	62.97	4.08	1.25	0.33	6.39	581	8.323 5
8	1.74	20.72	25.75	51.79	26.17	66.36	4.18	1.18	0.25	5.57	595	7.196 1
9	5.64	9.22	27.94	57.22	27.25	68.54	3.94	0.96	0.41	11.31	484	9.478 2
10	3.79	23.14	26.89	46.18	23.46	57.91	3.77	1.13	0.62	9.64	562	7.9612
11	1.45	17.57	24.58	56.40	28.86	70.1	4.22	1.17	0.5	4.99	585	6.809 3
12	1.55	21.27	26.37	50.81	26.82	65.85	4.22	1.2	0.51	5.40	580	7.375 2
13	2.03	32.99	23.65	41.33	21.65	53.19	3.72	1.09	0.29	6.72	607	6.161 8
14	3.15	27.2	26.91	42.92	22.59	57.04	4.08	1.13	0.55	7.08	576	7.676 2
15	2.55	24.49	30.45	42.51	23.95	59.5	4.42	1.16	0.15	7.73	534	9.097 7
16	3.75	20.07	28.88	47.30	24.66	61.28	3.76	1.16	0.62	9.36	512	8.907 2
17	2.44	17.92	24.52	55.12	26.82	67.10	3.92	1.58	0.56	6.52	569	6.949 5
18	1.45	25.95	24.56	48.04	24.48	60.44	3.47	1.07	0.52	7.10	589	6.566 7
19	0.74	20.40	13.02	65.84	27.93	68.40	3.54	1.30	1.34	4.32	687	3.063 8
20	1.06	43.48	16.34	39.12	18.46	45.31	2.98	0.93	0.55	5.74	681	3.693 2
21	7.25	5.56	30.07	57.12	27.38	68.82	3.79	0.94	0.29	13.35	431	11.361 6
22	13.55	6.57	26.11	53.81	26.54	65.92	3.19	0.82	0.26	9.75	431	11.472 6
23	5.98	6.61	32.10	55.31	27.85	68.82	3.96	0.95	0.57	13.15	415	11.957 8
24	9.23	6.35	31.04	53.38	26.75	67.30	3.45	0.94	0.49	12.24	421	12.747 7

2 煤着火判别指数的建立

2.1 煤粉着火影响因素的确定

煤粉的燃烧过程是随着煤粉被加热, 挥发分首先析出并与氧气反应、着火, 放出的热量加热固定碳, 使表层固定碳着火并达到有明显的稳定火焰状态, 挥发分的析出、燃烧贯穿于整个煤粉的燃烧过程中, 与固定碳的燃烧没有明显的界限[1]。煤粉着火需要热量主要由挥发分燃烧放出的热量提供, 由灰分、固定碳和水分的吸收, 水分的存在对着火既有不利的一面, 又有有利的一面, 由于试验所用煤粉很细, 水分的存在主要是不利的影响。所以, 在煤粉的着火过程中, 挥发分起到了至关重要的作用, 它促进了固定碳的着火并稳定燃烧, 煤粉含有的水分和灰分对着火和燃烧没有好处, 它们既不可燃也不助燃, 同时灰分还阻碍了氧与碳的接触和反应, 不利于着火。

可见, 挥发分、水分、灰分、固定碳含量是影响煤着火特性的最重要的煤质指标[2]。单位质量煤中挥发分发热量的增加, 将使煤着火容易, 着火温度将降低; 若灰分、水分和固定碳升高, 单位温度的吸热量增加, 则煤的着火热量增加, 使煤粉着火困难, 着火温度升高。所以, 挥发分对煤着火特性的影响是正效应, 水分、灰分、固定碳对煤着火特性的影响是负效应。

研究煤粉的着火过程, 主要考察煤质特性对着火过程的影响, 因此, 忽略外部条件变化对煤粉着火过程的影响, 只从煤质特性研究煤粉的着火过程, 提出假设:

(1) 挥发分、水分、灰分、固定碳含量是影响煤着火特性的最重要的煤质指标。

(2) 煤粉着火过程所需热量主要由挥发分燃烧放出的热量提供, 挥发分对煤着火特性的影响是正效应。

(3) 挥发分燃烧放出的着火热主要由水分、灰分、固定碳吸收, 水分、灰分、固定碳对煤着火特性的影响是负效应。

2.2 煤粉着火判别指数

煤的着火温度 T_i 影响因素为: $\{V_{ad}, M_{ad}, A_{ad}, FC_{ad}\}$, 各因素对着火温度的贡献大小可以建立如下相关关系式:

$$T_i = (K_1 \cdot V_{ad} + K_2 \cdot M_{ad} + K_3 \cdot A_{ad} + K_4 \cdot FC_{ad}) \times 100 \quad (1)$$

式中: K_1、K_2、K_3、K_4— V_{ad}、M_{ad}、A_{ad}、FC_{ad} 对着火温度 T_i 的贡献大小。

根据表 2煤质分析数据组成多元方程组, 通过求解方程组的解, 求得 $K_1 = 1.5035$, $K_2 = -6.6956$, $K_3 = 9.2385$, $K_4 = 6.9170$。K_1、K_2、K_3、K_4 只是体现了 V_{ad}、M_{ad}、A_{ad}、FC_{ad} 对着火温度 T_i 的贡献大小, 没有表明 V_{ad} 对煤着火特性的影响是正效应, 也没表明 M_{ad}、A_{ad}、FC_{ad} 对煤着火特性的影响是负效应。

基于以上分析, 建立着火判别指数 δ:

$$\delta = \frac{K_1 V_{ad}}{K_4 FC_{ad} + K_3 A_{ad} + K_2 M_{ad}} \times 100 \quad (2)$$

其中, V_{ad} 对 δ 影响是正效应; FC_{ad}、A_{ad}、M_{ad} 对 δ 影响是负效应; $K_1 = 1.5035$, $K_2 = -6.6956$, $K_3 = 9.2385$, $K_4 = 6.9170$, δ 计算结果如表 2所示。

δ 与煤样的着火温度 T_i 相关, 着火温度与着火判别指数之间关系如图 2所示, 从图中可以看出, 随着着火判别指数的增加, 着火温度降低, 煤易燃; 反之, 着火判别指数降低, 着火温度增加, 煤难燃。着火判别指数与一维燃烧炉试验测得的着火温度相关系数为 0.9572, 说明着火判别指数与一维燃烧炉试验测得的着火温度显著相关。

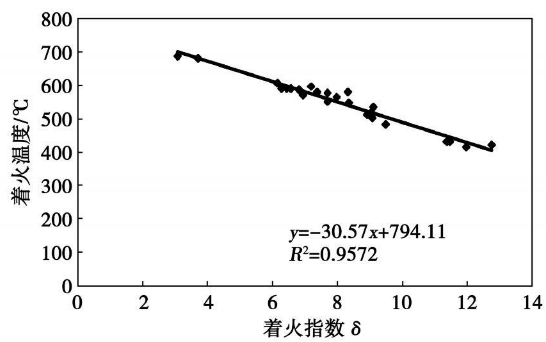

图 2　着火判别指数与着火温度的关系

依据前人研究结果[3], 将着火温度 T_i 进行等级划分, 如表 3所示。根据图 2着火温度与着火判别指数的相关曲线和表 3的着火温度划分对着火判别指数进行等级划分, 如表 4所示。

表 3　一维燃烧炉着火温度等级划分

着火温度 T_i/℃	煤粉着火情况
$T_i < 450$	易燃
$550 > T_i \geq 450$	较易燃
$650 > T_i \geq 550$	较难燃
$T_i \geq 650$	难燃

表 4　一维燃烧炉着火温度判别指数等级划分

着火温度指数 δ	煤粉着火情况
δ>11.2565	易燃
11.2565>δ≥7.9853	较易燃
7.9853>δ≥4.7141	较难燃
δ<4.7141	难燃

2.3　煤粉着火温度判别指数的检验

为检验利用着火判别指数求得的着火温度的可信度，将利用着火判别指数求得的着火温度与试验测得的着火温度进行了对比分析，图 3是根据煤质基础分析数据，利用着火判别指数求得的着火温度与试验测得的着火温度的拟合直线。二者的相关系数为 0.9571，说明利用着火判别指数求得的着火温度与试验测得的着火温度十分相近，表明这种评价煤着火特性的方法比较精确、可靠。

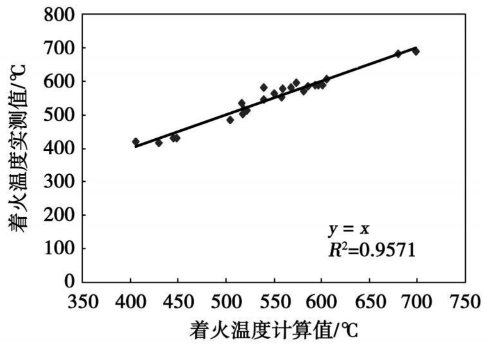

图 3　着火温度计算值与实测值相关性

3　结　论

通过一维燃烧炉对煤粉的着火特性进行了试验研究，对影响煤粉着火过程的煤质特性挥发分、水分、灰分、固定碳含量进行了分析，利用挥发分、水分、灰分、固定碳含量对着火特性的影响效应，提出了着火判别指数 δ，使现场工作人员在没有专门的仪器设备时，可以通过煤质分析数据计算出 δ，从而判断煤样的着火特性。该判断能较好地体现一维燃烧炉实验结果，使煤着火特性可以在仅具有基础、简单的数据条件下实现较准确的判断，减少了燃烧试验需要的时间和消耗。

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An ignition and combustion stability test of a low-heating-value coal gas was performed respectively on a direct flow type burner and a flare type direct flow one with different cone semi-angles. It has been found that when the direct flow burner has an inner diameter of less than 8 mm, its quenching effect will seriously affect the stability of the flames. An enhancement of H_2 concentration can improve the combustion stability characteristics of the low-heating-value coal gas. For the above coal gas, the combustion stability performance of the flare type direct flow burner is superior to that of a conventional one. When the cone semi-angle of the flare type direct flow burner is greater than 10 degrees, it can produce a dual ignition ring and enhance the flame blow-off limits. Key words: combustion stability characteristics, burner, direct flow type, coaxial jet, low-heating-value coal gas

两层多孔介质燃烧器的数值模拟＝Numerical Simulation of a Dual-layer Porous Medium Burner[刊，汉] / SHI Jun-rui, XU You-ning, XUE Zhi-jia (Shenyang City Key Laboratory on Circulating Fluidized Bed Combustion Technology, Shenyang Engineering College, Shenyang, China, Post Code: 110136), XIE Mao-zhao (College of Energy Source and Power, Dalian University of Science and Technology, Dalian, China, Post Code: 116024) // Journal of Engineering for Thermal Energy & Power. —2010, 25(5). —521 ~524

A one-dimensional numerical simulation was performed of the combustion characteristics of a premixed gas in a dual-layer porous medium burner. The super-adiabatic combustion and stable flame zone in the burner under discussion were mainly studied. The research results show that the premixed gas can produce super-adiabatic combustion to a certain extent inside the dual-layer porous medium and the lean combustion limits can be extended to 0.45. The dual-layer porous medium can stabilize the flame at the interface within a relatively wide flow speed range. The minimum and maximum flame promulgation speeds obtained from a numerical prediction assume a same tendency as the test ones, which are at least three times higher than those in a free space. Key words: premixed gas, dual-layer porous medium burner, numerical simulation

我国动力用煤煤质与着火特性试验研究＝Experimental Study of the Quality and Ignition Characteristics of Coals for Use in Power Plants of China[刊，汉] / XIE Ji-dong, JIANG Ying (Beijing Coal Chemical Research Institute, Chinese Academy of Coal Sciences, Beijing, China, Post Code: 100013) // Journal of Engineering for Thermal Energy & Power. —2010, 25(5). —525 ~528

The coal quality characteristics constitute an important factor influencing its ignition ones. The authors have experimentally studied the ignition characteristics of coal for use in power plants in a one-dimensional combustion furnace and analyzed the coal quality characteristics influencing the ignition process of the pulverized coal. By utilizing the influence of the volatile, water, ash and fixed carbon content on the ignition characteristics of the coal, an ignition judgement index δ was established and a method was proposed for calculating the index under discussion δ by utilizing the coal quality analytic data of the coal, thereby judging the method of its ignition characteristics. In addition, a fitting was performed of the ignition temperatures calculated and those measured through the test, of which the correlation factor was assessed as 0.9571. This shows that the method under discussion is relatively precise and reliable. Key words: combustion, pulverized coal, coal quality characteristics, ignition characteristics, one-dimensional combustion furnace, coal for use in power plants

碳化氨水中碳/氨含量快速测定方法＝A Method for Quickly Determining the Carbon/ammonia Content in Carbonized Ammonia[刊,汉]/ZHAO Qing, WANG Shu-juan, CHEN Cang-he, et al(Education Ministry Key Laboratory on Thermal Sciences and Power Engineering, Thermal Energy Engineering Department, Tsinghua University, Beijing, China, Post Code: 100084)//Journal of Engineering for Thermal Energy & Power. －2010, 25(5). －529～533

The ammonium carbonate and bicarbonate at an analytic purity were used to prepare carbonized ammonia with different total ammonia concentrations [A] and CO_2 load-carrying degrees [C]/[A]. [A] was determined as 0.55, 0.88, 1.10, 1.32, 1.65 and 2.20 mol/L respectively and [C]/[A], 0.46, 0.55, 0.65, 0.76, 0.88 and 1.00 respectively. When the solutions under discussion were 15, 18, 21, 24, 27 and 30 ℃ respectively, their PH values and electrical conductivities were measured simultaneously. The test results show that the PH value of the carbonized ammonia mainly reflects [C]/[A] while the electrical conductivity mirrors [A]. Through an analysis of the test data, the relationships between the PH value and electrical conductivity as well as between [C]/[A] and [A] were obtained. To this end, a method for quickly obtaining [A] and [C]/[A] by measuring the PH value and electrical conductivity of the carbonized ammonia at the sampling temperature was proposed. The method under discussion is applicable for carbonized ammonia at a temperature from 15 to 30 ℃ of which [A] is 0.55 to 2.20 mol/L and [C]/[A] is 0.46 to 1.00. The foregoing can provide a convenient and quick measurement and monitoring means for a test of CO_2 absorption by using ammonia at a low concentration. Key words: carbonized ammonia, CO_2 load-carrying degree, PH value, electrical conductivity

氧载体 $CaSO_4$ 与 CO的化学链循环试验研究＝Experimental Study on the Chemical Chain Cycle of Oxygen Carrier $CaSO_4$ and CO[刊,汉]/ZHANG Lu(National Key Laboratory on Coal Combustion, Central China University of Science and Technology, Wuhan, China, Post Code: 430074), ZHU Yi-cheng(College of Thermal Energy Engineering, Shandong Architectural University, Jinan, China, Post Code: 250101)//Journal of Engineering for Thermal Energy & Power. －2010, 25(5). －534～538

With a non-metal $CaSO_4$ serving as an oxygen carrier, studied on a fixed bed reactor was the circulation reactivity of $CaSO_4$ and CO/air at 950 ℃. During the reaction, the constituents of the exhaust gas produced were recorded and analyzed. The solids remained after the reaction were collected and a characteristic analysis was performed by using XRD (X-ray diffraction) and FSEM (fast scanning electron microscope) etc. The authors concluded that at 950 ℃, the reaction of $CaSO_4$ and CO mainly produces CaS in its reduction reaction stage and an extremely small quantity of CaO. Furthermore, no carbon deposition phenomenon emerges. Gas SO_2 is mainly generated in the initial stage of the oxidation reaction. When the oxygen volumetric concentration reaches 4%, the maximum SO_2 volumetric concentration can hit 0.5%. The characteristic analysis shows that $CaSO_4$ boasts very good mechanical properties and the capability to resist agglomeration and sintering but a poor continuous cycling capacity. Key words: chemical chain combustion, fixed bed reactor, $CaSO_4$, carbon deposition, SO_2 release