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滚筒式冷渣器灰渣运动实验与模拟

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摘 要: 通过灰渣在滚筒冷渣器内的运动实验, 建立了滚筒内灰渣的轴向运动模型, 研究了滚筒转速、倾斜角、填充度和滚筒直径等参数对灰渣平均停留时间的影响。结果表明: 滚落状态下灰渣在滚筒内停留时间约为滑移状态的1.5倍, 灰渣间混合良好; 在其它条件不变的情况下, 随转速和倾斜角、直径的增大或填充度的减小, 灰渣在滚筒内的停留时间减小; 转速越大灰渣间混合越强, 填充度越大混合越弱。

关 键 词: 滚筒式冷渣器; 倾斜角; 填充度; 转速; 平均停留时间

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引 言

灰渣在滚筒冷渣器内的运动包括横向和轴向运动, 轴向运动速率影响冷渣器的出力以及轴向扩散, 横向运动影响灰渣的横向混合, 混合越均匀越有利于灰渣的传热[1]。滚落状态是灰渣运动的理想状态[2], 在滚落状态下, 灰渣截面根据运动特点可分为两部分: (1) 底部灰渣随筒体围绕圆心做圆周运动, 灰渣间无相对运动, 为固定层。(2) 表面灰渣从高端随机、无序地自由滑落至低端, 为滚落层。

通过灰渣运动实验对灰渣的运动状态进行了观察, 由于灰渣运动存在随机性, 因此以同工况下灰渣的平均停留时间作为分析依据, 对不同工况下灰渣停留时间进行了测试, 然后参考文献[3~7]对停留时间以及扩散特性的相关研究以及冷渣器的运动特性, 建立了螺旋肋板冷渣器的灰渣运动特性模型, 分析了不同运行工况下灰渣的运动特点。

1 灰渣运动实验与模型的建立

1.1 实验装置与实验方法

运动实验装置主要由滚筒筒体、电机和给料绞龙组成, 如图1所示。实验物料从绞龙加入, 滚筒旋转的过程中, 在重力的作用下向前流动。滚筒由有机玻璃制成, 长4 m、外径为800 mm、壁厚10 mm。为比较有肋和无肋时灰渣的运动状态, 滚筒内壁面均匀布置有8根纵肋, 长度为2 m, 布置在滚筒出口处, 停留时间的测量主要针对有肋段(有效段); 出口设有高60 mm的挡板, 用以提高灰渣填充度, 比较不同填充度下灰渣运动特点。

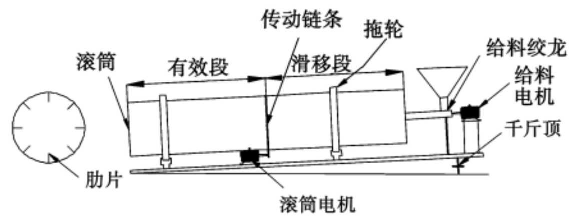

图1 滚筒式冷渣器运动实验装置示意图
Fig. 1 Schematic drawing of a roller type slag cooler movement test device

实验物料平均粒径为0.428 mm, 堆积密度为1 456 kg/m^3, 筛分特性如表1所示。通过颜色示踪方法测定停留时间, 为便于示踪粒子的分离, 示踪粒子粒径略大于实验灰渣粒径, 粒径范围为1~1.25 mm。示踪粒子在入口加入, 从进入有效段开始计时, 示踪粒子在运动中发生扩散, 以一半示踪粒子到达出口的时间作为该工况下的平均停留时间。实验中保持最大给料速率保持163.72 g/s, 停留时间测试实验主要针对变转速和变倾斜角, 具体实验工况如表2所示。

表1 石英砂粒度分布特性
Tab. 1 Distribution characteristics of quartz sand particle sizes

	1	2	3	4	5
尺寸/mm	<0.15	0.15~0.22	0.22~0.45	0.45~0.63	0.63~1
份额/%	4.6	2.1	58.2	21.6	13.5

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表2　运动实验工况

Tab. 2 Operating conditions of the movement test

	工况							
转速/r·min^{-1}	113	129	234	340	550	169	179	189
滚筒倾角/(°)	1.9	1.9	1.9	1.9	1.9	1.5	2.5	3.0

1.2　运动一维轴向模型

对于水平布置的转动设备,表面灰渣在重力和螺旋肋板(或倾斜肋板)共同作用下沿肋板的滑动等效于倾角与螺旋肋板角度相同的倾斜布置的滚筒冷渣器[8]。根据运动试验,滚筒式冷渣器内灰渣颗粒在滚筒内的运动轨迹可用图2来表示,以位置零处的灰渣为例:灰渣颗粒在滚落层内,在重力和肋板的作用下,沿着螺旋肋板方向滑落至1点,然后进入固定层并随滚筒作圆周运动至位置2,颗粒从位置2处再次随机滚落至位置3,随着滚筒的转动灰渣在冷渣器内部来回运动,直至从冷渣器出口流出。

对于布置有螺旋肋板的冷渣器,沿轴向冷渣器内灰渣厚度变化不大,可认为料床厚度一致,等于螺旋肋板高度,则渣床表面为平面且与滚筒内壁的交线为直线。当物料运动处于滚落状态时,结合滚筒冷渣器自身特点和相关研究假设:(1)灰渣在表面滚落层的时间忽略不计,停留时间近似为固定层内的时间。(2)灰渣轴向位移和灰渣的轴向扩散仅取决于表面滚落层的滚落运动。

滚筒冷渣器内的空间直角坐标系如图2所示,以灰渣料床截面为x轴,垂直料床表面且经过圆心的直线为y轴,沿轴向灰渣表面中心为z轴。设螺旋肋板高度为h_0,令$m=0.5AB$,则$m=(R^2-(R-h_0))^{0.5}=(h_0(2R-h_0))^{0.5}$,$L$为滚筒长度,则直线AC的方程为:

$$\begin{cases}x=m\\y=0\end{cases}$$

对固定层内任意点$b(x_b,y_b,z_b)$处灰渣,其从点$c(-({x_b}^2+{y_b}^2+2y_b(R-h_0))^{0.5},0,z_b)$进入滚落层点,灰渣在此过程中经历的时间$t=\angle(boc)/\omega$,转过的角度$\angle(boc)=\arcsin(x_b/({x_b}^2+(y_b+R-h_0)^2)^{0.5})-\arcsin(x_c/({x_b}^2+(y_b+R-h_0)^2)^{0.5})$,$\omega$为转动角速度。

若灰渣滑落轨迹与x轴夹角为φ,则对$0(x_0,0,z_0)$处灰渣(如图2(a)所示),其第一次滚落,滚落层轨迹为$(x-x_0)\tan\varphi=z-z_0$,对于螺旋式肋板$\tan\varphi=$螺距/内筒周长。直线AC与灰渣滚落轨迹直线$0G$的交点G坐标为$(m,0,(x_G-x_0)\tan\varphi+z_0)$。受灰渣颗粒间的摩擦、碰撞影响,灰渣进入固定层的位置为$0G$上随机某点。ζ为概率密度函数为$f(\zeta)=2\zeta$ $(x/x_G=\zeta,0\leqslant\zeta\leqslant1)$的随机数,灰渣进入固定层点$H$的坐标为:$(\zeta\cdot x_G,0,(\zeta\cdot x_G-x_0)\tan\varphi+z_0)$。

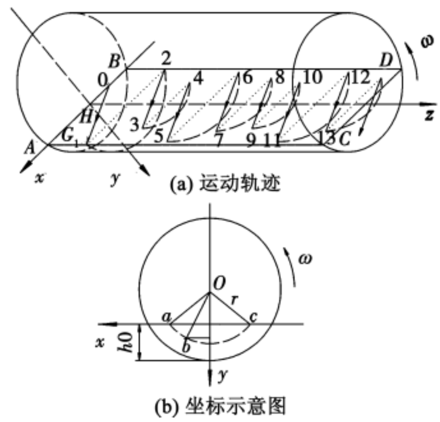

图2　灰渣在滚筒内的运动轨迹及坐标示意图

Fig. 2 Schematic diagram of the movement trajectory and coordinates of the slag inside the roller

灰渣向前运动的同时发生横向混合,完全混合所需时间越短则说明混合越剧烈。将灰渣料床截面分为4部分,示踪粒子从同一位置进入,当第4区域示踪粒子浓度基本一致则认为灰渣完全混合。

灰渣在单次滚落过程中,沿滚筒轴向移动距离为:

$$d=z_H-z_0=(\zeta x_G-x_0)\tan\varphi$$

灰渣从滚落层进入固定层位置的期望为:

$$E=\int_0^1\zeta\times2\zeta d\zeta\cdot m=2m/3$$

因此,单历程固定层的时间期望为:

$$Ti=2\arctan\left(\frac{\frac{2}{3}\sqrt{h_0(2R-h_0)}}{R-h_0}\right)/\omega$$

单次滑落距离为:

$$di=2\times\frac{2}{3}m\tan\varphi=\frac{4}{3}m\tan\varphi=\frac{4}{3}\sqrt{h_0(2R-h_0)}\tan\varphi$$

灰渣从入口到出口的平均停留时间为:

$$T=Ti\cdot(L/di)=\frac{3}{4\pi}\frac{L}{n}\frac{1}{\tan\varphi}\frac{\arctan\left(\frac{2}{3}\frac{\sqrt{h_0(2R-h_0)}}{R-h_0}\right)}{\sqrt{h_0(2R-h_0)}}$$

2　结果与讨论

2.1　灰渣颗粒的停留时间

实验表明,无纵肋部分灰渣为滑移运动状态,纵肋和出口挡板能延长灰渣在滚筒内的停留时间。灰

渣在滚筒内停留时间随转速变化情况如图 3 所示。灰渣在滚落状态(有肋段)的停留时间约为滑移状态(无肋)的 1.5 倍。在转速较慢时(<2 r/min),随着滚筒转速的增加,灰渣在滚筒内的停留时间快速减小;当转速增加到一定程度(>2 r/min),停留时间缩短幅度明显减小;停留时间与转速呈明显的反比关系。这是因为转速的增加使得灰渣在固定层停留时间缩短,单位时间内固定层运送至料床表面滚落层的灰渣增多,在相同时间内有更多的灰渣向前滑落,从而使得灰渣在冷渣器内的停留时间减小。

停留时间随倾斜角的变化如图 4 所示,随滚筒倾角的增加,停留时间逐渐减少,且减小幅度亦逐渐变缓。这是因为倾角的增加使滚落层的轴向重力分力增加,渣床表面灰渣的运动速度加大,表面灰渣轴向运动速率加大,单次滚落距离也加大,使停留时间减小。

在滚落状态下灰渣在滚筒内的停留时间的计算值与实验值吻合较好,表明模型能较为准确地预测灰渣在滚筒内的停留时间。

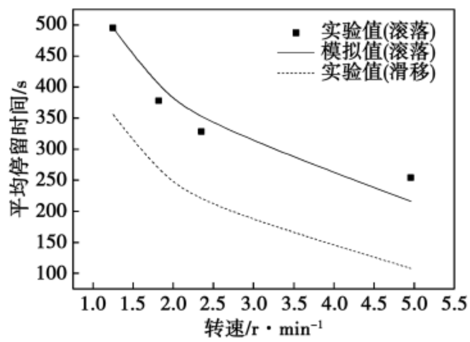

图 3 转速对停留时间的影响

Fig. 3 Effect of the rotating speed on the mean residence time (MRT)

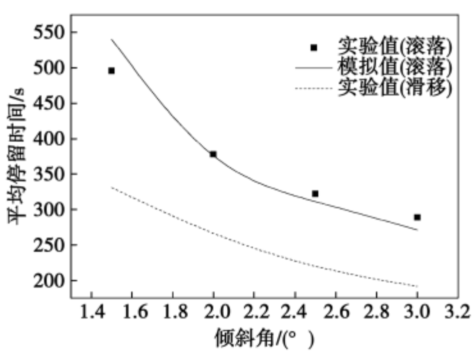

图 4 倾斜角对停留时间的影响

Fig. 4 Effect of the inclination angle on the MRT

相同填充度,不同滚筒直径下的停留时间模拟结果如图 5 所示。随着直径的加大停留时间逐渐减小,这是因为在相同的填充度下,直径越小每次塌落灰渣轴向移动越小,停留时间越大。直径一定,填充度对停留时间的影响如图 6 所示,随料床厚度增加灰渣填充度增大,停留时间增加逐渐加大的。这是因为直径一定,厚度增加时,灰渣固定层停留时间加大,同时滚落层表面加大,单历程轴向运动距离加大,但灰渣滚落层表面影响小于填充度的影响,使得停留时间随填充度增加的增加幅度加大。

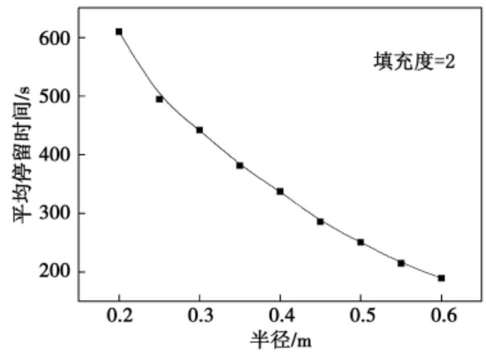

图 5 滚筒半径对停留时间的影响

Fig. 5 Effect of the radius of the roller on the MRT

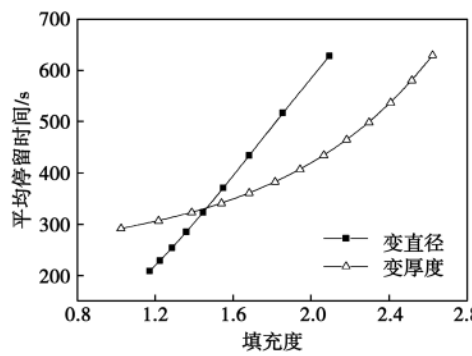

图 6 填充度对停留时间的影响

Fig. 6 Effect of the filling-up degree on the MRT

2.2 滚筒内灰渣横向扩散特性研究

滚筒转速对灰渣横向混合影响如图 7 所示,灰渣完全混合所需时间与转速呈反比,这是因为转速增加灰渣在固定层的时间缩短,单位时间内有更多的灰渣参与混合,完全混合所需时间缩短。因此,转速的提高可以有效地加强灰渣的混合,优化截面灰渣间的传热,对提高冷渣器冷渣效果十分有利。

填充度对灰渣混合的影响如图 8 所示,填充度的增加使得灰渣完全混合所需要时间增加。填充度增加,滚落层灰渣数量增多,但同时由于截面灰渣总

量增加导致横向混合是减弱的。填充度的加大,灰渣间混合程度减弱,降低了滚筒的冷渣效果。

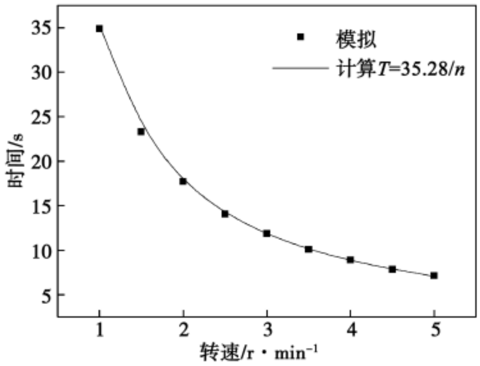

图7　转速对混合时间的影响

Fig. 7 Effect of the rotating speed on the mixing duration

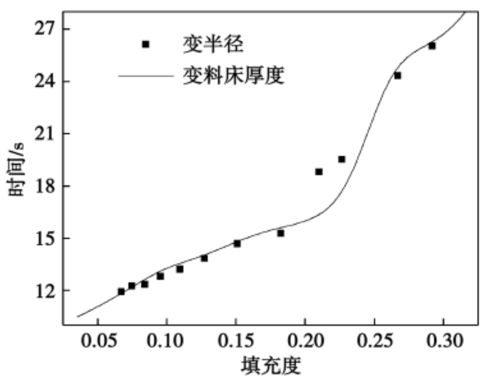

图8　填充度对混合时间的影响

Fig。8 Effect of the filling-up degree on the mixing duration

3　结　论

采用颜色示踪技术对灰渣在滚筒内的运动特点进行了实验研究,建立了滚筒冷渣器运动模型,得出结论:

(1) 填充度较低时,灰渣处在滑移和塌落状态,灰渣混合较弱; 同等条件下,填充度增大,灰渣易进入滚落状态,灰渣混合加强。

(2) 滚落状态下灰渣在冷渣器内的停留时间约为滑移状态的1.5倍,且转速与灰渣在滚筒内的停留时间成反比,转速加大灰渣横向混合加强,转速大于1 r/min 理想状态下半分中内即可完全混合; 提高滚筒转速能有效提高灰渣出力,增强灰渣热量的释放。

(3) 在滚落状态下,填充度越大灰渣停留时间越长,灰渣间横向混合越弱; 填充度一定,增大滚筒直径停留时间缩短,滚筒出力加大。

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(丛　敏　编辑)

structure,the heat lost can be effectively recovered,making the micro-burner have a good heat performance. It has been proven that the porous medium heat recuperation micro-burner thus designed is regarded as one with a high combustion efficiency and a low heat loss rate. **Key words:** porous medium heat recuperation micro-burner, premixed combustion,heat loss,numerical simulation

旋流式气液同轴式喷油器在加压空间中流量特性的试验研究 = Experimental Study of the Flow Rate Characteristics of a Swirling Flow Type Gas-liquid Coaxial Oil Sprayer in a Pressurized Space 刊,汉 WANG Yong-tang,WU Shao-hua(College of Energy Science and Engineering,Harbin Institute of Technology,Harbin,China,Post Code: 150001) ,CHEN Ming,DU Xiao-jian(CSIC Harbin No. 703 Research Institute,Harbin,China,Post Code: 150036) //Journal of Engineering for Thermal Energy & Power. - 2012,27(2). -212 ~217

Under the pressurization condition,experimentally studied were the flow rate characteristics of a swirling flow type gas-liquid coaxial oil sprayer. At a variety of ambient back pressures,the influence of the gas/liquid ratio and ambient back pressure on the fuel oil flow coefficient and atomization air flow coefficient was investigated respectively. The research results show that the sprayer under discussion can have a stable fuel oil flow coefficient of 0.2971,not influenced by gas/liquid ratio and ambient back pressure etc. factors. The atomization air flow coefficient will decrease with an increase of the pressure ratio of the ambient back pressure and the pressure at the inlet of the atomization air passage of the oil sprayer,independent of the gas/liquid ratio. On the basis of the test data,a fitting formula of the atomization air flow coefficient can be obtained,which can accurately predict any test datum. **Key words:** swirling flow type gas-liquid coaxial oil sprayer,pressurized space,fuel oil flow coefficient,excess air ratio, fitting formula

滚筒式冷渣器灰渣运动实验与模拟 = Experimental and Simulation Study of the Ash and Slag Movement in a Roller Type Slag Cooler 刊,汉 ZHUANG Yu (Shanghai Electrical and Power Plant Group Engineering Company,Shanghai,China,Post Code: 201199) ,CHEN Han-ping,WANG Xian-hua,ZHANG Shi-hong(National Key Laboratory on Coal Combustion,Central China University of Science and Technology,Wuhan,China,Post Code: 430074) //Journal of Engineering for Thermal Energy & Power. - 2012,27(2). -218 ~221

Through a movement test of slag inside a roller slag cooler,established was an axial movement model inside the roller and studied was the influence of the rotating speed,inclination angle,filling-up degree and diameter of the roller on the mean residence time of the slag. It has been found that in the rolling-down state,the residence time of the slag in the roller is about 1.5 times of that in the sliding movement state and the ash and slag are well mixed. Under the condition that other conditions are kept unchanged,the residence time of the ash and slag in the roller will be shortened with an increase of the rotating speed, inclination angle and diameter or a decrease of the filling-up degree. The higher the rotating speed, the ash and slag are mixed better. The higher the filling-up degree, the ash and slag are mixed worse. **Key words:** roller type slag cooler, inclination angle, filling-up degree, rotating speed, mean residence time

油页岩干馏废水流化床焚烧过程中 NO_x 和 SO_2 的排放特性 = Emissions Characteristics of NO_x and SO_2 During the Incineration of Oil Shale Dry Distillation Waste-water in a Fluidized Bed［刊，汉］MA Ji-liang, CHEN Xiao-ping, LIU Dao-yin (Thermal Energy Engineering Research Institute, Southeast University, Nanjing, China, Post Code: 210096), LI Xiao-jun (Daqing Oil Field Co. Ltd. Daqing, China, Post Code: 163453) //Journal of Engineering for Thermal Energy & Power. - 2012, 27(2). -222~226

On a bubbling fluidized bed incineration test device with a thermal input power of 90 kW, an oil shale dry distillation waste water incineration test was conducted and the influence of the bed temperature, excess air factor, primary/secondary air ratio and Ca/S ratio on the NO_x and SO_2 concentration in the flue gas discharged was also investigated. The research results show that due to a high ammonia and nitrogen content in the waste water, the NO_x emission concentration will displays a variation tendency to first fall and then rise with an increase of the bed temperature but not exhibit an widely accepted monotonous ascending variation law. The SO_2 emission concentration will exhibit an ascending variation tendency. With an increase of the excess air factor, the NO_x emission concentration will display a variation tendency of first increase and then decrease while the SO_2 emission concentration will show a descending variation tendency. With an increase of the secondary air flow rate, the NO_x emission concentration will assume a desending tendency while the SO_2 emission concentration will show an ascending variation tendency. With an increase of the Ca/S ratio, the NO_x emission concentration will first increase and then decrease while the SO_2 emission concentration will gradually decrease. The NO_x emission concentration under various operating conditions during the test ranged from 104.2 mg/m^3 to 257.9 mg/m^3 while the SO_2 emission concentration ranged from 36.7 mg/m^3 to 179.8 mg/m^3, both of which meet the national emissions standard. **Key words:** oil shale dry distillation waste water, bubbling fluidized bed, incineration, NO_x, SO_2

高温下煤焦表面含氧官能团对 NO-煤焦还原反应的影响 = Influence of the Oxygen-contained Functional Groups on the Surface of Coal Coke at a High Temperature on the NO-Coal Coke Reduction Reaction［刊，汉］XIAO Meng, WANG Jun-chao, LI Yu, FAN Wei-dong (College of Mechanical and Power Engineering, Shanghai Jiaotong University, Shanghai, China, Post Code: 200240) //Journal of Engineering for Thermal Energy & Power. - 2012, 27(2). -227~231