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渐近线型污垢生长的参数特性及测量方法

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摘 要: 根据渐近型函数的特点, 对渐近线型污垢生长的时间常数和污垢热阻渐近值的特性进行分析, 指出污垢时间常数与两次测量得到的污垢生长速率比值的对数成反比, 与两次测量时间的间隔成正比。污垢热阻渐近值可以通过第二次测量的污垢热阻、污垢生长速度以及首次测量的污垢生长速度表示。此方法可以在污垢生长过程中获得渐近线型污垢的时间常数和热阻渐近值, 节省了实验时间, 是对热阻法测量污垢生长过程方法的改进, 同时该方法适用于渐近线型污垢生长过程的预测。

关 键 词: 污垢参数; 测量方法; 预测方法

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引 言

换热面上的积垢影响到换热设备的连续稳定运行, 增加传热过程的熵增, 造成目前多数换热设备均需定期清洗以保证稳定运行。污垢的生长速度与换热设备内流体工质的成分、工作温度、换热面的状态等均有关, 污垢生长模型有渐近线型、线性型、幂率型和降率型几种[1], 但目前还不能提供一个准确的理论模型。工业运行和实验室中遇到的污垢有许多是渐近线型污垢。而使用稳态热阻法进行污垢的测量历时长, 需要监测到污垢停止生长或生长缓慢后, 污垢热阻的渐近值和时间常数才能获得。污垢的预测是污垢研究中很重要的方面, 可为换热设备的清洗时间提供参考对此学界已有很多研究。吴立铎等人使用灰色理论对污垢生长进行了预测[2], 可以较准确地预测污垢热阻随时间的变化趋势。柴海棣等人应用径向基神经网络 RBF 和 BP 网络分别对污垢形成进行预测[3], 指出 RBF 能更好的预测污垢热阻, 均是污垢预测方法中的进展。渐近型污垢的生长曲线可以用一定的函数进行描述, 而在测量和预测中适当运用函数的特点, 可以为污垢测量过程中数据的处理方式提出改进的方法。

1 渐近线型污垢热阻的时间常数的特性

渐近线型的污垢生长模型[2], 以污垢热阻随时间变化的形式表示为:

$$R_f = R_f^*\left(1-\exp\left(-\frac{\theta}{\theta_c}\right)\right) \tag{1}$$

式中: R_f^* —污垢热阻渐近值。即换热面结垢时间 θ 趋于无限长时换热表面的污垢热阻值; θ_c 为污垢生长的时间常数。定义为以初始的污垢生长速率增长到污垢热阻渐近值所需要的时间。

假设在污垢生长过程中取任意时刻 θ', 则此时的污垢热阻 R'_f 表示为:

$$R'_f = R_f^*\left(1-\exp\left(-\frac{\theta'}{\theta_c}\right)\right) \tag{2}$$

θ'时刻的污垢生长速度 k, 即污垢生长曲线在此刻对时间的导数表示为:

$$k = R_f^* \circ \frac{1}{\theta_c}\exp\left(-\frac{\theta'}{\theta_c}\right) \tag{3}$$

若污垢以 θ'时刻的速度进行生长, 则生长过程中 θ 时刻的污垢热阻 $R_{f,\theta}$ 表示为:

$$R_{f,\theta} - R_f^*\left(1-\exp\left(-\frac{\theta'}{\theta_c}\right)\right) = R_f^* \circ \frac{1}{\theta_c}\exp\left(-\frac{\theta'}{\theta_c}\right) \times (\theta-\theta') \tag{4}$$

因此若要使污垢热阻从 θ' 时刻线性增长到 R_f^*, 所需要的时间为 $\theta-\theta'=\theta_c$, 由此看出, 达到污垢热阻渐近值的时间常数与污垢生长起始点和结束点均无关, 这一特点可为时间常数的测量提供借鉴。

2 时间常数和污垢热阻渐近值的测量方法

图 1 为在污垢生长过程中通过热阻法测量污垢热阻发展曲线。第一次测量时刻为 θ_0, 一般取污垢

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生长的初始时刻, 测得的污垢生长速度以 k_0 表示; 第二次测量得到的生长速度以 k_1 表示; k_0 和 k_1 之间的测量时间间隔为 θ_1。则 k_0 和 k_1 分别表示为:

$$k_0 = R_f^* \cdot \frac{1}{\theta_c} \exp\left(-\frac{\theta_0}{\theta_c}\right) \tag{5}$$

$$k_1 = R_f^* \cdot \frac{1}{\theta_c} \exp\left(-\frac{\theta_0 + \theta_1}{\theta_c}\right) \tag{6}$$

此方程中有两个未知数 R_f^* 和 θ_c, 对两方程作比较, 可以得到时间常数为:

$$\theta_c = \theta_1 / \ln(k_0 / k_1) \tag{7}$$

通过式(7)看出, 时间常数 θ_c 与两个测点间的时间间隔成正比, 与两次测量的速度比值的对数成反比。

此时的污垢热阻渐近值 R_f^* 未知, 而在测量过程中可以得到 θ_1 时刻的污垢热阻 $R_{f,\theta 1}$, 代入式(1), 与式(5)和式(6)联立得到污垢热阻渐近值为:

$$R_f^* = R_{f,x} / (1 - k_1 / k_0) \tag{8}$$

3　对测量方法进行验证

用换热面上结晶污垢生长过程的测量数据对上述方法进行验证, 该实验得到的渐近型生长过程如图 1 所示, 点为不同时刻测得的实际污垢热阻数据, 污垢生长曲线为通过最小二乘法拟和得到的污垢生长曲线, 这一过程的时间常数为 5.26 h, 污垢热阻渐近值为 2.0×10^{-4} m²·℃/W。

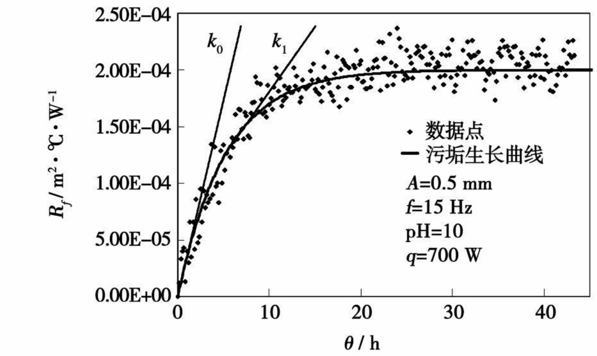

图 1　换热面上生成的碳酸钙结晶污垢热阻测量曲线

用上述方法对实验数据进行处理, 得到的在各时刻 R_f^* 和 θ_c 的数据如表 1 所示, 可以通过求多次平均值将 R_f^* 和 θ_c 表示的更准确。

表 1 最后得到的 θ_c 平均值 5.17 h 与污垢生长曲线得到的 5.26 h 偏差 2.1%, R_f^* 与污垢生长曲线的结果偏差 6.5%, 而此时的实验时间仅为 8 h, 从图 1 中可以看出污垢生长最终达到渐近线值水平历经 30 h, 可见这一方法较好地测量了污垢生长的参数, 同时缩短了实验时间。而在污垢生长过程中获得生长的参数, 表明这一方法可应用到污垢生长的预测中。

表 1　不同时刻下该测量方法的测量值列表

时间 /h	R_f/m²·℃·W⁻¹ (×10⁵)	K/m²·℃·(W·h)⁻¹ (×10⁵)	θ_c /h	R_f^*/m²·℃·W⁻¹ (×10⁵)
—	0	0.000	0.000	5.34
0.5	4.000	3.366	4.70	39.6
1.0	4.000	3.085	5.17	22.7
1.5	3.500	2.899	5.86	15.5
2.0	8.580	2.391	4.46	23.7
2.5	9.514	2.149	4.50	22.3
3.0	7.841	2.221	5.74	19.3
3.5	8.641	2.069	5.90	19.3
4.0	13.240	1.329	3.86	20.5
4.5	8.300	2.030	7.35	18.1
5.0	13.400	1.250	4.56	20.1
5.5	12.297	1.463	5.85	20.2
6.0	13.711	1.195	5.25	20.1
6.5	16.520	0.490	3.19	19.0
7.0	13.916	1.199	6.15	20.5
7.5	14.213	1.166	6.43	20.6
8.0	17.112	0.387	3.53	19.1
时间常数、污垢热阻渐近值 平均值			5.17	21.3

4　结　论

通过对渐近线型污垢生长过程的分析, 提出稳态热阻法测量污垢热阻时间常数和渐近值的改进方法, 指出污垢时间常数反比于两次测量得到的污垢生长速率比值的对数, 正比于两次测量时间的间隔。污垢热阻渐近值可以通过第二次测量的污垢热阻、污垢生长速度以及首次测量的污垢生长速度表示。此方法可以在污垢生长过程中获得渐近线型污垢的时间常数和热阻渐近值。对此方法进行实验验证, 说明该方法可以在短时间内测量污垢的时间常数和渐近值, 可为渐近线型污垢生长的测量和预测提供参考。

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flecting in—furnace combustion conditions were obtained by utilizing computer—based image processing technology. The detection tests of in—furnace radiant energy characteristics were carried out at two stable loads, 300 MW and 250 MW, featuring oxygen—content variation conditions. The test results show that there exists a good negative correlation between the radiant energy and oxygen—content signal with the absolute value of the negative correlation coefficient at a low load being higher than 0.9. The change of radiant—energy signal emerged in advance of that of the oxygen content with the time in advance being 30 to 40 seconds. **Key words**: coal—fired boiler, radiant energy, variable oxygen content, characteristic detection, correlation analysis

渐近线型污垢生长的参数特性及测量方法=**Parameter Characteristics and Measurement Method for Asymptotic Type Fouling Growth**[刊,汉] / LENG Xue—li, TIAN Mao—cheng, PAN Ji—hong, FAN Ming—xiu (College of Energy Source and Power Engineering, Shandong University, Jinan, China, Post Code: 250061)// Journal of Engineering for Thermal Energy & Power. — 2008, 23(3). —278～279

In the light of the specific features of asymptotic type functions, analyzed were the characteristics governing the time constant of asymptotic type fouling growth and the fouling heat—resistance asymptotic value. It is noted that the fouling time constant is in inverse proportion to the logarithm of the ratio of the fouling growth rates obtained from two measurements, and in direct proportion to the time interval of two measurements. The fouling heat—resistance asymptotic value can be expressed by the fouling heat—resistance and fouling growth rate obtained by the second—time measurement and the fouling growth rate obtained by the first—time measurement. The method under discussion can be used to obtain the time constant and heat—resistance asymptotic value of the asymptotic type fouling in its growth process, thus saving experiment time. It is an improvement on the heat—resistance method for measuring fouling growth process and at the same time is suitable for the forecast of asymptotic type fouling growth process. **Key words**: fouling parameter, measurement method, forecast method

半焦气力输送模型及在煤拔头中试装置中的应用=**A Semi—coke Pneumatic Transmission Model and its Applications in a Coal—topping Pilot Plant**[刊,汉] / ZHAO Guang—bo, ZHAO Dan—ni, QIN Ming, WANG Wen—yu (College of Energy Science and Engineering, Harbin Institute of Technology, Harbin, China, Post Code: 150001)// Journal of Engineering for Thermal Energy & Power. — 2008, 23(3). —280～284

A one—dimensional mathematical model was established for a semi—coke pneumatic transmission system. In this connection, a variety of semi—coke pneumatic transmission processes were taken into account. They include: solid particle movement, convection and radiation heat exchange between gas and solid, precipitation and combustion of residual volatile component in semi—coke, combustion of coke, reduction of CO_2 on the coke surface and combustion of CO in gas phase etc. The pilot plant of coal topping and its systematic configuration were described, and the model thus established was used to numerically simulate the material transmission and distribution system. A variety of parameters in the semi—coke transmission process were obtained, including sectional gas—solid average speed, en route pressure loss and gas—solid two—phase temperature etc., providing guidance for the running of the pilot plant. The calculation results show that in the semi—coke pneumatic transmission process, the combustion of coke can be neglected. The combustion of volatile component can lead to an increase of gas temperature from 180 ℃ to 800 ℃. An increase of gas speed will increase the pressure loss. In the meanwhile, it can also result in a serious wear and tear of pipes. Hence, a variable tube—diameter transmission method is recommended for the pilot—plant test. **Key words**: coal topping, semi—coke, pneumatic transmission, numerical simulation

炉管泄漏的声学特性研究=**A Study of Acoustic Characteristics of Leakage from Boiler Tubes**[刊,汉] /ZHANG Xiao—dong (College of Energy Source and Power Engineering, North China Electric Power University, Beijing, China, Post Code: 102206), CHEN Dong—hui (Clyde Bergemann Huatong Material Handling Co. Ltd., Beijing, China, Post Code: 100035), DU Yun—gui (CPI Yuanda Environmental Protection Engineering Co. Ltd., Chongqing, China, Post Code: 400060)// Journal of Engineering for Thermal Energy & Power. — 2008, 23(3). —285～287