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能量分析与一次风煤粉浓度测量

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摘　要: 在火力发电厂的锅炉运行中, 煤粉燃烧器的一次风煤粉流量的均匀性对锅炉的安全经济运行起着重要的作用。一次风煤粉浓度的准确测量一直是工程技术上的前沿问题, 尤其是对乏气送粉锅炉进行煤粉浓度监测更是缺乏有效的方法。通过对一次风气流与煤粉颗粒混合过程的分析, 从开放系统的能量方程出发, 确立了乏气送粉锅炉一次风煤粉浓度的测量方法, 并成功应用于生产实践, 为一次风煤粉浓度在线监测提供了新的途径。

关　键　词: 一次风; 煤粉浓度; 能量方程; 测量

中图分类号: TK227　　文献标识码: B

1　引　言

在火力发电厂的锅炉运行中, 燃烧器的煤粉流量和风煤配比对锅炉的安全经济运行起着重要的作用。保持均匀、适当的一次风煤粉浓度是稳定燃烧的必要条件。目前的锅炉机组普遍缺乏可靠的煤粉浓度监测手段。煤粉浓度的准确测量多年来一直是动力工程技术人员致力解决的难题。煤粉颗粒在一次风中的运动过程是非常复杂的气固两相流动。气固两相流动各种流动参数的测量问题是学术上的前沿问题之一。自 20 世纪 70 年代以来, 日本、德国、美国、前苏联及意大利开始在大型锅炉上采用同位素法、激光法、温差法、微波、亚微米波等方法对一次风煤粉浓度进行监测, 但都存在误差大、滞后时间长、环境污染大等问题。对于热风送粉的锅炉机组, 热平衡法是较为成熟的测量方法, 其基本原理是根据一次风气流与煤粉颗粒混合前后的温度变化, 利用热平衡方程计算煤粉浓度。但对于乏气送粉的情况, 由于乏气与煤粉的温度基本相同, 混合前后温度近乎不变, 热平衡法就无能为力。研究适用于乏气送粉情况, 合理、简单、实用、准确的煤粉浓度测量方法仍是摆在科研技术人员面前的重要课题。

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2　风粉混合过程的热力学分析

为了研究煤粉与气流混合过程的参数变化与煤粉浓度的关系, 首先选定水平一次风管道上混合前后的一段区域为研究对象, 如图 1 虚线范围所示。控制体的左边界选在气流与煤粉即混合的位置, 右边界为混合完成, 煤粉颗粒加速到与气流速度一致时的位置。气流和煤粉不断通过边界进入控制体, 一次风粉混合物则通过边界流出控制体, 因此所选研究对象为一开放系统。

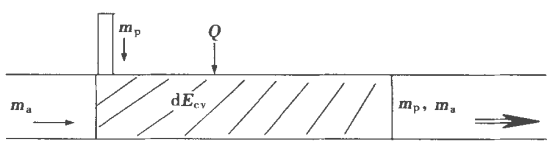

图 1　煤粉与气流混合过程示意图

根据热力学第一定律开放系统的能量方程, 可知系统的热力参数满足如下关系:

$$m_a\left(u_{a1}+P_1v_1+gz+\frac{V_1^2}{2}\right)+m_p\left(u_{p1}+\frac{V_0^2}{2}+gz_0\right)+Q=m_a\left(u_{a2}+P_2v_2+gz+\frac{V_2^2}{2}\right)+m_p\left(u_{p2}+gz+\frac{V_p^2}{2}\right)+W_{net}+dE_{cv} \quad (1)$$

其中: Q 为系统与外界交换的热量;

W_{net} 为系统对外界输出的净功;

dE_{cv} 为系统内部储存能的变化;

V_1、V_2、V_0 和 V_p 分别为混合前后气流和煤粉颗粒的速度;

m_a, m_p 分别为煤粉和空气的流量;

g 为重力加速度;

z 为控制体所的水平面高度;

z_0 为煤粉颗粒的初始位置的高度;

P_1、P_2 分别为混合前后气流的静压;

v_1、v_2 分别为混合前后气流的比容, $v = \frac{1}{\rho}$;

u_{a1}、u_{a2}、u_{p1} 和 u_{p2} 分别为气流和煤粉混合前后的内能;根据热力学定律,对于固体和理想气体, $u = c_v T$, c_v 为物质的定容比热。

考虑稳定的混合流动过程,系统内部储存能不发生变化,即 $dE_{cv} = 0$。为了进一步研究的方便,作如下假定:

(1) 忽略摩擦的影响,系统不对外输出净功,即 $W_{net} = 0$;

(2) 忽略系统与外界的热交换,即 $Q = 0$;

(3) 忽略煤粉颗粒进入控制体时的速度,即 $V_0 = 0$;

(4) 忽略重力位能的变化,即 $z_0 = z$。

由此化简式(1),并合并同类项可得:

$$m_a(c_{v,a}T_{a,1}) + \frac{P_1}{\rho_1} + \frac{V_1^2}{2} + m_p c_{v,p} T_{p,1} = m_a(c_{v,a}T_{a,2} + \frac{P_2}{\rho_2} + \frac{V_2^2}{2}) + m_p c_{v,p} T_{p,2} + m_p \frac{V_p^2}{2} \quad (2)$$

其中: $c_{v,a}$, $c_{v,p}$ 分别为空气和煤粉的定容比热;

$T_{a,1}$、$T_{a,2}$、$T_{p,1}$ 和 $T_{p,2}$ 分别为空气和煤粉混合前后的温度;下标 1 代表混合前的状态,下标 2 代表混合后的状态;

ρ_1、ρ_2 分别为混合前后气流的密度。

根据热平衡,有:

$$m_a c_{v,a} T_{a,1} + m_p c_{v,p} T_{p,1} = m_a c_{v,a} T_{a,2} + m_p c_{v,p} T_{p,2} \quad (3)$$

这就是在热风送粉的情况下应用的测量公式,可以看出热平衡只是能量平衡的一个特例。在乏气送粉的情况下,输粉气流是制粉乏气,混合前后温度基本一致,用 T 表示这个温度,即:

$$T = T_{a,1} = T_{a,2} = T_{p,1} = T_{p,2} \quad (4)$$

因为温度不变,混合前后气流的密度也不变,用 ρ 表示这个密度,即:

$$\rho = \rho_1 = \rho_2 \quad (5)$$

把式(3) ~ 式(5)代入式(2),得到:

$$m_a(\frac{P_1}{\rho} + \frac{V_1^2}{2}) = m_a(\frac{P_2}{\rho} + \frac{V_2^2}{2}) + m_p \frac{V_p^2}{2} \quad (6)$$

一次风粉混合物中煤粉与空气的质量比,即煤粉浓度 μ,在 0 ~ 1 的范围之内,一般为 0.5 左右。煤粉颗粒的密度为 1 400 ~ 1 600 kg/m^3,是空气密度的 1 500 多倍。由此可见,煤粉颗粒在一次风粉混合物中所占据的体积非常小,所以在煤粉颗粒速度与气流速度达到一致时,煤粉颗粒的存在对气流的速度几乎没有影响。因为混合前后气流的密度基本不变,所以混合前后气流的速度基本不变,在流动达到平衡状态时,气流速度与颗粒速度几乎相同,即:

$$V_2 = V_p = V_1 \quad (7)$$

把式(7)代入式(6),并令 $\mu = \frac{m_p}{m_a}$,得到:

$$\mu = \frac{P_1 - P_2}{\frac{1}{2}\rho V_1^2} \quad (8)$$

式(8)即为乏气送粉条件下的煤粉浓度计算公式,反映的物理意义是混合前后气流做功能力的减少等于煤粉颗粒动能的增加,就是说气流携带煤粉颗粒,使其获得运动速度,消耗了自身的一部分静压,即气流的静压降低用于煤粉颗粒的加速,这正是能量守恒的体现。

3 乏气送粉煤粉浓度测量方法的实际应用

在式(8)的推导过程中忽略了摩擦的影响,实际情况是:在一次风管道中,沿着流动方向,气流的静压不断降低以克服管壁的摩擦。因此,需要引入一定的修正。假定在煤粉浓度为零时,测量管段对于气流的阻力系数为 α,即管道阻力 ΔP_0 与气流流速满足:

$$\Delta P_0 = \alpha \frac{1}{2}\rho V_1^2$$

则修正后的煤粉浓度测量式为:

$$\mu = \frac{P_1 - P_2}{\frac{1}{2}\rho V_1^2} - \alpha \quad (9)$$

生产现场的测量系统如图 2 所示。一次风速信号和混合前后差压信号由变送器送至控制系统,利用式(9)计算煤粉浓度。

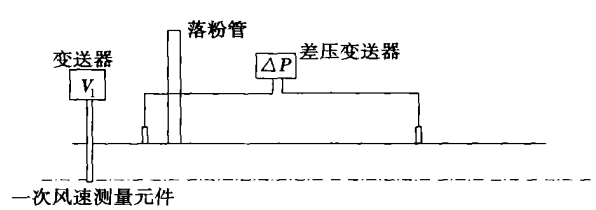

图 2 现场测量系统示意图

本方法已经成功地应用于 420 t/h 和 1 000 t/h 的多台锅炉机组。在实际应用中,根据一次风速、煤粉浓度、一次风管道尺寸等数据计算锅炉的燃煤消

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炼油厂热动系统优化与节能改造

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摘　要: 介绍了某炼油厂热能动力系统节能优化配置, 分析了汽轮机低真空供暖与炼油工艺装置中低温热源间的联合热利用改造措施, 采用新增机组实现对蒸汽使用的弹性调节; 合理利用凝汽潜热。经改造及低温热联合利用节约了能源, 效益显著。

关　键　词: 热能动力; 优化配置; 节能改造

中图分类号: TK11　　文献标识码: B

1　前　言

炼油厂在原油处理及石油产品生产过程中要消耗可观的一次、二次能源。经近年努力, 我国炼油企业能耗指标在明显降低, 但不少企业的能耗指标普遍高于国外同类企业, 其中重要的原因是原油处理过程中的各类工艺装置及相关的各辅助系统, 在设备与能量的配置上存在不合理状况。炼油厂的热能动力装置及系统、炼油工艺装置产生的工艺热、各辅助系统用热及供暖用热之间的热联合利用等方面还有很大节能潜力挖掘。本文工作建立在某炼油厂过程能量系统优化工程的基础上, 重点探讨了热动系统设备优化配置、催化装置与炼油工艺装置及辅助系统的产热与用热间的综合节能改造。

2　改造对象系统描述

2.1　热能动力系统简介

该厂西部热电车间原装有 4 台 65 t/h 旧中压蒸汽锅炉和 2 台已运行 16 年的背压汽轮发电机组。其中 B6－3.43/0.5 型为适应炼油装置供热需要, 拆除了两级透平叶轮, 机组技术性能差, 汽耗率高。由于外界原因, 西部热电车间不能继续维持生产, 全厂热电车间转移到厂东部锅炉房, 该处已投运 3 台 65 t/h 新中压锅炉。位于厂东部的催化车间有 3 套中压蒸汽装置和 1 台 2 MW 汽压机。催化车间发汽装置平均产中压汽 53 t/h, 蒸汽参数偏低, 优化后将提升到中压等级。驱动 2 MW 汽压机, 汽源来自燃渣油的中压锅炉。优化前系统简图见图 1。改造前的蒸汽平衡见表 1。

表 1　改造前全厂中压蒸汽产用平衡表　　($\times 10^4 t \cdot a^{-1}$)

总产量	催化汽压机用	背压汽轮机用	减温减压用
75.3	22.6	26.47	26.23

2.2　系统存在的问题与分析

2.2.1　总体布局与机组配置的不合理约束了热电联产效益

改造前全厂年产中压蒸汽减去催化汽压机用掉的蒸汽量, 共有 52.7×10^4 t 中压汽可用于背压汽轮机发电, 由于汽轮机效率低, 实际年发电 $1\,527\times 10^4$ kWh。在不增加发汽量条件下, 如果配置合理, 按目前同类型汽轮机发电耗汽 14.54 kg/(kWh)估算, 可多发 $2\,098\times 10^4$ kWh。按厂外购电价格 0.41 元/(kWh)计算, 一年可增收约 860 万元。仅此一项说明本系统优化配置机组有较大的节能空间。

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耗量与实际测得的燃煤消耗量十分吻合, 证明了所测得的煤粉浓度准确可靠。应用实践表明, 本方法测量乏气送粉系统的煤粉浓度简单、准确, 为运行调整提供了可靠的依据, 完全满足了生产现场的要求, 提高了机组的安全性和经济性。

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Conductivity of Deep-layer Rock Soil [刊, 汉] / YU Ming-zhi, PENG Xiao-feng (Thermal Engineering Department, Tsinghua University, Beijing, China, Post Code: 100084), FANG Zhao-hong (Shandong Institute of Architectural Engineering, Jinan, China, Post Code: 250014) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(5). —512 ~514, 518

To facilitate the on-site measurement of physical properties of media in engineering applications, a simplified heat-transfer analytical method is proposed to determine the thermal conductivity of deep-layer rock soil. The method under discussion does not need exact information about the following parameters: the specific location of an embedded tube in a borehole, the distance between a riser tube and a downcomer, and the physical properties of the embedded tube and backfill material, etc. As a result, all errors brought about by the measurement of the above parameters can be eliminated. An on-site measurement was taken of the heat flux of an embedded tube loop, the loop circulating water flow rate and the time-dependent change of inlet and outlet water temperature of the loop. On this basis and by utilizing a simplified analytical and optimized evaluation method the thermal conductivity of underground rock soil on a certain working site was determined, thus verifying and confirming the practicality and reliability of the recommended method. **Key words**: heat transfer model, measurement, rock soil, thermal conductivity

高、低压加热器低水位运行的分析研究= **Analytical Research on the Low Water-level Operation of High and Low Pressure Heaters** [刊, 汉] / SUN He-tai (Steam Turbine Department, Jiangsu Provincial Research Academy of Electric Power, Nanjing, China, Post Code: 210032) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(5). —515 ~518

The harmful effects of low water-level operation of high and low-pressure heaters are presented and discussed. By using an equivalent enthalpy-drop method a thermo-economic analysis was performed of 125MW and 200MW units involving low-pressure heaters operating at a low water level with the extent of negative influence being evaluated. From the viewpoint of structural design and on-site operating conditions, etc the causes leading to heaters operating at a low and even an absence of water level are identified with some measures for improvement being proposed. All the above may have a significant practical value for the guidance of power plant operation. **Key words**: heater, water level, economy, equivalent enthalpy-drop method

CC12 MW 供热汽轮发电机组热力系统简化设计及应用= **Simplified Design of a Thermodynamic System for a CC12 MW Heat-supply Turbogenerator and its Implementation** [刊, 汉] / JIN Bao-hua, CAO Yu (Power Generation Department, Liaoning Electric Power Exploration and Design Institution, Shenyang, China, Post Code: 110005), QIN Yan (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(5). —519 ~522

The simplified design philosophy and technical features of a CC12MW turbogenerator thermodynamic system for heat supply are described. Moreover, the economic benefits and operating conditions after the simplification of the thermodynamic system are also presented with an analysis of the still existing problems and relevant measures taken for their resolution. **Key words**: thermodynamic system, simplification, thermal load, rotating-film deaerator

能量分析与一次风煤粉浓度测量= **Energy Analysis and Measurement of Pulverized-Coal Concentration in Primary Air** [刊, 汉] / YIN Jing, YANG Xing-sen (Thermal Energy Research Institute under the Shandong Provincial Electric Power Academy, Jinan, China, Post Code: 250002) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(5). —523 ~525

During the boiler operation of a thermal power plant the uniformity of pulverized-coal flow of a pulverized-coal burner in primary air plays a key role in ensuring the safe and economic operation of a boiler. The accurate measurement of the concentration of pulverized coal in primary air is a problem of great importance, which has yet to be effectively solved. This is especially so in the case of pulverized coal monitoring in a boiler using exhaust gas for pulverized-coal transport. The mixed process of primary-air flow and pulverized coal particles is analyzed. On this basis and proceeding from the en-

ergy equation of an open system the authors have developed a method for measuring the concentration of pulverized coal in primary air for a boiler employing exhaust gas for transportng pulverized coal. This method has been successfully used in production practice, blazing a new path for the on-line monitoring of pulverized coal concentration in primary air. **Key words**: primary air, pulverized coal concentration, energy equation, measurement

炼油厂热动系统优化与节能改造＝**Optimization and Energy Conservation-oriented Modification of the Thermal Energy System of an Oil Refinery** [刊, 汉] / ZHANG Yan-chun, XU Hong-zhi (Department of Thermal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2003, 18(5). —525 ~528

The optimized configuration of the thermal energy engineering system of an oil refinery for energy savings is described. This is followed by an analysis of the low-vacuum heat supply by a steam turbine and the measures taken for the combined heat utilization of various low-temperature heat sources in an oil-refining process plant. A new turbine has been added to realize a flexible regulation of steam use, introducing a rational utilization of condensing-steam latent heat. As a result of the modification and the combined use of low-temperature heat energy significant energy savings and economic benefits have been achieved. **Key words**: thermal energy power, optimized configuration, energy conservation-oriented modification

电站锅炉热效率通用软件制作＝**Development of a Set of General Software for Calculating the Thermal Efficiency of Utility Boilers** [刊, 汉] / ZHAO Yong-gang (Inner Mongolia Electric Power Research Academy, Huhehot, Inner Mongolia, China, Post Code: 010020), REN Run-ping, ZHANG Cun-zhu (Monda Power Generation Co. Ltd., Dalada, Inner Mongolia, China, Post Code: 014300) // Journal of Engineering for Thermal Energy &Power. — 2003, 18(5). —529 ~ 531

Boiler thermal efficiency tests are listed among the most basic and commonly used thermodynamic tests of boiler equipment. On the basis of analyzing methods of calculating the thermal efficiency of utility boilers the development of a set of general software is expounded along with a description of its makeup. The use of this software can not only enhance the accuracy of thermal efficiency calculation for utility boilers, but also dramatically reduce calculation load, resulting in higher work efficiency. **Key words**: utility boiler, thermal efficiency, software making

35 t/h 锅炉 PLC 热工监控系统设计＝**Design of a Programmable Logic Controller-based Thermotechnical Control and Monitoring System for 35 t/h Boilers** [刊, 汉] / ZHANG Shao-juan, LU Shu-ju (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy &Power. — 2003, 18(5). —532 ~534

The design of a thermotechnical control system for two 35t/h boilers installed at Iran Shazand Power Station is described along with a brief account of the employed Siemens programmable logic controller-based hardware configuration and software programming as well as the functions of a monitoring system. The control system features strong control functions, high reliability and ease of operation. **Key words**: boiler, PLC, monitoring system

波纹管容积式换热器的失效及控制＝**Failure and Control of a Corrugated-tube Positive-displacement Heat Exchanger** [刊, 汉] / YANG Guan-zhen (Wuxi Municipal Inspection Institution for Boilers and Pressure Vessels, Wuxi, China, Post Code: 214025) // Journal of Engineering for Thermal Energy &Power. — 2003, 18(5). —535 ~536 **Key words**: heat exchanger, failure, control

全自动双效浓缩器控制技术＝**Control Technology for Fully Automatic Dual-effect Concentrating Devices** [刊, 汉] / SHI Jian-ping, LIU Qing-ge (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036), WEI Jing-wei (Harbin Technical Institute of Electric Power, Harbin, China, Post Code: 150040) // Journal of Engineering for Thermal Energy &Power. — 2003, 18(5). —537 ~538