

# 130 t/h 煤粉锅炉风—粉在线监测系统的应用和研究

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**摘 要:** 基于气、固两相流理论, 考虑了风—煤合流过程中的压力损失影响, 运用能量法提出了一种测量一次风管中风—粉混合后煤粉浓度的方法, 并介绍了利用动态链接库技术对一次风管中煤粉浓度、风速实现在线、实时监测的过程和方法。此在线监测系统在热力厂现场应用中取得了很好的效果。

**关 键 词:** 两相流; 煤粉浓度; 在线监测; 动态链接库 (DLL)

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## 1 引言

某集团公司热力厂, 现有 130 t/h 煤粉锅 3 台, 型号为 DG 130/9.8-I, 燃烧器呈四角布置, 炉膛尺寸 6 450×6 450 mm, 在炉膛形成的  $\Phi 600$  mm 假想切圆, 燃烧器自上而下为: 二、一、二、一、二次风, 制粉系统为钢球磨、中间储仓式、乏气送粉。由于热电厂实际燃烧煤种比原设计煤种着火性能好, 灰熔点温度也约低 100 °C, 再加上四角一次风流量不一样, 喷燃器出口煤粉浓度也不均, 造成运行过程中炉膛火焰中心偏斜, 炉膛气流冲刷后墙及右墙, 使得炉膛后侧及右侧水冷壁严重磨损, 高温过热器局部超温, 炉膛结焦严重, 影响了锅炉出力, 锅炉蒸发量长期在 110 ~ 120 t/h。工作人员主要是通过给粉机转速来调节煤粉浓度, 但给粉机的机械特性受多种因素的影响, 下粉量与给粉机转速是非线性的, 还经常发生堵粉现象, 这些都给锅炉的燃烧调节造成困难。

可见, 对一次风管中煤粉浓度、风速进行直观量化的有效监测, 不但有利于工作人员调节一次风量、煤粉浓度, 而且对四角切圆锅炉燃烧的稳定性、经济性和安全性都有着重要的意义。

对于气、固两相流动的煤粉浓度的精确测量来说, 目前还存在较大的困难。许多学者对于热风送粉锅炉的煤粉浓度测量做了大量的研究<sup>[2-4]</sup>, 乏气送

粉锅炉的煤粉浓度测量方法(激光法、电荷法等), 一次性投资比较大。为此, 作者所在的研究小组利用计算机仿真技术对两相流进行数值求解, 得出其速度场、温度场、浓度场的分布, 在数值求解的基础上, 经过大量的实验和研究后, 找到一种更简单、高效、实用适合工程应用的煤粉浓度测量的方法, 并已开发出相关软件。

## 2 建立数学模型

### 2.1 模型假设

风—粉混合物的流动属于气固两相流的范畴, 为了便于导出乏气送粉系统中煤粉浓度的计算公式, 对风—粉混合过程做如下假设<sup>[4]</sup>。

(1) 风—粉混合物在管道中的流动为稀疏相流动, 煤粉颗粒较均匀分布在管道中, 煤粉浓度  $\mu$  定义为单位质量的空气中所携带煤粉质量,  $\mu = m_0/m_1$ ,  $m_0$ —煤粉质量,  $m_1$ —空气质量;

(2) 一次风中煤粉混合物的流动属于旺盛的紊流状态, 煤粉粒子具有相同的尺寸, 且均为球形。混合前一次风携带极少量的煤粉, 视为纯空气来考虑;

(3) 假设一次风中风、粉充分混合后, 空气和其所携带的煤粉均有相同的流速;

(4) 由于系统采用乏气送粉方式, 煤粉仓中煤粉的温度和一次风的温度非常接近, 可认为风—粉混合前后的温度相同。

### 2.2 测量原理

在锅炉燃烧系统送粉管道中, 风—粉混合物属于稀疏相气固两相流动, 忽略混合前后过程中的散热损失和压缩性, 则混合前后的过程满足气体状态方程、连续性方程和能量守恒方程<sup>[4]</sup>。风—粉混合示于图 1。

#### 2.2.1 气体状态方程

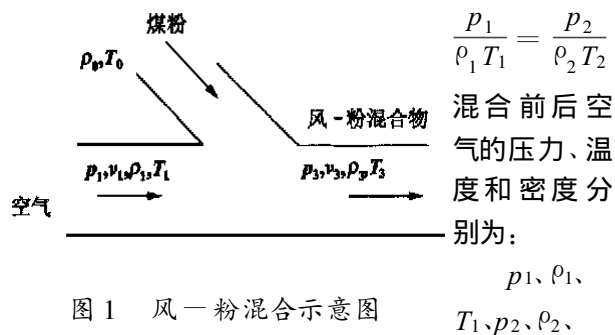


图1 风-粉混合示意图

T<sub>2</sub>;

2.2.2 气体的连续性方程

ρ<sub>1</sub>V<sub>1</sub> = (1-z)ρ<sub>1</sub>v<sub>1</sub> = (1-z)ρ<sub>2</sub>v<sub>2</sub>,

由假设知: v<sub>2</sub> = v<sub>3</sub>;

2.2.3 混合物状态修正方程<sup>[2]</sup>

p<sub>3</sub> · (1-z) = (1-K<sub>p</sub>) · ρ<sub>3</sub>RT<sub>3</sub>

混合物的物性参数: p<sub>3</sub>、ρ<sub>3</sub>、T<sub>3</sub>、z、K<sub>p</sub> 分别是混合物的质量比、体积比;

2.2.4 混合前后能量守恒方程

p<sub>1</sub>/r + v<sub>1</sub><sup>2</sup>/2g = v<sub>3</sub><sup>2</sup>/2g + (p<sub>3</sub> + Δp<sub>f</sub> + Δp<sub>j</sub>)/r

沿程阻力损失: Δp<sub>f</sub> = (1+mK)λ(L/D) · (ρ<sub>1</sub>v<sub>1</sub><sup>2</sup>)/2,

1+mK = a, 根据日本学者刀根英明提出的公式<sup>[3]</sup>,

压损比: a = 0.2/m + √(30/v<sub>1</sub>),

沿程阻力系数 λ 在两相流气力输送中多采用柏列斯

公式: λ = 0.0125 + 0.0011/D;

局部阻力损失: Δp<sub>j</sub> = ξ · (ρv<sup>2</sup>)/2, 根据参考文献[6], 在乏气送粉系统中风粉混合处的局部阻力 ξ 系数可在 0.15 ~ 0.4 范围内取值, 或现场直接标定. 结合以上各式且风、粉混前后一次风的温度、压力、速度可测, 混合后风粉混合物的温度、压力可测的情况下, 风粉混合后风粉混合物的密度 ρ<sub>3</sub>、流速 v<sub>3</sub>、Δp<sub>f</sub> 和 Δp<sub>j</sub> 均为煤粉浓度 μ 的函数, 即可以得到乏气送粉方式下进入炉膛一次风管内的煤粉浓度 μ 的方程:

ρ<sub>2</sub>μ<sup>2</sup> + (ρ<sub>2</sub> + ρ<sub>1</sub>)μ + (ρ<sub>0</sub> - 2A<sub>1</sub>/A<sub>2</sub>) = 0

A<sub>1</sub> = 1/2 ρ<sub>1</sub>v<sub>1</sub><sup>2</sup> + p<sub>1</sub> - p<sub>3</sub>

A<sub>2</sub> = (1 + λ(L/D) + ξ) + ρ<sub>1</sub><sup>2</sup>v<sub>1</sub><sup>2</sup>/(ρ<sub>2</sub>ρ<sub>0</sub>).

3 软件的开发和集成

3.1 软件系统的组成

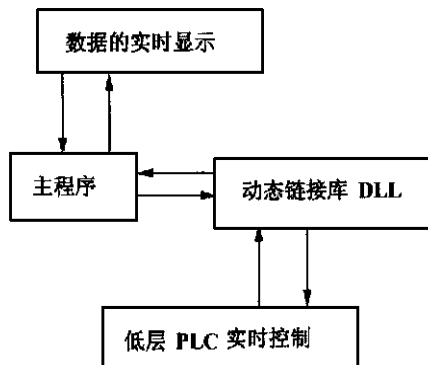


图2 软件结构图

系统由上位计算机、PLC 构成的数据采集系统, 及大量的温度、压力变送器 and 差压变送器等构成, 上位机软件由 VB6.0 开发而成,

VB6.0 是一种面向对象的程序设计语言, 因其代码简单、灵活性好、效率高等特点成为 Windows 环境下软件开发的重要工具之一, 并且具有良好的数据封装性和继承性. 特别便于实时数据的访问和查询<sup>[1]</sup>. 上位计算机软件组成结构如图 2 所示, 主要实现如下功能.

3.1.1 用户界面

和现场环境相对应, 以实时数据和图形的形式形象地表现速度、浓度的变化.

3.1.2 数据库的管理

考虑到实现的方便及性能的要求, 采用了 Access 数据库, 利用 VB 的 DataEnvironment 和 Access 数据库相连<sup>[1]</sup>, 记录各种数据随运行时间变化的变化, 以及查询、打印、定时删除.

3.1.3 数据通信

采用 DLL 技术, 取得各种测量值并送入上下限设定值.

3.1.4 报警打印

当风速、煤粉浓度参数超过上下限值时, 将显示当前报警信号, 提醒工作人员进行处理, 报警时实时打印, 一项报警打印一行.

但由于 VB 没有提供直接的 I/O 操作功能, 当用户使用 AD 转换卡或图像采集卡(即插即用的功能板)给 VB 用户编程带来困难, 用户可运用 Mscmm.vbx 串行通讯控件、动态数据交换 DDE 或动态链接库 DLL 技术. 关于这三种不同技术参考文献[1]已有较详细的说明, 为适应现场的需要, 笔者运用的是 DLL 技术. DLL 是 Microsoft Windows 的重

要特点, 程序人员利用它可以实现应用程序共享代码和 Windows 的重要资源。其主要优点是: DLL 可与用户的程序分开, 用户可更新 DLL 而不用更改可执行文件, 特别有利于维护整个监测系统运行的稳定性。

### 3.2 动态链接库 DLL 的开发

用 Borland C++ Builder 4.0<sup>[3]</sup> 编制动态链接库 DLL 其基本框架结构是三个函数: LibMain() 函数、WEP 出口函数、自定义函数, LibMain() 函数是 Windows DLL 主入口点, 完成初始化工作, 出口函数 WEP 主要做一些清除工作。自定义函数是 DLL 核心部分。自定义函数由其它的应用程序调用来实现数据 I/O, 作者开发的 DLL 部分程序如下(这部分是 DLL 库函数的核心部分):

```
//源文件 DLL.CPP
#include "windows.h"
#include "stlib.h"
#include "dos.h"
#include "drv.h"

int FAR PASCAL Libmain (HANDLE hinstance, WORD wDataseg, WORD wHeapsize, LPSTR lpszCmdline)
{ //动态链接库初始化
if (wHeapsize != 0) unlock Data (0);
return (1);}

int FAR PASCAL WEP (int bsystemExit)
{---
if (wHeapsize != 0) unlock Data(0);
return 1; }
// you can add other function here
int FAR PASCAL set _base (int b) /*接口板的基地址 */

void far export OutPO (unsigned port, unsigned char value)
{ outputb(port, value);
return 1; }

int far export INPO (unsigned port)
{ int result;
result; inportb (port);
return (result); }
```

在开发 DLL 后, 拷贝到上位机系统目录 systems 下, 就可在 VB 中直接通过 DECLARE 声明来访问 DLL

及其编译器, 实现 VB 与 PLC 之间的数据通信。监测系统运行的主界面如图 3 所示。

	风速 m/s	空气温度 /℃	煤粉浓度 kg/kg
1#风管	30.2	128.95	0.362
2#风管	29.31	131.11	0.358
3#风管	29.92	131.11	0.321
4#风管	28.31	129.15	0.328
5#风管	30.10	138.30	0.402
6#风管	31.82	137.31	0.394
7#风管	29.10	139.20	0.445
8#风管	29.48	134.11	0.461

Buttons: 实时数据, 历史曲线, 数据查询

图 3 在线监测系统主界面

## 4 结语

该软件在热力厂 2 号煤粉锅炉上应用后, 从现场的情况来看, 取得很好的效果, 工作人员根据在线显示的风速、煤粉浓度调节一次风量, 基本上保证了 8 根一次风管的煤粉浓度, 风速一致, 确保了切圆不偏离中心, 使锅炉燃烧器以四角切圆方式稳定燃烧, 大大缓解了锅炉在烧褐煤的结焦情况, 同时, 锅炉出力也达到了额定出力。可见本文所采用的方法是可靠的, 模型和算法是可靠的。由此开发的软件得到推广和应用, 将可为乏气送粉、四角切圆方式燃烧锅炉运行的稳定性、经济性和安全性提供可靠的保障, 以及锅炉的运行操作和控制决策提供有力的支持。

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(何静芳 编辑)

高风温无焰燃烧及其火焰特性的实验研究= Experimental Study of High-temperature Air and Flameless Combustion and Its Flame Characteristics [刊, 汉] / AI Yuan-fang, JIANG Shao-jian, ZHOU Jie-min, et al (Applied Physics and Thermal Energy Engineering Department, Zhongnan Industrial University, Changsha, China, Post Code: 410083), WANG Yang-yang (Zhuzhou Industrial Furnace Manufacturing Co., Zhuzhou, Hunan Province, China, Post Code: 412005) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6). — 615 ~ 617

An experimental study was conducted of the high-temperature and low-oxygen air burning of propane and its flame characteristics along with a discussion of its possible industrial applications. The results of the study indicate that when burning at a combustion-assisting air temperature in excess of 800 °C and oxygen-containing volume concentration lower than 15% the flame volume was markedly enlarged. Meanwhile, the flame boundary was found to be unstable with the flame luminosity being weakened and its color significantly changed. The lower the oxygen concentration, the higher will be the temperature of the combustion-assisting air, which is needed for achieving a stable combustion. The key to the industrial application of this new combustion process consists in the use of a highly effective regenerator to absorb the latent heat of gases with the same temperature as that of the furnace, thereby producing the high-temperature air. In the meanwhile, low oxygen-concentration airflow is also being created in the furnace. **Key words:** high-temperature air combustion, flame characteristics, experimental study

钙基脱硫剂孔隙分形特性的实验研究= Experimental Investigation on Fractal Properties of Pore Structure in Calcium-based Sorbents [刊, 汉] / MIAO Ming-feng, SHEN Xiang-lin (Education Ministry Key Lab of Clean Coal-based Power Generation and Combustion Technology under the Southeastern University, Nanjing, China, Post Code: 210096) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—618 ~ 621

Fractal dimension, as an important parameter describing a fractal structure, reflects the regularity degree of a structure. By way of experiments investigated is the effect on pore structure fractal dimension of calcium-based sorbents under calcination conditions of various temperatures, atmospheres and sintering durations as well as the effect of fractal properties on the sulfating ability of the sorbents. The test results show that calcination temperature has a relatively small influence on CaO pore structure. The fractal dimension of the CaO pore will decrease with the increase in CO<sub>2</sub> concentration in the calcination atmosphere and also decrease with the prolongation of the sintering time. The quantity of inaccessible pores formed during the process of sorbent sulfation will increase with an increase in the fractal dimension. **Key words:** calcium-based sorbent, fractal dimension, pore structure

进水温度对汽液两相流激波升压特性影响的实验研究= Experimental Study of the Influence of Inlet Water Temperature on the Shock Wave Pressure-rise Characteristics of Steam-water Two-phase Flows [刊, 汉] / LIU Ji-ping, YAN Jun-jie, CHEN Guo-hui, et al (Energy and Power Engineering Institute under the Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—622 ~ 624

Through the use of an experimental method the influence of inlet water temperature on the shock wave pressure-rise characteristics of steam-water two-phase flows has been investigated. During the tests steam was extracted from a cogeneration plant to serve as the power source. A shock-wave pressure-rise device of the two-phase flow is composed of a steam nozzle, a mixing chamber and relevant valves and piping. An inlet water critical temperature has been discovered in the course of the tests. If the inlet water temperature is greater than the critical value, the pressure-rise characteristics of the above-cited pressure-rise device will decrease dramatically. **Key words:** steam-water two-phase flow, shock wave, injector unit

130 t/h 煤粉锅炉风—粉在线监测系统的应用和研究= The Research and Application of an air/pulverized Coal On-line Monitoring System for a 130 t/h Pulverized Coal-fired Boiler [刊, 汉] / WANG Qiang, ZHOU Nai-jun

(Applied Physics and Thermal Energy Engineering Department, Zhongnan University, Changsha, Hunan Province, China, Post Code: 410083) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—625 ~ 627

Based on a gas-solid two-phase theory and taking into account the pressure loss effect in the air-coal combined flow process a method was proposed for measuring the pulverized coal concentration in primary air pipe after the mixing of air and the pulverized coal. The above measurement was carried out through the use of an energy balance method. Also described are the method and procedures for conducting the on-line and real-time monitoring of the pulverized coal and air speed in the primary air pipe with the use of a dynamic link library technique. The above-cited on-line monitoring method has been found to be very effective for its intended purposes when used on-site at thermal power plants. **Key words:** two-phase flow, pulverized coal concentration, on-line monitoring, dynamic link library technique

**循环流化床锅炉在线监测与状态诊断专家系统 = An Expert System for the On-line Monitoring and Condition Diagnosis of Circulating Fluidized Bed Boilers** [刊, 汉] / LU Ji-dong, HUANG Yi-hua, SHEN Kai, CHEN Jiao-shun (National Key Lab of Coal Combustion under the Huazhong University of Science and Technology, Wuhan, China, Post Code: 430074) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—628 ~ 631

In the light of the special characteristics and system requirements of circulating fluidized bed boilers (CFBB) an expert system for on-line monitoring and condition diagnosis of such boilers has been designed. On the basis of analyzing commonly seen faults of CFBB and frequently used diagnostic techniques the authors expound in detail the design process, software realization and system functions of the above-mentioned expert system. The feasibility of the latter has been verified by engineering practice on site. **Key words:** boiler, circulating fluidized bed, on-line monitoring, condition diagnosis, expert system

**Visual Basic 编程语言用于热电厂在线监测与资源共享 = The Use of Programming Language Visual Basic for On-line Monitoring and Resource Sharing in Thermal Power Plants** [刊, 汉] / WANG Shi-zhong, QIU Jing-hui, YU Shi-sheng (Department of Aeronautic Engineering and Mechanics, Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—632 ~ 634

Through the adoption of an advanced 893 network intelligent distribution type of data acquisition device IDCB the problem of millivolt voltage signal interference (analog magnitude), which has troubled a factory for years, was successfully resolved. With Windows 98 serving as an operating system and Visual Basic 6.0 as a programming language, software Heatwork.Vbp has been prepared and operated on a "Pentium 586" industrial control machine, thus realizing an on-line monitoring and resource sharing. **Key words:** thermal power plant, power generating unit, on-line monitoring, resource sharing

**压缩机中间冷却器采用不锈钢波纹管的试验研究 = Experimental Research of the Use of Stainless Steel Corrugated Tubes for a Compressor Intercooler** [刊, 汉] / CHEN Jia-xin, TAN Yu-fei (Electromechanical School under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2001, 16(6)—635 ~ 636

The modification of a compressor intercooler was conducted by replacing the straight tubes of a shell-tube heat exchanger with a new type of stainless steel corrugated tubes. Furthermore, measurements and tests were performed during the operation of the intercooler followed by a comparative analysis. It has been found that the natural gas outlet temperature of the corrugated tube heat exchanger can attain the compressor design value and even lower. The compressor enjoys a normal and stable operation with its heat exchange efficiency higher than that of an in-tube layout heat exchanger by 61%. The considerable reduction in maintenance work can contribute to a long-cycle operation of the intercooler. **Key words:** compressor intercooler, new type of stainless steel corrugated tube, high-efficiency heat exchanger, experimental research

**电站锅炉神经网络燃烧诊断系统应用研究 = Applied Research of a Neural Network-based Combustion Diagnostic System for a Utility Boiler** [刊, 汉] / YANG Hong-min, MA Wei-min, GU Fan, XU Yi-qian (Research Insti-