

# 基于 VF 的循环流化床 热力计算通用程序设计

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[摘要] 利用 VF 语言编程开发了一个适用于循环流化床锅炉的通用热力计算程序。该程序可自由选择受热面结构组合形式, 适用于受热面布置复杂多变的流化床锅炉热力计算, 且使用方便。

[关键词] 循环流化床锅炉; 热力计算; 程序; 校核计算

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循环流化床(CFB)锅炉是近 20 年来发展起来的煤清洁燃烧装置, 具有燃料适应性广、污染物排放低、负荷调节容易和燃烧效率高等一系列优点。热力计算是 CFB 锅炉设计、性能校核的基本依据, 是设计中最复杂、单调的过程。由于 CFB 锅炉结构复杂, 其热力计算工作量大, 需要进行复杂的迭代计算。传统的手工计算, 由于计算手段落后, 计算速率低下, 需花费大量时间。目前国内多数锅炉厂家设计时采用了锅炉热力计算软件, 但这些软件大多是针对某一特定炉型编制的, 用于其它新的炉型就要修改相应的程序。此外, 以往的热力计算软件采用的是 Fortran、C、Basic、VC 等语言, 这些语言虽然都具备了强大的计算能力, 但受语言本身的限制, 在实际的热力计算过程中, 参数的输入与输出界面不太友好, 对于实际操作人员来讲存在一些困难, 其只适合编程人员使用。锅炉热力计算过程中要涉及大量的公式、表格、线算图和大规模的迭代, 一般的语言处理起来比较困难, 而 Visual Foxpro (VF) 在表格处理方面具有强大的功能, 可以很方便地对表、公式进行操作。加之其具有良好的用户界面和可视化编程技术, 无论对一般用户还是程序员都非常有利。本文介绍了基于 VF 平台开发的 CFB 热力计算通用软件, 并将其用于 65 t/h 油页岩锅炉的热力计算。

## 1 编程基础

所编程序根据 JB/DQ1060-83《层状燃烧及沸腾燃烧工业锅炉热力计算标准》, 并对其进行了修正。由于 CFB 锅炉具有飞灰回燃系统, 因此在计算 CFB 锅炉入炉热量  $Q_L$  时比其它类型锅炉多了循环灰带入的热量  $I_h$  (这份热量是飞灰在循环前烟道中的表观热量) 即:

$$Q_L = Q_r \frac{100 - q_3 - q_4 - q_6}{100 - q_4} + Q_{rk} + I_h \quad (1)$$

式中  $Q_r$ ——锅炉的输入热量, kJ/kg;  
 $Q_{rk}$ ——预热空气输入热量, kJ/kg;  
 $I_h$ ——循环灰焓值, kJ/kg;  
 $q_3$ ——烟气不完全燃烧热损失, %;  
 $q_4$ ——飞灰不完全燃烧热损失, %;  
 $q_6$ ——灰渣物理热损失, %。

由于循环灰的加入, 使入炉热量提高很多。

### 1.1 飞灰浓度对传热的影响

CFB 锅炉床内及分离器以前烟道部分的飞灰浓度与循环倍率  $R$  和分离器的分离效率  $\eta$  有直接关系。

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上述部位的飞灰浓度随  $R$  与  $\eta$  的增大而增大。计算表明分离器以前烟道中的飞灰浓度与循环倍率成正比。对于这部分飞灰浓度的计算公式如下:

$$\mu_{fh} = \frac{R[A_{ar} \cdot (CO_2)_{ad}]}{100G} \times \frac{100}{100 - q_4} \times \frac{100}{100 - G_{fh}} \quad (2)$$

式中  $\mu_{fh}$  —— 飞灰浓度,  $kg/m^3$ ;  
 $\alpha_{fh}$  —— 计算部位的飞灰份额, %;  
 $A_{ar}$  —— 应用基含灰量, %;  
 $[CO_2]_{ad}$  —— 油页岩的裂解特性;  
 $G$  —— 烟气重量,  $kg$ ;  
 $G_{fh}$  —— 飞灰含碳量, %。

### 1.2 飞灰浓度对过热器传热计算的影响

由于烟气侧辐射放热系数  $\alpha_r$  及对流放热系数  $\alpha_d$  的提高, 由式(3)可知烟气侧放热系数  $\alpha_1$  将提高许多, 在过热器传热量一定的条件下, 据式(4)在传热系数  $K$  随着  $\alpha_1$  的增大而增大时, 传热面积  $H$  将相应减小。以前设计的CFB锅炉, 由于对飞灰浓度增大对传热的影响考虑不足, 使得计算过热器传热系数时, 数值偏小, 从而导致过热器面积布置过大, 致使过热器过热爆管事故的发生。

$$\alpha_1 = \alpha_r + \alpha_d \quad (3)$$

$$Q_{cr,g} = \frac{K \cdot \Delta t \cdot H}{B_j} \quad (4)$$

式中  $\alpha_1$  —— 烟气对管壁的放热系数,  $kJ/(m^2 \cdot h \cdot ^\circ C)$ ;  
 $Q_{cr,g}$  —— 过热器的传热量,  $kJ/kg$ ;  
 $\Delta t$  —— 烟气和工质间的平均传热温差,  $^\circ C$ ;  
 $K$  —— 对流传热系数,  $kJ/(m^2 \cdot h \cdot ^\circ C)$ ;  
 $H$  —— 对流传热面积,  $m^2$ ;  
 $B_j$  —— 锅炉计算燃料消耗量,  $kg/h$ 。

## 2 热力计算程序结构

### 2.1 前期工作

基于VF的CFB锅炉热力计算程序主要包括辅助性计算、炉膛传热计算以及受热面传热计算3部分。所有计算模块均由相关功能表单进行控制。用VF进行CFB锅炉热力计算时, 首先要建立计算过程中需要用到的基本参数表。程序的计算顺序基本同手工计算过程一致, 以利于程序的运行调试; 整个程序按结构化程序设计原则进行设计, 将不同受热面的传热计算编制成独立的模块, 如辅助计算模块、炉膛传热计算、高温过热器等8大模块。各种变量的定义合理, 如高温

过热器出口烟温  $T_{gy}$ 、平均比热容  $c_{gp}$  等, 所有输入的原始数据均存入相关的表中, 随着输入值的更改而相应变化, 更改后对数据进行保存。所编软件是比较典型的CFB锅炉热力计算程序, 在实际使用时, 有的受热面可以省略掉。程序考虑了受热面的自由组合。由于CFB受热面布置十分灵活, 通过逻辑变量控制受热面, 可以适应不同结构流化床的热力计算, 这样保证了程序良好的通用性。程序在计算结束时, 可以自动生成一张结果表, 热力计算结果全部存入表中, 并可以打印输出。

除此之外, 还编制了自定义函数模块, 主要包括热力计算过程中遇到的水蒸汽、烟气、空气及饱和水的焓值和常用物性参数程序, 以及对流换热系数、辐射换热系数、烟气黑度等计算模块。图1为热力计算程序结构。

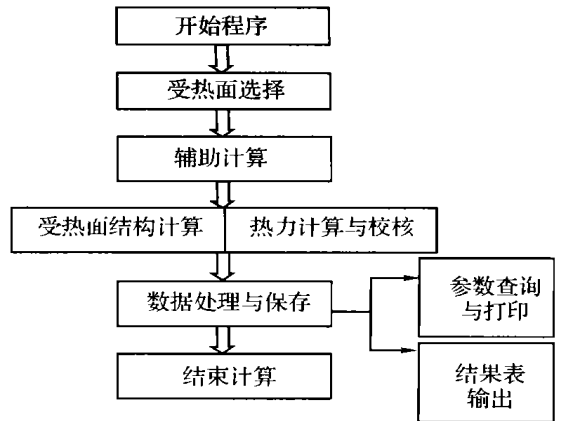


图1 热力计算程序结构

### 2.2 辅助性计算

辅助性计算是进行热力计算的预备性计算, 是各项传热计算的基础。在这一模块中, 以5个公用表为基础。这5个表分别是: 漏风系数及过量空气系数表; 燃料元素分析表; 烟气特性表; 标准空、烟气焓温表; 实际空、烟气焓温表。数据输入后, 通过用户图形界面, 直接存入表中, 也可以随时修改表中的数据。计算时, 通过数组或字段名进行运算。燃料元素分析表给定了几十种典型燃料的工业分析值, 用户可以自由选择, 也可以自行添加所要使用的燃料数据。漏风系数及空气过量系数是根据经验选择的, 程序给出了各种情况下的选取范围以供用户参考。CFB锅炉的热平衡计算, 是在稳定工况下对锅炉的输入、输出热量及各项热损失之间的平衡计算。通过热平衡计算可获得锅炉效率与锅炉的燃煤量。辅助计算工作量比较大, 需要输入大量的物性参数, 而且需要将各种公式、大量的线算图

转化成 VF 程序格式。有些物性参数要进行单独计算,有的需要用插入法计算,还有的需要进行拟合计算。例如,已知温度和压力计算焓值等。这样可以保证较高的运算精度,并降低程序编制的难度。辅助计算是热力计算的关键和基础,对下一步的炉膛计算和受热面的热力计算非常重要。

### 2.3 热力计算

#### 2.3.1 炉膛传热计算

炉膛传热计算模块主要由锅炉规范表单和炉膛传热计算表单组成。在锅炉规范表单中,用户可以输入锅炉规范参数以及锅炉的各种热损失值  $q_2$ 、 $q_3$ 、 $q_4$ 、 $q_5$  等。锅炉传热计算表单主要由锅炉结构特性参数表单和炉膛参数表单组成。炉膛的传热计算将获得炉膛出口烟温、受热面积、吸热量等参数。其中炉膛出口烟温是先假设 1 个值,再校核,程序自动调整,直至达到误差范围以内为止。

#### 2.3.2 各种受热面的计算

CFB 锅炉各受热面的计算是整个热力计算过程中最复杂、最困难的过程,不仅要进行各受热面的设计计算,更要进行其校核计算。手工计算时不仅计算工作量大、过程单调,而且还容易出错;而程序计算则不仅速度快,且计算精度有保证。首先,程序可以实现各种受热面的自由组合,在每个被选择的受热面的传热计算中都包含结构特性表单和传热计算表单。每个受热面的出口烟温都是以先假定、后校核的计算模式进行。在程序中,语句后一般都加了注释,这样既可以让用户理解,又便于程序查错。所有的计算结果或中间变量都存入表格。有些变量随着程序的运行,将被新的数值所覆盖。当进行热力计算时,如果参数没有达到所规定的误差,程序会自动弹出校核界面,用户只需用鼠标点击“确定”,程序即可进行自动校核计算直至达到规定的误差范围之内为止。图 2 为 CFB 热力计算主流程图。

## 3 计算实例

以某 65 t/h 油页岩 CFB 锅炉的热力计算为例,油页岩元素分析见表 1,计算结果见表 2。

表 1 油页岩元素分析 %

| C    | H    | O    | N     | S     | 灰分    | 水分   | 可燃基挥发分 |
|------|------|------|-------|-------|-------|------|--------|
| 20.4 | 2.54 | 9.82 | 0.505 | 1.015 | 54.82 | 10.9 | 80.7   |

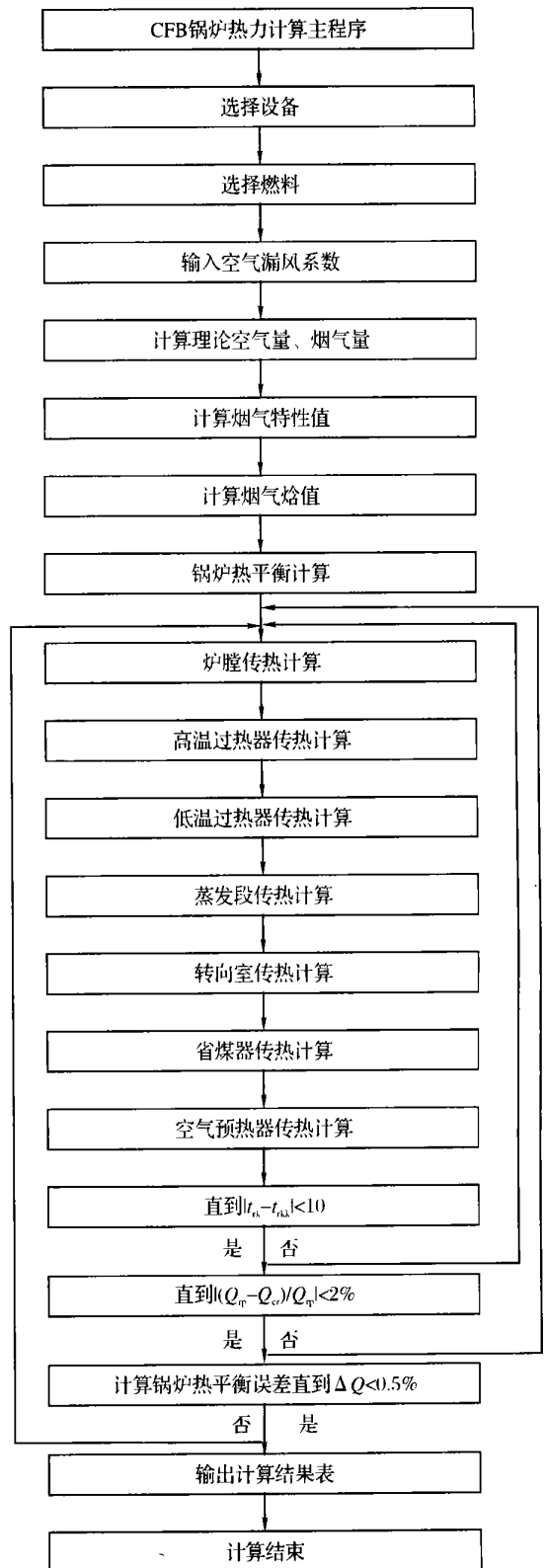


图 2 热力计算主体流程

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图2 含水量为23%的浆液脱水物电镜图

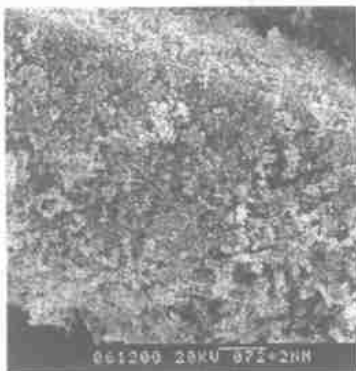


图3 含水量为38%的浆液脱水物电镜图

## 4 结 语

南宁冶炼厂脱硫系统是采用国内技术和主要设备的脱硫示范项目,其相当于1台670 t/h锅炉(以燃煤 $S_{ar}=1.3\%$ 计)的脱硫工程。该系统的成功运行,不仅取得了较大的社会和经济效益,还为以后推广此技术积累了经验。

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表2 计算机计算结果

| 名称   | 炉膛        | 高温<br>过热器 | 低温<br>过热器 | 蒸发段       | 转向室     | 省煤器       | 空气<br>预热器 |
|--|-----------|-----------|-----------|-----------|---------|-----------|-----------|
| 入口烟温/ $^{\circ}\text{C}$                                   |           | 850.00    | 774.00    | 660.00    | 611.00  | 594.50    | 353.00    |
| 出口烟温/ $^{\circ}\text{C}$                                   | 850.00    | 774.00    | 660.00    | 611.00    | 594.50  | 353.00    | 147.00    |
| 工质进口温度/ $^{\circ}\text{C}$                                 |           | 363.04    | 274.30    |           |         | 150.00    | 20.00     |
| 工质出口温度/ $^{\circ}\text{C}$                                 |           | 450.00    | 443.91    |           |         | 270.95    | 293.00    |
| 烟气流速/ $\text{m}^3\text{s}^{-1}$                            |           | 4.11      | 3.25      | 4.59      | 4.57    | 6.69      | 16.67     |
| 工质流速/ $\text{m}^3\text{s}^{-1}$                            |           | 20.57     | 28.19     |           |         |           | 8.91      |
| 传热系数/ $\text{kJ}(\text{m}^2\text{h}^{\circ}\text{C})^{-1}$ | 453.613 6 | 370.724 2 | 395.887 8 | 69.262 6  | 108.471 | 172.174 2 | 116.747 4 |
| 受热面积/ $\text{m}^2$   | 251.70    | 110.80    | 207.70    | 384.70    | 69.84   | 827.00    | 3 457.00  |
| 附加受热面积/ $\text{m}^2$                                       |           | 15.10     | 15.90     | 71.80     |         |           |           |
| 温度/ $^{\circ}\text{C}$                                     | 575.70    | 405.45    | 357.18    | 360.65    | 328.45  | 258.61    | 83.73     |
| 吸热量/ $\text{kJkg}^{-1}$                                    | 2 776.899 | 703.535 8 | 1 240.791 | 481.870 4 | 105.127 | 1 430.271 | 964.284 2 |
| 附加吸热量/ $\text{kJkg}^{-1}$                                  |           | 138.316 2 | 41.8      |           |         |           |           |

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## 4 结 论

利用 Visual Foxpro 语言编制了基于 Windows 操作系统的 CFB 锅炉通用热力计算程序, 该程序能够完成各种 CFB 锅炉的热力计算, 实现了各种受热面的自由组合, 且界面友好, 操作简便, 即使不太熟悉计算机编程的锅炉技术人员也可以很方便地使用。

The governing behavior of hydraulic coupling has been expounded, and the causes resulting in instability of outlet flow rate of the said pump being analysed. Through some improvement measures such as restoring the cam mechanism and improving profile of the cam, reducing the transmission ratio between tooth-bar and gear wheel, enhancing the governing behavior of the ladle pipe etc., the feed-water pump equipped with hydraulic coupling speed-governing system has been kept in normal operation satisfying basically the requirements of load regulation.

**TEST METHOD FOR PERIODIC PERFORMANCE MONITORING OF LARGE-SCALE CONDENSING STEAM TURBINES ..... TANG Xiao-ni (48)**

A test method for long-term performance monitoring of steam turbines has been presented. Comparing with traditional performance testing method based on «Routine test code of American Society of Mechanical Engineers-ASME Pt6.5», the suggested test method can decrease test instruments and test personnel, lowering test cost. This method does not require excessive absolute test accuracy, but emphasizes good test repetitiveness, having more applicable value for satisfying practical requirements.

**DEVELOPMENT AND APPLICATION OF RGS-2000 TYPE MICROPROCESSOR-OPERATED THERMOTECHEMICAL PROTECTIVE SYSTEM ..... XU Gao-shan et al (52)**

In view of the present situation and the problems existing in the thermotechnical protection of thermal power plants, a microprocessor-operated thermotechnical protective system composed of multiple programmable logic controllers and a upper-positioned processor has been developed and brought into being. The structure, features, functions, software design and application in the field of the said system have been presented as well.

**DESIGN OF GENERAL PROGRAM FOR THERMAL PERFORMANCE CALCULATION CONCERNING CFB BOILERS BASED ON VF ..... GAO Ning-bo et al (55)**

A program of thermal performance calculation suitable for circulating fluidized bed (CFB) boilers has been developed by using Visual Foxpro (VF) language programming. This program can freely select the build-up type of heat-surface structure, being suitable for the thermal performance calculation of CFB boilers having complicated and varied heat-surface arrangement, the man-machine interface being friendly, and convenient to use.

**REALIZATION OF EXACT TEMPERATURE DETECTING IN PULVERIZED COAL MONITORING SYSTEM ..... JIN Xu-dong et al (58)**

The functions and features of  $\Sigma-\Delta$  A/D conversion chip AD 7114 have been briefly presented. Combined with the actual condition of zx 300 MW units in Zhangshan Power Plant, Shanxi Province, an application example of exact temperature detecting in pulverized coal monitoring system has been given.

**OPTIMAL FEEDBACK CONTROL STRATEGY FOR MAIN STEAM TEMPERATURE ..... LI Yang-chun et al (61)**

Based on optimal feedback control principle, a strategy of optimal feedback control for main steam temperature has been put forward to optimize and resolve the state feedback matrix, realizing rapid and stable follow-up to settled value of steam temperature by using desuperheating water quantity as little as possible. At the same time, the DID control can be eliminated, and the control system may be simplified. Besides in order to overcome the steady-state deviation, an improved and simplified method, namely addition of steady-state deviation discriminator and BP network corrector into the optimal feedback strategy for main steam temperature has been given. Simulation shows that the said method has good effectiveness.

**APPLICATION OF TRL-004B WATER QUALITY STABILIZING AGENT IN POWER PLANT FOR WATER-SAVING ..... LI Jian-xi et al (65)**

Through industrial utilization tests in the laboratory and in the field, a water-saving technological scheme, in which the TRL-004B water quality stabilizing agent was used for industrial drainage treatment and then the water being used as make-up water for circulatory cooling water, has been put forward. The said stabilizing agent is suitable for water quality with high alkalinity and high hardness, in a duration of five years for utilizing the said stabilizing agent in a thermal power plant of Shanxi Branch Company under China Aluminium Corp. desired effectiveness of corrosion inhibition and scale retardation has been obtained, allowing the said thermal power plant to have been saving water of  $2.16 \times 10^6$  m<sup>3</sup> annually, having remarkable water-saving result.

**PERFORMANCE TEST AND TECHNICAL ANALYSIS OF NEW TYPE LIQUID-COLUMN INJECTING DESULPHURIZATION TECHNOLOGY ..... HUANG Bin et al (68)**

The technique process and system structure of liquid-column injecting desulphurization used in Nanning Smeltery, Guangxi Province, has been presented giving out design parameters, initial capital investment and operating cost. An elementary analysis of occurred problems in commissioning test, such as clogging, corrosion, and dehydrolysis etc., have been carried out, and relevant recommendations being given. Through monitoring appraisal of The State Environmental Protection Bureau, it is confirmed the SO<sub>2</sub> concentration at inlet and outlet is 15,000  $\mu$ L/L and 300  $\mu$ L/L respectively. Under conditions of high concentration and large-amplitude variation, the efficiency of desulphurization is over 95%; the capital investment and operating cost of the said desulphurization system to be lower, and the operation of said system keeping basically in normality.

**EXPERIMENTAL STUDY ON MERCURY EMISSION AND CONTROL FOR CFB BOILERS ..... ZHOU Jing-song et al (72)**

Using self-designed measuring facility of mercury formation in flue gas from fud coal, an experimental study on mercury emission and control has been carried out on a circulating fluidized bed (CFB) boiler firing stone coal. Results of experiment show that the electric precipitator (EP) has certain control effect for mercury emission, the mercury content in flue gas after EP is obviously lower than that before EP, the variation of mercury formation distribution in flue gas after EP being comparatively large. The mercury discharged into atmosphere is mainly mercury in single substance state. After adding lime-stone into fuel coal, transformation of gaseous state mercury into solid state mercury in the flue gas has occurred, being helpful for alleviating mercury.

**APPLICATION OF STEAM-BLISTER ATOMIZING TYPE OIL GUNS AND IMPROVING MEASURES THEREOF ..... HE Rong-qiang et al (76)**

In view of troublesome problems existing in steam-blister atomizing type heavy-oil guns, such as difficult ignition, bad atomization, and non-full combustion etc., at Zhanjiang Power Plant, corresponding improvement measures have been put forward from aspects of installing, operating and maintaining the oil gun facility at the same time of analyzing the causes leading to the occurrence of the said problems. After implementation of the above-mentioned measures, comparatively good results have been obtained, making problems of difficult direct ignition by using cold-state heavy-oil guns to be solved.

**ANALYSIS OF MAIN STEAM CONDUIT VIBRATION OF 35MW STEAM TURBINE AND REMEDIAL MEASURES THEREOF ..... MA Hong et al (81)**

Through vibration calculation, analysis and measurement, the vibration behavior of main steam conduit has been grasped. On this basis, and combined with the practical situation of the pipeline, a remedial scheme for said vibration, such as increasing offset installation of supports and hangers for the steam conduit tubulature, as well as increasing the parallel connection between steam conduits, to strengthen the confinement of tubulature and to increase the stiffness of said tubulature. After carrying out the above-mentioned remedial measures, vibration of the pipeline has been obviously lowered, having remarkable effectiveness.

**CAUSE ANALYSIS AND TREATMENT FOR VIBRATION OF BEARING SHOE NO. 4 ON STEAM TURBINE NO. 2 IN LONGYAN-HENG POWER PLANT ..... YAO Yi-wen (84)**

The axial vibration of bearing shoe NO. 4 on unit NO. 2 in Longyanheng Power Plant has been seriously surpassing the specified limit after major repair in June, 2000, bring about harmfulness for safe and stable operation of the unit. Through dismounting inspection of each equipment in major repair, it was considered that the main cause leading to serious axial vibration of the bearing shoe NO. 4 was the deformation of bearing pedestal. After eliminating the cause resulting in fault, operation of the said unit always keeps in stability.

**PRACTICE OF USING RESIDENTIAL SEWERAGE AFTER TREATMENT AS CIRCULATORY COOLING WATER IN GANGE-FIRING THERMAL POWER PLANT OF DATUN COAL AND POWER COMPANY ..... HAN Dong-ti et al (86)**

The situation of using residential sewerage after treatment as circulatory cooling water in gang-firing thermal power plant of Datun Coal & Power Company in order to reduce water consumption has been presented. For discharged water from the sewerage treatment plant, if suspended matter in the said water is less than 20 mg/L, the discharged water can directly be used for circulatory cooling, otherwise, pretreatment as coagulation and settlement should be carried out. Other treatment measures, such as bactericide dosing, treatment for scale-retarding, gum-ball cleaning and ferrous-sulfate film-forming in condenser tubes etc., have been taken as in common power plants. In consecutive two years after putting the said project into operation, the terminal temperature difference of condenser keeps lower than 5 $^{\circ}$ C in the whole year, satisfying fully the requirements of power plant, and retrieving the capital investments only in more than one year, having remarkable economic and environmental benefits.

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