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CFB 锅炉水冷排渣余热利用的分析与优化

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摘 要: 以某电厂 400 t/h CFB 锅炉的水冷排渣余热回收利用系统为原型, 分析了从回热系统引出部分凝结水到冷渣器, 吸收高温排渣余热后再引入回热系统中的各种方案。利用等效热降法分析了高温排渣的余热输入到回热系统中获得的经济效益, 并比较了额定工况和 75% 工况下的经济性。计算结果表明: 将排渣的热量分别输入至 2 号低压加热器和 3 号低压加热器均能回收大量的余热, 而且得出后者是最佳的余热利用方式。

关 键 词: CFB 锅炉; 冷渣器; 等效热降; 余热回收系统; 经济效益

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1 前 言

循环流化床锅炉技术是近年来迅速发展起来的一项高效低污染清洁技术, 这项技术在电站锅炉、工业锅炉以及废弃物处理利用等领域已得到广泛应用。由于流化床锅炉通常燃用高灰份燃料, 因此排渣热损失较大, 若能将锅炉排渣的热量进行回收利用, 则可大大提高电厂运行的经济性。

冷渣器是循环流化床锅炉的关键辅机之一。冷渣器的冷却介质一般为水、空气和烟气。空气和烟气同时也是灰渣的流化介质[1]。流化介质在流化、冷却灰渣的同时自身的温度也不断升高, 被加热的流化介质最终由冷却室出风管排出, 作为煤燃烧用二次风送入炉膛, 提高燃烧效率和石灰石利用率。用水作为冷却介质时, 热量利用方式有以下几种[2~3]: (1)作单独的循环系统, 用于冬季供暖或将回收的热量直接送到散热塔排掉。这种方式的优点是对系统没有影响, 但受季节和地域的限制, 还需设有辅助供热系统, 送到散热塔排掉更是不科学的, 采用的较少。(2)利用风水联合冷渣器, 高温段冷却介质采用给水, 作为给水旁路送入省煤器中, 低温段冷却介质采用凝结水, 送入回热系统中。渣中的大部分热量被送回锅炉本体, 减少了热量损失。(3)从冷凝器取水, 冷却介质被加热后再送回到锅炉的回热系统。这是一种比较常用的热量回收方式, 可提高系统的热利用率, 但由于回送的热量破坏了回热系统的平衡, 在一定程度上影响了回热系统的效率, 而且当底渣量较大时, 回热系统无法处理过多的热量, 因此, 有一定的局限性。(4)回收热量代替工业用抽汽。如某造纸厂化学水处理车间将回收的热量用于加热生水, 以减少抽汽的消耗量。

本文研究采用以水冷为主风冷为辅的风水联合流化床冷渣器, 主要分析水冷渣获得的热量给系统带来的经济性, 并进行各种热量利用的方案比较, 以期得到最优的方案, 获得最大的余热利用效果。

2 水冷排渣余热回收利用系统

水冷排渣余热回收利用系统就是将回热系统的部分凝结水从某个位置引出, 并引入冷渣器, 吸收热量后再返回到回热系统。显然, 从回热系统引出水的位置不同, 引入水的位置不同, 获得的经济性是不同的。根据引出、引入水的位置, 水冷排渣余热利用系统有如下几种方案。

2.1 冷渣器与 1 号低压加热器并联(方案一)

如图 1 所示, 冷却水引自回热系统轴封加热器出口, 在冷渣器吸收热量后返回到 2 号低压加热器

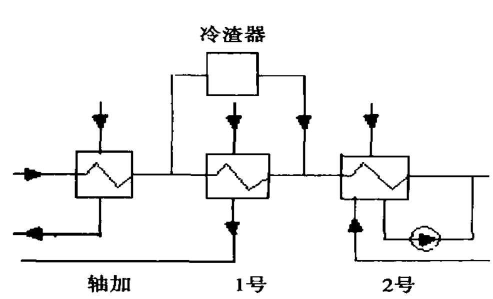

图 1 冷渣器与 1 号低压加热器并联

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的入口。按照热力循环理论,排渣余热的引入将减少1号低压加热器和2号低压加热器的抽汽量,即对回热抽汽产生排挤作用。

2.2　冷渣器与2号低压加热器并联(方案二)

如图2所示,将1号低压加热器出口的部分凝结水引入冷渣器中,吸收锅炉排渣的余热后,与2号低压加热器的出口水相混合,然后进入3号低压加热器。将排渣的热量回收输入至3号低压加热器。

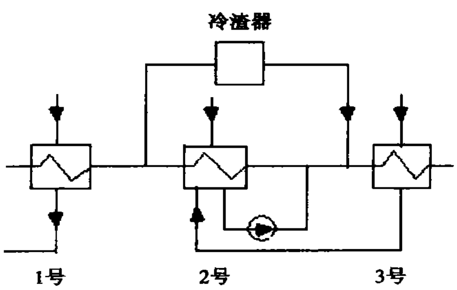

图2　冷渣器与2号低压加热器并联

2.3　冷渣器与3号低压加热器并联(方案三)

如图3所示,从2号低压加热器的出口抽出部分凝结水引到冷渣器中,吸收排渣的余热后,与3号低压加热器的出口水相混合,然后进入除氧器中。

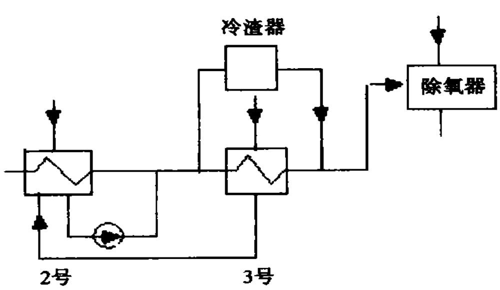

图3　冷渣器与3号低压加热器并联

根据能级利用的观点,余热回收介质的温度越高,则能量品质越高,经济性越高。因此,水冷排渣后,引入2号低压加热器或3号低压加热器出口,比引入1号低压加热器出口更为合理。但是根据热传递理论,引入冷渣器的凝结水温越高,则由于冷渣器内为顺流换热,换热平均温差越小,传热量越少,则余热回收的效果不好。

对于如图3所示的系统,由于从2号低压加热器的出口抽出的部分凝结水通过冷渣器时吸收的热量较少,需提高冷渣器的抽水份额及冷却风量才能满足冷渣要求,但限于锅炉的总凝结水量及所需的风量,提高有限,这就使得冷渣器内的冷却介质在该能级处不能有效地冷却排渣,因而不能达到流化床锅炉的冷渣要求。这一现象在75%工况时更为突出。所以,对于该锅炉机组使用的冷渣器型式,不宜采用此种系统。

因此,下面将从方案一和方案二中寻找出最佳的热量利用能级。

3　等效热降分析与系统优化

3.1　等效热降分析

为了便于分析比较,选定额定工况作为计算工况,采用等效热降法进行热经济性分析计算[4~6]。

排渣余热作为外部纯热量加入系统,该热量的做功也就是新蒸汽等效热降的变化。当余热输入2号低压加热器入口时,新蒸汽等效热降的增量:

$$\Delta H=\alpha_f[(h''_{1z}-t_1)\eta_2+\tau_1\eta_1]$$

当余热输入3号低压加热器入口时,新蒸汽等效热降的增量:

$$\Delta H=\alpha_f[(h''_{1z}-t_2)\eta_3+\tau_2\eta_2]$$

式中:α_f—冷渣器的抽水份额,$\alpha_f=D_{lz}/D_0$;D_{lz}—冷渣器的抽水量,kg/h;D_0—主蒸汽流量,kg/h;h''_{lz}—冷渣器出口水焓,kJ/kg;t_1、t_2—1号、2号低加给水焓,kJ/kg;τ_1、τ_2—1号,2号低加中的工质焓升,kJ/kg;η_1、η_2、η_3—1号、2号,3号低加的抽汽效率。

装置热经济性的变化,因外来热量为余热利用,则循环加入热量保持不变,而利用外部热量后的新蒸汽等效热降为:

$$H'=H+\Delta H$$

故,装置效率相对提高为:

$$\Delta\eta=(\Delta H/H)\times 100\%$$

式中:H—引入排渣余热前新蒸汽的等效热降,kJ/kg。

热耗率降低值:$\Delta q=\Delta\eta q_0$

式中:q_0—引入排渣余热前机组的热耗率,kJ(kW·h)。

标准煤耗降低值:$\Delta b=\Delta q/\eta_{gl}\cdot Q_s$

式中:η_{gl}—锅炉效率,$\eta_{gl}=90\%$;

Q_s—低位发热量,$Q_s=29\ 300$ kJ/kg。

年节标准煤量:$\Delta B=P_e\cdot\tau\cdot\Delta b$

式中:P_e—机组发电功率,kW;

τ—年运行小时数,取$\tau=6\ 500$ h。

年经济效益:$S_l=C_e\cdot\Delta B$

式中:C_e—标准煤价,取$C_e=350$元/t。

3.2　方案一和方案二的热经济性分析比较

额定工况下机组热力参数如表1所示。利用上述公式计算两种方案下机组获得的经济效益,如表2所示。

表 1　额定工况下机组热力参数

	数值
主蒸汽流量 D_0/ kg·h^{-1}	382 112
再热蒸汽流量 D_{zr}/ kg·h^{-1}	334 463
主蒸汽焓 h_0/ kJ·kg^{-1}	3 427.5
给水焓 h_{fw}/ kJ·kg^{-1}	1 033.2
再热器进口蒸汽焓 h'_{zr}/ kJ·kg^{-1}	3 104.2
再热蒸汽焓 h''_{zr}/ kJ·kg^{-1}	3 534.3
机组功率 P_e/ kW	130 057
机电效率 η_{jd}	0.96
冷渣器进水温度 t'_{1z}/ ℃	34(方案一)
出口水温 t''_{1z}/ ℃	102(方案一)
冷渣器进水温度 t'_{1z}/ ℃	66.3(方案二)
出口水温 t''_{1z}/ ℃	120(方案二)
抽水量 D_{lz}/ kg·h^{-1}	80 000
低压缸排汽焓 h_n/ kJ·kg^{-1}	2 355
1 号低加抽汽焓 h_1/ kJ·kg^{-1}	2 567.5
2 号低加抽汽焓 h_2/ kJ·kg^{-1}	2 757.5
3 号低加抽汽焓 h_3/ kJ·kg^{-1}	2 943
凝结水焓 t_n/ kJ·kg^{-1}	136.3
1 号低加给水焓 t_1/ kJ·kg^{-1}	278.9
2 号低加给水焓 t_2/ kJ·kg^{-1}	422.4
3 号低加给水焓 t_3/ kJ·kg^{-1}	550.6
疏水焓 t_{s3}/ kJ·kg^{-1}	562.5

表 2　额定工况下方案一和方案二的比较

	方案一	方案二
ΔH/ kJ·kg^{-1}	7.543 7	8.434 2
$\Delta\eta$/ %	0.591	0.660 8
Δq/ kJ·(kWh)$^{-1}$	48.112 8	53.796 4
Δb/ g·(kWh)$^{-1}$	1.824 5	2.040 1
ΔB/ t	1 542.378 5	1 724.609
S_l/ 万元	53.983 2	60.361 3

从表 2 中可知, 两种方案都使机组的等效热降有不同程度的增加, 都给机组带来了明显的经济收益, 并且方案二较方案一的效果更显著。采用方案一时, 机组的等效热降增量为 7.543 7 kJ/kg, 装置效率相对提高 0.591%, 热耗率降低 48.112 8 kJ/(kWh), 标准煤耗降低 1.824 5 g/(kWh)。若年运行 6 500 h, 年节标准煤量 1 542.378 5 t, 可获经济效益 53.983 2 万元。采用方案二时, 机组的等效热降增量为 8.434 2 kJ/kg, 装置效率相对提高 0.660 8%, 热耗降低 53.796 4 kJ/(kWh), 标准煤耗降低 2.040 1 g/(kWh), 若年运行 6 500 h, 年节标准煤耗 1 724.609 t, 可获经济效益 60.361 3 万元。

本文还研究了变工况时两种方案的经济效益。在 75%工况时(冷渣器的抽水量为 60 000 kg/h), 若采用方案一, 机组的等效热降增量为 7.466 1 kJ/kg, 装置效率相对提高 0.574 3%, 热耗率降低 47.623 4 kJ/(kWh), 标准煤耗降低 1.806 g/(kWh)。采用方案二时, 热耗降低 52.035 1 kJ/(kWh), 标准煤耗降低 2.631 0 g/(kWh)。

相对于方案一来说, 方案二中虽然冷却水的吸热量有所降低, 但却使 2 号、3 号低压加热器排挤的抽汽返回汽轮机时获得的等效热降更多。可见, 将排渣余热输入至 3 号低压加热器上, 获得了更大的收益, 显现出了更可观的经济性。

因此, 水冷排渣余热利用时, 将冷渣器与 2 号低压加热器并联, 将回收的余热输入至 3 号低压加热器, 为最佳的余热利用型式。

4　结论与建议

(1) 从回热系统中抽出部分凝结水送到冷渣器, 吸收排渣余热后再返回到热力系统中, 回收了大量灰渣余热, 可以提高锅炉机组的效率。这种余热利用方式是可行的。

(2) 通过等效热降分析计算, 得出了将冷渣器与 1 号和 2 号低压加热器分别并联使用时两种方案的经济效益, 这两种方案均可以提高锅炉效率, 而且后者的效果更好。

本课题仅限于所研究机组的冷渣器结构型式。必须指出, 冷渣器的结构还可以改进, 使该系统的性能更好, 经济性更高, 这是进一步研究的内容。

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(辉　编辑)

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An investigation was conducted of the flow distribution characteristics of distribution header water-wall tubes under a supercritical pressure for a home-made 600 MW once-through boiler. The test parameters can be listed as follows: pressure p=23 ~ 25 MPa, mass flow rate G= 400 ~ 1200 kg/(m^2.s), working medium temperature t=10 ~400 ℃. An experimental study has been conducted of the impact of working medium pressure, mass flow rate and working medium temperature on the vertical water-wall tube flow distribution characteristics of the distribution header. The test results show that with an increase in mass flow rate, the uniformity of flow distribution among the vertical water-wall tubes could be enhanced. The non-uniformity of flow distribution will undergo a step increase near the quasi-critical points. Moreover, with an increasing pressure, the above-mentioned step increase will become weaker. By employing a discrete model of the parallel-connected branch tubes of the distribution header, the flow distribution among the distribution header vertical water-wall tubes was calculated and the calculation results are in good agreement with the test ones. **Key words**: once-through boiler, supercritical pressure, distribution header, vertical water-wall tubes

USC 直流炉水冷壁壁温监测有限元分析= **Finite Element Analysis of the Monitoring of Water-wall Water Temperatures in an Ultra-supercritical-pressure Once-through Boiler**[刊, 汉] /WANG Hong-yue, BI Xiao-long, SI Feng-qi, et al (Power Engineering Department of Southeast University, Nanjing, Jiangsu, China, Post Code: 210096)// Journal of Engineering for Thermal Energy &Power. — 2006, 21(3). —303 ~306, 310

It has all along been rather difficult to realize an on-line monitoring of the hazardous-point wall temperatures of a flame-facing membrane wall in an ultra-supercritical-pressure once-through boiler. Based on a finite-element analysis theory, the authors have come up with a method for the numerical simulation of water-wall cross-section two-dimensional temperature field for the on-line temperature field of a 900 MW ultra-supercritical-pressure utility boiler water wall. Through a theoretical analysis and an experimental verification it has been found that the numerical simulation features a solution of high precision and good confidence level, providing a new monitoring method for the indirect measurement of hazardous-point temperatures in the flame-facing water wall of an ultra-supercritical-pressure once-through boiler. **Key words**: membrane wall, finite element, wall temperature, on-line monitoring, simulation

轮南电站燃气轮发电机组运行方式的试验研究= **Experimental Study of Operation Modes for Gas Turbine Generator Units at Lun-nan Power Station**[刊, 汉] / CHEN Ren-gui, YUAN Jun, HUANG Xin (Oil and Gas Production Technical Service Department of Tarim Oil Field, Korla, Xinjiang, China, Post Code: 841000), WU Bin (Postgraduate Department of Northeast College of Electric Power, Jilin, China, Post Code: 132012)// Journal of Engineering for Thermal Energy &Power. — 2006, 21(3). —307 ~310

Through an analysis of the relevant parameters associated with the process of dynamic-abrupt rise in rotation speed of Lunnan Power Station gas turbine unit after a load rejection, the dynamic characteristics of the unit were compared when the latter assumes the following three speed control modes: droop control, zero-droop control, and droop and zero-droop mixed control. On the basis of the specific features of the gas turbine unit itself and the current status of isolated electric grid operation of the power station it is recommended that the power station should adopt a droop speed control mode. **Key words**: load rejection, speed control mode, droop control, zero-droop control

CFB 锅炉水冷排渣余热利用的分析与优化= **An Analysis and Optimization of Waste Heat Utilization Involving Water-cooled Ash-slag Discharged from CFB (Circulating Fluidized Bed) Boilers**[刊, 汉] / ZHANG Ning, SUN

Feng-zhong, HUANG Xin-yuan (Energy Source and Power Engineering College under the Shandong University, Jinan, Shandong Province, China, Post Code: 250061), DING Xing-wu (Shandong Yunhe Power Station, Jining, Shandong, China, Post Code: 272003)// Journal of Engineering for Thermal Energy &Power. — 2006, 21(3). —311~313

With a waste heat recovery and utilization system involving water cooled slag being discharged from a 400 t/h CFB (Circulating Fluidized Bed) boiler serving as a prototype, various schemes were analyzed, which are based on the extraction of a portion of condensate water from a recuperation system for feeding into a slag cooler to absorb the waste heat of high temperature slag and then reintroducing the condensate into the recuperation system. By employing an equivalent heat-drop method, analyzed were the economic benefits gained by transferring the waste heat of high-temperature slag to the recuperation system. Moreover, a comparison was also made of the cost-effectiveness achieved in the case of a rated operation regime and 75% operation regime. The calculation results show that by transferring the heat quantity in the discharged slag to either No. 2 LP heater or No. 3 LP heater it is possible to recover a large amount of waste heat. Moreover, the authors have concluded that the latter version (to No. 3 LP header) represents an optimum mode of waste heat utilization. **Key words**: CFB boiler, slag cooler, equivalent heat-drop, waste heat recovery system, economic benefit

某型压气机高压进气机匣的改进设计= **An Improved Design of a HP Air Inlet Casing of a Certain Compressor** [刊, 汉] / CHEN Ying, WANG Shi-an, ZOU Ji-guo, et al (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036)// Journal of Engineering for Thermal Energy &Power. — 2006, 21(3). —314~316

To lower the total-pressure loss of the inlet casing of a certain compressor, three kinds of improved scheme of inlet casing structure design are given after drawing on the authors' experience in designing flow passages and on the basis of inlet design typical structure and relevant design principles. By making use of software Fluent three-dimensional flow field CFD (Computational Fluid Dynamics) calculations are conducted of the original scheme and three improved ones. A comparatively ideal improved scheme was obtained after the calculation results of these schemes have been compared and analyzed. As a result, the optimized improved scheme has finally lowered its inlet casing total-pressure loss to 1/4 of that of the original scheme. Some basic methods and effective measures for improving inlet passage design are summarized and proposed. **Key words**: air inlet turbine casing, total-pressure loss, optimized design

丙烯腈装置焚烧炉余热回收利用的分析= **An Analysis of the Recovery and Utilization of Waste Heat from a Acrylonitrile Plant Incinerator** [刊, 汉] / CHENG Xian-biao (Biochemical Workshop of Polymer No. 1 Factory under the Daqing Oil Refining and Chemical Co. Daqing, Heilongjiang, China, Post Code: 163411)// Journal of Engineering for Thermal Energy &Power. — 2006, 21(3). —317~319

An analysis is conducted of the irrational factors concerning the utilization of waste heat energy produced after the wastewater is burned by using an old acrylonitrile plant incinerator. A scheme is proposed to additionally install a horizontal incinerator and to use heat-conduction oil as a heat carrier to recover and utilize the waste heat produced after the incineration of waste water. Expounded are such problems as the corrosion of heat conduction oil furnace-tubes during the operation of the waste heat recovery system and scale deposit formed on furnace tubes and their underlying causes. The furnace tube corrosion problem has been solved through a change in waste water incineration flow path and the implementation of separate incineration of different flows of waste water. The problem of scale deposit formation on furnace tubes was solved by additionally installing soot blowers on the new incinerators, thus attaining the aim of rationally utilizing the waste heat produced by the incinerators. **Key words**: acrylonitrile, incinerator, recovery of waste heat, heat-conduction oil furnace tube