

注汽涡轮增压柴油机的试验研究

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摘 要:文献[1]提出一种新的注汽涡轮增压柴油机系统, 本文对此注汽涡轮增压柴油机进行了试验, 得出不同柴油机工况下注入增压器涡轮的蒸汽流量与温度对涡轮增压器及涡轮增压柴油机性能的影响, 并对其进行分析。验证了注汽涡轮增压柴油机在改善低工况性能方面的有效性。

关 键 词:涡轮增压器柴油机; 涡轮增压器注蒸汽

中图分类号: TK42 文献标识码: A

1 前 言

文献[1]提出一种新型涡轮增压器系统, 它能大幅度提高涡轮增压器的压比, 尤其是低工况下的压比, 从而改善低工况的性能, 提高涡轮增压内燃机的功率, 降低涡轮增压内燃机的耗油率。

本系统是在涡轮增压器的基础上, 利用涡轮增压器的排气余热, 设置一个朗肯回热循环, 构成一种新颖的注汽涡轮增压系统。即, 余热所产生的蒸汽注入涡轮中将大幅度地提高涡轮功率, 使其驱动的压气机的压比及流量增加, 从而达到提高涡轮增压柴油机的功率, 降低其耗油率, 明显改善低工况性能的目的。

文献[1]中曾对是否注水蒸气及水蒸气的参数对涡轮增压柴油机性能的影响进行了数值分析。为了检验计算结果的准确性和工程应用性提供可靠的

资料, 进行注蒸汽对涡轮增压柴油机性能的影响和对涡轮增压器的影响的试验研究是十分必要的。

2 试验装置简介

本试验以 N6135G 涡轮增压柴油机(见图 2)为基础, 建立了注汽涡轮增压柴油机试验台, 并进行了首次涡轮增压器的涡轮注蒸汽试验。

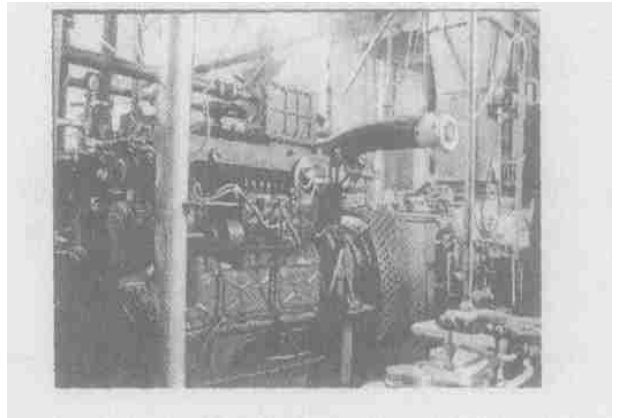


图 2 N6135G 涡轮增压柴油机

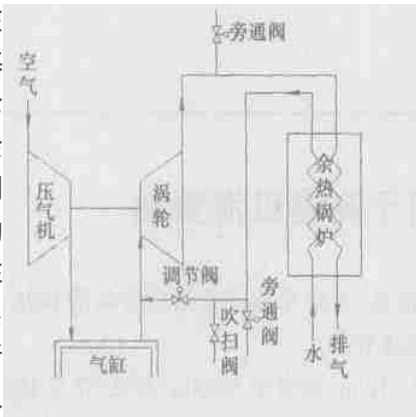


图 1 注蒸汽的涡轮增压柴油机示意图

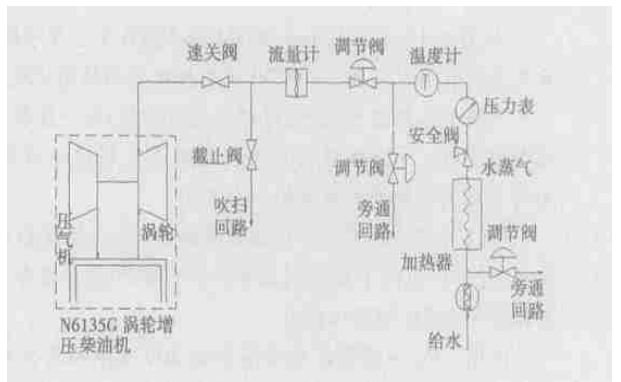


图 3 试验装置简图

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N6135G 涡轮增压柴油机为直列式 4 冲程、6 缸和水中冷涡轮增压柴油机, 额定功率为 150 kW, 柴油机额定转速 1 500 r/min, 排气管采用水冷。其涡轮增压器为 HT3B 型径流式涡轮增压器, 最大转速 80 000 r/min, 最高压比 3, 空气流量为 0.16 ~ 0.60 kg/s。N6135G 涡轮增压柴油机的负载为电测功器。

根据数值分析结果, 水蒸气的质量流量和温度对涡轮增压器工作点的变化有很大的影响, 在试验中控制汽气比和水蒸气温度的变化显得十分重要。在本试验中设计了一套注蒸汽系统来保证对水蒸气的质量流量和温度的要求, 采用电加热来产生水蒸气。

进行注汽系统改造后的 N6135G 涡轮增压柴油机的系统简图如图 3 所示, 改造的原则是以少的改动来实现蒸汽注入。由于 N6135G 涡轮增压柴油机的排气管为水冷布置, 为了减少对柴油机的改动, 水蒸气的注入点选在涡轮入口处, 采用逆流喷射。

3 试验内容及结果分析

对注汽涡轮增压柴油机来说, 主要的调节变量为蒸汽流量和温度, 试验时在不对柴油机进行任何调整的情况下, 涡轮增压柴油机功率不同时, 验证这两个参数对压气机压比、压气机出口空气温度、涡轮增压器转速、压气机空气流量、膨胀比和柴油机油耗率的影响, 同时也可以计算水蒸气的注入对压气机效率和涡轮效率的影响。

轮内混合工质做功能力不断增强(涡轮内质量流量增加及单位质量工质做功能力增强)造成的结果。

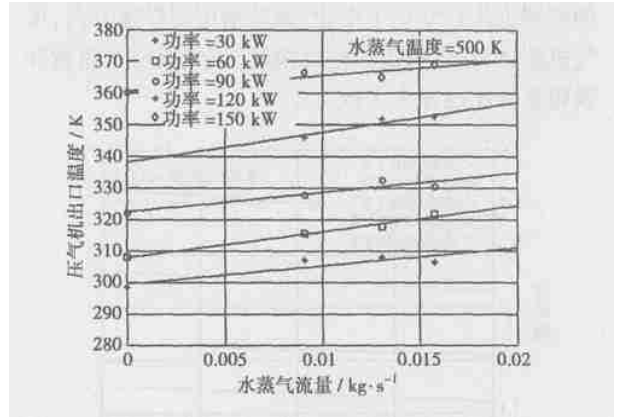


图 5 水蒸气流量对压气机出口空气温度的影响

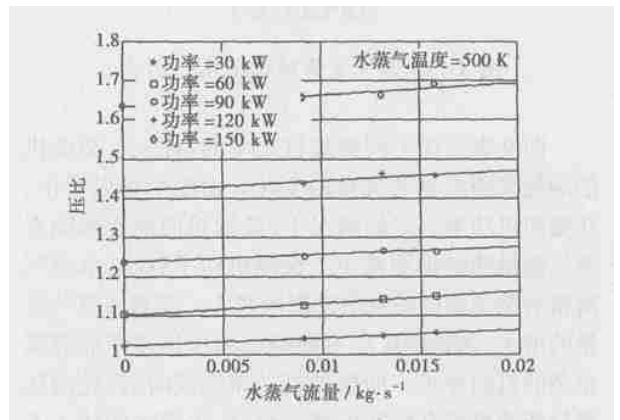


图 6 水蒸气流量对压比的影响

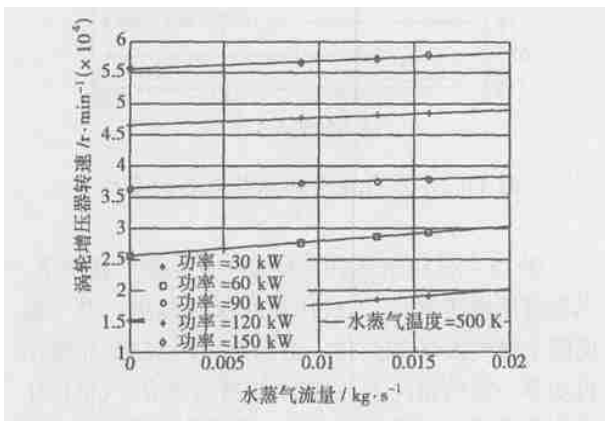


图 4 水蒸气流量对涡轮增压器转速的影响

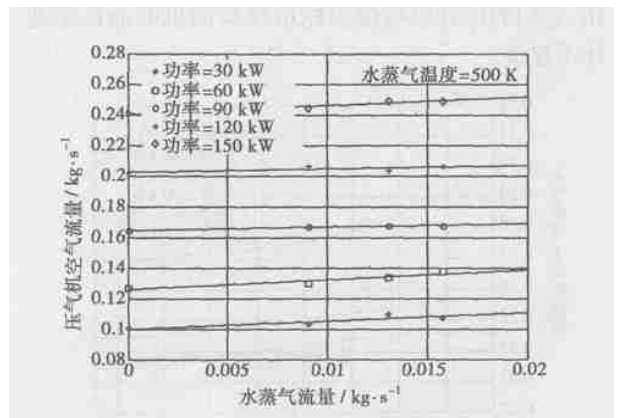


图 7 水蒸气流量对压气机空气流量的影响

图 4 表示在不同柴油机功率的情况下, 涡轮增压器转速随水蒸气流量的变化。由图中可以看出, 在柴油机功率一定的情况下, 涡轮增压器转速随着注入涡轮内水蒸气流量的增加而增大, 这是由于涡

图 5~图 8 表示在不同柴油机功率的情况下, 压气机出口空气温度、压气机压比、压气机空气流量和涡轮膨胀比随水蒸气流量的变化。由图中可以看出, 在柴油机功率一定的情况下, 这些参数随水蒸气

流量的增加而升高。同图 4 一样, 由于注入水蒸气流量的增加, 涡轮内混合工质的做功能力增强, 涡轮增压器工作点发生了变化, 涡轮增压器转速升高, 压气机压比、压气机出口空气温度、压气机空气流量和涡轮膨胀比也发生了改变。

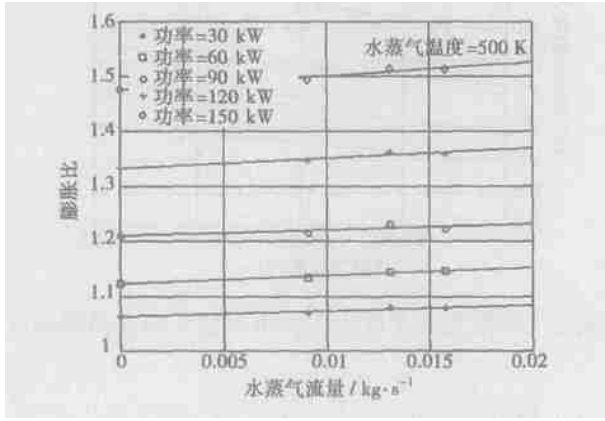


图 8 水蒸气流量对膨胀比的影响

图 9 表示在不同柴油机功率的情况下, 柴油机的油耗率随水蒸气流量的变化。由图中可以看出, 在柴油机功率一定的情况下, 柴油机的油耗率随水蒸气流量的增加而减小。柴油机功率越小, 水蒸气流量对柴油机的油耗率的影响越大。随着水蒸气流量的增大, 涡轮增压器所能提供的压比逐渐能够满足柴油机的要求。而柴油机功率较高时, 涡轮增压器与柴油机原有的匹配情况较好, 水蒸气的注入不仅使压比增大, 也使得压气机和涡轮效率发生了变化, 它们的综合影响使涡轮增压柴油机的油耗率变化不显著。

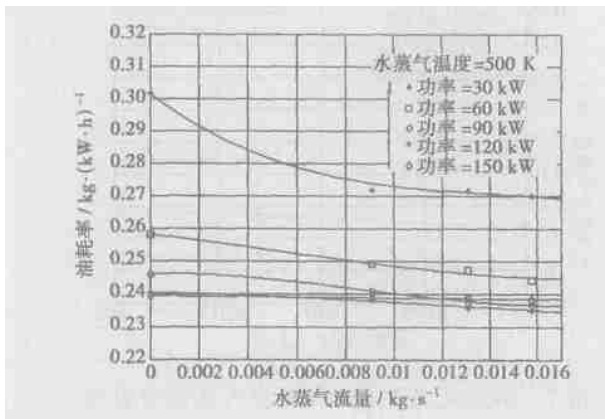


图 9 水蒸气流量对油耗率的影响

根据以上试验结果, 计算出了压气机效率随水蒸气流量的变化情况, 如图 10 所示。由图中可以看

出, 在功率为 60 kW 时, 压气机效率随水蒸气流量的增加而升高。在低工况时, 涡轮增压器转速的升高使得压气机运行点向高效率区移动。同样根据试验结果, 计算出了涡轮效率随水蒸气流量的变化情况, 如图 11 所示。由图中可以看出, 在功率为 60 kW 时, 涡轮效率随水蒸气流量的增加而增大, 但增大幅度很小, 在低工况时, 涡轮增压器转速的升高使得涡轮运行点向高效率区移动。

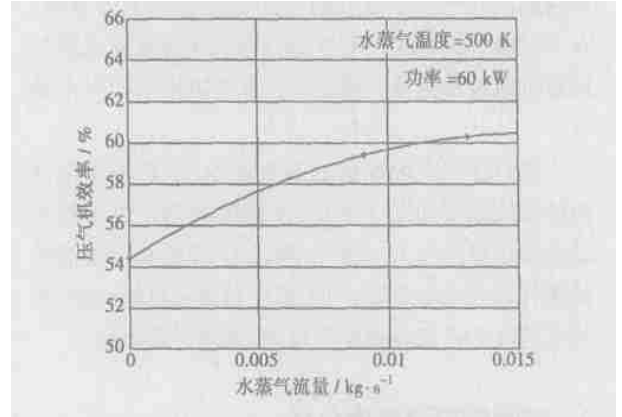


图 10 水蒸气流量对压气机效率的影响

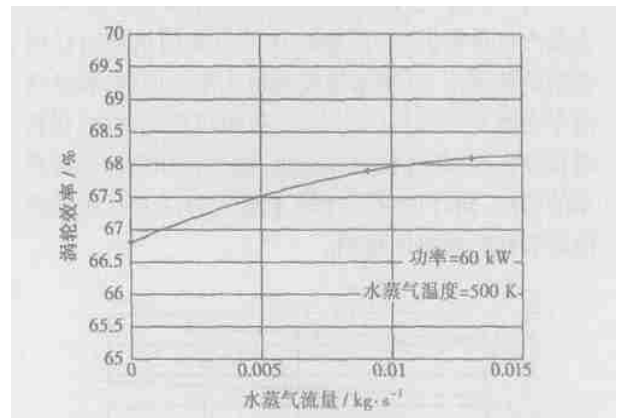


图 11 水蒸气流量对涡轮效率的影响

图 12 ~ 图 14 表示在不同柴油机功率的情况下, 涡轮增压器转速、压气机压比和压气机出口空气温度随水蒸气温度的变化。由图中可以看出, 在柴油机功率一定的情况下, 涡轮增压器转速、压气机压比和压气机后空气温度随着注入涡轮内水蒸气温度的变化而略有增大, 这是由于水蒸气的定压比热随着温度的升高而升高, 涡轮内工质的做功能力增强, 但同时也表明水蒸气温度的变化对涡轮增压柴油机的影响较小。

图 15 表示在不同柴油机功率的情况下, 柴油机

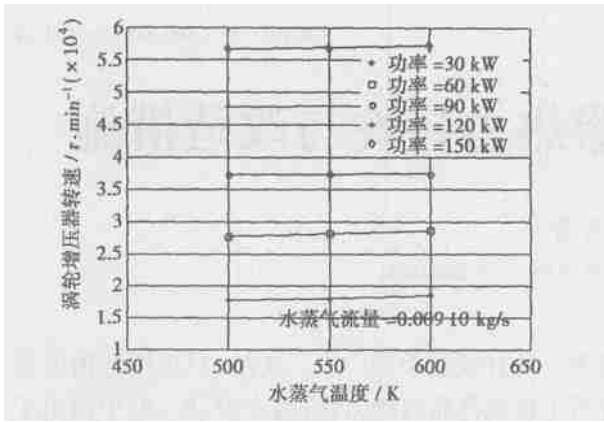


图 12 水蒸气温度对涡轮增压器转速的影响

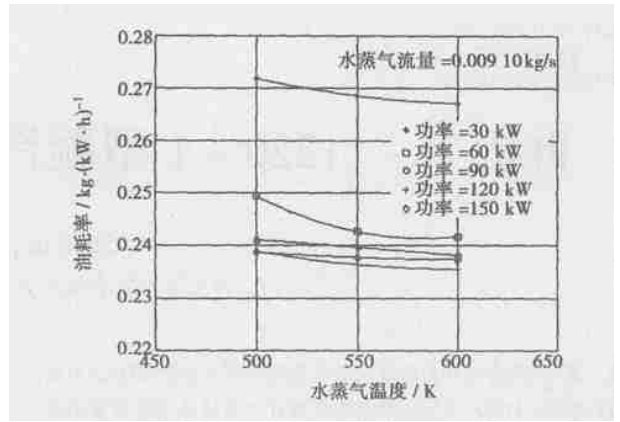


图 15 水蒸气温度对油耗率的影响

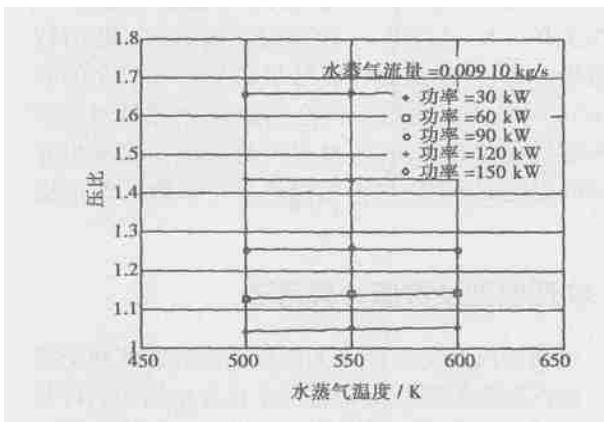


图 13 水蒸气温度对压比的影响

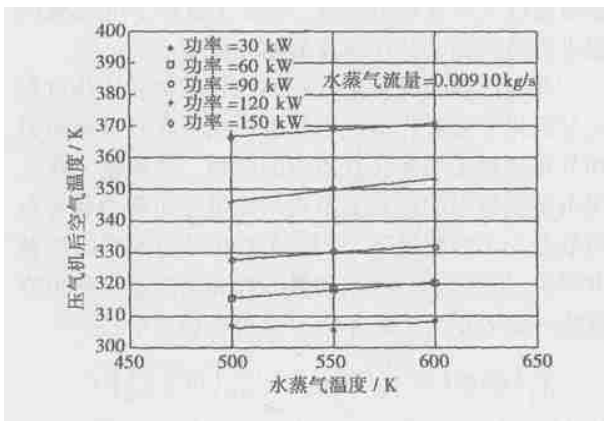


图 14 水蒸气温度对压气机后空气温度的影响

的油耗率随水蒸气温度的变化。由图中可以看出, 在柴油机功率一定的情况下, 柴油机的油耗率随水蒸气温度的增加而略有减小。

4 结 论

首次进行的注汽涡轮增压柴油机试验验证了文献[1~2]所提出的注汽涡轮增压柴油机系统在改善柴油机低工况性能方面的有效性。对注汽涡轮增压柴油机的工程应用具有重要借鉴意义。

(1)当涡轮增压器的涡轮内注入一定温度的水蒸气时,在不同的柴油机功率下,涡轮增压器的压比、压气机出口空气温度和空气流量、涡轮增压器转速和膨胀比随着水蒸气流量的增加而增大。

(2)在某一柴油机工况下,涡轮内一定温度的水蒸气的注入使得压气机和涡轮效率升高。

(3)在柴油机功率不变时,涡轮增压柴油机的油耗率随注入具有一定温度的水蒸气流量的增加而减小,在低功率时,涡轮增压柴油机的油耗率改进尤为明显。

(4)注入某一流量的水蒸气后,在不同的柴油机功率时,涡轮增压器的压比、压气机后空气温度和涡轮增压器转速随着水蒸气温度的增加而略有增大。

(5)在柴油机功率和水蒸气流量一定时,涡轮增压柴油机的油耗率随注入水蒸气温度的增加而减小,在低功率时,影响尤为显著。总的来说温度的影响幅度不如水蒸气流量的影响幅度大。

参考文献:

[1] 闻雪友, 陆 翀. 内燃机注汽涡轮增压系统[P]. 中国专利: 01101560. 2002-08-08.
 [2] 闻雪友, 陆 翀, 夏军宏. 柴油机注汽涡轮增压系统[J]. 热能动力工程, 2003, 18(2): 190-193.
 [3] 陆 翀, 闻雪友. 注蒸汽对涡轮增压器的影响[J]. 热能动力工程, 2003, 18(3): 272-275.

verized coal a study was conducted of the operating characteristics of the MPS coal pulverizer. During a series of tests a study was conducted to mainly identify the impact of some major factors on the operating characteristics of the MPS coal pulverizer. Such factors include: the damper opening degree of a static classifier, the rotating speed of a dynamic classifier, the hydraulic loading force of a grinding roll, pulverizer inlet temperature and primary airflow rate. The above study can be helpful in providing design reference data for domestic manufacturers of the MPS coal pulverizer and offering operational guide for MPS coal pulverizers now in commission and also those soon to be put into operation. **Key words:** zero-pressure pendulum sampler, isokinetic sampling of pulverized coal, MPS coal pulverizer

加湿热空气对流冷凝换热冷凝液量的实验研究 = **Experimental Research of Condensate Flow Rate of Convection-condensation Heat Exchange of Humidified Hot Air Flow** [刊, 汉] / ZHUANG Zheng-ning, LI Jiang-long, CHE De-fu, et al (College of Energy & Power Engineering under the Xi'an Jiaotong University, Xi'an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 69 ~ 72

The condensing heating surfaces of a condensing-type gas-fired boiler were used to serve as a prototype. On this basis a simulation of the flue gases in the above-mentioned boiler tail section was conducted by using humidified hot air. Through a single-row bare-tube recuperator a condensation heat exchange was carried out. Within a relatively wide range of humidified hot air temperature (100-200 °C) and vapor volumetric factor (4%-16%) a study was conducted of the generation law of condensate flow rate. The result of tests indicate that vapor partial pressure, cooling water flow rate and humidified hot airflow rate are major influencing factors of vapor condensate flow rate. Vapor condensation rate is 40% - 75%. After a multivariate linear regression analysis of experimental data a new empirical relation was proposed to calculate the condensate flow rate. **Key words:** condensation type boiler, humidified hot air, condensate, convection condensation heat exchange

非均等配风下的风水冷选择性冷渣器冷态排渣特性 = **Cold-state Slag Discharge Characteristics of an Air-water Cooled Selective Slag Cooler under a Non-uniform Air Distribution** [刊, 汉] / YE Xue-min, LI Chun-xi, FAN Xu, et al (Department of Power Engineering, North China University of Electric Power, Baoding, China, Post Code: 071003) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 73 ~ 75

With the air-water cooled selective slag cooler of a 450 t/h circulating fluidized bed boiler serving as a prototype and through a cold-state simulation test a study was conducted of the slag discharge characteristics in various chambers under a uniform and non-uniform air distribution. The impact of airflow ratios in various chambers on the slag discharge rate was analyzed. The results of the tests indicate that the lower limit of actual fluidized airflow of the slag cooler is higher than the design value. Under the condition of a basically unchanged total airflow rate of an air blower and even under a decreased airflow rate and through adjustment of airflow ratio in various chambers it is possible to significantly enhance the slag discharge speed of the slag cooler. The experimental data thus obtained can serve as a guide and reference for ensuring the safe operation of slag coolers. **Key words:** circulating fluidized bed, air-water cooled selective slag cooler, slag discharge characteristics, non-uniform air distribution

注汽涡轮增压柴油机的试验研究 = **Experimental Study of a Steam-injected Turbo-charged Diesel** [刊, 汉] / LU Ben (Key Laboratory of Thermal Power Engineering & Thermal Sciences under the Tsinghua University, Beijing, China, Post Code: 100084), WEN Xue-you (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 76 ~ 79

Tests were conducted on a steam-injected turbo-charged diesel, a new type of power system. Under various diesel operat-

ing conditions the impact of the flow rate and temperature of steam injected into a turbocharger turbine on the performance of the turbocharger and turbo-charged diesel was identified along with an analysis of the results. The effectiveness of the steam-injected turbo-charged diesel in improving its part load performance has been verified. **Key words:** turbo-charged diesel, steam-injected turbocharger

再析 N-11220-1 型凝汽器热力特性与改造措施 = **A Renewed Analysis of the Thermodynamic Characteristics and Measures Taken at the Retrofitting of a N-11220-1 Condenser** [刊, 汉] / WANG Guo-shan, MAO Xing-qing (College of Mechanical and Power Engineering under the Jiaotong University, Shanghai, China, Post Code: 200030) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 80~84

By using the latest edition of self-developed software PPOC3.0 designed for the numerical simulation of condensers a renewed numerical calculation and analysis was conducted of the thermodynamic characteristics of a power-plant Chinese-made condenser (Model N-11220-1) at its designed operating condition. Numerous numerical simulation tests aimed at addressing the problem of a relatively great steam flow resistance in this type of condenser indicate that the relatively great steam flow resistance at the condenser shell-side was mainly caused by a irrational layout of the steam passage of the condenser. Further numerical calculations and analyses have shown that for such condensers already put into operation there exist two methods of retrofitting to improve their operating performance. They are either an increase in steam passage dimensions around the condenser tube bundles or a replacement of the old tube bundles by new and more advanced ones. **Key words:** power plant condenser, thermodynamic characteristics, numerical analysis, retrofitting

湿法烟气脱硫吸收塔循环氧化槽的改进 = **An Improvement on the Circulation Oxidation Tank of an Absorption Tower for Wet Flue-gas Desulfurization** [刊, 汉] / DU Qian, WU Shao-hua, LIU Hui, et al (College of Energy Science & Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 85~88

After the three towers of a wet flue-gas desulfurization system was grouped into one, there emerged the problem of a decrease in desulfurization efficiency and gypsum quality. To cope with this problem, an improved scheme was put forward, which consists in dividing the circulation oxidation tank at the bottom of the absorption tower into an oxidation tank and a material-feed tank. Moreover, tests were conducted on a parallel-flow falling-film wet desulfurization plant before and after the implementation of the improved scheme. The results of the tests indicate that the improved desulfurization plant has alleviated the contradiction between the desulfurization efficiency and the gypsum quality. The high pH value of the material-feed tank makes it possible to maintain a high desulfurization efficiency in the tower, while the low pH value of the oxidation tank is favorable to the dissolution of limestone and the oxidation of SIV, thereby enhancing the quality of gypsum. **Key words:** wet flue-gas desulfurization, oxidation tank, material-feed tank, gypsum

煤粉浓缩预热调节燃烧系统在 150 t/h 煤粉炉上的应用 = **The Application of a Combustion System of Pulverized Coal Concentration and Preheating Regulation on a 150 t/h Pulverized Coal-fired Boiler** [刊, 汉] / ZHANG Jian-sheng, LU Jun-fu, ZHANG Hai, et al (Department of Thermal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(1). — 89~92

A description is given of a combustion system newly developed by Tsinghua University, which comprises an automatic control unit for concentrating primary pulverized coal and preheating primary air. The combustion system utilizes a primary-air pipe bend to carry out dense/lean separation of the pulverized coal, and features a simple construction and good separation efficiency. Through temperature measurements it is possible to control the opening degree of a preheat-regulat-