

压缩机中间冷却器采用不锈钢波纹管的试验研究

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摘要: 采用新型不锈钢波纹管代替壳管式换热器中的直管, 对压缩机中间冷却器进行了改造, 并进行了实际运行测试和比较分析。结果表明: 波纹管换热器的天然气出口温度能够达到甚至低于压缩机的设计值。换热效率比列管换热器的高 61%, 压缩机的操作正常平稳, 维护工作量大大降低, 达到长周期运行的目的。

关键词: 压缩机中间冷却器; 新型不锈钢波纹管; 高效能换热器; 试验研究

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1 前言

近年来波纹管型换热器以其传热效果好, 同时具有原传统的固定管板换热器结构简单、适用性强等优点, 在热电系统、化工、医药、食品等行业获得广泛的应用。这种换热器采用波节型强化换热管代替壳管式换热器中的直管, 将波节管的优点与壳管结构的优点结合起来, 成为一种新型、高效能的换热器。但从目前波纹管型换热器的运行情况看, 最致命的弱点是承压低、容易发生内漏, 导致个别波纹管断裂, 换热效率降低, 经济损失巨大甚至发生危险。

本文介绍了一种新型不锈钢多层波纹管的构造, 并应用该种波纹管对 2D12 型压缩机中间冷却器进行了改造。该中间冷却器原为普通列管式, 管程采用 $\Phi 10$ 铜管的光管, 传热效率低, 尤其是夏季冷却水温较高时, 无法达到冷却效果, 并且铜管管径太小, 容易堵塞, 清理维护困难, 多次清洗后容易造成泄漏。采用新型不锈钢波纹管替换中间冷却器中的直管, 进行实际运行测试和比较分析后的结果表明: 波纹管换热器的天然气出口温度能够达到甚至低于压缩机的设计值。换热效率比列管换热器高 61%, 压缩机的操作正常平稳, 维护工作量大大降低, 达到长周期运行的目的。

2 新型不锈钢多层波纹管的构造

选取壁厚为 $\delta = 0.4 \sim 0.5$ mm 的特种不锈钢板材, 冲压卷成外径为 $D_0 = 20 \sim 34$ mm 的几种规格圆形薄壁光管, 直径相差 $\Delta d = 0.8 \sim 1.0$ mm, 将焊缝错开套装成多层薄壁圆形光管, 在经特殊工艺凸起成型为多层波纹管, 凸起直径达基管直径的 1.2 倍。图 1 为波纹管换热元件。

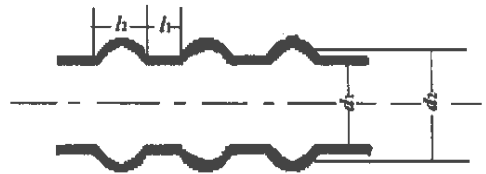


图 1 波纹管换热元件

两层波纹管基本结构计算知:

$$\frac{d_2}{d_1} = 1.3 \quad \frac{l_2}{l_1} = 0.3 \quad \frac{l_1}{d_1} = 0.35$$

式中: d_2 —弧形段内径, m; d_1 —直线段内径, m; l_2 —弧形段长度, m; l_1 —直线段长度, m。

新型不锈钢波纹管的波峰与波谷之间高度为 10 mm 左右, 管内流动分为等直径流速型式和弧形流速型式, 由于流速和压力周期性的变化, 冷热流体流动时会产生强烈扰动, 使流体的流动状态达到充分湍流, 极大破坏了边界层和污垢层的实际厚度, 因此比直管的换热系数明显提高。同时超薄设计 (0.5 ~ 0.8 mm), 热阻很小, 波峰与波谷的存在, 使其轴向伸缩能力较强, 有效地减小了温差应力, 适应温度变化。另外, 波纹管的表面曲率大, 可伸缩, 产生结垢容易脱落, 因此, 具有较强的防垢和自动除垢能力。

现今市场上的不锈钢波纹管是由不锈钢无缝管涨制而成, 而新型不锈钢波纹管是采用两层以上板

材焊缝错开套装而成, 由于板材和无缝管的加工工艺不同且采用多层, 因此可承担较高压力, 有效地防止内漏的发生。

3 波纹管换热器的设计与运行测试

波纹管换热器的设计考虑了以下 3 个条件:

(1) 波纹管换热器的管束为波纹管, 管程不能采用径向折流板, 只能采用轴向折流板。

(2) 波纹管换热器在运行中, 要析出冷凝液, 应该考虑到冷凝液的排放, 即天然气出口位置尽可能低, 管程折流板开适当的排液孔。

(3) 为了不改变压缩机冷却水管线与中间冷却器原接口位置, 波纹管换热器的管程和壳程进出口位置应以现场安装尺寸为准。

设计条件: 天然气进口温度: 100 °C ~ 110 °C

天然气出口温度: 35 °C ~ 40 °C

天然气流量: 4 200 m³/h

冷却水进口温度: 30 °C ~ 35 °C

冷却水出口温度: 40 °C ~ 45 °C

冷却水流量: ≤ 45 m³/h

设计结果: 设计压力 1.0 MPa 设计温度 150 °C

工作压力 0.4 MPa 换热面积 45 m²

规格: Φ700 × 2110

结构: 管程数 2 壳程数 3

波节换热管: Φ32 × 0.8 × 2110

材质: 0Cr18Ni9Ti 数量 204 根

将安装了波纹管的换热器(1号机)与普通列管换热器(2号机)分别进行了运行测试, 测试条件见表 1, 测试结果见表 2。

表 1 测试条件

	管程	壳程
工作压力 /MPa	0.4	1.2
介 质	水	天然气
流 量	19 620 kg/h	4 200 m ³ /h

根据天然气的组分, 以下午 1 时的实测数据为准, 分别计算了两种机型的换热量, 结果如下:

表 2 两种换热器实测数据比较

介质	进出口	不同时间的实测温度 / °C					
		普通列管换热器 (2号机)			波纹管换热器 (1号机)		
		8:00 时	13:00 时	16:00 时	8:00 时	13:00 时	16:00 时
天然气	入口	92	94	95	93	94	95
	出口	53	54	54	32	34	34
冷却水	入口	20	22	22	20	22	22
	出口	22.5	25	25	26	28	28

换热面积: 2号机 $A_1 = 58 \text{ m}^2$

1号机 $A_2 = 45 \text{ m}^2$

2号机换热量: $\Sigma q_i = (94 - 54) \times \Sigma (m_i \times C_{pi}) / A_1 = 1\ 560.05 \text{ W}$

1号机换热量: $\Sigma Q_i = (94 - 44) \times \Sigma (m_i \times C_{pi}) / A_2 = 2\ 516.10 \text{ W}$

换热量比率 $(\Sigma Q_i - \Sigma q_i) / \Sigma q_i = 61\%$

从计算结果可以看出, 波纹管换热器的换热效率比列管换热器高 61%。

4 结论

(1) 波纹管换热器的换热效率高于原普通列管式换热器, 在压缩机原运行环境下, 波纹管换热器的天然气出口温度能够达到甚至低于压缩机的设计值。

(2) 波纹管换热器的管束采用不锈钢, 耐腐蚀, 适应较大的温差应力, 不易泄漏, 使压缩机的操作正常平稳, 维护工作量大大降低, 达到长周期运行的目的。

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欢迎投稿

欢迎订阅

(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-