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多股流板翅式换热器温度交叉的数值分析

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摘　要: 以平行多股流板翅式换热器为研究对象, 给出了考虑翅片旁通作用的多股流板翅式换热器流体和翅片的能量方程。在改变多股流板翅式换热器各通道的流体参数、流动方式及换热器的结构参数等情况下, 对能量方程进行数值求解, 获得了各通道的流体温度分布情况及相邻通道的流体温度差, 并分析了流体参数、流动方式和结构参数的变化对相邻通道流体温度交叉的影响。

关　键　词: 多股流板翅式换热器; 温度交叉; 翅片旁通; 流动方式

中图分类号: TK172; O351. 2　　文献标识码: A

1　引　言

多股流板翅式换热器作为紧凑式换热器的一种, 由于其效率高、投资少、结构紧凑等突出优点而应用于石油化工、能源动力及其它工业部门。多股流板翅式换热器的流动和传热情况非常复杂, 通道排列和翅片旁通效应都可以影响多股流板翅式换热器的性能, 因此近年来许多研究者对多股流板翅式换热器的性能预测进行了研究。B. S. V. Prasad[1~2] 介绍了多股流板翅式换热器性能评估算法的发展和应用, 研究了多股流板翅式热交换器的性能预测方法, 考虑了翅片旁通的影响, 并发现在其研究的问题中翅片旁通对换热器的性能有利。王松汉[3] 介绍了由于多股流板翅式换热器通道排列的不同可能导致温度交叉现象, 这种温度交叉与文献[4] 讨论的换热器温度交叉不同, 前一种情况出现冷流体变热流体、热流体变成冷流体的现象; 而后一种情况冷、热流体温度只是接近至相同, 但在这两种情况下都会对换热器的性能产生一定的负面影响。

通过对多股流板翅式换热器的能量方程进行数值计算, 获得了各通道的流体温度分布情况及相邻通道的流体温度差, 发现在某些工况下, 相邻通道会出现温度交叉现象, 其交叉程度的大小与各通道流体的工况参数、流动方式以及换热器的结构参数的不同等因素有关, 并分析了这些因素对温度交叉的影响。

2　理论模型

取矩形截面平直型板翅通道为模型实体, 如图 1 所示, 建立多股流板翅式换热器的数学模型[5]。流体能量方程:

$$(FGC_P)_i \frac{dT_{i(z)}}{dZ} = (1-\xi\delta)_i\alpha_i(t_{i(0,z)} + t_{i(bi,z)} - 2T_{i(z)}) + 2\xi_i\alpha_i\int_0^{bi}(t_{i(x,z)} - 2T_{i(z)})dx \quad (1)$$

翅片导热方程:

$$(\xi\delta)_i\lambda\left(\frac{\partial^2 t_{i(x,z)}}{\partial x^2} + \frac{\partial^2 t_{i(x,z)}}{\partial z^2}\right) - 2\xi_i\alpha_i(t_{i(x,z)} - T_{i(z)}) = 0 \quad (2)$$

式中: 下标 i 代表第 i 通道, T, t 分别表示流体、翅片温度, ξ 为单位通道宽度上的翅片数, F 流动方向符号, 当取某一流体流动方向为参考基准(本文为流体 1) 时, 与之相同的为 $F=+1$, 反之则为 $F=-1$。

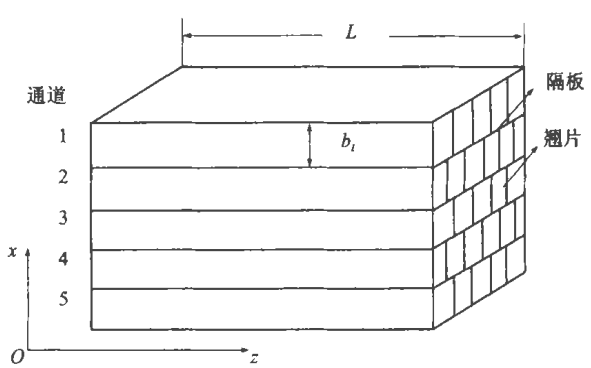

图 1　三股流换热器物理模型

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$Z = 0$, $T_{i(0)} = T_{i,\mathrm{IN}}$, $(F = +1)$; $Z = L$, $T_{i(L)} = T_{i,\mathrm{IN}}$ $(F = -1)$ (3)

$$\frac{\partial t_{i(x,z)}}{\partial z}\Big|_{z=0} = 0;\quad \frac{\partial t_{i(x,z)}}{\partial z}\Big|_{z=L} = 0 \tag{4}$$

式中: $T_{i,\mathrm{IN}}$ 为各通道进口温度, L 为换热器长度。

3 计算结果及讨论

本文的数值计算以一个三股流五通道板翅式换热器为对象, 其中通道 1 和 5、2 和 4 中分别通过相同的流体, 采取对称布置的方式[5]。

能量方程组的求解采用有限差分法, 中间节点用中心差分, 边界节点用向前或向后差分, 流体温度和翅片温度采用交替迭代的方法求解[6]。

流体参数的变动以文献[5]中实验值为基础, 改变流体参数时, 三股流体中的某一股流体按表 1 所示参数值变动, 其它流体参数保持原实验值不变, 分别在不同的工况点下计算流体温度分布及相邻通道的流体温度差(图 2 ~ 图 4)。

改变五个通道中 2(4) 通道的流动方向, 使其与其它通道的流动形成逆流和顺流两种流动方式, 并分别在两种情况下改变 2(4) 通道和 3 通道流体的流量, 计算得到 2(4) 通道和 3 通道的流体温度差在逆流和顺流两种流动方式下随流量变化的曲线(图 5)。

表 1 各通道的流动方式与工况改变的参数值

通道	流动方式		工况点(流量 G/kg·(s·m)$^{-1}$, 温度 T/℃)				
	顺流	逆流	K_1	K_2	K_3	K_4	K_5
1(5)	→	→	1.08, 9.8	1.08, 9.8	1.08, 9.8	1.08, 9.8	1.08, 9.8
2(4)	→	←	0.6, 31.0	0.8, 32.0	1.0, 34.0	1.2, 36.0	1.4, 38.0
3	→	→	0.6, 34.0	0.8, 35.0	1.0, 37.0	1.2, 39.0	1.4, 41.0

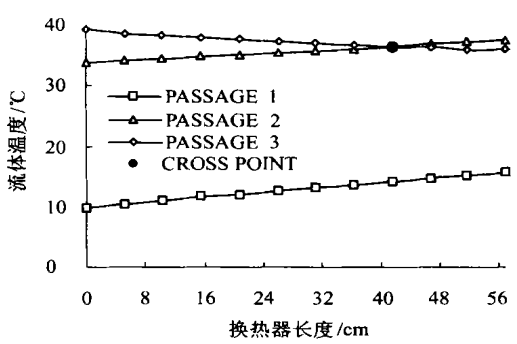


图 2 1、2、3 通道的流体温度

由计算得到的各条曲线可以看出 2(4) 通道与 3 通道之间的流体温度差(负值为温度交叉值)与流体参数、流动方式和换热器结构参数之间的关系。

图 2 为某一工况下的流体温度分布, 从图 2 可以看出, 因 1(5) 通道流体温度较低, 吸收热量使温度升高, 但由于和相邻的 2(4) 通道流体的温度相差较大, 在整个换热流程中 2(4) 通道流体的温度始终高于 1(5) 通道流体的温度, 故没有温度交叉现象发生。由于 1(5) 通道冷流体的存在, 它通过中介通道 2(4) 的翅片旁通作用与 3 通道热流体之间进行热传递, 加速了 3 通道中流体温度的下降速度, 当这种热传递作用达到一定程度时, 就会出现图 2 中从黑点表示的交叉点开始以后的温度交叉现象, 2(4) 通道的流体温度反而高于 3 通道的流体温度, 也就是出现了原来的冷流体变成热流体, 原来的热流体变成冷流体的现象, 这样的结果将导致热量向相反的方向传递(对 2(4) 和 3 通道而言), 对换热器整体的传热会产生一定的负作用。

3.1 各通道的流体参数对温度交叉的影响

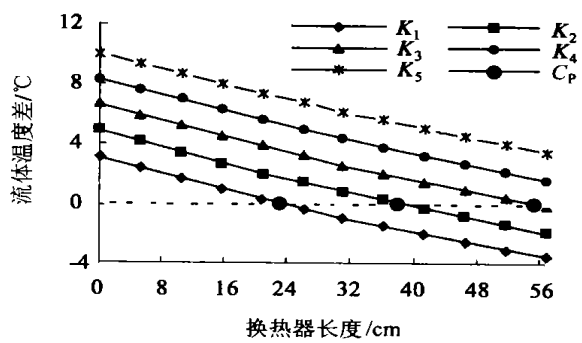


图 3 改变 3 通道流体参数时 2(4) 和 3 通道的流体温度差

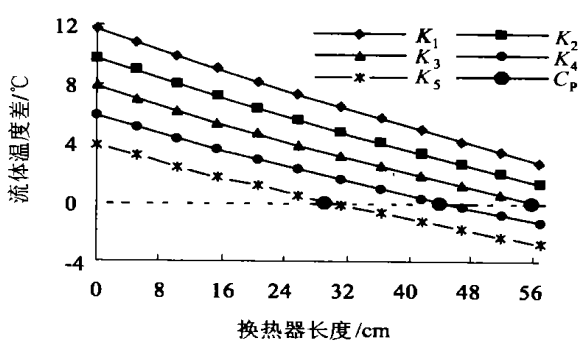


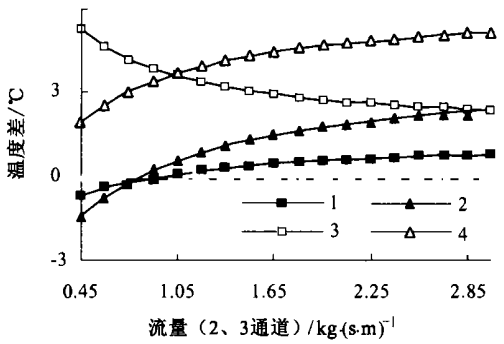
图 4 改变 2(4) 通道流体参数时 2(4) 和 3 通道的流体温度差

由图 3 可以看出, 随着 3 通道流体参数的减小(由 $K_5 - K_1$), 2(4) 和 3 通道之间的流体温度差减小, 从某一工况(图 3 中的 K_3 工况)开始将出现温度

交叉, 并且温度交叉值随流体参数的减小而增加。

由图 4 可以看出, 2(4)通道流体参数的变化对 2(4)和 3 通道流体温度差的影响作用与 3 通道流体参数的变化对其的影响相反, 也就是随着流体参数的增加(由 K_1—K_5), 2(4)和 3 通道之间的流体温度差减小, 而温度交叉值也随着 2(4)通道流体参数的增加而增加。

3.2　流动方式对温度交叉的影响



1—逆流改变2(4)通道流体流量; 2—逆流方式改变3通道流体流量
3—顺流改变2(4)通道流体流量; 4—顺流方式改变3通道流体流量

图 5　流动方式对 2 和 3 通道流体温度差的影响

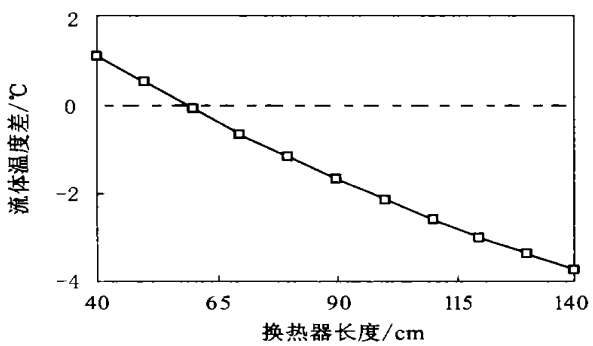


图 6　2(4)和 3 通道的流体温度差随换热器长度的变化

由图 5 可以看出, 逆流方式时改变 2(4)通道和 3 通道的流体流量对温度差的影响相同, 顺流方式时改变 2(4)通道和 3 通道的流体流量对温度差的影响却相反。但无论是改变 2(4)通道流体的流量还是改变 3 通道流体的流量, 在本文研究范围内逆流的温度差比顺流时小, 逆流在某些工况出现了温度交叉, 而顺流没有出现温度交叉现象。

3.3　换热器结构参数对温度交叉的影响

由图 6 可以看出, 随着换热器长度的增加温度差将减小, 在某一长度处出现温度交叉, 然后随着长度的增加温度交叉值逐渐增大, 这是由于长度的增加使得翅片旁通的作用更加充分的结果。

由图 7 可以看出, 随着翅片高度的减少, 温度差亦减少, 在出现温度交叉现象时温度交叉值增大, 由此可以看出当翅片高度减少时, 翅片旁通的作用是增强的, 它能够将更多的热量在相互间隔的二通道间传递。

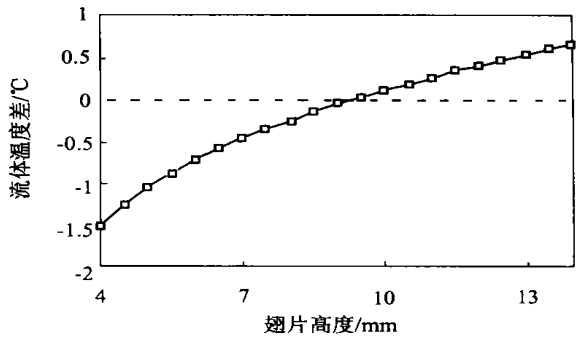


图 7　2(4)和 3 通道的流体温度差随翅片高度的变化

4　结论

通过以上的讨论, 可以在本文研究的范围内, 得出如下结论:

(1)多股流板翅式换热器在一定的工况下可能出现相邻通道的温度交叉现象;

(2)不同的工况参数、流动方式及结构参数对换热器的温度交叉都将产生影响, 只是影响的程度不同;

(3)翅片旁通是多股流板翅式换热器产生温度交叉的根本原因, 因此应对翅片旁通对换热器性能的影响做具体的分析。

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(辉　编辑)

"W" Flame Boiler [刊, 汉] / MIAO Chang-xin, LIU Zhi-chao (Shandong Electric Power Research Institute, Jinan, China, Post Code: 250002) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —599 ~ 602, 631

Presented are the design features and combustion characteristics of a W-flame boiler designed and manufactured by British MBEL Co. and installed at Heze Power Plant. In connection with the commissioning test results expounded and analyzed are the air distribution of burners, the characteristics of fuel burn-out and NOx and SO_2 emissions. In addition, there existed a whole range of problems, such as the poor mixing of combustion-air distribution in a parallel-flow field at a later stage, the slag formation on a lower furnace refractory-belt, and the excessive amount of NOx emissions. To deal with these problems, the authors have made some preliminary recommendations to alleviate them. **Key words**: W-flame boiler, design features, combustion characteristics, proposals for improvement

内置过滤元件流化床的最小流化速度= **Minimum Fluidizing Speed of a Fluidized Bed with Built-in Filtration Elements** [刊, 汉] / ZHANG Shi-hong, LIU De-chang, ZHENG Chu-guang (National Key Laboratory of Coal Combustion under the Huazhong University of Science & Technology, Wuhan, China, Post Code: 430074) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —603 ~ 606

With a novel fluidized-bed granular filter (FBGF) serving as an object of application an experimental investigation was conducted of the minimum fluidizing speed of a fluidized bed with built-in filtration elements. It has been discovered by the investigation that the greater the effective area of immersed material layer of the filtration element, the greater the minimum fluidizing speed. In this regard a dimensionless magnitude has been defined as the ratio between the following two items: the effective surface area of a filtration element immersed in the bed material, and the fluidized bed cross-section area. And, by means of regression obtained was an empirical expression of the minimum fluidizing speed of a fluidized bed with built-in filtration elements. This has laid a solid basis for the further study of a fluidized-bed granular filter. **Key words**: minimum fluidizing speed, fluidized bed with built-in filtration elements, granular filter

连续转子轴承系统的非线性动力学行为研究= **Research on the Nonlinear Dynamic Behavior of a Continuous Rotor-bearing System** [刊, 汉] / JING Jian-ping, SUN Yi, XIA Song-bo (School of Energy Science & Engineering under the Harbin Institute of Technology, Harbin, China, Post Code: 150001), LI Jian-zhao (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. - 2002, 17(6). —607 ~ 610

By using a finite element method a nonlinear continuous rotor-bearing system model has been set up for a rotor-bearing system. With the use of respectively a direct integration method and modality synthesis method the rotor nonlinear dynamic behavior under unbalanced conditions was analyzed. The results of comparison of the above two methods indicate that the direct integration method is more effective for solving nonlinear vibration problems. The rotor-bearing system was analyzed by using a simple discrete method. The results of the analysis are quite different from those obtained under the finite-element analysis method. The results of the latter method show that the dynamic response of a rotor-bearing system is of a typical oil-whip process with its nonlinear dynamic-motion behavior being of a Hopf bifurcation form. **Key words**: continuous rotor system, nonlinearity, finite element, oil whip

多股流板翅式换热器温度交叉的数值分析= **Numerical Analysis of the Temperature Crossover of a Multi-stream Plate-fin Heat Exchanger** [刊, 汉] / LU Hong-bo, CUI Guo-min, LI Mei-ling (Research Institute of Thermal Energy Engineering under the Shanghai University of Science & Technology, Shanghai, China, Post Code: 200093) // Journal of Engineering for Thermal Energy & Power. — 2002, 17(6). —611 ~ 613

With a parallel multi-stream plate-fin heat exchanger serving as a target of study the authors have presented an energy equation for both the fluid and fins of the said heat exchanger, taking into account the bypass effect of the fins. A numerical solution is conducted of the energy equation under the conditions of changing the fluid parameters and flow modes of

various channels as well as the structural parameters of the heat exchanger. As a result, obtained were the fluid temperature distribution of various channels and the fluid temperature difference of neighboring channels. Furthermore, analyzed was the effect of the variation of fluid parameters, flow modes and structural parameters on the fluid temperature crossover of the neighboring channels. **Key words**: multi-stream plate-fin heat exchanger, temperature crossover, fin bypass, flow mode

烟气含氧量软测量新方法研究＝**The Study of a New Method Incorporating the Soft Sensing of Oxygen-content in Flue Gases** [刊, 汉] / LU Yong, XU Xiang-dong (Department of Thermal Engineering, Tsinghua University, Beijing, China, Post Code: 100084) //Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —614～617

In view of the high first cost of conventional oxygen-content analyzers for industrial applications, their high maintenance expenses and low durability the authors have on the basis of comparing several commonly used methods come up with a new method for measuring oxygen content in flue gases. The proposed method involves an oxygen-content soft sensing model set up through the use of a NNPLS (neutral network partial least square) approach based on statistical analyses and neural network technology. It enjoys both the merits of PLSR (partial least square regression) and neural network technology, making it possible to identify a target model by utilizing historical process data. A simulation verification of the method has been conducted by using on-site industrial data. In addition, the simulation results are compared with traditional linear PLSR method and the direct neural network-based modeling method. The results of comparison indicate that the soft sensing model based on the NNPLS approach features a more effective generalizing ability. Furthermore, an extension of a static model to a dynamic one was also performed. **Key words**: soft sensing, partial two least squares, neural network, cross validation, generalizing ability

用预报误差校正的锅炉燃烧系统预测控制研究＝**A Study of the Predictive Control of a Boiler Combustion System through the Correction of a Forecast Error** [刊, 汉] / ZHU Xue-li, QI Wei-gui, LI Li-yan (School of Electric Engineering and Automation under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) //Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —618～621

To improve the performance of a boiler-combustion control system, a dynamic matrix control (DMC)-based algorithm with the correction of a forecast error has been put forward to fulfill relevant control functions. After a brief description of the DMC composition and an internal-model control structure a model error is predicted based on a time sequence analysis, parameter estimation and an optimum forecast theory. Furthermore, by forecasting the model error and using the model forecast error to replace the model error the rolling optimization of a predictive control can be duly corrected. Finally, through the simulation tests of the predictive control for the boiler control system it is shown that the correction of the forecast error can result in a marked improvement in such characteristics as tracking ability, anti-interference and robustness when compared with an error correction algorithm in general. **Key words**: combustion system, predictive control, time sequence, forecast error

劳伦斯法在热工对象动态特性辨识中的应用＝**The Application of Lawrence Algorithm in the Identification of Dynamic Behavior of Thermodynamic Objects** [刊, 汉] / XU Hou-qian, JIANG Gui-zhen (Power Engineering College under the Nanjing University of Science &Technology, Nanjing, China, Post Code: 210094) //Journal of Engineering for Thermal Energy &Power. — 2002, 17(6). —622～624

Described is the process of a transfer-function fitting performed through the use of Lawrence algorithm by way of frequency domain data. Furthermore, the above method was employed to conduct the fitting of transfer functions for a split-shaft gas turbine under three operating conditions. Under various operating conditions the results of fitting agree relatively well with those of experiments, testifying to the credibility of the Lawrence algorithm. In addition, by using a method, which com-