

气液两相流流经突缩再突扩管道的压力降研究

吴东垠 (电力部热工研究院)

林宗虎 (西安交通大学)

〔摘要〕 突缩再突扩管道并非突缩和突扩接头的简单叠加。试验发现,当突缩、突扩接头的距离一定时,管道压力降与两相流干度和气体流量有关,文中由此得出了相应的计算式。

关键词 突扩 突缩 气液两相流 压力降

分类号 TK222

符号说明:

P —两相流的静压, Pa;

A —管道的截面积, m^2 ;

A_c —突缩部分的喉口截面积, m^2 ;

β —管道的两截面积之比;

α —截面含气率;

x —两相流的干度;

G_m —两相流的质量流速, $\text{kg}/(\text{m}^2 \cdot \text{s})$;

ρ_0 —气体的密度, kg/m^3 ;

ρ_L —液体的密度, kg/m^3 ;

W_0 —气体的质量流量, kg/s ;

ΔP_M —局部阻力压力降, Pa;

η —突缩再突扩管道的两相流静压降的修正系数。

角标: G—气相 L—液相

1 综述

在并联管子系统中,两相流体沿联箱的压力分布以及流量分配是一个重要而复杂的问题,作者就此进行了专门的试验研究^{〔1〕}。在

试验过程中,为了流量分配均匀,在分配联箱过渡区装设了小截面加速管,用来提高分配联箱内的轴向流速,在加速管两端形成了突缩再突扩管道。

1.1 气液两相流流经突扩接头和突缩接头的压力降

文献〔2〕列出了突缩接头和突扩接头的压力降计算式。

设气液两相流流经突扩接头作分相流动时,如图1所示,截面1和截面2的静压差如下:

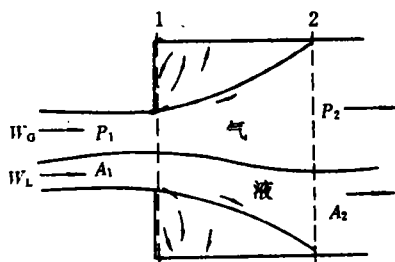


图1 突扩接头两相流动工况

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$$P_2 - P_1 = \frac{G^2 \beta (1 - \beta)}{\rho_L} \left[\frac{(1 - x)^2}{(1 - \alpha)} + \left(\frac{\rho_L}{\rho_0} \right) \frac{x^2}{\alpha} \right] \quad (1)$$

当流过突扩接头的气液两相流是均相流动时,则两截面之间的静压降为:

$$P_2 - P_1 = \frac{G^2 \beta (1 - \beta)}{\rho_L} [1 + x \left(\frac{\rho_L}{\rho_0} - 1 \right)] \quad (2)$$

气液两相流体流过突缩接头时的流动工况示于图2。如令 $\beta_c = A_c/A_2$, 其中 A_c 为喉口截面 C 的流体截面积, 为试验值。

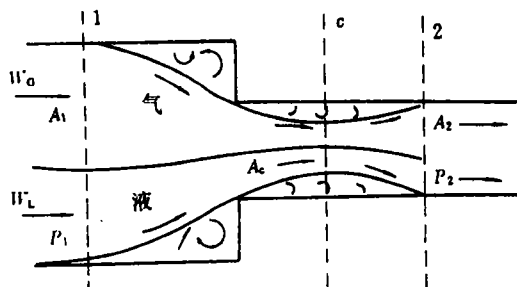
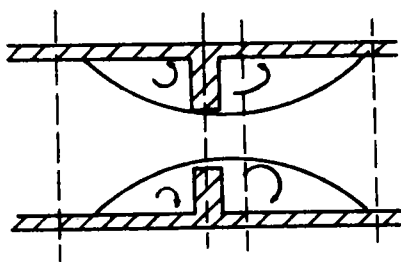
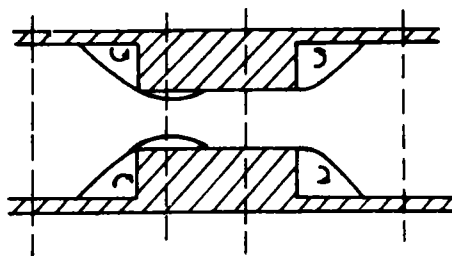


图2 突缩接头两相流动工况



(a) 长插入



(b) 短插入

图3 矩形管道中加入锐边插入物的示意图

在图3(a)中,对于长的锐边插入物来说,管道收缩部分得到充分发展,可以把突缩接头和突扩接头分开计算;在图3(b)中,对于短的锐边插入物来说,其收缩截面在节流件外形成,两端的压力降可以按孔板公式计算。

以上两种情况均有较成熟的理论,现有的计算方法已能进行计算。但是,对于锐边插

入物介于长插入和短插入之间的情况却没有进行研究,完成这方面的工作十分必要。

对于分相流动,气液两相流体流过突缩接头的静压降为:

$$P_1 - P_2 = \Delta P_m + G^2 (1/\beta^2 - 1) \left[\frac{x^3}{\alpha^2 \rho_0^2} + \frac{(1-x)^3}{\rho_L^2 (1-\alpha)^2} \right] \quad (3)$$

$$2 \left[\frac{x}{\rho_0} + \frac{(1-x)}{\rho_L} \right]$$

对于均相流动模型,静压降则可按下式计算:

$$P_1 - P_2 = \frac{G^2}{2\rho_L} \left[\left(\frac{1}{\beta_c} - 1 \right)^2 + (1 - \beta^2) \right] \quad (4)$$

$$[1 + x \left(\frac{\rho_L}{\rho_0} - 1 \right)]$$

1.2 矩形垂直管道中有锐边插入物时的两相流压力降

A Tapucuetal 研究了常压下在矩形垂直管道中有锐边插入物时的两相流压力降^[3]。在该项研究中,是以突缩接头连着一个突扩接头,中间放入锐边插入物为研究对象。根据锐边插入物的长度,分两种极限情况,即短插入和长插入,如图3所示。

入物介于长插入和短插入之间的情况却没有进行研究,完成这方面的工作十分必要。

2 试验研究

以图4所示的突缩再突扩管道为研究对象。选用工质为水—空气混合物,试验参数

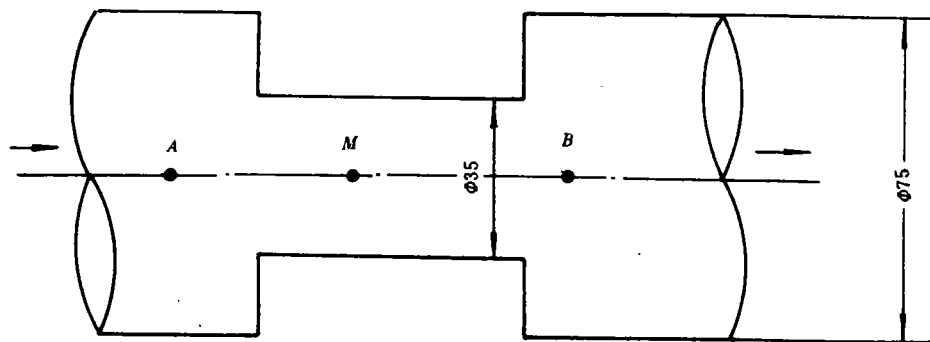


图4 突缩再突扩管道流动工况

范围如下:

压力: $P = 0.102 \sim 0.135 \text{ MPa}$;

质量流速: $G = 10 \sim 240 \text{ kg}/(\text{m}^2 \cdot \text{s})$;

质量含气率: $x = 0.10 \sim 0.70$ 。

在图4所示的通道流过气液两相流,通道A、B两点所处的圆截面各钻有 $12 \times \phi 1.8 \text{ mm}$ 的取压孔,气水混合物通过这些小孔流入套在外面的取压环,从取压环引出的气水混合物经过气水分离器将气水分离。最后,把气体引入U型管差压计用来测量A、B两点的压差,根据压力的大小,差压计内分别以四氯化碳、水银为介质。

在试验过程中,先将空气调至一定参数,改变水的流量,待工况稳定后,记录有关数据。空气流量由转子流量计监视,而水和空气的质量流量及两相流干度是应用林宗虎教授的专利——单孔板双相流量计测量^[4]。

3 理论分析

如图4所示,试验测得通道两端A、B两点的静压差为 $P_a - P_b$,设M点的静压为 P_m ,该点所处截面的质量流量为 G_m ,而A、B两点的静压分别为 P_a, P_b 。因此, $P_a - P_m$ 为突缩接头的静压差, $P_b - P_m$ 为突扩接头的静压差,通道两端的静压差 $P_a - P_b$ 由突缩接头的静压差 $P_a - P_m$ 和突扩接头的静压差 $P_b - P_m$ 之

差求得。

在本文试验范围内,由于管道截面积较小,两相流的质量流速较大,管内两相流体接近均相流动,经过计算也可以发现按均相模型计算式更接近试验值,联立式(2)和式(4),并化简可得均相模型计算式。

$$P_a - P_b = [1 + x(\frac{P_L}{P_0} - 1)] \frac{G_m^2}{P_L} \left\{ \frac{1}{2} \left[\left(\frac{1}{\beta_c} - 1 \right)^2 + (1 - \beta^2) \right] - \beta(1 - \beta) \right\} \quad (5)$$

尽管如此,应用式(5)计算所得的计算值与试验值相比误差仍然很大,其最大相对误差达到 $\pm 40\%$ 。这是因为直圆管中的流场因局部损失的存在而改变,流场要经过一段距离后才能消除该局部损失的影响,重新建立正常的流场和稳定的流型,对于气液两相流动来讲,局部损失的涉及长度更长。式(5)只有在突缩接头和突扩接头之间的距离比较大时才能适用,而两接头距离比较小时,两端压力降则可以用孔板公式进行计算。显然,文中试验研究管道的突扩接头和突缩接头之间的距离介于上述两种情况之间,两接头的局部损失相互影响,直接叠加必然会产生误差,在计算过程中需要进行修正。

设 η 为突缩再突扩管道中气液两相流的静压降修正系数,即令:

$$\eta = \frac{(P_a - P_b)_{\text{试验}}}{(P_a - P_b)_{\text{理论}}} \quad (6)$$

将 η 的数据加以整理,得到如图5所示

的关系曲线。从图中可以看出,当空气质量流量 W_0 一定时,静压降的修正系数 η 与两相流干度 x 成线性关系,即:

$$\eta = E + F(x - 10) \quad (7)$$

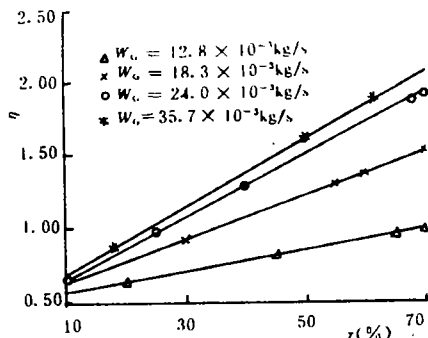


图5 当空气质量流量一定时局部阻力压力降的修正系数 η 和工质干度 x 的关系曲线

式中 E, F 均为空气质量流量 W_0 的函数,表1列出了变量 E, F 与空气质量流量 W_0 的关系。

表1 变量 E, F 的数值表

$W_0 \times 10^3 \text{ kg/s}$	E	F
12.8	0.560	0.007
18.3	0.616	0.015
24.0	0.653	0.021
35.7	0.677	0.023

将 E, F 拟合成如下关系式:

$$E = 0.3331635 + 2.377174 \times 10^{-2} W_0 - 5.155769 \times 10^{-4} W_0^2 + 3.347203 \times 10^{-6} W_0^3 \quad (8)$$

$$F = -1.639261 \times 10^{-2} + 1.937177 \times 10^{-3} W_0 - 2.961835 \times 10^{-7} W_0^2 - 6.458632 \times 10^{-7} W_0^3 \quad (9)$$

在式(8)和式(9)中, W_0 为突缩再突扩管道中的空气质量流量,是已知量,可以计算系数 E, F ,由式(7)计算可得突缩再突扩管道

中两相流的静压降修正系数 η 。因此,将突缩再突扩管道的静压降 $P_1 - P_0$ 的计算式归纳如下:

$$P_1 - P_0 = \eta \left[1 + x \left(\frac{P_1}{P_0} - 1 \right) \right] \frac{G_m^2}{P_1} \left\{ \frac{1}{2} \left[\left(\frac{1}{\beta} - 1 \right)^2 + (1 - \beta^2) \right] - \beta(1 - \beta) \right\} \quad (10)$$

试验时先调解空气质量流量为定值,改变水的流量,待稳定后记录有关数据。对应每一个空气质量流量,改变10次水的流量(即改变两相流的干度),分别记录管道两相流压力降的试验值,经过整理与应用式(10)计算得到的理论值进行比较。总体来讲,试验数据具有一定的规律性,与理论值吻合较好。文中选择了四个有代表性的空气质量流量的试验数据,即空气质量流量分别为 0.0128 kg/s, 0.0183 kg/s, 0.0240 kg/s, 0.0357 kg/s, 每个空气质量流量对应10个不同干度的试验数据,如图6至图9所示,其中理论值由式(10)计算可以连成一条曲线,“·”表示试验点,每图各有10点。

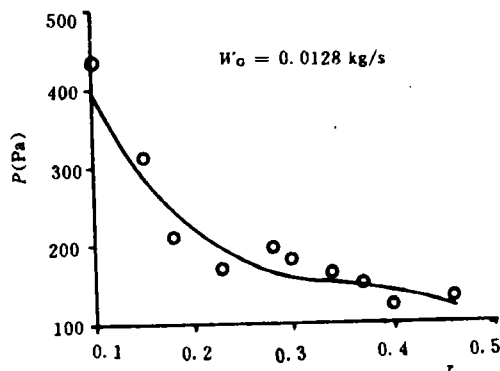


图6 两相流干度 x 变化,管道压力降理论值与试验值的比较

由图可见,理论值与试验值偏差不大,其均方根误差在15%以内,可见,在本文试验范围内,应用文中介绍的方法分析类似问题,并应用式(10)计算文中涉及的突缩再突扩管道的两相流压力降是可行的。

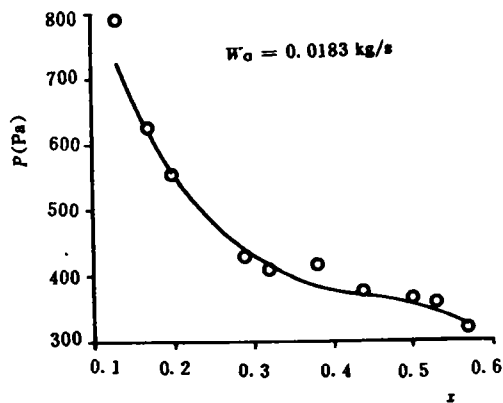


图7 两相流干度 x 变化, 管道压力降
理论值与试验值的比较

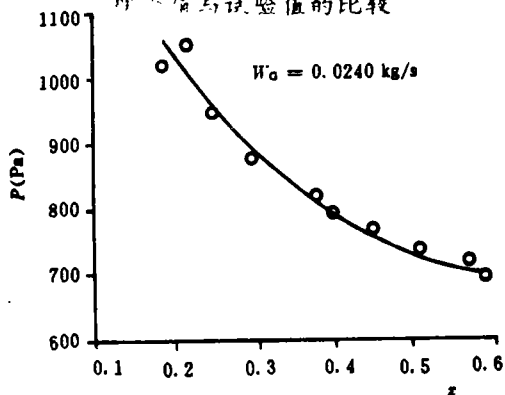


图8 两相流干度 x 变化, 管道压力降
理论值与试验值的比较

4 结论

文中所述的突缩再突扩管道可视为突缩接头和突扩接头之间放入锐边插入物, 但并非如前所述的长插入和短插入两种极限情况, 而是一种普遍形式, 目前尚无较成熟的理论。

首先可将突缩接头和突扩接头分开计算, 然后进行叠加, 并引入突缩再突扩管道的

两相流静压降修正系数。研究发现, 在本文试

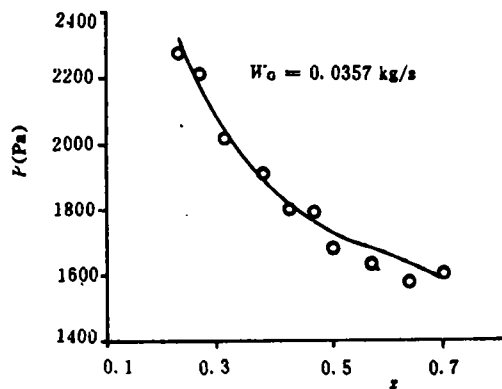


图9 两相流干度 x 变化, 管道压力降
理论值与试验值的比较

验范围内, 管道的静压降修正系数与两相流干度和气体的质量流量有关, 在此基础上, 总结了相应的计算式, 本文的研究方法为相关的计算提供了依据。

计算值与试验值比较表明两者相符良好, 其均方根误差在 15% 以内, 本文的处理方法是合适的。

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作者简介: 吴东垠, 男, 1966 年生。1989 年毕业于东北电力学院, 同年考入西安交通大学, 从师于林宗虎院士, 1992 年获硕士学位。主要从事锅炉过热器、再热器、省煤器和水冷壁等方面的研究工作。现在电力部热工研究院锅炉与环保研究所工作(西安市 710032)

国内外燃煤增压流化床联合循环发电技术的现状与前景=The Present Status and Development Prospects of Coal-Fired Pressurized Fluidized Bed-Based Combined Cycle Power Generation Technology Both at Home and Abroad [刊, 中]/Xu Hongsheng, Zhong Shiming (Thermal Power Engineering Design Institute of Southeastern University) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -343~348

There exist many kinds of coal-fired combined cycle power generation plants with their respective outstanding features and development prospects. Among them the integrated coal gasification combined cycle (IGCC) and pressurized fluidized bed combustion combined cycle (PFBC-CC) have been considered as the most likely candidates to take the place of the traditional coal-fired power generation plants from the end of this century up to the next century. This paper gives a brief description of the present status and development prospects of the PFBC-CC technology which has at the moment seen relatively intensive development. Also presented is a review of the current research conducted in this field by Chinese engineers and the practical significance to China of developing the said technology. Key words: pressurized fluidized bed, gas/steam combined cycle, power station under intermediate test

国内火电厂热力系统优化运行理论的研究=A Study of Thermal System Optimum Operation in Domestic Thermal Power Plant [刊, 中]/Hong Bo, Yang Zifen, Qian Wenhuan (Shanghai Jiaotong University) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -349~353

This paper summarizes optimum objects and methods of thermal system of domestic thermal power plant. According to the research and practice experience, it indicates developmental trends and application prospects of optimization technology in thermal power plant. Key words: Thermal System, Optimum Operation, Definite Optimization

稳燃腔煤粉燃烧器对煤粉燃烧稳定和强化的研究=A Study of the Pulverized Coal Combustion Stabilization and Intensification Role Played by a Combustion Stabilization Cavity Pulverized Coal Burner [刊, 中]/Qiu Jihua, Chen Gang, Zhang Zhiguo, Li Fujin (Central China University of Science & Technology) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -354~358

From both the theoretical and experimental viewpoints of pulverized coal combustion stabilization and intensification an analysis has been conducted of the role of the said stabilization and intensification played by a combustion cavity pulverized coal burner. In addition, the results of a laboratory study and practical engineering applications are also presented. Key words: combustion, pulverized coal, burner

某船用锅炉联箱在复杂换热条件下的瞬态温度场有限元分析=The Finite Element Analysis of Transient Temperature Field of a Marine Boiler Header Under Complicated Heat Transfer Conditions [刊, 中]/Yang Zichun, Huang Yuying (Central China University of Science & Technology), Hu Deming (Naval Engineering Academy) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -359~365

By the use of the basic theory of transient temperature fields and non-linear finite element method a reverse calculation has been successfully conducted of the convection heat transfer coefficient of a marine main boiler header under complicated heat transfer conditions. On this basis a nonlinear finite element analysis of the boiler header three-dimensional temperature distribution has been performed with a colored three-dimensional temperature profile being plotted. Key words: Water/steam header, convection heat transfer coefficient, non-linear finite element method

气液两相流流经突缩再突扩管道的压力降研究=Investigation of Pressure Drop of a Gas/Liquid Dual-Phase Flow During its Passage through an Abrupt Convergent and an Abrupt Divergent Piping [刊, 中]/Wu Dongyin (Thermal Engineering Academy of the Ministry of Electric Power), Lin Zonghu (Xi'an Jiaotong University) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -366~370

An abrupt converging and abrupt diverging piping should not be viewed as a simple superimposition of an abrupt converging connection to an abrupt diverging one. It has been found through tests that under the condition of a given distance of the abrupt convergent and abrupt divergent connection the pressure drop in a piping is related to the dual-phase flow dryness and gas flow rate for which the authors have derived the corresponding calculation formulas. Key words: abrupt convergence, abrupt divergence, gas/liquid dual-phase flow, pressure drop

磁化水在冷却循环和供暖系统中的应用研究—An Applied Study of Magnetized Water in a Cooling Circulation and Heat Supply System [刊, 中]/ Guo Ping (Kunming Non-ferrous Metallurgy Design institute), Zhao Danya (Yunnan Industrial University) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -371~374

On the basis of the experimental research conducted by scientists of the former Soviet Union a series of theoretical analyses have been carried out regarding the mechanism of fouling prevention and elimination of magnetized water when used in a cooling circulation and heat supply system with the aim that such a technology may eventually find widespread uses in China. Key words: solubility product, salt hardness, hydration, magnetic field force, complex compound

循环流化床煤燃烧过程中 N_2O/NO_x 的排放研究—An Investigation on the Emissions of N_2O/NO_x During the Process of Circulating Fluidized Bed Coal Combustion [刊, 中]/ Lu Jianxin, Liu Hao, Feng Bo, Lin Zhijie, Liu Dechang (Central China University of Science & Technology) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -375~380

On a circulating fluidized bed hot state test rig an investigation has been conducted of the generation during coal combustion of nitrogen oxides (including N_2O and NO_x) with the variation of their concentration along the bed height being measured. It has been found through tests that there emerged a continuous increase in N_2O and a drastic decrease in NO_x with the increase in furnace height. The N_2O attained a maximum value at the furnace outlet with a dramatic increase in emissions. The authors have analysed the underlying causes of such phenomena and also studied the effect of operating parameters on the N_2O and NO_x emissions. Key words: circulating fluidized bed, coal burning, nitrogen oxides

发电厂省煤器管镍基合金喷熔层组织与性能的研究—Study on Structures and Properties of the Nickel Based Alloy Spray Welding Layers on the Pipes of Economizers of Coal-Fired Power Stations [刊, 中]/ Liu Shaoguang, Wang Ping, Shu Delin (Anhui Institute of Technology) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -381~384

In this paper, the authors investigated on purpose the structures and properties of the nickel based alloy spray welding layers, considering the serious actual situation of high temperature erosion of the pipes of economizers of coal-fired power stations. It has been shown that there are the complex structures, higher hardness and connecting strength, excellent oxidation resistance and high temperature erosion resistance on the layers. It is fairly suitable to deal with the high temperature erosion problem of the pipes of the economizers. Key words: economizers, high temperature erosion, nickel based alloy spray welding layers, structures and properties

工业汽轮机转子高温疲劳及寿命评估—High-temperature Fatigue and Service Life Evaluation of Industrial Steam Turbine Rotors [刊, 中]/ Guo Yimu, Lu Zutong, (Zhejiang University), Ni Jinhu, Sun Yinghai (Hangzhou Industrial Steam Turbine Research Institute) // Journal of Engineering for Thermal Energy & Power. -1995, 10(6). -385~392

On the basis of industrial turbine rotor material low-cycle fatigue tests and the analysis under actual operating conditions of the rotor transient temperature and stress field a prediction of the rotor effective life has been conducted with the ensuing development of a special software. The analysis of specific examples shows that the software is capable of effectively