Research Journal of Recent Sciences ISSN 2277-2502
Vol. **7(2),** 12-16, February **(2018)** *Res. J. Recent Sci.*

Analysis of the performance parameter of ducts for optimization

Bheesham Kumar Dewangan[1*] and S.S.K. Deepak[2]
Rungta College of Engineering and Technology, Near Nandanvan, Raipur, CG, India
bheeshamdewangan@gmail.com

Available online at: www.isca.in, www.isca.me
Received 29th September 2017, revised 19th January 2018, accepted 30th January 2018

Abstract

Energy conservation can be achieved by the reduction of consumption of energy by optimize the maximum of an energy service. This can be achieved by using energy more efficiently and reducing losses of parts of energy. The components and performance of component used in energy transfer process both should be optimum. One of energy transfer components is duct. Ducts play important role in field of HVAC and other flow device. When fluid flow inside the duct there chances to loss of heat energy and pressure energy. So need to reduce the losses from duct and improve the performance of ducts. For making duct more effectively, need to well known about performance parameter and ways optimization. So, an effective study of performance parameter required to optimize duct and reduce losses of energy.

Keywords: Energy, thermal energy, duct, optimization.

Introduction

Fluids (liquid or gas) are flow from one point to another point using natural or artificial conveyance geometry. If the fluid is liquid then area of the cross section of this geometry either closed or open from top surface whereas if fluid is gas then cross section of this geometry is closed circumferentially. The structures which have closed from tops are generally called as closed pipe or duct and otherwise if it is open from top then it referred as opened channels. Ducts and pipe may be metallic or non metallic and flow section may be in many geometry like circular, oval, orthogonal (rectangular and square) or polygonal (triangular, pentagonal, trapezoidal, double trapezoidal)[1,2]. Generally circular flow cross section called pipe and non circular shape flow section called as ducts[3,4]. In case of improvement in performance of duct, knowledge of the factor related to duct such as fluid flow and heat transfer parameter play important role because the use of these parameters in fluid flow and heat transfer reduction in similarity of problems i.e. the number of experiments can runs is avoided.

Performance parameters of ducts

Fluid flow and heat transfer parameters are direct affect the performance of duct. These parameter may be physical quantity such as mean flow temperature, heat transfer coefficient and wall shear stress etc or may be dimensionless numbers such as Reynolds number Prandtl number etc. Other ducts physical factors are cross sectional shape, inlet velocity and temperature profiles, boundary condition and boundary conditions[5]. In this paper the physical quantity and non dimensional number of fluid flow and heat transfer are described.

Fluid flow parameters: i. Physical quantity, ii. Dimensionless number, iii. Physical quantity.

Fluids Mean Axial Velocity: When fluid flow inside the ducts, the velocity of fluid varies point to point. At the cross sectional center of duct the fluid velocity is the maximum and at wall the velocity of fluid minimum. So that it is difficult to calculate other fluid properties. So need to find the average velocity which can used to calculate other fluid properties and numbers. The fluid means axial velocity the integrated average velocity to the flow area[5].

$$u_{avg} = \frac{1}{A_C}\int_{A_C} u\,dA_C$$

Where A_c stands for duct's the cross section whereas u_{avg} stands for average flow velocity. Velocity variation can be calculated for any point in given cross section of duct by above equation.

Wall Shear Stress: When fluid have tendency to flow due to shear stress. Amount of shear stress also applied to solid surface by a fluid flowing over it, is important to appreciate the performance of various systems. Calculations of the wall shear stress can be applied to optimize drag reduction in pipe flow or skin friction in aerodynamics. The wall shear stress determination can be mesh with velocity measurements of fluid to evaluate the performance of fundamental models[6]. Wall shear stress can presents mathematically

$$\tau = G\frac{du}{dy} = \frac{Gu}{t}$$

Where G is the shear modulus, t is the distance perpendicular to flow direction, and u is the fluid layer displacement.

Solution with the above method, for the calculation of wall shear stresses no need to full knowledge of fluid properties.

Hydrodynamic entrance length (HDEL): The distance at which the flow is fully developed referred as hydrodynamic entrance length. When fluid enters into the duct at uniform velocity, the fluid practical is come contact with the inner surface of the pipe then velocity distribution varies with radius of duct. At flow direction the velocity of fluid increasing toward in center. At distance from entrance point to point where velocity of fluid become maximum at center and zero at wall, that distance referred as HDEL

Hydrodynamic Entrance Length of laminar flow is

$$(L_H)_{Laminar} = 0.05(ReD).$$

For turbulence flow Hydrodynamic Entrance Length is given as

$$L_{H_{Turb}} = 10D$$

Under hydrodynamic entrance length friction factor is inversely proportional to hydraulics boundary layer thickness i.e.

$$f\alpha \ {}^{1}/_{y_h}$$

after hydrodynamic entrance length

$$\frac{dU}{dx} = 0 \text{ And } f = constant$$

Dimensionless group: Fanning Friction Factor: The Fanning friction is non dimension number defined as shear stress divided by the flow kinetic energy density .It is named after John Thomas Fanning and mathematically given by

$$f = \frac{2\tau}{\rho u^2}$$

Where: τ = shear stress, u= bulk flow velocity, ρ = density of the fluid, f = Fanning friction factor (dimensionless).

Where: u is the given by volume flow rate through the duct divided by cross-section of the duct (Q/A_c) called as average velocity of flow

Head loss calculation using fanning friction factor

$$h_f = f\left(\frac{L}{D_h}\right).\left(\frac{V^2}{4g}\right)$$

Where: h_f is loss of head (m), L is pipe length (meter), D_h is hydraulic Diameters of duct (meter), v is fluid velocity (meter /sec), g is gravitational acceleration(meter/sec).

The Darcy-Weisbach formula approximately similar to the above formula but one thing making different between them that use the pipe hydraulic diameter instead the diameter of pipe[5].

Dimensionless axial distance: The ratio of longitudinal distance to multiply of Reynolds number and hydraulic diameter referred as dimensionless axial distance in direction of flow for hydrodynamic entrance region. It represents the any distance from entrance point to any point within hydrodynamic entrance length to hydrodynamic entrance length.

$$X^+ = \frac{X}{D_H.Re}$$

Where: X is axial distance in pipe and Re is the Reynolds numbers:

Momentum Kinetic and Energy Flux Correction Factor: Generally, in energy and momentum equations the velocity is assumed to be uniform, constant with respect to time and also no vertically variation but in actual case the boundary resistance disturbs the velocity distribution. The velocity at the boundaries varies as respectively variation of distance from the boundaries. Further, in cases where the velocity distribution is also disturbed in case sudden expansions/contractions of cross Section or through natural channels or varying cross sections. So that a need a factor for correction to be used for both in energy and momentum equations for optimum analysis of flow. The mean velocity ($\bar{V}$) of flow is usually determining using continuity equation[7].

Energy coefficient or energy correction factor can be estimated as follows

$$\alpha = \frac{\int_0^A v^3 dA}{\bar{V}^3 A} = \frac{\sum_{i=1}^{n} v^3}{\bar{V}^3 A}$$

Momentum correction coefficient

$$\beta = \frac{\int_0^A v^2 dA}{\bar{V}^2 A} = \frac{\sum_{i=1}^{n} v^2}{\bar{V}^2 A}$$

Where: $\bar{V}$= mean velocity, v = velocity at local point, A = area of cross section duct, α= energy correction factor, β= momentum correction factor.

Heat transfer parameter: Physical Quantity: Mean Temperatures: When fluid flow inside the ducts, the temperature distribution varies point to point. At the cross sectional center of duct the fluid velocity is the maximum and at wall the velocity of fluid minimum. At the inner wall of duct, the fluid temperature is maximum whereas at middle of cross section the temperature of fluid is minimum i.e. temperature increased with radius. So that it is difficult to calculate other thermal properties of fluid based on temperature. So need to find the average temperature which can used to calculate other fluid parameters such as coefficient of viscosity, specific heat, thermal conductivity etc.

$$t_{m,w} = \frac{1}{P}\int_r^R t_w ds$$

$$t_m = \frac{1}{A_c u_m}\int utdA_C$$

Where: t_m stand for fluid mean bulk temperature and $t_{w,m}$ is wall mean temperature of duct:

Convection heat transfer coefficient (h): Convection is mode of heat exchanging caused by the relative motion between two adjusting layer (fluid and fluid or fluid and solid surface). For duct, according to Newton's law of convection the rate of heat exchange is function to inner surface area of duct as well as difference temperature of fluid and surface of duct. Hence heat transfer through convection is given as

$$Q_{Con} = h.A.dT$$

Where: h is coefficient of convective heat transfer having SI unit watt/square meter kelvine. Nusselt number given in form of heat transfer coefficient as follow

$$Nu = \frac{hs}{k}$$

$$Nu = \int(Re, \mathrm{Pr})$$

Hence

$$h = \int\left[\frac{\rho v D_h}{\mu}, \frac{\mu c_p}{k}\right]$$

Where: K= thermal conductivity of surface upon which fluid is flow, Re= Reynolds's number, Nu = Nusselt number, Pr= Prandtl number.

From above equations we conclude that h is not only function of fluid motion but it depends upon the most of properties fluid (μ, ρ, and k). Convection is the combine effect of conduction and fluid motion.

Dimensionless group: Reynolds number: The Reynolds number plays an important role in analyzing of flowing of fluid and convection heat transfer. It is one of the non dimensional numbers and defined as the inertial forces divided by the viscous forces within a fluid. Laminar flow exist at low Reynolds numbers (Re<2000 in case of flow through pipe), when the inertia forces are lower, and have constant and smooth fluid motion where as in case Re>4000 in case of flow through pipe) the flow is termed as turbulence or zigzag flow where and higher inertia force acting on fluid, which cause to zigzag flow chaotic eddies, vortices and fluid layer fight to each other[8].

$$Re = \frac{inertia\ forces}{viscous\ force}$$

$$Re = \frac{2\rho . R_h . V}{\mu}$$

Where: ρ, v and μ stands for the density, velocity and viscosity of fluid respectively.

R_h is the hydraulic radius and given as

$$R_h = \frac{2A_C}{P}$$

Where: A_C is pipe or duct's area of cross sectional and P is wet perimeter.

Consider a square duct having sides **a** (width) and **b** (height) and filled with fluid up to height **h** from base. Then hydraulic radius given as

$$R_h = \frac{2ab}{(a+2h)}$$

Prandtl Number**-**The Prandtl number (p_r) is one of non dimensional number and given as thickness of velocity boundary layer divided by the thickness thermal boundary layer. That is, the Prandtl number is given as

$$Pr = \frac{velocity\ boundary\ layer\ thickness}{thermal\ boundary\ layer\ thickness}$$

Also the another form of p_r is

$$Pr = \frac{momentum\ diffusivity}{thermal\ diffusivity} = \frac{\mu Cp}{k}$$

Significance of Prandtl Number: i. When Pr< 1 then the fluid hydrodynamic fully developed before thermally fully development and rate of heat transfer decrease. ii. Pr > 1 Hydrodynamic fully developed occurs before thermal fully developed and rate of heat transfer increase. iii. It is conclude that for grater of heat transfer the thermal entrance length should be lower than hydrodynamic entrance length.

Nusselt Number: Mode of heat transfer for ducts are directly depends upon Nusselt number and it is define as the conductive resistance divided by conductive resistance Nusselt number also given as the $Q_{Connvection}$ divided by $Q_{Conduction}$. Nusselt number depends upon of Re and Pr number.

$$Nu = \frac{hs}{k} = \frac{conduction\ rasistance}{convection\ rasistance}$$

$$Nu = \frac{Q_{convection}}{Q_{conduction}}$$

Where: Q stands for heat transfer.

Significance of Nusselt number: i. Nu is the function of Re and Pr so Nu increase with increase in fluid velocity, specific heat of fluid, ii. If Nu >> 1, it represent that convection is more effective. As value Nu increase than increase in convection, iii. Nu = 1, represent that heat transfer through convection is equal to conduction across layer. iv. This presents to us about how much amount of the heat transfer is increased due to motion fluid. v. Nu is always greater than 1 for convection. vi. Nu talks about the quality of heat transfer rather than its quantity. vii. It is a key parameter in determining mode of heat transfer[9].

Peclet Number (Pc): It is one of the dimensionless number and given as heat transfer due to fluid movements divided by conductive heat transfer. For the case of the thermal analysis of fluids flow, the thermal Pc is equal to the multiplication result of the Prandtl number and Reynolds number[10]. Mathematically Peclet Number is given as

$$Pc = \frac{advective\ transport\ rate}{diffusive\ transport\ rate}$$

$$Pc = \frac{\mu L}{k}$$

Where: k thermal conductivity, μ is viscosity coefficient and L is characteristic length.

It is also expressed as multiplication of Reynolds number to Prandtl number.

Eckert number (Ec): The Eckert number (Ec) is one of the non dimensional parameter g presents the relationship between flow thermal energy and mechanical energy i.e. ratio of kinetic energy of fluid (due to flow) and change in enthalpy at boundary layer, and is used to in heat transfer. Mathematically

$$Ec = \frac{Advective\ Trantsport}{Heat\ dissipation}$$

$$Ec = \frac{U^2}{Cp \vartriangle T}$$

Where: U, C_p and $\vartriangle T$ is the velocity of flow, constant-pressure specific heat and the difference between temperature of wall respectively.

Brinkman Number (Br): It is a non dimensional parameters and given as the viscous distraction heat generated divided by the conductive heat transported. The higher its value, the heat loss through conduction is less then heat generated by viscous dissipation. Hence temperature increases.

$$Br = \frac{heat\ generated\ by\ viscous\ dissipation}{heat\ transported\ by\ conduction}$$

Stanton Number: One of the non-dimension parameter is Stanton number which gives the direct relationship between convective heat loss and thermal capacity of the flowing fluid. The Stanton number is generally defined as convection heat transfer to heat capacity of fluid and applicable for heat transfer.

$$St = \frac{hAdT}{mCpdT}$$

Or

$$St = \frac{Nu}{RePr}$$

Conclusion

This paper describe a relationship among some of the most important dimensionless numbers and physical quantity which used in analysis of fluid flow as well as heat transfer, like Nusselt number, Prandtl number and Reynolds number. The numbers are defining in such manner that they show physical relationship between them along with numerically relations. Also the physical quantity represent in such a way that makes easy to gather the basic of physical mechanism as well as to better interpretation of this non dimensional number. This paper also contains the physical signification of non dimensional number which helps to us that how we improve to these numbers for optimizing the performance of duct. For example the rate of heat transfer from duct increase with increase Nusselt number and Nusselt number depends also upon thermal conductivity of duct. So for increase in heat transfer from duct we need to use duct material which have higher thermal conductivity.

References

1. Bheesham Dewangan and S.S.K. Deepak (2017). Analysis ff Duct for Performance Improvements. *International Journal of Scientific and Engineering Research*, 8(9). ISSN 2229-5518.

2. Turgut O. (2014). Numerical Investigation of Laminar Flow and Heat Transfer in Hexagonal Ducts Under Isothermal and Constant Heat Flux Boundary Conditions. *IJST, Transactions of Mechanical Engineering*, 38(M1), 45-56.

3. Bhatia A. (2012). HVAC Ducting-Principal and Fundamental. PDH online course M246(4PDH).

4. Yunis Cengel A. (2007). Heat and Mass Transfer. Tata McGraw-Hill publishing company limited New Delhi. ISBN-13; 978-0-07-063453-4

5. Shah R.K. and London A.L. (1978). Laminar flow force convection. Academic Press New York San Francisco London. ISBN 0-12-020051-1

6. Gijsen F.J.H., Goijaerts A. and Van de Vosse F.N. (1996). A new method to determine wall shear stress distribution. *Department of Mechanical Engineering, Eindhoven University of Technology*, P.O. Box 513, 5600 MB Eindhoven, The Netherlands.

7. Wali U.G. (2013). Kinetic energy and momentum correction coefficients for a small irrigation channel.

International Journal of Emerging Technology and Advanced Engineering, 3(9), 315-322. ISSN 2250-2459.

8. Maliska C.R. (1990). On the Physical Significance of Some Dimensionless Numbers Used in Heat Transfer and Fluid Flow. Federal University of Santa Catarina, Florianópolis, SC.

9. Nakamura H. and Igarashi T. (2004). Variation of Nusselt number with flow regimes behind a circular cylinder for Reynolds numbers from 70 to 30 000. *International journal of heat and mass transfer*, 47(23), 5169-5173.

10. Huysmans M. and Dassargues A. (2005). Review of the use of Péclet numbers to determine the relative importance of advection and diffusion in low permeability environments. *Hydrogeology Journal*, 13(5-6), 895-904.