Flow Measurement and Instrumentation 46 (2015) 44–50

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

On the performance of perforated plate with optimized hole geometry

S. Shaaban

Mechanical Engineering Department, College of Engineering and Technology-Cairo Campus, Arab Academy for Science, Technology and Maritime Transport (AASTMT), Egypt

ARTICLE INFO

Article history:
Received 5 June 2015
Received in revised form
10 August 2015
Accepted 24 August 2015
Available online 28 August 2015

Keywords:
Perforated plate
Flow meter
Losses
Discharge coefficient
CFD

ABSTRACT

Perforated plates have many advantages compared to other differential type flow meters. Their permanent pressure loss could be lower than that of the standard orifice plates but significantly higher than that of the flow nozzles and the venturi meters. This high permanent pressure loss increases the energy consumption and hence the cost of flow metering. Therefore, the present study aims at minimizing the permanent pressure loss of perforated plates by optimizing their hole geometry. A convergent–divergent hole geometry is proposed for use with perforated plates. This geometry was numerically investigated and optimized by solving the Reynolds Averaged Navier–Stokes Equation (RANS) at different hole geometries. Numerical results show that the optimized convergent–divergent hole geometry reduces the permanent pressure loss by 51.7% at Reynolds number $Re = 3.5 \times 10^4$. The discharge coefficient of the optimized perforated plate is higher than that of the flow nozzle and comparable to that of the venturi meter. Moreover, a significant improvement of the cavitation number was recorded for the perforated plate with optimized convergent–divergent hole geometry.

1. Introduction

Flow rate measurement is one of the most important processes that takes place in many laboratories and industrial facilities. The main objective of any flow meter is to measure the flow rate accurately and with a minimum loss of energy due to flow metering. Reliability and availability of flow meter are also two important features for any industrial facility. Therefore, differential type flow meters are still attractive in many industrial applications. The small size, simple design, absence of moving parts and low cost of orifice plates make them the most commonly used differential type flow meters. However, orifice plates increase the energy consumption and hence the pumping cost due to their high permanent pressure loss. Moreover, they are non-linear and sensitive to incoming flow distortions. Authors have proposed different designs to overcome the known orifice plate disadvantages. Ouazzane and Barigou [1] investigated the effect of flow conditioners upstream the standard orifice plate and showed that they can considerably reduce the installation length. Beck and Mazille [2] introduced a swirler upstream an orifice plate to make its performance insensitive to inlet flow conditions. Manshoor et al. [3] showed that fractal flow conditioner causes orifice plates to be broadly insensitive to upstream flow disturbances. Shaaban [4] introduced a method to reduce the pressure loss of orifice plates by placing a ring downstream the orifice. This method can save up to 33.5% of the orifice plate pressure loss. However, the orifice loss coefficient still clearly higher than that of the flow nozzle and the venturi meter after applying the downstream ring.

Slotted-plate, fractal-plate and perforated plate are differential type flow meters that aim at overcoming the disadvantages of standard orifice plates while maintaining their advantages (i.e.; small size, inexpensive, no moving parts and simplicity of design and manufacturing). They are less sensitive to inlet flow distortions and have more stable discharge coefficient, wider application range and lower permanent pressure loss and critical Reynolds number compared to the standard orifice plates. Morrison et al. [5,6] introduced the slotted plates and showed that they have lower head loss compared to the standard orifice plates. Morrison et al. [7], Geng et al. [8], Yuxing et al. [9] and Kumar et al. [10] investigated the application of slotted plates in measuring the flow rate of wet gases. They showed that there is no accumulation of water upstream and downstream the slotted plate and a low area ratio is recommended for measuring the flow of wet gases.

Perforated plates are similar in concept to the slotted plates but with holes in lieu of the slots. Kolodzie and Van Winkle [11] experimentally investigated the design variables that affect the pressure drop across dry perforated plates. They established a correlation to estimate the pressure drop of perforated plates as a function of the hole diameter, hole pitch, plate thickness, fraction of the plate covered by the perforated area, and a Reynolds

E-mail address: sameh.shaaban@aast.edu

http://dx.doi.org/10.1016/j.flowmeasinst.2015.08.012
0955-5986/© 2015 Published by Elsevier Ltd.

Nomenclature

A	pipe cross sectional area (m^2)
A_0	hole cross sectional area (m^2)
A_h	total cross sectional area of the holes (m^2)
C_D	discharge coefficient (–)
D	pipe diameter (m)
d_i	hole circle diameter (m)
d_0	hole diameter (m)
E_d	exergy destruction (J/kg)
K	loss coefficient (–)
K_{cav}	cavitation number (–)
$\dot{m}$	mass flow rate (kg/s)
n	number of holes (–)
Δp	pressure difference (Pa)
Δp_{loss}	pressure loss (Pa)
p	static pressure (Pa)
Re	pipe Reynolds number (–)
S	entropy (kJ/kg K)
T	temperature (K)
V	pipe velocity (m/s)

Greek

α_1	hole convergent angle (°)
α_2	hole divergent angle (°)
β	porisity (–)
ρ	water density (kg/m^3)
μ	water viscosity (Pa s)

Subscript

1	at distance 1D upstream the perforated plate
2	at upstream surface of the perforated plate
3	at downstream surface of the perforated plate
4	at distance 6D downstream the perforated plate
5	at distance 10D downstream the perforated plate
0	ambient condition

number based on the hole diameter. Smith and Van Winkle [12] extended the correlation of Kolodzie and Van Winkle [11] down to a Reynolds number of $Re=400$. Gan and Riffat [13] numerically and experimentally investigated the pressure loss characteristics of square edged orifice and perforated plates. They found that at an area ratio of 0.5, the pressure loss coefficient of a perforated plate in a square duct is higher than that of an orifice plate. Weber et al. [14] experimentally investigated the pressure loss characteristics of perforated plates having different geometries. They reported that the effect of Reynolds number Re on the pressure loss was not significant for the majority of the tested geometries within the tested range of Reynolds number, Re = 1941–33,204.

Ma et al. [15] experimentally investigated the discharge coefficient, the head loss and anti-swirl performance of perforated plates. They showed that the discharge coefficient of perforated plate is more stable and less sensitive to upstream swirl compared to the standard orifice plate. Moreover, the head loss of perforated plate is close to that of the standard orifice plate. Huang et al. [16,17] theoretically and experimentally investigated the performance of perforated plates. They showed that perforated plates have more stable discharge coefficient and broader application ranges with smaller critical Reynolds number compared to the standard orifice plate. Huang et al. [17] reported that parameters such as hole diameter, plate thickness, plate porosity, and spatial distribution affect the performance of perforated plates. Each of these parameters has not monotonic but complex effect on perforated plates' performance. Zhao et al. [18] experimentally investigated the performance of perforated plates with different geometries. They also developed correlations for predicting the pressure loss and discharge coefficient of perforated plates as function of the plate geometry. Malavasi et al. [19] tested several plates with different geometrical characteristics. They showed that the loss coefficient of the perforated plate is less than that of the standard orifice plate. Huang et al. [20] theoretically and experimentally investigated the performance of perforated plates with different geometries. The experimental results showed that the discharge coefficient of a perforated plate is 22.5–25.6% larger but with a weaker scattering than that of the corresponding standard orifice. They also indicated that perforated plates have lower critical Reynolds number and stronger anti-disturbance ability compared to the standard orifice plate. Filho et al. [21] numerically investigated the effect of chamfering on the pressure drop of perforated plates with thin orifices proposed for debris filtering end pieces. For a thickness to diameter ratio close to 5, they studied chamfering angles 90°, 60° and 30° either at one side of the plate or at both sides of the plate. The numerical results showed that the pressure loss decreases rapidly for small chamfers and more slowly for larger chamfers. Filho et al. [21] concluded that the lowest pressure drop can be achieved with different chamfers at inlet and outlet.

Liu and Ting [22] experimentally investigated the turbulent flow downstream perforated plates with sharp-edged orificed openings and finite-thickness straight openings. They showed that the orificed perforated plate produces a higher level of turbulence due to the well-defined flow separation from its sharp edge openings. Gronych et al. [23] experimentally investigated the use of perforated plate to maintain the molecular flow at higher pressure and high total conductance of the plate. They studied the distance between holes and showed that at center-to-center distances shorter than approximately three times the diameter of the hole, notable differences in the total conductance can be seen in the pressure range where the transition from the molecular to transitional flow regime occurs. Malavasi et al. [24] investigated the incipient cavitation number of perforated plates. They showed that lower area ratio results in a delayed onset of cavitation. Chenzhen and Zhao [25] conducted two dimensional numerical simulation of acoustically excited flow through perforated plates with different geometrical shapes by using lattice Boltzmann method. They found that the square-shaped hole is associated with larger damping effect than that of a rounded one. Moreover, the maximum sound absorption and the effective frequency bandwidth strongly depend on the combination of the bias flow Mach number and the plate thickness.

Authors have investigated many geometrical and operating parameters of perforated plates as presented above. In these investigations, the hole diameter was constant across the plate thickness. The present study proposes the implementation of variable hole geometry across the plate thickness.

2. Aim of the present work

Perforated plates are simple in design and manufacturing and less sensitive to inlet flow distortion compared to standard orifice