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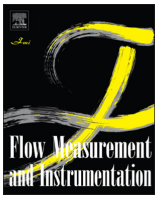

The numerical simulation of a rectifying device with a perforated plate

Di Li*, Fagen Zhang, Jianyou Long, Dinggui Luo

Guangdong Provincial Key Laboratory of Radionuclides Pollution Control and Resources, School of Environmental Science and Engineering,
Guangzhou University, Guangzhou 510006, China

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A B S T R A C T

The aim of this research is to verify a perforated plate design technique for generating a certain velocity and turbulence distribution by introducing the connection condition that demonstrates the disturbance attenuation characteristics of the plate. The application range on the downstream side of the perforated plate is studied based on a numerical simulation of the resistance characteristics of perforated plates. The optimum numerical simulations of turbulent flows through perforated plates are then clarified. The numerical simulation results and the experimental data for the disturbance attenuation are highly consistent with the numerical simulation and experimental data for the perforated plates with fixed opening ratios and pore diameters. In addition, the calculation results for the downstream disturbance distribution almost correspond with the experimental results when the opening ratio of the perforated plate is fixed but the pore diameter is variable. Consequently, the disturbance numerical simulation technique developed in this research by utilising the connection conditions for perforated plates clarifies the reliability of the rectifying device design method used to generate the velocity and turbulence distribution of perforated plates.

1. Introduction

With increasing numbers of large-scale pipeline systems being deployed in industrial plants, such as the facilities used within the petroleum processing industry, the chemical industry, and steel plants, ensuring that straight pipe lengths are used on the upstream side of a flow meter has become a significant challenge. Therefore, the generation of developed flows in relatively short pipe lengths is critical [1,2]. This technology focuses on the generation of a specific velocity distribution [3–5]. However, if the developed velocity distribution is forced to flow through resisting objects in the pipe, that is, from the cross-section to the downstream side for a distance that is several times greater than the pipe diameter, the velocity distribution tends to be uniform. After this point, as a result of inner wall friction, developed flows form [6,7]. An analysis of the previous phenomenon shows that the generated turbulence will be comparatively similar in terms of strength because the jet flow will have formed downstream of the resistant object and the velocity distribution will tend to be the same as the diffusion effect of the jet flow.

According to this analysis, for the purpose of generating and maintaining a developed flow in the pipe by applying a rectifying technique, it is necessary to study both the velocity distribution and the turbulence distribution [8].

To determine the generation of turbulence distributions near a perforated plate, the first step is to clarify the entire process of turbulence generation, development, diffusion and attenuation within the downstream jet set of the perforated plate [9,10].

Once these features and the geometric and mechanic conditions and relations corresponding to the perforated plate have been elucidated, this mechanism can be applied to analyse the generation of downstream turbulence distributions. From the results of recent studies, it is clear that a large-scale coherent structure develops in turbulent shear flow and that this structure is controlled by the flow characteristics [11–14]. The processes of jet set generation, development and diffusion when the set is structurally treated as a single circular jet have been studied in detail, and the associated organisational structure has been clarified [15–17].

The further application of this velocity and turbulence distribution generation form to various industrial applications requires that it be simple, reliable and of low cost. In this case, a desired flow field can be freely generated under the condition of fixed velocity and turbulence distributions by establishing an appropriate perforated plate. To obtain the downstream flow using the disturbance attenuation characteristics and resistance characteristics of perforated plates, the use of a numerical flow simulation technique becomes necessary [18–20].

The purpose of this research is to develop a numerical simulation technique for rectification devices that utilises the resistance

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* Corresponding author. Tel.: +86 20 3936 6937; fax: +86 20 3936 6946.
E-mail address: lidi@gzhu.edu.cn (D. Li).

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Nomenclature

C_l	turbulence scale coefficient
K	resistance coefficient of a perforated plate
K_0	average resistance coefficient of a perforated plate
L_2, L_1	non-dimensional length of a simulation area
R_e	the Reynolds number for the width of the flow path
R_{ep}	the Reynolds number for the pore diameter of a perforated plate
S_ϕ	generation for each variable
W	non-dimensional flow path length
D	non-dimensional perforated plate pore diameter
K	non-dimensional turbulent energy
l_p	non-dimensional perforated plate hole pitch
l_m	non-dimensional perforated plate average hole pitch
p	non-dimensional pressure
p'	non-dimensional pressure correction
u	non-dimensional main flow direction time average velocity
v	non-dimensional transverse time average velocity
v_τ	non-dimensional frictional velocity
x	non-dimensional main flow direction coordinate
y	non-dimensional main flow direction coordinate in the vertical direction
Γ_ϕ	diffusion coefficient for each variable
B	opening ratio of a perforated plate
E	non-dimensional turbulent energy dissipation rate
ϕ	various variables such as u, v, k, ε, p, and p'
K	Karman Constant
N	non-dimensional kinematic viscosity coefficient
ν_t	non-dimensional eddy viscosity coefficient

properties and disturbance attenuation characteristics of perforated plates to advance the rectifier device used to generate the time average velocity and the disturbance distributions. Therefore, the connection conditions are introduced, and the turbulent flow field through the perforated plate is numerically simulated. An evaluation of the disturbance attenuation of the perforated plates with fixed pore diameters and opening ratios reveals that the calculation and experimental results are highly consistent. The calculations yield a disturbance distribution that corresponds with the experimental results obtained near the perforated plates with fixed opening ratios and variable pore diameters. Therefore, these calculation results have validated the reliability of this rectification device design technique.

2. Experimental equipment and method

Fig. 1 details the experimental equipment. A blower emits air into a wind tunnel, which travels through an inserted perforated plate to a rectangular duct that is composed of acrylic, with a side length of 150 mm; the air subsequently exits the duct. On the downside duct of the perforated plate, the measurements of air flow temperature and velocity are conducted by an electronic thermometer and an X Hot wire probe.

The wind tunnel is composed of wood; the flange portion of the tunnel chamber has been installed on a rectifying industrial sieve.

The experimental perforated plate is placed on the flange between the wind tunnel and the rectangular duct. A total of 17 pieces of the perforated plate with circular holes in a Plover array arrangement were used in the experiment; these plates had 2 different thicknesses—0.4 and 2.5; 5 different pore diameters—3.0, 5.0, 7.5, 15.0 and 30.0 mm and 4 different opening ratios—0.35, 0.45, 0.55 and 0.65.

3. The calculation fields and analytical model of the downstream field for a perforated plate

3.1. Calculation fields

The calculation fields and coordinate systems are shown in Fig. 2. The fields before and after the perforated plate are named Field 1 and Field 2, respectively. The length of the flow path $W_*=150$ mm is normalised to 4. Therefore, the range of the coordinates for Y is $y=0$ to 1; the range of the coordinates for Field 1 is $x_1=-4$ to 0; and the range of the coordinates for Field 2 is $x_2=x_{2d}$ to $4+x_{2d}$. Because of the complicated structures of group jet flows and jet interference generation immediately following the perforated plate, a three-dimensional calculation should be performed for relatively small mesh areas. To perform two-dimensional calculations for such mesh spaces, the proper simulation space must first be determined and is noted to begin downstream of the perforated plate. Therefore, the downstream field of the chosen space is a boundary. It is also necessary to evaluate turbulence based on certain proper conditions. Because the pores on the perforated plate may be either evenly or unevenly distributed, the calculation methods for sub-Field 1 and sub-Field

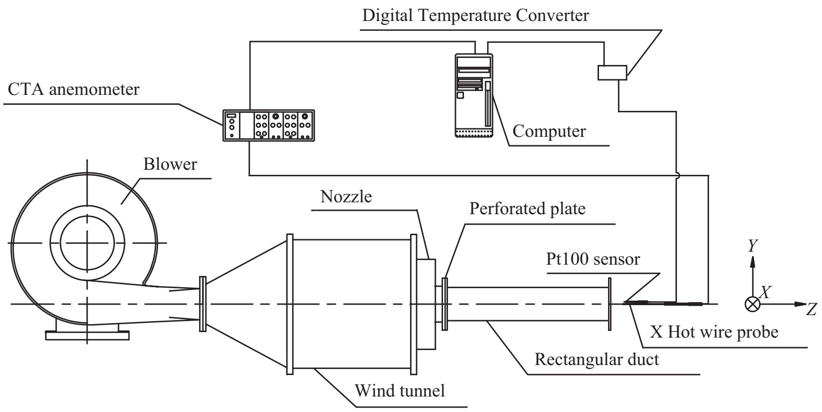

Fig. 1. Schematic of experimental equipment.