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Research Paper

Effect of the rectangular exit-port geometry of a distribution manifold on the flow performance

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HIGHLIGHTS

- Effect of the inlet Reynolds number on the flow distribution uniformity was studied.
- Effect of the aspect ratio (AR) of the rectangle exit-port on the flow distribution uniformity was studied.
- The flow pressure drop of the distribution manifold was investigated.
- Design variables that affect the flow performance were suggested.

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ABSTRACT

Flow distribution performance of the distribution manifold is the most important index to evaluate its design rationality. To date, many published literatures have extensively investigated the effect of the manifold geometry on its flow distribution performance; however, there is no related study regarding the effect of the aspect ratio (AR) of the rectangle exit-port. In this paper, the effect of the AR on the flow distribution performance in the turbulent-flow regime is numerically simulated and analyzed. The research results are as follows: (i) With constant AR, the variation of the inlet Reynolds number (*Re*, 1.0×10^5–1.0×10^6) has little effect on the flow distribution uniformity in the obvious turbulent-flow regime. (ii) With a constant inlet Reynolds number, the corresponding uniformity coefficient decreases from 89.81% to 82.60% when the AR increases from 0.2 to 4.0, which indicates that the flow distribution becomes less uniform with the increase in AR. (iii) With the same inlet Reynolds number, the flow pressure drop of the distribution manifold maintains a decelerated increasing trend with increased AR, which becomes stable after the AR reaches 2.0. The research results can provide a reference for the geometrical optimization of distribution manifolds.

1. Introduction

Distribution manifolds are widely used in industry applications, such as perforated ventilation ducts, [1–3], various micro-channel devices [4–8], heat exchangers [9–12], and flow distribution systems. In these engineering applications, a uniform flow distribution requirement is critical because it significantly affects the performance of a distribution manifold. Therefore, for most applications, the goal of distribution manifold design is to achieve a uniform flow distribution through all exit-ports. Many factors affect the flow distribution uniformity of the manifold, such as the manifold structure, hole spacing, manifold length, aperture ratio (which is defined as the ratio of the total discharge area to the cross-sectional area of the manifold), *Re*, and roughness. Among these factors, Reynolds number is related to the operating conditions, and the roughness of the distribution manifold is related to the material. The remaining factors are related to the geometrical structure of the manifold.

Many researchers have experimentally, analytically and numerically studied the effect of the manifold geometry on the flow distribution uniformity. Jimmy C.K. Tong et al. [13] studied the effect of the cross-sectional geometry of the distribution manifold on the uniformity of the flow distribution in a laminar-flow regime. They obtained the geometry of the distribution manifold in favor of uniformity, which is to increase the sectional area of the distribution manifolds or use the tapered distribution manifold. The results of the study also show that the flow distribution uniformity of the

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Nomenclature

AR	aspect ratio of the rectangle (b/a)
L	Total length of manifold (m)
n	numbers of exit-ports
a	length of each rectangle exit-port (m)
b	width of each rectangle exit-port (m)
l	exit-port spacing (m)
W	width of manifold cross-section (m)
H	height of manifold cross-section (m)
Re	Reynolds number
Q	volumetric flow (m^3/s)
x	distance from the entrance of manifold in the x-axis direction (m)
Q_{aver}	averaged volumetric flow through all exit-ports (m^3/s)
Q_i	volumetric flow through the ith exit-port (m^3/s)
π	uniformity coefficient, defined by Eq. (1)

distribution manifold significantly increases with increasing flow Reynolds number regardless of the geometric configuration. Hassan et al. [14] conducted a comparative study of the uniformity of the flow distribution of the longitudinal and cross-sectional distribution manifolds in the turbulent-flow regime using experimental and numerical simulations. These researchers show that ($Re > 10 \times 10^4$) has no effect on the uniformity of the flow distribution, and the cross-sectional distribution manifolds have better distribution uniformity than the longitudinal distribution manifolds. Cloud and Morey [15] find that the hole spacing has an effect on the uniformity. Air follows the path of least resistance. The path of least resistance in ventilation ducts is the straight section from the beginning to the end of the duct. In rough-wall ducts, there is generally more open area near the front of the duct than the distal end to obtain a uniform distribution. Carpenter [16] tested 3 m, 5 m, 10 m, 20 m, and 90 m polyethylene perforated ducts and found that the duct length of 20 m and less had similar performance. The discharge of air steadily increased from the entrance to the distal end. The 90 m duct discharged more uniformly over its entire length because of the increased friction loss in longer ducts. Lee et al. [17] numerically investigated the effects of the blockage ratio via the changes in number of orifices on the flow distribution performance in a multi-perforated tubes. Their result indicates that a larger increase in blockage ratio of multi-perforated tubes corresponds to a more uniform flow distribution among the orifices.

The effect of the exit-port geometry of distribution manifolds on the flow distribution performance is clearly of practical relevance but appears rarely investigated in the published literature. An in-depth literature search shows only one reference that attempted to investigate the effect of the shape of the exit-ports on the flow distribution uniformity. In that paper, Chen and Sparrow [18] investigated the effect of three candidate exit-port geometries on the flow distribution characteristics of manifolds using a numerical simulation method. The numerical results indicate that the single continuous slot provides the optimal flow distribution with end-to-end mass flow variations of less than ±5%, the discrete array of rectangular orifices provides a uniformity of ±10%, and the discrete circular orifices provide a uniformity of ±15%. However, in practical engineering, in many cases, the design of exit-ports of the single continuous slot is not permitted. It is currently common to design the exit-ports of distribution manifolds as discrete rectangles. To date, the effect of the AR of rectangular exit-port on the flow distribution uniformity has not been studied.

The literature review shows that previous studies on the flow characteristics of distribution manifolds mainly used the experimental method, and a recent study used the numerical simulation technology. Numerical simulation using computational fluid dynamics is the current method of choice to solve the flow distribution uniformity problem of distribution manifolds, which can be found in the published literature [4,13,14,17–20]. Chen and Sparrow [20] used the synergistic combination method of numerical simulation and laboratory experiments to investigate three turbulence models, which can be used in the distribution manifolds flow. The numerical predictions obtained from the application of these models were compared with the experimental results, and the realizable k-ε model was found to provide the best representation of the data.

Thus, this study investigates the effect of the changes in AR of exit-ports and inlet Reynolds number on the flow distribution performance using numerical simulation. The effect of the pressure drop was also investigated; ultimately, design variables that affect the flow distribution were pursued.

2. Geometric issues

In this study, the studied distribution manifold is the airflow distribution channel of the large bag filter. For the airflow distribution channel into a large fabric bag house, uniform gas distribution and low pressure drop are desired, ensuring each individual bag house to receive gas flow from specific exit-port. The shape of the distribution manifolds for the work is illustrated in Fig. 1. Fig. 1 consists of a schematic of the distribution manifold and definitions of the geometric parameter. The longitudinal direction of the distribution manifold was set as an axial direction (flow direction, x axis direction). The end of the distribution manifold is blocked, and the interval between the starting and ending points is L.

For the distribution manifold, the rectangular exit-ports were installed on the side of the rectangular distribution manifold with an AR of 0.86. The aperture ratio of the distribution manifolds was 1.0. The aperture ratio is defined as the ratio of the total discharge area to the cross-sectional area of the manifold. Here, the number of exit-ports was determined to be 10 ($n = 10$). The changes in AR of the rectangular exit-ports and other required data are shown in Table 1. As pointed by Chen and Sparrow [18] single slot with AR of 0.19 presented the best flow performance. However, since in our channel to the bag house, discrete exit-port must be adopted. Therefore, we chose AR = 0.2 as the lower limit of experimental conditions, to determine the flow uniformity and pressure drop, because it is quite close to 0.19.

3. Analysis methods

3.1. Numerical model

A CFD model with the identical geometry and dimensions as the scaled distribution manifold model was created using the software Fluent (version 6.3.26) [21]. The solver used the finite-volume method and second-order upwind scheme. The SIMPLE algorithm, which was proposed by Patankar and Spalding [22], was used to achieve the pressure-velocity coupling.