Possibility of a Straightening Flow-Meter by Using Woven Screen

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Abstract

In this paper, the possibility of the flow rate measurement for a circular pipe flow by using a woven screen with the property of straightening un-uniform flows is discussed. The resistance coefficient and the flow rate coefficient are estimated from the pressure difference caused by the woven screen under the experiment ranges of the wire Reynolds number, $Re_d = 2.2 \times 10^2 - 1.8 \times 10^3$, and of the open area ratio, $\beta = 0.28 - 0.65$. As a result, the resistance coefficient decreases and the flow rate coefficient increases as the wire Reynolds number Re_d or the open area ratio β increases. In addition, both coefficients are not affected by the difference between uniform and turbulent pipe flows approaching the woven screen. Therefore, the possibility of a flow-meter having the property to straighten the un-uniform flow is expected.

Keywords

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1. Introduction

It is a significant assignment to measure the flow rate exactly in engineering fields using pipe line flows. A flow-meter generally requires a long runway approaching it and/or a straightening device, such as perforated plates, honeycombs or woven screens upstream of it. As for a woven screen, often used to straighten un-uniform flows such as a prejudice flow and a turbulent flow in many engineering fields [1] [2], there have been a lot of studies on resistance thus far [3]-[10]. In recent years, the requirements of downsizing the apparatus have appeared.

Therefore, an idea of measuring the flow rate by using a woven screen is proposed in this paper, because it is expected that it could play both the role of straightening the flow as well as measuring the flow rate. The possibility as a flow-meter having the ability to straighten an un-uniform flow from the measurements of the flow rate coefficient and resistance coefficient of a woven screen for two different pipe flow fields is discussed.

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2. Experimental Approach

Figure 1 shows a summary of this experiment and nomenclature. The experimental apparatus is composed of the entrance nozzle and a straight circular pipe with an inner diameter of $D = 42$ mm. On the inner wall of the pipe, there are many pressure measurement holes (diameter 0.5 mm) along the flow direction. The woven screen is set at the position $L = 210$ mm or 1080 mm downstream from the tip of the entrance nozzle. The woven screen is made of stainless steel wires of 1.0 mm diameter and has four open area ratios. The wire Reynolds number, Re_d, is defined in Equation (1) based on the wire diameter, the velocity averaged in the pipe's cross section and the kinematic viscosity of the air was varied from 2.2×10^2 to 1.8×10^3.

$$\text{Re}_d = \frac{U_m d}{\nu} \tag{1}$$

Table 1 shows the geometric parameters of woven screen models used in this study. M is number of the meshes, and β is the open area ratio defined as $(s - d)^2 / s^2$. **Figure 2** shows the velocity distribution in the pipe's cross section measured at the positions of $L = 1080$ mm and 210 mm under the Reynolds number based on the circular pipe diameter, $\text{Re}_D = 8.3 \times 10^3 - 8.7 \times 10^4$, before the woven screens is set. The velocity in the pipe is obtained from the pressure difference between total pressure measured by a small handmade total pressure tube and static pressure taken from a pressure hole in the position nearest to the tip of the total pressure tube.

It is understood that the velocity distributions obtained at the pipe's cross section in the case of $L = 1080$ mm are almost consistent with the 1/6-power law as shown in **Figure 2(a)**. Because the inner flow in the case of $L = 1080$ mm can be regarded as a developed turbulent pipe flow, thereafter it is called "the turbulent pipe flow". On the other hand, the velocity distributions in the case of $L = 210$ mm are almost uniform, except in the vicinity of the pipe wall as shown in **Figure 2(b)**. Because the constant velocity region occupies about 70% in the pipe's cross section, thereafter the inner flow is called "the uniform pipe flow". For all pressure measurements, a Gottingen type manometer (minimum scale 0.05 mm) is used.

3. Experimental Results and Discussions

3.1. Wall Pressure Distribution

Figure 3 shows a typical example of the x direction distribution of a wall pressure coefficient C_p upstream and downstream of the woven screen. The wall pressure coefficient is defined as

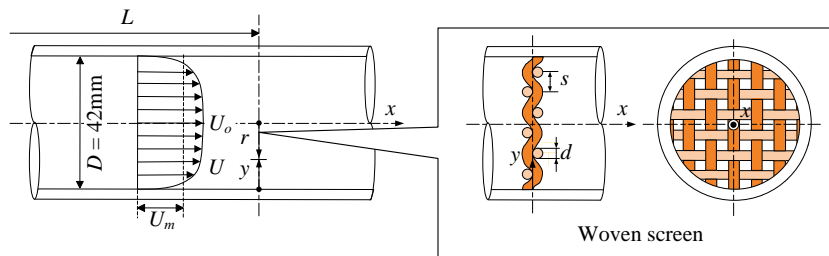$$C_p = \frac{P - P_\infty}{(1/2)\rho_{\text{air}} U_m^2} \tag{2}$$

Figure 1. Experimental apparatus and coordinate system.

Table 1. Geometric parameters of woven screen models.

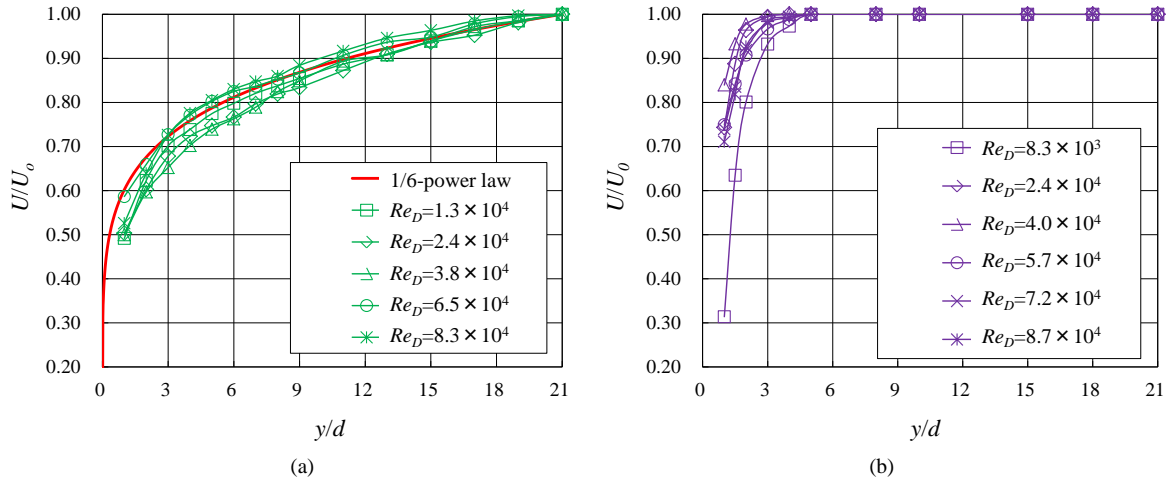| d [mm]	M	β	Symbol
1.0	12	0.28	◆
1.0	8	0.47	■
1.0	6	0.58	▲
1.0	5	0.65	●

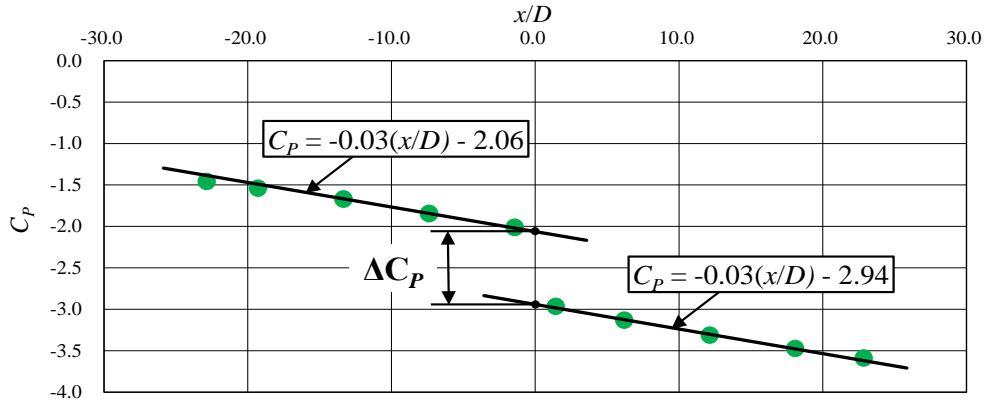**Figure 2.** Velocity profiles in circular pipe flow. (a) Turbulent pipe flow; (b) Uniform pipe flow.

Figure 3. Wall pressure distribution in circular pipe ($\beta = 0.65$, Turbulent pipe flow, $\text{Re}_d = 990$).

where P is the wall pressure, P_∞ is the atmospheric pressure and ρ_{air} is the density of the air. It is noted that the wall pressure varies linearly over the wide range of x/D, and that a difference in the wall pressure coefficient, ΔC_p, occurs between the regions upstream and downstream of the woven screen.

3.2. Resistance Coefficient

Figure 4(a) shows the relationship between the resistance coefficient K and the wire Reynolds number Re_d. The resistance coefficient K is defined as

$$K = \Delta C_p = \frac{\Delta P}{\frac{1}{2}\rho_{\text{air}}U_m^2}. \tag{3}$$

The resistance coefficient K decreases as the wire Reynolds number Re_d and the open area ratio β increase. Although the resistance coefficients K for each β is obtained under two different pipe flow approaching the woven screen, the turbulent flow and the uniform flow, they agree very well. Then, it is noted that the resistance coefficient is not affected by the difference of flow approaching the woven screen. This may be because two approaching-flows become similar to each other by the damming effect which occurs in front of the woven screen. Therefore, it is expected that the woven screen has a property which could straighten the turbulent pipe flow as well as the uniform pipe flow. The black-lines in **Figure 4(a)** exhibit the approximation of the obtained resistance coefficient K and are given by the following Equation (4), depending on the wire Reynolds number Re_d and the open area ratio β. They approximate the resistance coefficient K very well.

$$K = \frac{C_1}{\text{Re}_d} + C_2 \dots\dots C_1 = 1.21 \times 10^4 e^{-6.75\beta}, C_2 = 0.26\beta^{-2.45} \tag{4}$$

3.3. Flow Rate Coefficient

Figure 4(b) shows the variation of the flow rate coefficient α for the wire Reynolds number Re_d and the open area ratio β. The flow rate coefficient α is derived from general formulas, $Q = \alpha A_o \left(2\Delta P/\rho_{\text{air}}\right)^{0.5}$, where A_o is the open area of the woven screen. The flow rate coefficient α increases as the wire Reynolds number Re_d and the open area ratio β increases. In addition, it was noticed that the flow rate coefficient α obtained in two different pipe flows, the turbulent pipe flow and the uniform pipe flow, are close to each other. On the other hand, the flow rate coefficient α can be calculated from the wall pressure difference based on the following Equation (5), where A is the pipe cross-sectional area.

$$\alpha = \frac{Q}{A_o\sqrt{\dfrac{2\Delta P}{\rho_{\text{air}}}}} = \frac{1}{\dfrac{A_o}{A}\sqrt{\dfrac{\Delta P}{\dfrac{1}{2}\rho_{\text{air}}U_m^2}}} = \frac{1}{\beta\sqrt{K}} \tag{5}$$

The black-lines in **Figure 4(b)** are converted from the black-lines in **Figure 4(a)**, and agree with the experimental results of the flow rate coefficient α.

3.4. Reconfirmation from Direct Pressure Drop

Generally, in the case of the flow rate measurement using the pressure difference, the pressure difference ΔP is decided as the wall pressure drop between the front and the back of a device's position. Therefore, the measurement of the pressure drop in the case of the transient pipe flow was attempted in the vicinity of the woven screen as shown in **Figure 5**. Because the pressure drop coefficient ΔC_p measured between two positions nearest to the woven screen, $x = -1.05\ D$ and $0.10\ D$, is fairly larger than the ΔC_p obtained from the pressure difference of the two pressure distribution lines as shown in **Figure 3**, the property as flow-meter is expected to be good when taking the pressure drop in the downstream position nearer to the woven screen.

4. Conclusion

The resistance coefficient K and the flow rate coefficient α of the woven screen placed in the circular pipe were experimentally investigated. As a result, although the flow rate coefficient α varies depending on the wire Reynolds number Re_d and the open area ratio β increases, both coefficients is not affected by the difference between
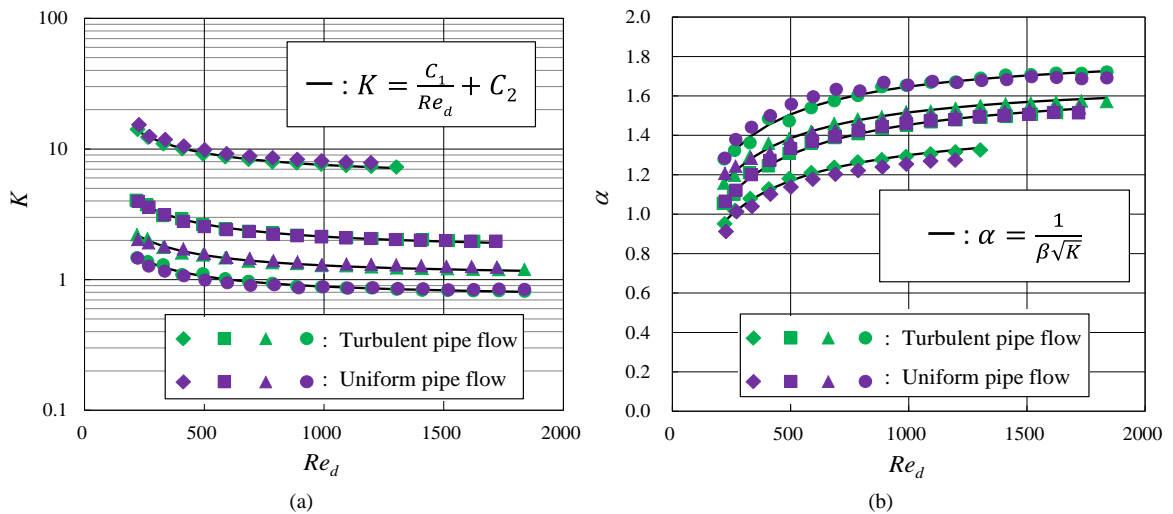

Figure 4. Influence of Reynolds number and open area ratio. (a) Resistance coefficient; (b) Flow rate coefficient.
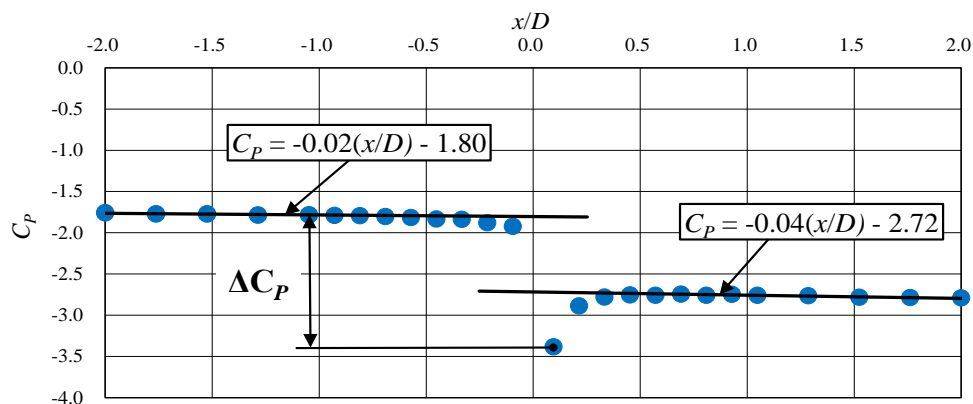
Figure 5. Wall pressure distribution in circular pipe ($\beta = 0.65$, Transient pipe flow, $\text{Re}_d = 880$).

a uniform and a turbulent pipe flows approaching the woven screen. Therefore, the possibility of a flow-meter having the ability of straightening an un-uniform flow can be expected. Furthermore, considering the pressure measurement points, the numbers of woven screens and/or combination with perforated plates and honeycombs, its ability as a straightening flow-meter will rise.

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