Retraction Notice

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Editor guiding this retraction: Prof. Heuy Dong Kim (EiC, OJFD)

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Simple Estimated Formula of Delay Time of Measurement Pressure Using a Pressure Guide Tube Connected with Different Diameter Tubes

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Abstract

The construction of prediction formula to estimate the delay time and time variation in pressure of measurement pressure is reported. The difference pressure is measured using a long pressure guide tube which the measurement side is distant from sensor side. Using the long tube results in time delay of the measurement pressure. It is needed to know how long it takes to reach a constant pressure over the delay time of the measurement pressure. Furthermore, the difference of the delay time between reference side and measurement side of the tubes results in an apparent error in measurement pressure. For such the difference pressure measurement, it is often used a pressure guide tube connected with different internal diameter tubes. Therefore, this paper reports the construction of the prediction formula to estimate the delay time and the availability by comparing the time variation in pressure between the estimation and experimental results. The results showed that the empirical results have been shown to essentially match the prediction results. Based on the prediction formula, it is important for shortening the delay time of measurement pressure that the internal diameter of exit side is increased compared with that of sensor side and the volume in the tube is minimized as much as possible.

Keywords

Delay Time, Pressure Measurement System, Wind Tunnel Test, Different Internal Diameter, Pressure Guide Tube

1. Introduction

Difference pressure measurements is generally conducted in fluids experiments such as wind tunnel tests, on-road tests of vehicles, flight tests and so on for investigating flow field of an object. The pressure measurement is needed to make preparations of making a hole in an object surface, tubing pressure guide tubes, the other pressure tube connecting to a location to measure the reference static pressure of main flow or an atmospheric pressure as a reference pressure, and connecting them to the pressure sensors. For the difference pressure measurement in averaged evaluation in steady state flow, it is necessary to wait a time to reach a constant measurement pressure because of a long pressure guide tube [1]-[4]. The pressure sensor is normally built into wind tunnel measurement system, and the length of the pressure guide tube from measurement holes to pressure sensor is long. **Figure 1** shows an example of the time delay in pressure, determined by prediction formula of previous study [1], which is comparison of time variation in pressure between "Without time delay" and "With time delay" when the pressure of measurement-hole side was suddenly changed from 100 Pa to 0 Pa in gage pressure. In **Figure 1**, the "Without time delay" means directly pressure measurement that pressure receiving surface of pressure sensor is located on an object surface in parallel and in no small step. On the other hand, the "With time delay" is the case of using a pressure guide tube which is the length of 30m and the internal diameter of 0.001 m.

In recent years, wind tunnels which can generate low frequency incoming turbulence flow were constructed to investigate the aerodynamic effect to a vehicle body for more closely real-world environment evaluation [5] [6]. Furthermore, wind tunnel originally has characteristics of static pressure fluctuation, called pulsation, which is very low frequency [7]-[11]. **Figure 2** shows estimated results of time variation in pressure, determined by prediction formula referencing to previous report [1], when both pressure guide tubes of reference side and measurement side are different in length and internal diameter, as an example of pressure measurement in described above the pressure fields which is low frequency fluctuation. From **Figure 2**, the difference of time variation in

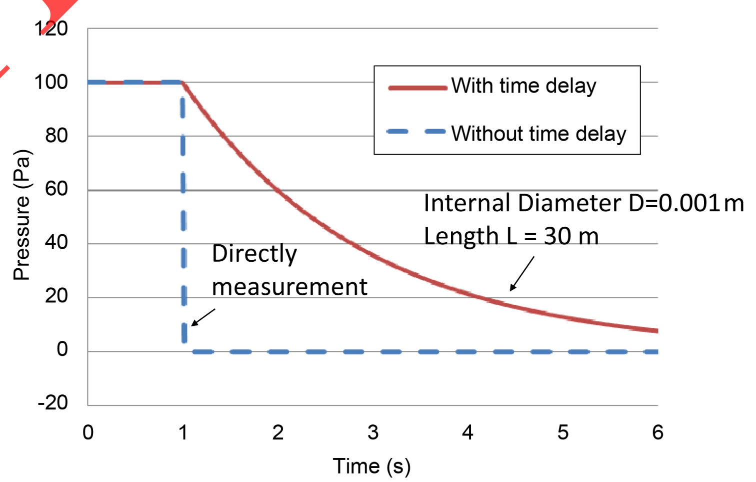

Figure 1. An example of the time delay in pressure. Comparison of time variation in pressure between "With time delay" and "Without time delay" when the pressure of measurement-hole side was suddenly changed from 100 Pa to 0 Pa in gage pressure.

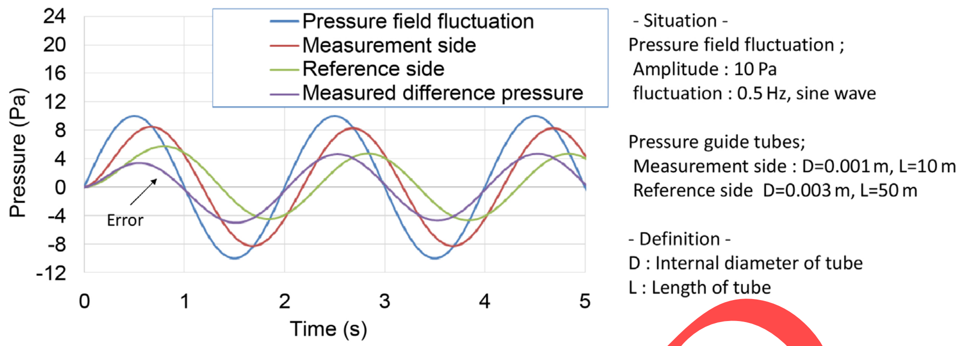

Figure 2. Estimated results of time variation in pressure when both pressure guide tubes are different in length and internal diameter.

pressure between reference side and measurement side involves an effect on time-series measurement of difference pressure depending on the pressure field fluctuation. The difference is an error of measured difference pressure, which affects not only time variation but also averaged evaluation depending on measurement time, the magnitude and frequency of static pressure fluctuation in test section. If both tubes of reference side and measurement side have same time variation in pressure, even supposing that the test section has static pressure fluctuation, the difference would not be developed.

Therefore, the purpose of this study is to achieve a simple and quick approach to estimating the delay time and time variation of measurement pressure. For the pressure measurement, using unified one type pressure guide tubes is desirable for the measurement in terms of management of the experiment. In previous report [1], the prediction formula for same internal diameter pressure tube through the tube, without connection with different internal diameter tubes, was reported. However, in some experiments, a connected tube with two different internal diameter pressure guide tubes is used in terms of measurement accuracy improvement (small measuring part is preferable to reduce a flow interference) and preparation efficiency. Past study was reported an estimated equation, for a connected tube with two different internal diameter pressure guide tubes, which can calculate the delay time and the time variation in pressure [12]. However the result determined by the estimated formula was different from author's experiment result, and to the best of the author's knowledge, no report has been made to predict the effects of connected with different pressure tubes empirically and analytically in detail.

This paper reports the construction and availability of prediction formula estimating the delay time and time variation in pressure, in the case of using a pressure guide tube connected with two different internal diameter tubes, including the effects of each internal diameter and length.

2. Experimental Apparatus and Procedures

2.1. Measurement of Delay Time

Figure 3 shows schematic view of pressure guide tube and pressure sensor. The expe-

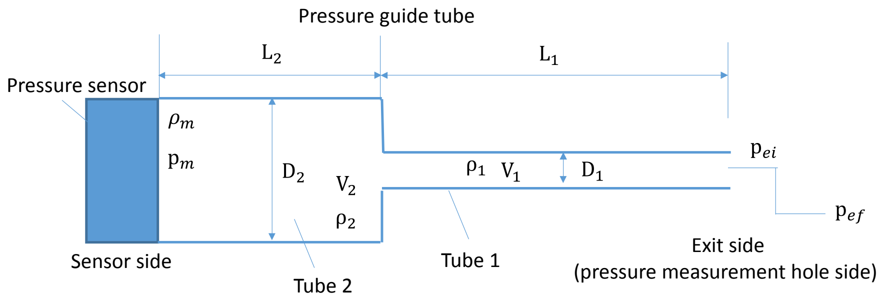

Figure 3. Schematic view of pressure guide tube (one-step tube) and pressure sensor.

riment is conducted using the pressure guide tube connected with two different internal diameter tubes (hereinafter called "One-step tube"). The difference pressure instrument is DSA3200, made by Scanivalve Corp., which is the precision of ±0.05% F.S. The full scale is 2.5 kPa. The sampling rate is used 20 Hz. The digital pressure controller is PPC4, made by Fluke Calibration which the precision of the pressure control is ±0.002% reading [1]. The delay time and time variation in pressure was measured in accordance with following procedure [1]; A targeted pressure is applied to the pressure guide tube from the pressure controller, the time series pressure data is measured, then the pressure of measurement-hole side is suddenly released to atmospheric air (initial pressure p_{ei} and released pressure p_{ef} at exit side) and continue to measure until the difference pressure to zero. The reference side of the difference pressure instrument is open to the atmospheric air.

2.2. Test Cases

Table 1 shows test cases and test conditions. It can be evaluated the effect of the magnitude of the applied pressure, a pressure guide tube connected with different internal diameters (One-step tube), the length and the internal diameter of each pressure guide tube.

3. Construction of an Estimated Formula

3.1. Approach to Constructing an Estimated Formula

It is considered how to determine the estimated formula calculating the time variation in pressure, when the pressure of measurement-hole side was suddenly released to atmospheric air (here, initial pressure is p_{ei} and released pressure is p_{ef} at exit side as shown in Figure 3). For the construction of the estimated equation in the case of "One-step tube" as shown in Figure 3, the whole delay time and the time variation in pressure can be estimated by summation of delay time in respective tubes. Because the time variation in pressure of the "One-step tube" cannot be determined by the prediction equation for a pressure tube with same internal diameter through the tube [1], that results from prior calculation and experiment.

3.2. Estimation of the Delay Time and the Time Variation in Pressure for "Tube 2"

First, the flow in tube 2 as shown in Figure 3 is considered. Basically, the time variation

Table 1. Test cases and test conditions in pressure.

Case	Pressure	Tube (exit side)		Tube (sensor side)	
		Length L_1	Diameter D_1	Length L_2	Diameter D_2
1	1.5 kPa, 1 kPa, 0.5 kPa, 0.3 kPa, 0.1 kPa	5 m	0.001 m	10 m	0.003 m
2		6 m	0.001 m	9 m	0.002 m
3		10 m	0.003 m	5 m	0.001 m

in pressure can be determined by same manner of the previous study [1], for this reason, derivation of the equation in detail is skipped. After all, the delay time and the time variation in pressure of the tube 2 is expressed by Equation (1) and Equation (2).

$$p_m = \left(p_{ei} - p_{ef}\right) \cdot \exp\left(-A_2 t_2\right) + p_{ef} \tag{1}$$

Here, $A_2 = 2\kappa \cdot p_{ef} \rho_{ef}^{1-\kappa} \pi D_2^4 / 128 \mu L_2 V_2$

$$t_2 = -1/A_2 \cdot \ln\left[\left(p_m - p_{ef}\right)/\left(p_{ei} - p_{ef}\right)\right] \tag{2}$$

Here, p_m is pressure of sensor side. p_{ei} is initial pressure at exit of the tube 2 before the pressure suddenly released. p_{ef} is final pressure at exit of the tube 2 after the pressure suddenly released. ρ_{ef} is fluid density at exit of pressure guide tube after pressure suddenly released. κ is specific heat ratio of fluid. μ is viscosity of fluid. D_2 is internal diameter of the tube 2. L_2 is length of the tube 2. V_2 is volume of the tube 2. t_2 is time for the tube 2.

3.3. Estimation of the Delay Time and the Time Variation in Pressure for "Tube 1" and "Tube 2" in Total

Second, the flow in tube 1 as shown in Figure 3 and total delay time and time variation in pressure is considered. Note, the volume to be considered is $V_1 + V_2$, not V_1 because it is needed to include the volume to pressure sensor side, the mass flow change at tube exit in unit of time is equal to whole mass change in pressure tube 1 and 2. Therefore the mass change $\left(V_1 + V_2\right) \mathrm{d}\rho_1$ due to the density change in considerable volume is equaled to mass flow rate $\dot{m}_{e1}$ in unit of time at tube exit of the tube 1, then the relationship is expressed by Equation (3).

$$-\left(V_1 + V_2\right) \mathrm{d}\rho_2 = \dot{m}_{e1} \mathrm{d}t_1 \tag{3}$$

Following equations are determined in the same derivation as the previous study [1].

$$p_m = \left(p_{ei} - p_{ef}\right) \cdot \exp\left(-A_1 t_1\right) + p_{ef} \tag{4}$$

Here, $A_1 = 2\kappa \cdot p_{ef} \rho_{ef}^{1-\kappa} \pi D_1^4 / 128 \mu L_1 \left(V_1 + V_2\right)$

$$t_1 = -1/A_1 \cdot \ln\left[\left(p_m - p_{ef}\right)/\left(p_{ei} - p_{ef}\right)\right] \tag{5}$$

Consequently, the delay time and the time variation in pressure can be determined by Equations (6) and (7), using Equations (2) and (5).

$$t = t_1 + t_2 = -\left(1/A_1 + 1/A_2\right) \cdot \ln\left[\left(p_m - p_{ef}\right)/\left(p_{ei} - p_{ef}\right)\right] \tag{6}$$

$$p_m = \left(p_{ei} - p_{ef}\right) \cdot \mathrm{p}\exp\left(-Bt\right) + p_{ef} \tag{7}$$

Here, $B = A_1 A_2 / \left(A_1 + A_2\right)$

Note, Equations (1), (2), (4)-(7) are not exactly correct expression in physics because the flow in tube was assumed Hagen-Poiseuille flow and isentropic change. The isentropic change means adiabatic and reversible process, but the energy loss is occurred in Hagen-Poiseuille flow because of friction drag, then the isentropic change is not strictly realized. However, as shown in results and discussion of chapter 4, the prediction formula can estimate the delay time and time variation in pressure in a way that allows to essentially match the empirical results. Therefore, it is presumed that the increase of the entropy is small in the change of the state in tube flow.

4. Results and Discussions

4.1. Comparison of Time Variation in Pressure between Estimation and Experimental Result

Figures 4(a)-(c) show comparison of time variation in pressure between prediction and experimental results. The results show the cases of applied pressure magnitude 1000 Pa only because the magnitude of applied pressure is not depending on the ratio of the pressure change on the basis of the experimental results as shown in the case of Table 1 and previous report [1]. In all cases, the empirical results have been shown to essentially match the prediction results.

4.2. Effect of Different Tube Combination

Figure 5(a) and Figure 5(b) show estimated results of the time variation in pressure determined by Equation (7) when the pressure guide tube is used "One-step tube", to discuss the effect of different-tube combination. Figure 5(a) shows three estimated results that the tubes of exit side are same length and same internal diameter, 10 m and 0.001 m, respectively, the respective tubes of sensor side have same length of 10 m and different internal diameter of 0.001 m, 0.002 m and 0.003 m, respectively. The combination of the tubes is shown in Figure 5(a). The estimated results of these combinations allow to discuss the effect of the tube volume on the delay time. From Figure 5(a), it takes a long time to pass the fluid out of the tube as the tube volume increases. That is because the volume to pass out of the tube is increased in spite of same mass flow rate in the tube 1 (exit side) in these combinations. Therefore, for shortening the delay time of measurement pressure, it is important that the internal diameter of tube 2 (sensor side) is not sized up to expectantly increase the flow rate of tube 2.

Figure 5(b) shows the other three estimated results that the tubes of sensor side are same length and same internal diameter, 18 m and 0.001 m, respectively, the respective tubes of exit side have same length of 2 m and different internal diameter of 0.0005 m, 0.001 m and 0.0015 m, respectively. The combination of the tubes is shown in Figure 5(b). The estimated results of these combinations allow to discuss the effect of internal diameter in exit side, on the delay time in the condition of almost same whole tube volume. From Figure 5(b), the delay time is increased as the internal diameter of the exit

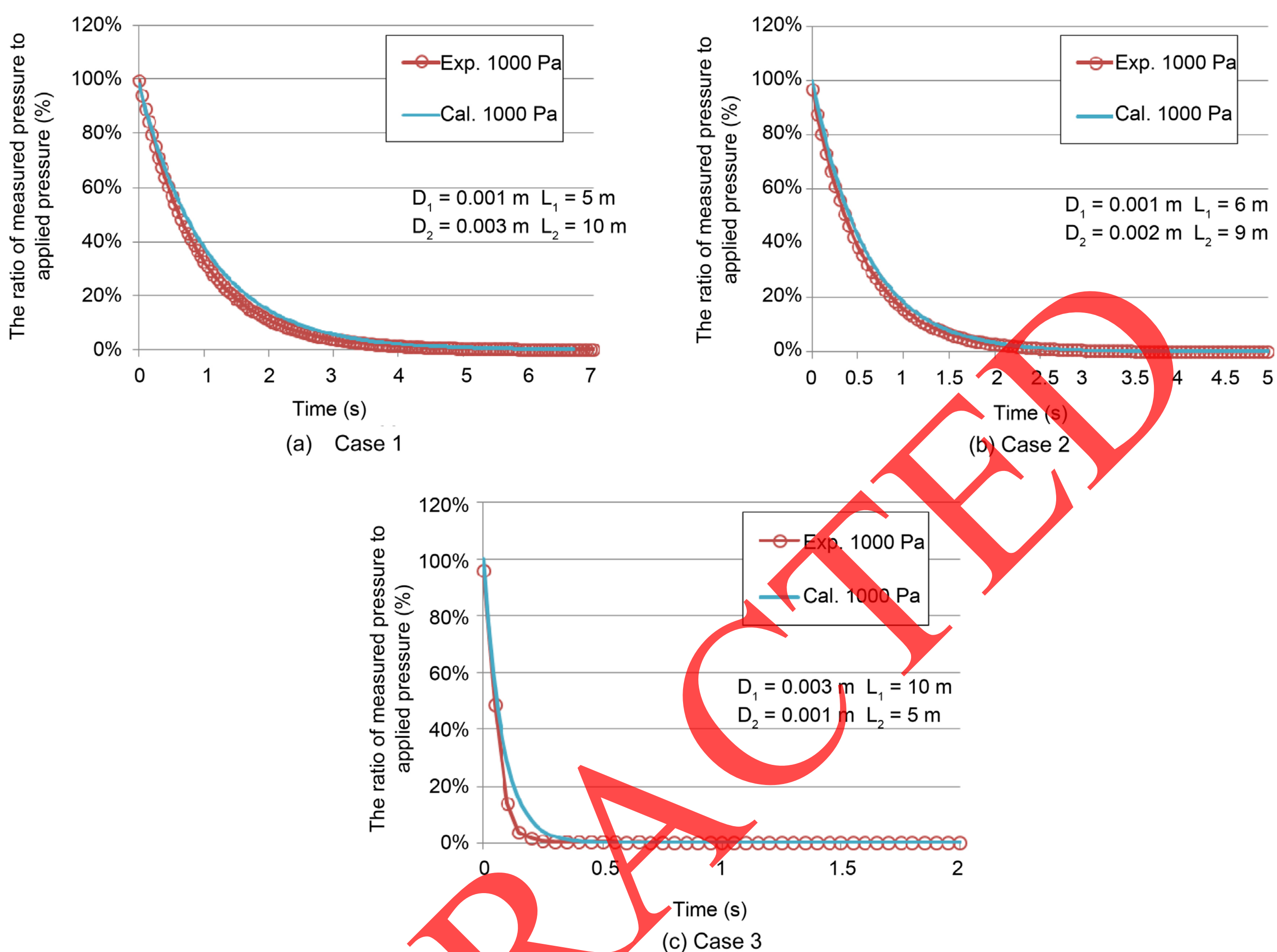

Figure 4. Comparison of time variation in pressure between prediction and experimental result.

side is decreased. That is because the mass flow rate is decreased due to small internal diameter of the tube 1 (exit side), although the volume to pass out of the tube is almost same. The larger internal diameter in tube 1 (exit side) compared with that of tube 2 (sensor side) can shorten the delay time.

When wind tunnel test is conducted, small internal diameter tube of the exit side is normally used to reduce the flow interference between main flow and pressure instruments, for example, omni-probe (12-hole probe, 18-hole probe etc.) or pressure tubing into an object to measure the surface pressure, however it is to be noted that smaller internal diameter of exit side increases the delay time.

5. Conclusion

Experimental and analytical study is conducted to construct a prediction formula to estimate the delay time and time variation in pressure, including the effects of a pressure guide tube connected with different internal diameter tubes, the length and the internal diameter of each pressure guide tube. The availability was confirmed by comparing the

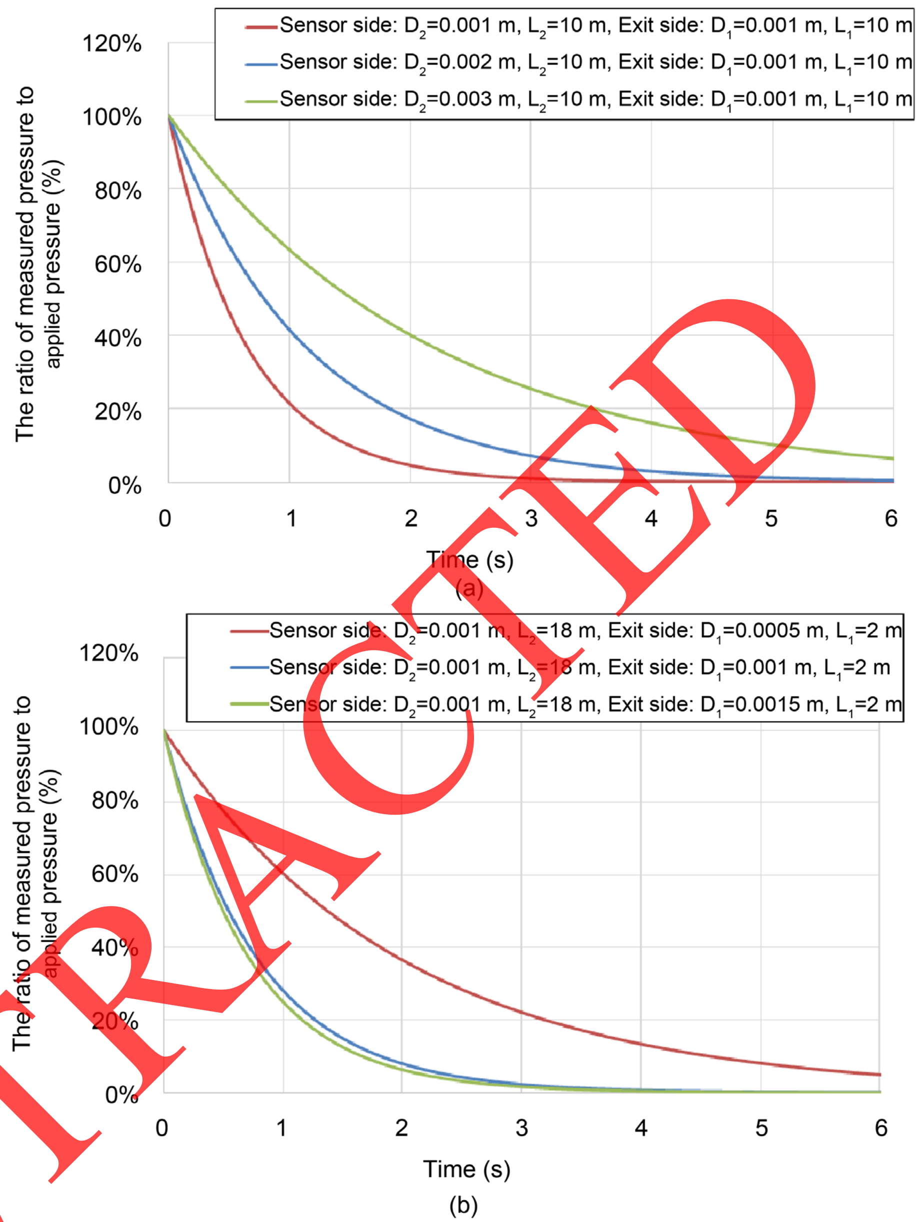

Figure 5. Estimated results by Equation (14) for the time variation in pressure when the pressure guide tube is "One-step tube". (a) Same internal diameter and length for exit side tube. (b) Same internal diameter and length for sensor side tube.

time variation in pressure between the estimation and experimental results, which the empirical results have been shown to essentially match the prediction results. It is important for shortening the delay time of measurement pressure that the internal diameter of exit side is increased compared with that of sensor side and the volume of the tube is minimized as much as possible.

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