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# Analysis of Gas Flow Rate and Pressure Loss of Medical Mask Differential Pressure Tester

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**Abstract:** The objective of this study is to find a suitable method to overcome the pressure loss problem in the gas pipe during the gas exchange detection of medical masks. Based on the European Standards EN 14683, the parameters of a medical mask differential pressure tester were selected, subsequently two schemes of gas pipe layouts were designed, including four kinds of pipe diameter which are 4, 5, 6.5, and 8mm respectively. Lastly, the models of each scheme were established and imported into *Fluent*, and the relevant parameters were set for simulation. After data analysis, the results showed that among the four different pipe diameters, the pressure loss of 8mm diameter of the pipe was lower in both the schemes, additionally the pressure loss of the second scheme (the gas pipe was short and smooth) was lower under the same pipe diameter. At the flow rate of $v = 8$L/min, the pressure loss from the inlet to the measurement point is less than 200Pa, and the estimated measurement error is less than 1.5%. In conclusion, shortening the length of the pipe, and increasing the diameter of the pipe can reduce the gas pressure loss, subsequently improve the measurement accuracy of the medical mask differential pressure tester.

**Keywords:** Medical mask; Differential pressure; Flow rate; Pressure loss; Fluid simulation

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## 1. Introduction

The COVID-19 pandemic has spread rapidly around the world during the year 2020. The primary transmission of COVID-19 is through the respiratory droplets produced by sneezing, coughing, and talking [1], therefore masks have become essential for people to protect themselves against the epidemic. In additional, medical masks are used to protect against droplet spread, subsequently reduce the risk of infections [2]. With the significant increase in the demand for medical masks due to the COVID-19 pandemic, ensuring the quality of medical masks has become an urgent problem to be solved. Among many standards medical masks, the differential pressure is one of the critical measurement parameters, where the differential pressure reflects the permeability of the mask and affects people breathability, therefore it is an essential indicator for judging whether the mask is qualified to use, and how the level of protection [3].

At present, there are some medical mask differential pressure testers on the market, and Laura H. Kwong study the influence of different materials for the masks on the differential pressure [4]. However, there is a lack of research on the flow rate and pressure loss in medical mask differential pressure testers. Pressure testers device is used to test the pressure difference between the two sides of a mask when a gas at a certain flow rate passes through a specified area of the mask. Currently, existing products mostly use a positive pressure air supply, thereby the pressure at the outlet cannot be detected in real-time, therefore, the measured result has a large error and the requirements of EN 14683-2019 unable to achieve [5]. In this study, we chose the scheme that was provided by EN 14683-2019 document using negative pressure air extraction. However, the gas in the device needs to flow through the mass flow meter, mass flow controller, and gas pipe, which might cause large pressure resistance and loss, and subsequently may affect the gas flow rate.

This study focuses on analyzing the effect of pipe diameter, length, and layout on the gas flow rate and pressure loss, to provides a theoretical basis for the selection and layout of the pipe on the experimental platform. Based on the simulation results, the optimal scheme is selected, subsequently the actual experiments are conducted, and an interesting experimental result has been obtained.

## 2. Principle

### 2.1. Working and testing principles

The working principle of the medical mask differential pressure tester is shown in **Figure 1**. A vacuum pump is installed at the end of the device as a negative pressure air source. The gas flow into the device through a mass flow meter, subsequently to the test area via the pipe. After that, the gas flow through pipes to a mass flow controller, which control the velocity of the gas. In addition, two pressure sensors are installed before and after the test area to measure the working pressure level. In summary, the gas factors affecting the performance of the device are including the pressure loss of the gas in the pipe, the mass flow controller, and leakage of the pipe. This paper mainly studies the flow rate and pressure loss of pipes with two different device configurations, which indicated by the green box in **Figure 1**.

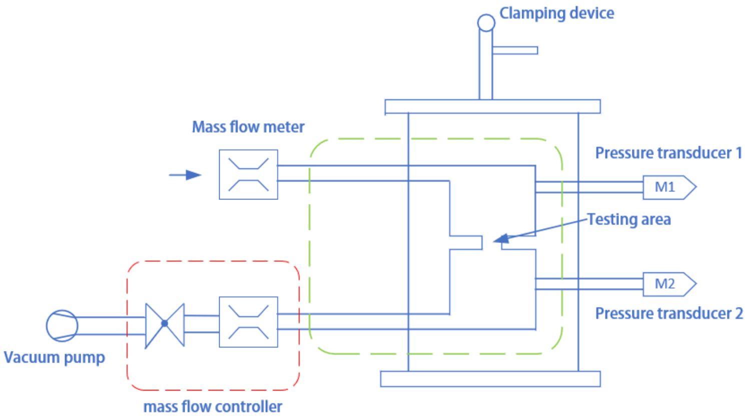


**Figure 1.** Schematic diagram of the test device

### 2.2. Gas state calculation

According to the standard EN 14683-2019, the gas flow rate of the test is (8±0.2) L/min, the diameter of the test area is 25mm, and the gas flow rate of the test area is $v_0$ which can be calculated by Eq. (1):

$$v_0 = \frac{q}{A} \tag{1}$$

It is calculated that $v_o = 0.27$m/s.

Typical diameters of gas pipes are $d_1 = 4$mm, $d_2 = 5$mm, $d_3 = 6.5$mm, and $d_4 = 8$mm, respectively. The flow velocity corresponding to each pipe diameter and the Mach number corresponding to each flow velocity can be calculated by equations (2) and (3):

$$v_i = \frac{4q}{\pi d_i^2} \tag{2}$$

$$M_{a_i} = \frac{v_i}{c} \quad (3)$$

where $c$ is the local speed of sound. Through $d_1$, $d_2$, $d_3$, $d_4$, $M_{a1} = 0.031$, $M_{a2} = 0.020$, $M_{a3} = 0.012$, $M_{a4} = 0.007$ are obtained respectively, and they are much less than $M_{a0} = 0.3$ which is obtained from $v_o$, therefore, the gas studied is considered as an incompressible fluid.

## 3. Methods

### 3.1. Scheme 1

**Figure 2A** is the schematic diagram of the overall appearance of the device, while **Figure 2B** is the schematic diagram of the internal pipe model of the device. The blue part shown in the schematic diagram is representing the gas pipe. The typical diameter of gas pipes is 4mm, 5mm, 6.5mm, and 8mm as shown in **Figure 2B**, and these four specifications were used for fluid simulation analysis. **Figure 2C** is the schematic diagram of the layout of the pipe model, where there are two gas inlets, two pressure test points, and a gas outlet. The flow rate test area is in the middle of the two pressure test points.

The working principle of the model is as follows; Inlet 1 is used as the gas inlet for daily use, where the gas enters the device through inlet 1, subsequently reach the sample detection area through the pipe, and then continues to flow out of the device through the outlet. Inlet 2 is used as the detection port of gas calibration, and is usually closed. The pressure difference between the two sides of the sample is obtained by measuring the pressure values at the two pressure test points. The gas flow rate between the two pressure test points should meet the standard requirements.

Simulation objectives were conducted to obtain the pressure difference between the gas inlet and outlet when the required gas flow rate is reached, and the influence of different pipe diameters on gas velocity and pressure loss were also analyzed.

The simulation process is as described below:

(1) Close the inlet 2, open inlet 1, subsequently note down 50Pa, 100Pa, and 200Pa as the initial pressure difference between the gas inlet and outlet, respectively, followed by simulation experiments to verify if the gas can reach the standard flow rate.

(2) Once the required of gas flow rate achieved, the simulation experiments are conducted on gas pipes models which in 4mm, 5mm, 6.5mm, and 8mm diameter, to obtain a scheme with a minimum gas pressure loss.

(3) After completing (1) and (2), inlet 1 is closed, in contrast inlet 2 is opened as the gas inlet. Simulation is conducted according to the optimal parameters obtained in (1) and (2) to verify the influence of different inlets on the gas flow of the device.

The model was imported into *Ansys* for grid division, and then imported into *Fluent* for simulation analysis. The initial parameters were set as follows; The gas inlet pressure is one atmosphere, and the initial pressure difference between the pipe inlet and outlet is 50Pa/100Pa/200Pa respectively. Three groups of simulation experiments were conducted. During the experiment, the monitoring point of the cross-section average gas velocity is established on the cross-section of the flow test area between the two pressure test points, and the obtained simulation results are shown in **Figure 3(A–D)**.

Under condition 1, the inlet 1 is used as the gas inlet, while inlet 2 is closed. The gas inlet is set as pressure inlet, which is set at one atmosphere, meanwhile the gas outlet is set as pressure outlet with the pressure difference between outlet and inlet is 50Pa/100Pa/ 200Pa, respectively. The average gas velocity on the cross-section of the measurement area is obtained, and is shown as a solid line. The dashed line data are obtained when inlet 1 is closed, in contrast inlet 2 is used as the gas inlet while other conditions remain unchanged, also noted as condition 2.

When the gas flow rate is stable, the average gas flow rate on the cross-section of the measurement area is shown in **Table 1** under condition 1. Under condition 2, where inlet 1 is closed, in contrast inlet 2 is used as the gas inlet, the average gas velocity on the cross-section of the measurement area is shown in **Table 2**.

Of the two different schemes, the gas flow rate of the scheme with a pipe diameter of 5mm, and pressure differences of 100Pa and 200Pa, and the scheme with a pipe diameter of 8mm and pressure difference of 200Pa meet both the standard requirements.


**Figure 2.** Schematic diagram of design scheme 1; **(A)** appearance of the device; **(B)** model of internal pipe; **(C)** layout of the pipe model

**Table 1.** Stable flow rate (m/s) of the method that inlet 1 is used as the gas inlet and inlet 2 is closed

| | 4mm | 5mm | 6.5mm | 8mm |
|---|---|---|---|---|
| 50Pa | 0.06 | 0.23 | 0.09 | 0.16 |
| 100Pa | 0.11 | 0.33 | 0.15 | 0.23 |
| 200Pa | 0.19 | 0.46 | 0.25 | 0.33 |

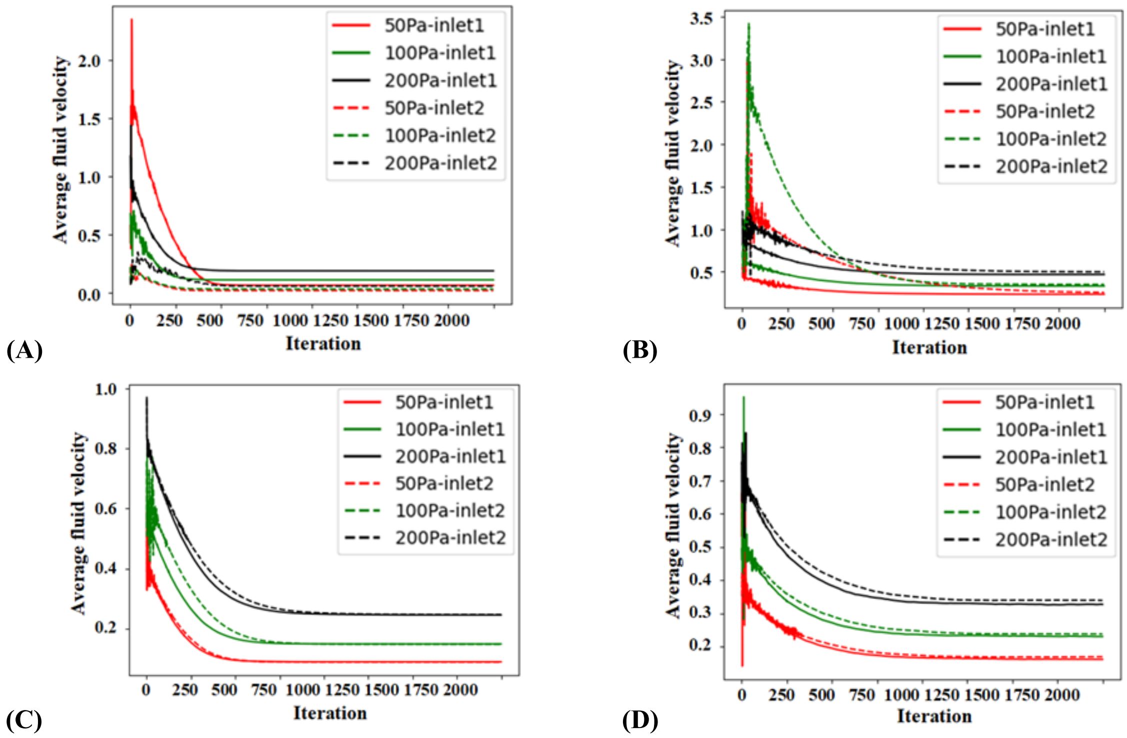


**Figure 3.** Simulation results of scheme 1; **(A)** simulation results of pipe diameter of 4mm; **(B)** simulation results of pipe diameter of 5mm; **(C)** simulation results of pipe diameter of 6.5mm; **(D)** simulation results of pipe diameter of 8mm

**Table 2.** Stable flow rate(m/s) of the method that inlet 1 is closed and inlet 2 is used as the gas inlet

| | 4mm | 5mm | 6.5mm | 8mm |
|---|---|---|---|---|
| 50Pa | 0.02 | 0.25 | 0.09 | 0.17 |
| 100Pa | 0.03 | 0.30 | 0.15 | 0.24 |
| 200Pa | 0.06 | 0.49 | 0.25 | 0.34 |

### 3.2. Analysis of scheme 1

As shown in **Figure 3(A–D)**, the simulation result shows that using different piping layouts can influence final gas velocity. In the gas pipe with almost the same length, there is a right-angle bend in condition 1 which causes more local loss, however, in condition 2 the pipe layout designed is smoother. When the pipe diameter is 4mm, the local loss caused by the right-angle bend is lower, than the head loss caused by the pipe length, therefore the steady flow rate of the former is higher than that of the latter. When the pipe diameter is 5mm and 6.5mm, the pressure loss and the steady flow rate of these two parts are similar. When the pipe diameter is 8mm, the local loss caused by the right-angle bend is higher, than the loss due to the pipe length difference, therefore, the steady flow rate of the former is lower than that of the latter.

Considering the factors affecting the gas flow rate, the gas pipe is optimized by reducing the length of the gas pipe, avoiding the route with a sharp angle, such as a right-angle bend in the gas pipe layout, and reduce the section ratio between different sections of the pipe, subsequently the scheme 2 was obtained.

### 3.3. Scheme 2

According to the step mentioned above (subheading 3.1), the pipe model of scheme 2 was simulated and analyzed. The device model and pipe model of scheme 2 are shown in **Figure 4**. **Figure 4A** is the schematic diagram of the overall appearance of the device, while **Figure 4B** is the schematic diagram of the model of the internal pipe of the device. The blue part of **Figure 4B** is the gas pipe with four typical diameters, and **Figure 4C** is a schematic diagram of the pipe model. Compared with scheme 1, scheme 2 includes optimization of the pipe layout, overall length of the pipe is shorter, gas inlet for calibration is removed, and only one inlet was set as a public interface. The test point and flow rate test area are the same as scheme 1.

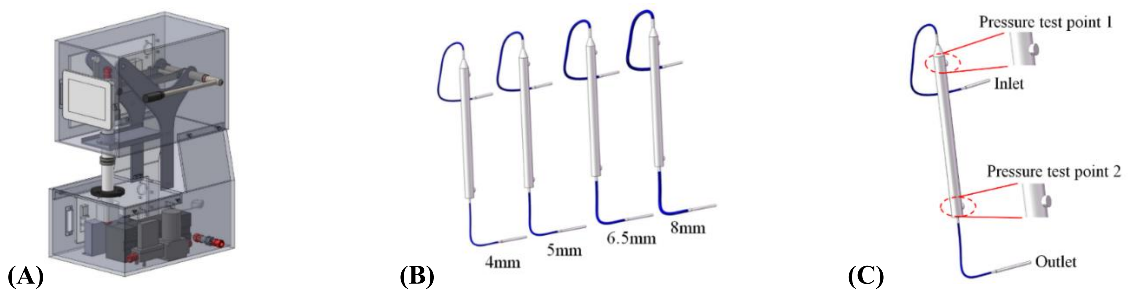


**Figure 4.** Schematic diagram of design scheme 2; **(A)** appearance of the device; **(B)** model of internal pipe; **(C)** layout of the pipe model

The simulation target and process are the same as those mentioned above (subheading 3.1), the gas inlet is set as the pressure inlet with a pressure at one atmosphere, the gas outlet as the pressure outlet, and the pressure difference between the outlet and the inlet is 50Pa/100Pa/200Pa, respectively. The simulation results of the average gas velocity on the cross-section of the measurement area are shown in **Figure 5(A–D)**. When the gas flow state is stable, the average gas velocity on the cross-section of the measurement area is shown in **Table 3**.

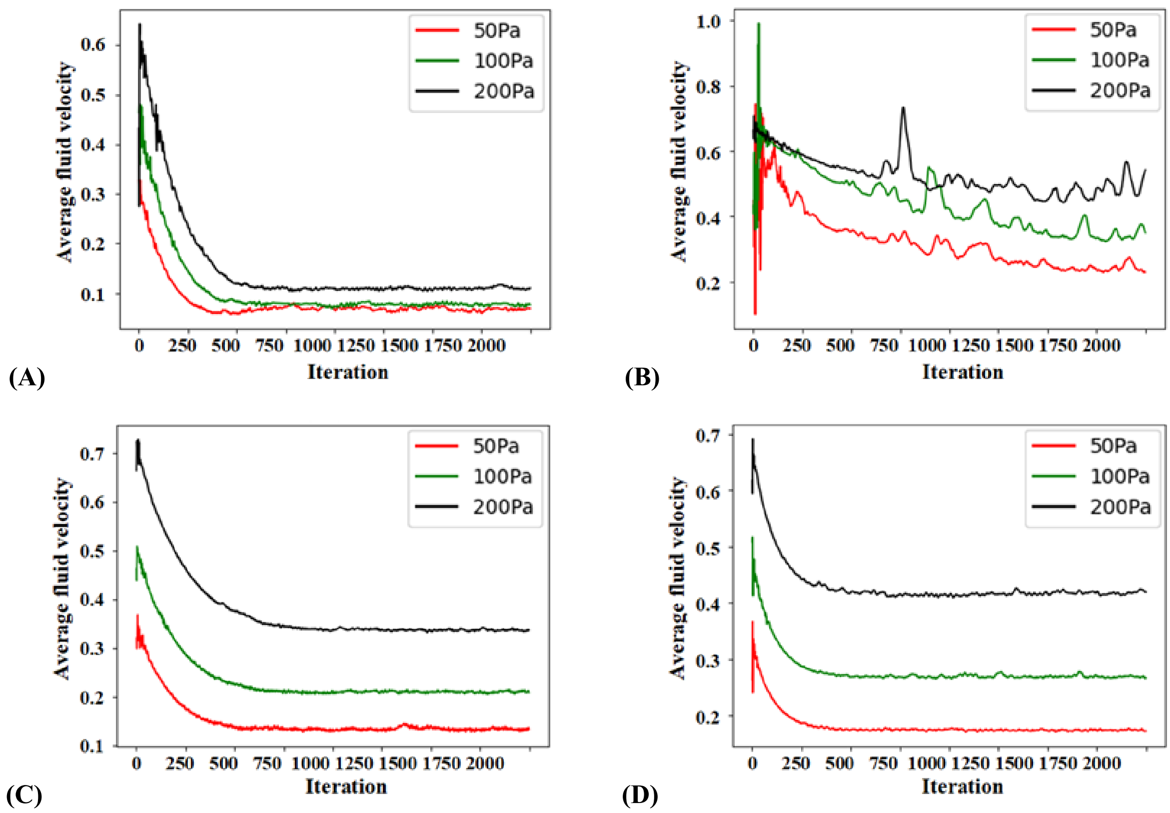


**Figure 5.** Simulation results of scheme 2; **(A)** simulation results of pipe diameter of 4mm; **(B)** simulation results of pipe diameter of 5mm; **(C)** simulation results of pipe diameter of 6.5mm; **(D)** simulation results of pipe diameter of 8mm

**Table 3.** Stable flow rate(m/s) of the scheme 2

| | **4mm** | **5mm** | **6.5mm** | **8mm** |
|---|---|---|---|---|
| 50Pa | 0.06 | 0.23 | 0.13 | 0.17 |
| 100Pa | 0.07 | 0.34 | 0.21 | 0.26 |
| 200Pa | 0.11 | 0.54 | 0.34 | 0.42 |

According to the experimental data in **Table 3**, the gas flow rate of the scheme with a pipe diameter of 5mm and pressure differences of 100Pa and 200Pa, the scheme with a pipe diameter of 6.5mm and pressure of 200Pa and the scheme with a pipe diameter of 8mm and pressure differences of 100Pa and 200Pa could meet all the standard flow requirements.

## 4. Experiment

To verify scheme 2, a pipe diameter of 8mm was used to build a prototype, as shown in **Figure 6**. Seven groups of mask samples with calibration pressure parameters of 106Pa, 114Pa, 163Pa, 174Pa, 217Pa, 219Pa, and 382Pa was tested with the prototype, and each group of samples was tested ten times. The test data and average deviation of each group are shown in **Figure 7(A–B)**. The maximum mean deviation of measurement is 4.98Pa, and the maximum error is less than 1.5%. The scheme with a pipe diameter of 8mm in scheme 2 has high accuracy and good stability.

**Figure 6.** Schematic diagram of the prototype

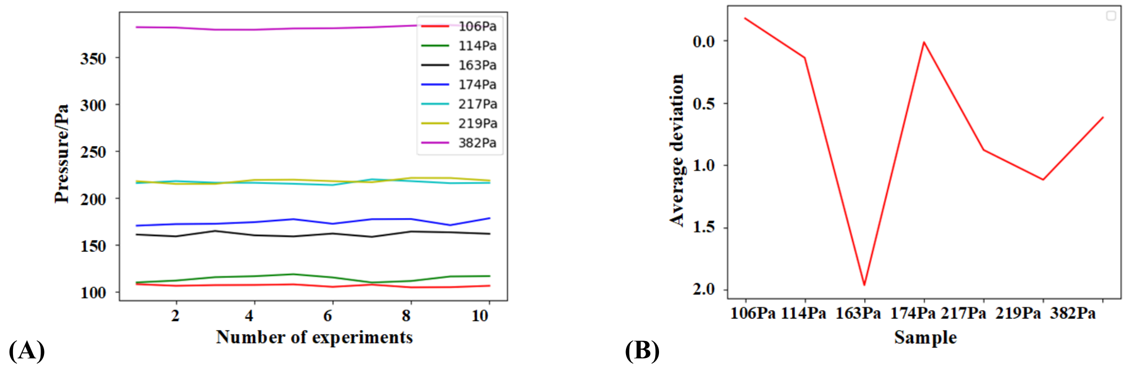


**Figure 7.** Results of measurement; **(A)** test pressure difference of the sample; **(B)** average deviation of the test data

## 5. Conclusion

In this paper, two types of pipe gas layout schemes are designed for the medical mask differential pressure tester. The model of the two schemes was designed, and the gas flow rate and pressure loss of the two schemes models are analyzed. *Fluent* was used to simulate the gas flow in these models, and the scheme with a good standard diameter pipe was determined.

Comparing the simulation results in **Figure 3,** and **Figure 5**, the steady-state flow rate of gas in scheme 2 is generally higher, compared to scheme 1.

In different pipe parameters in scheme 2, the pipe diameters of 5mm, 6.5mm, and 8mm can meet the standard requirements within the pressure difference of 200Pa. However, as can be observed from the simulation results in **Figure 5**, when the pipe diameter is 5mm, the stability of the gas flow state is relatively poor. Additionally, when the pipe diameter is 8mm, the pressure loss of gas passing through the pipe is small, in contrast the steady-state flow rate is high. In short, a small pressure difference is needed to achieve a standard flow rate. Therefore, the pipe diameter of 8mm in scheme 2 is selected as the final scheme.

Through experimental verification, the scheme 2 with 8mm pipe diameter can achieve the standard gas flow rate of 8L/min, effectively reduce the pressure loss, and subsequently improve the test accuracy and stability.

## Disclosure statement

The authors declare no conflict of interest.

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