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Study on Design of Pressure Chamber in a Linear-Jet Type Air Curtain System for Prevention of Smoke Spread

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Abstract

Death toll by smoke in fire is estimated at 70% which emphasizes the importance of smoke control system to deal with the fire smoke. In advanced countries, the studies on method to prevent smoke spread by forming the air curtain using high velocity jet flow are underway now. In this study, a linear-jet type air curtain system is proposed to prevent the smoke spread and analysis of flow characteristics of pressure chamber, which is the core component, is conducted through numerical analysis and experimental approach. Consequently, the pressure was increased in 2D functional way to input air flowrate and about 595 Pa pressure was formed at pressure chamber inlet in response to 30 m/s nozzle jet velocity.

Keywords

Smoke Spread Prevention, Linear Jet, Air Curtain System, Fire, Numerical Analysis, Experiment

1. Introduction

In line with increasing high-rise and large buildings in urban area, increasingly growing number of buildings become vulnerable to the fire and thus it's necessary to develop the measure to effectively secure the safety of the people in fire for application to the site. In viewing the damage by fire in Korea, fire frequency is on the rise, resulting in increase in damage to the people.

Particularly, the importance of smoke control system to deal with the smoke that causes the trouble with evacuation and fire suppression, threatening the life safety, has been emphasized. According to NFIRS (National Fire Incident Reporting System) death toll by smoke in fire is estimated at 70% [1].

In Korea, smoke exhaust system that discharges the smoke from fire to the outside and pressurized system to prevent the smoke from flowing into the evacuation route are available. On the other hand, the studies on method to prevent smoke spread by forming the air curtain using high velocity jet flow are underway now in advanced countries. That is, the study on preventing smoke spread between large space and connection space by using air curtain in large space building [2], the study on smoke spread prevention effect in channel structure depending on air blow velocity from air curtain [3], the study on smoke spread prevention performance of air curtain and major factor design through the down-scale model and numerical analysis while smoke is rising through the stair [4], the study on forming the air curtain by blowing the jet flow from the top and bottom of the evacuation passage to prevent the smoke from penetrating into the evacuation passage at tunnel sides [5] and the review of the need for preventing the fire and smoke spread and the phenomenon in a small zone was conducted [6].

As one of the system to prevent smoke spread in building, a linear-jet type air curtain system is under development and this paper is intended to introduce the research result to obtain the basic data for designing the pressure chamber which is the core component of a linear-jet type air curtain system. That is, basic model of pressure chamber is proposed and then analysis of flow characteristics of pressure chamber depending on input air flowrate through the numerical analysis and experiment is introduced. As a result, pressure formed at pressure chamber with related to air flowrate was obtained, and fan and pressure chamber of linear-jet type air curtain system could be designed based on such analysis result.

2. Proposal of a Linear-Jet Type Air Curtain System

A linear-jet type air curtain system which is under review to keep smoke from spreading is summarized as **Figure 1** below. As seen in figure, it comprises of air supply device, pressure chamber, nozzle, exhaust hood and mechanical exhaust device. In a system, the air is mechanically supplied to the pressure chamber by air blower and jet flow is formed through nozzle. And exhaust hood and mechanical exhaust device are set on the wall opposing to the wall on which the nozzle is set so as to suck the jet flow and part of the smoke. It's important to form the air curtain to cope with smoke-spreading force and design the system considering the space available for installation.

3. Numerical Analysis of Pressure Chamber

3.1. Numerical Analysis Model and Method

In the development process of a linear-jet type air curtain system, design of pressure chamber which is the core component that forms jet flow from supplied air is more than important. Pressure chamber shall be installed to minimize the pressure loss by flow and the size shall be determined in consideration of the

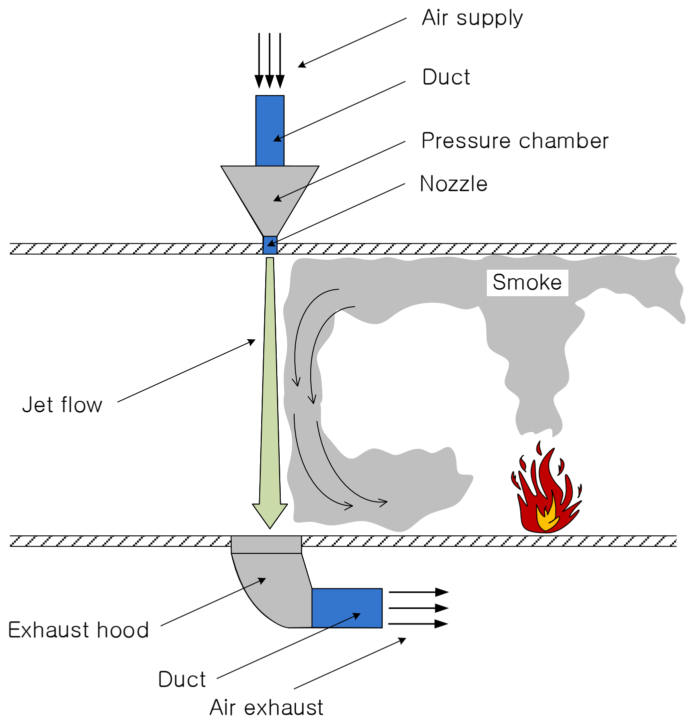


Figure 1. Diagram of a linear-jet type air curtain system.

space available for installation so as to ensure the uniform jet flow is formed. In this study, pressure chamber in Figure 2 is proposed first. As seen in Figure 2, pressure chamber is connected to air duct and has the connection and the nozzle in funnel shape in consideration of chamber height and pressure loss. The dimension of pressure chamber in detail is indicated in Figure 3.

As 3D numerical analysis program for this study, 3D commercial program CFX17 which accuracy and feasibility have been proven and widely used for heat & flow analysis was used in this study [7].

Figure 4 shows numerical analysis model. As boundary condition for numerical analysis, inlet velocity was given to make the condition at air duct inlet for the air flowrate and opening condition of pressure gradient "0" at nozzle outlet was given. Numerical analysis was conducted while blow velocity at nozzle outlet is increased by 5 m/s from 10 m/s up to 30 m/s and the inlet air flowrate was in the range from 360 CMH to 1080 CMH.

Figure 5 shows the grid structure to conduct the flow analysis by 3D numerical method for the proposed pressure chamber. A grid was generated in HEXA form and the total number of grid was about 2,300,000.

3.2. Numerical Analysis Result

Figure 6 and Figure 7 show the numerical analysis results when air flowrate is 1080 CMH, that is, discharge velocity at nozzle was 30m/s. Figure 6 shows velocity distribution at each section. Figure 6(a) shows the result at longitudinal central section, indicating that the air is supplied to satisfy the air supply at

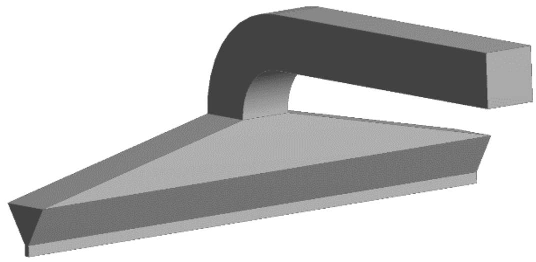
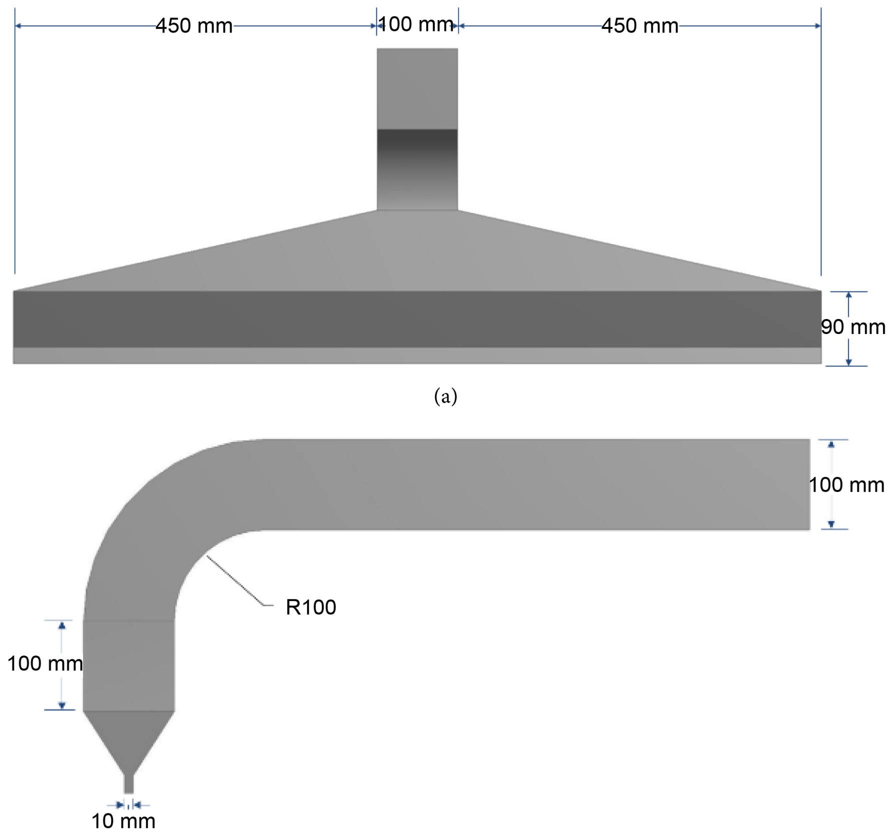


Figure 2. Pressure chamber diagram.



(a)

(b)

Figure 3. Drawing and dimension of pressure chamber. (a) Front view. (b) Side view.

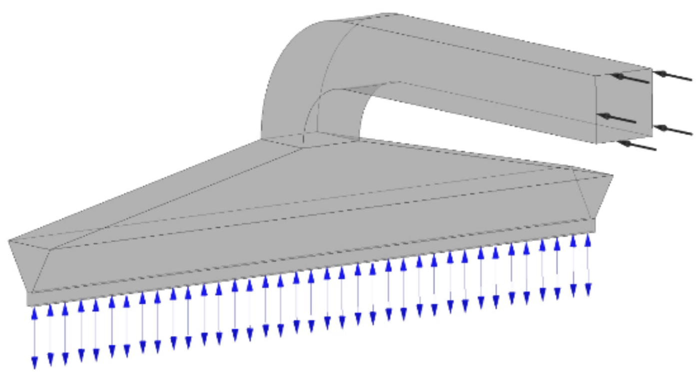


Figure 4. Numerical analysis domain and boundary condition of pressure chamber.

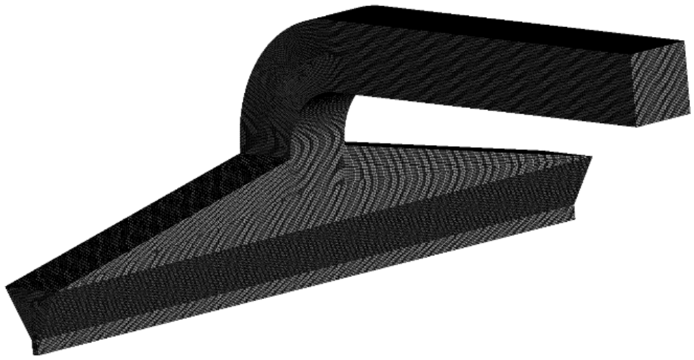
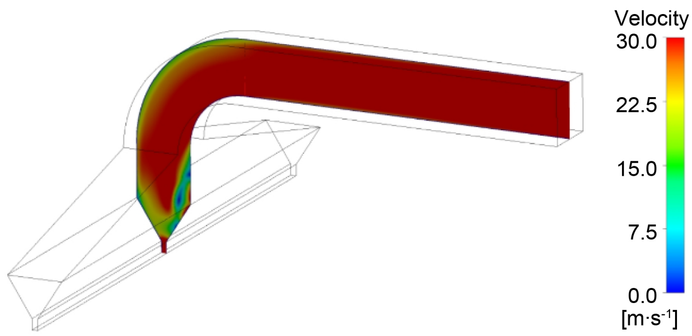
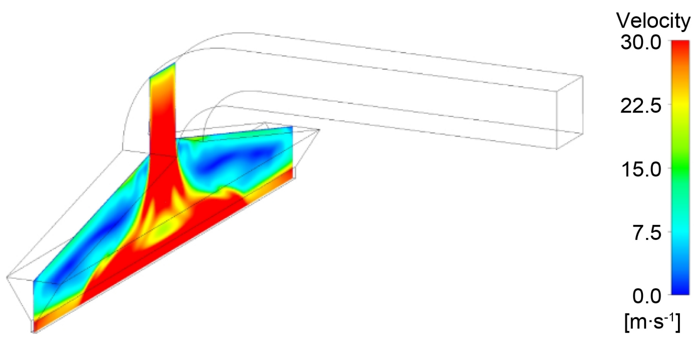


Figure 5. Grids of analysis domain.



(a)

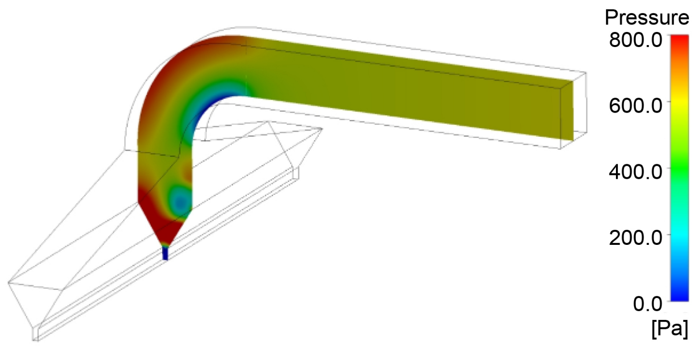


(b)

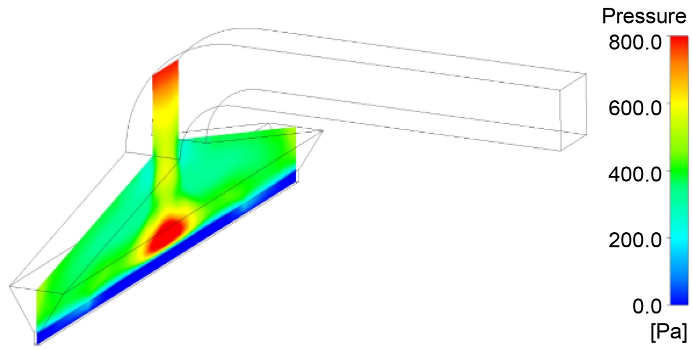
Figure 6. Velocity distribution for air flowrate 1080 CMH. (a) Longitudinal central section. (b) Horizontal central section.

connection duct inlet of pressure chamber and the air is blown from the nozzle at 30 m/s. On the other hand, pressure chamber and duct connection are met at 90˚ causing air velocity in pressure chamber to rise on one wall. Figure 6(b) shows the result at horizontal central section that the air flowing to the pressure chamber from connection duct dispersed horizontally in pressure chamber. As seen in figure, jet velocity at both ends is slightly lower than the central part, and thus it's required to design the pressure chamber to make jet velocity becomes equal at all locations.

Figure 7 shows pressure distribution at each section. Figure 7(a) shows the result at longitudinal central section that pressure of the supplied air rose toward the exterior wall at connection duct where the air is bent at 90˚ and the pressure



(a)



(b)

Figure 7. Pressure distribution for air volume 1080 CMH. (a) Longitudinal central section. (b) Horizontal central section.

at the rear part of pressure chamber also rose. About 595 Pa pressure was formed near the pressure chamber inlet. Figure 7(b) shows the result at horizontal central section that the pressure at central part in horizontal direction rose significantly by the air blowing from the connection duct.

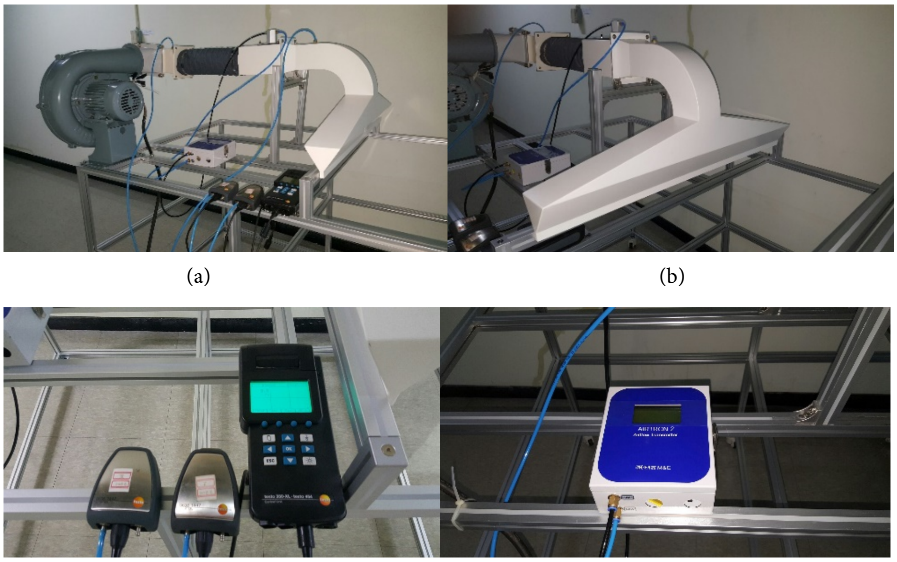
Table 1 summarizes the numerical analysis result showing the pressure values at pressure chamber inlet depending on air flowrate condition. As seen in table, the more the air flow the higher the pressure, and design of the fan and pressure chamber of a linear-jet type air curtain system could be based on such analysis result.

4. Experiment of Pressure Chamber

Same pressure chamber as the model used for numerical analysis was fabricated and the experimental device for flow test depending on nozzle discharge velocity was fabricated. Experimental result was compared to numerical analysis result. Figure 8 shows the experimental device. Figure 8(a) shows the overall view of experimental device. As seen in figure, the air is blown to pressure chamber by fan and rpm of the fan is controlled by inverter so as to adjust the air flowrate. Figure 8(b) shows the pressure chamber for the test which is same in shape as that for numerical analysis. Figure 8(c) shows the pressure sensor to measure the pressure at pressure chamber inlet and Figure 8(d) shows the air flowrate sensor to measure the air flowrate supplied to the pressure chamber.

Table 1. Pressure value at pressure chamber inlet in numerical analysis depending on air flowrate.

Flow rate (CMH)	Static pressure at inlet (Pa)
360	72.4
540	156.0
720	271.6
900	418.0
1080	595.0

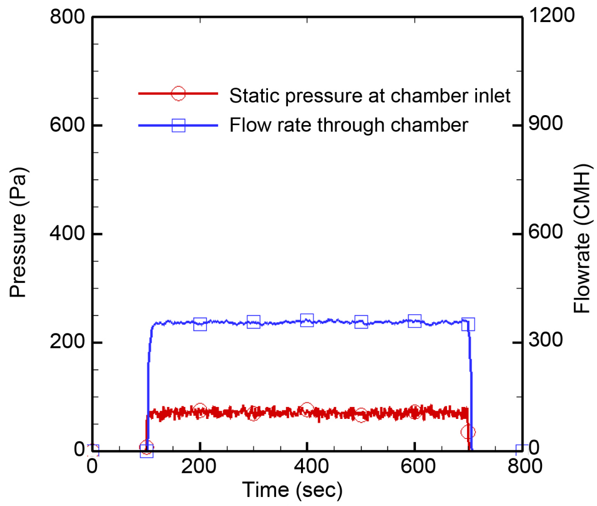


(a) (b) (c) (d)

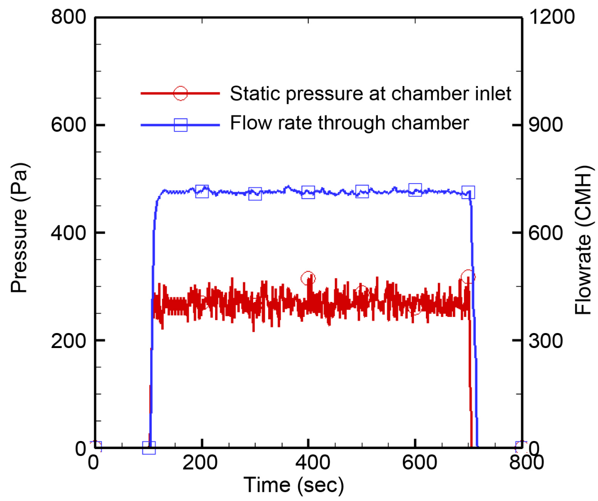
Figure 8. Experimental device for pressure chamber analysis. (a) Whole view. (b) Pressure chamber. (c) Pressure sensor (d) Air flowrate sensor (FMS).

Figure 9 shows the part of the experimental result indicating the pressure at pressure chamber inlet and air flowrate measured. Figure 9(a) is the experimental result when air flowrate is 360 CMH or nozzle discharge velocity is 10m/s. As seen in figure, when the fan equipped with inverter to generate the air flow as required for the test starts operating, air is supplied to the pressure chamber and the pressure formed at pressure chamber inlet is measured. The test was conducted for 15 minutes and the fan kept operating for 10 minutes. Figure 9(b) shows the test result when air flowrate was 720 CMH or nozzle discharge velocity was 20 m/s and Figure 9(c) shows the test result when air flowrate was 1080 CMH or nozzle discharge velocity was 30 m/s. As seen in figure, the more the air flowrate the higher the pressure at the pressure chamber inlet and the pressure variation amplitude as well. Representative experimental value to compare to numerical analysis value was the mean value of the values measured during fan operation.

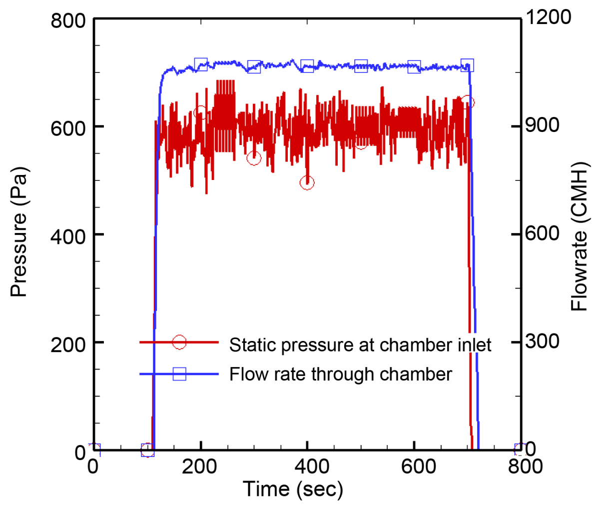
Figure 10 is the pressure value at pressure chamber inlet depending on air flowrate and compares the numerical analysis result with experimental result. As seen in figure, the pressure was increased in relation of two-dimensional



(a)



(b)



(c)

Figure 9. Experimental result of pressure variations depending on air flowrate. (a) Air flowrate 360 CMH. (b) Air flowrate 720 CMH. (c) Air flowrate 1080 CMH.

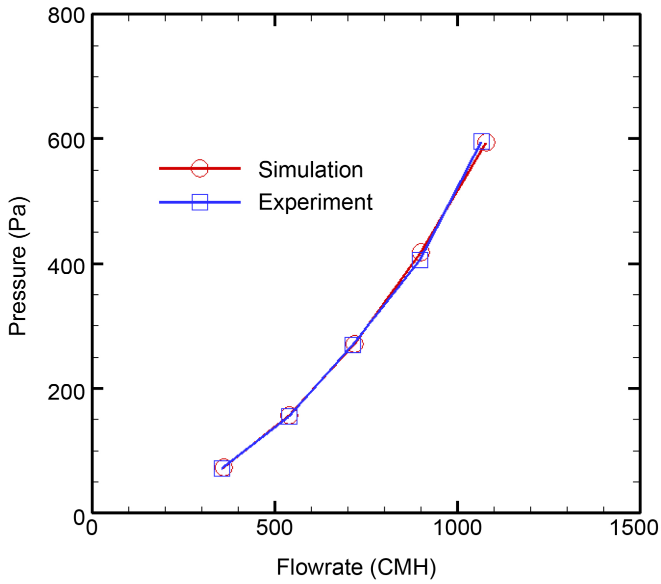


Figure 10. Pressure at pressure chamber inlet depending on air flowrate.

function in line with the increase in air flowrate. Based on such analysis result, design of a linear-jet type air curtain system is achievable. Numerical analysis result generally coincides with the experimental result, proving the reliability of the analysis result.

5. Conclusions

In this study, a basic model of pressure chamber which is the core component of linear-jet type air curtain system is proposed and analysis of flow characteristics of pressure chamber depending on air flowrate was conducted through numerical analysis and experiment of basic model and consequently, conclusion is made as follows.

1) Jet velocity at both ends of pressure chamber is slightly lower than the central part, and thus it's required to design the pressure chamber to make jet velocity becomes equal at all locations.

2) The pressure was increased in relation of two-dimensional function in line with the increase in air flowrate.

3) About 595 Pa pressure was formed near pressure chamber inlet in response to nozzle jet velocity of 30 m/s.

4) Pressure formed at pressure chamber inlet depending on air flowrate was obtained and fan and pressure chamber of linear-jet type air curtain system could be designed based on such analysis result.

Acknowledgements

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