NUMERICAL ANALYSIS OF AIR CURTAIN USED AS A SMOKE RESISTANCE AND OPTIMIZATION OF DIFFERENT PROCESS PARAMETERS

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Abstract

The performance of air curtain was evaluated on the basis stability of air jet at higher different pressure difference across the door. Here in this work it calculate the effect of different pressure difference on air jet stability, for calculating the effect of different pressure difference here in this work it considered six different pressure difference that is 1, 4, 6.25, 9, 12.25 and 16 Pa. at each pressure difference it calculated the value of volume flow rate of smoke at outer outlet. It also calculate the effect of different air jet angle on the volume flow rate of smoke, for analysing the effect of different air jet angle here it considered five different air jet angles that is 10, 15, 20, 25 and 30 degree. Through analysis it is found that at 25 degree air jet angle the performance of air curtain is higher as compared to other angle. After analysing the effect of different air jet angle, it also analysed the effect of different air jet velocity on volume flow rate of air, for analysing the effect of different air jet velocity it considered four different air jet velocities that is 8, 10, 12 and 13.5 m/s and calculates the value of volume flow rate of smoke for each velocity at different pressure difference.

Keywords- Air curtain, Air jet, Jet angle, Smoke resistance and Thermal resistance

Introduction

In general, high-rise buildings provide fewer exits compared to their large residential capacity. For security reasons, elevators are generally forbidden in case of high-rise building fire. Consequently, stairwells are planned as the “safe zone” for fire evacuation in high-rise buildings. Unfortunately, most of stairwells in high-rise buildings fail to satisfy such “safe zone” requirement. For example, the pressurization of staircases is a smoke protection system that is commonly used in buildings. However, it requires large amounts of air. As a result, air curtain could be a more effective way to block smoke propagation during a fire. Compared with conventional fire doors, another advantage of these virtual screens is the ease of evacuation of people while limiting the transmission of smoke and heat through the opening. Air infiltration is the uncontrolled flow of outside air into buildings through slits in the building envelope or via large admission such as doors. An air curtain or an air door is a device that inhibits air or contaminants from seeping from one region to another. The typical design of the air curtain is just like a fan mounted at the entrance to a building and facing downwards. It can also act as an opening among two spaces maintained at variant temperatures.

Mathematical Model used

For calculating the flow rate of air at different condition, here in this work it considered different mathematical relations. The mathematical relations that are used during the analysis were mention in the below section. The Calculated net volumetric airflow rates were then correlated to the pressure difference based on equation given by Yuill's infiltration mode [12]. To obtained the discharge coefficient (C).

$$\frac{Q_{angle}}{A\sqrt{2/\rho}} = C_D\sqrt{\Delta P_{oi}} \quad \ldots\ldots (1)$$

Where, Q_{angle} = volumetric air rate (m^3/sec), A = area of the door (m^2), ρ = density of air (kg/m^3), C_D = discharge coefficient, ΔP_{oi} = air pressure difference (Pa)

Material used and Development of Numerical model

Here in this work smoke is treated as air, so the different properties of air were used as a property for smoke Density (kg/m^3), Thermal conductivity (W/m-k), Specific heat (J/kg-K) and Dynamic Viscosity (Pa-s) is 1.22, 0.024, 1006 and 0.000017. For analysing the effect of different process parameters of air curtain, first it has to develop the numerical model of air curtain. For developing the numerical model of air curtain, first it has to develop the solid model of air curtain. The solid model of air curtain was developing on the basis of geometric dimension given in the base paper. The dimension of geometry were shown in the below fig.

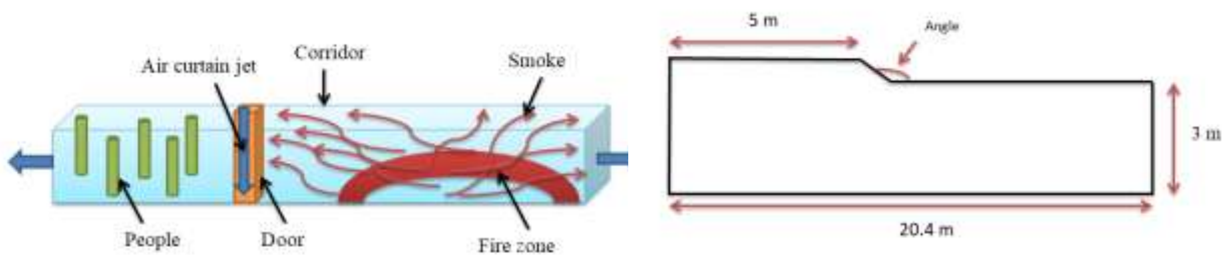

Fig.1 (a) schematic diagram of analysis zone, (b) shows the 2D geometric dimension of solid model

Meshing

For performing the numerical analysis, discretization of 2D model of air curtain were done. In order to get the perfect mesh different tools were used to refine the mesh of the geometry. The mesh of the given geometry is shown in the below figure.

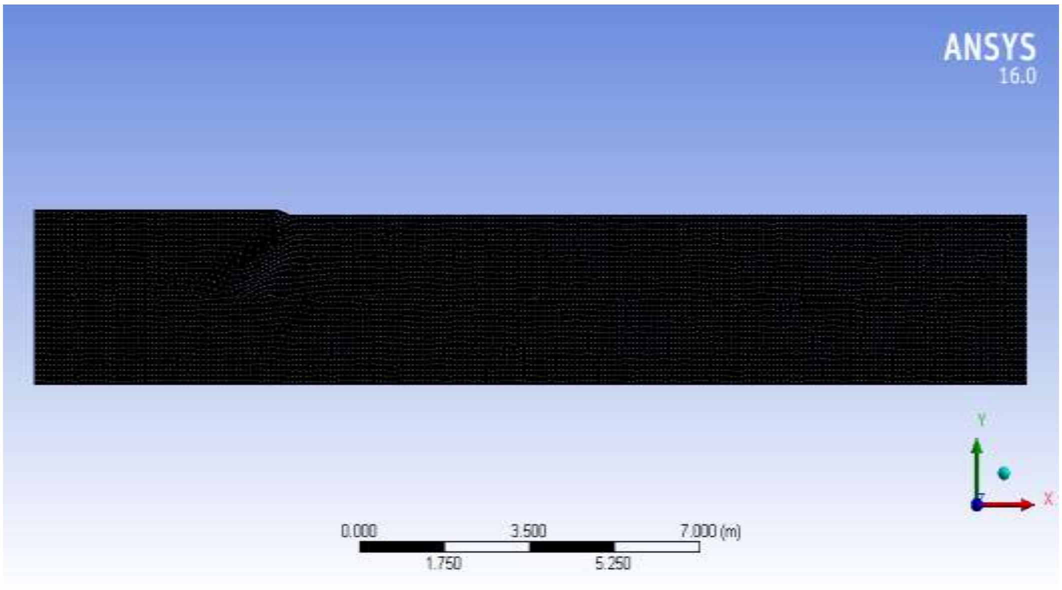

Fig.2 mesh of computational zone of air curtain

For analysing the effect of different numbers of nodes and elements, here in this work it perform the numerical analysis with different number of elements and nodes and calculate the volume flow rate of air at particular velocity of air curtain jet. Here in this work, first in order to validate the CFD model of air curtain here it considered air jet coming from the air curtain at a velocity of 15 m/s, whereas the temperature of air coming from the air curtain is 294.16 K as mention in the base paper.

Validation of CFD model of air curtain

For validating the CFD model of air curtain here it considered the same geometry and boundary conditions as considered during the experimental analysis performed by Wang et. al[13]. During the validation 20 degree air jet inclination where considered as considered during the experimental analysis, here velocity of air coming from the air curtain is considered as 15 m/s. For analysing the effect of different pressure difference on air jet stability here it considered six different pressure differences that are 1, 4, 6.25, 9, 12.25 and 16 Pa. At different pressure difference condition it calculated the value of volume flow rate of smoke through outdoor outlet. The velocity contours for different pressure drop were shown in the below fig.

For 1 Pa pressure difference

Here in this case 1 pa pressure different is applied on the inner outlet of air curtain, the velocity contours for this case is shown in the below fig

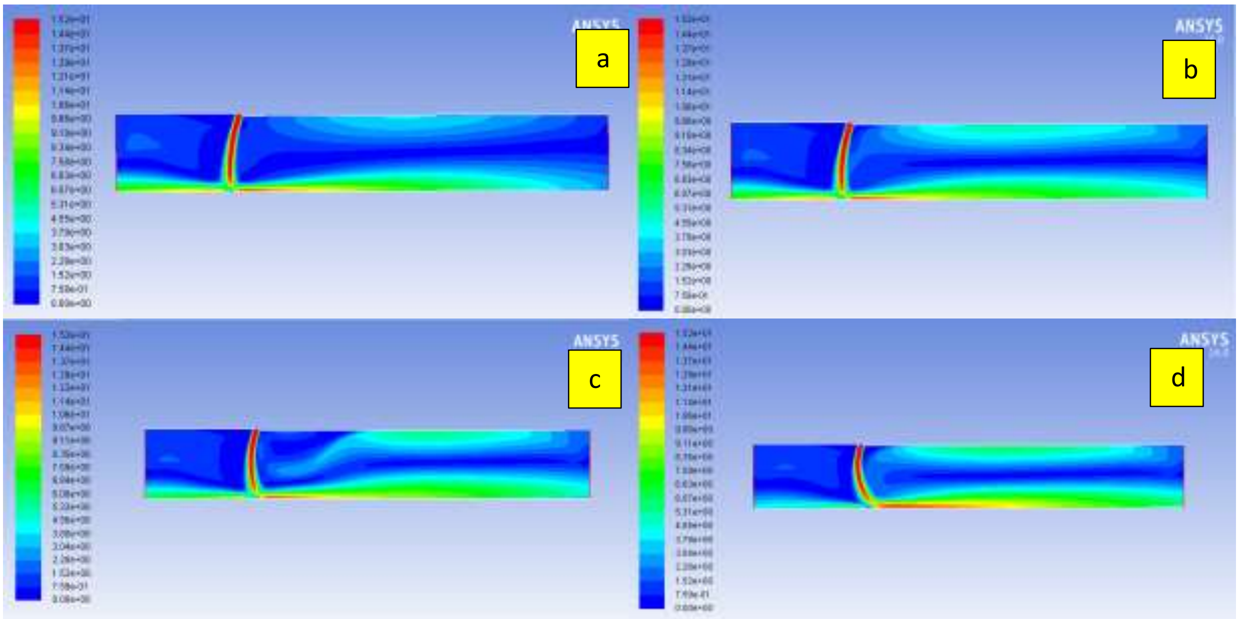

Fig.3 shows the contours of velocity at different pressure difference (a) at 1 Pa, (b) at 4 Pa, (c) at 9 Pa and (d) at 16 Pa

Through analysis here it calculates the value of volume flow rate of air at a particular different pressure difference. After calculating the value of ratio at different pressure difference it is then compared with the value of ratio given in base paper for same pressure difference. The comparison of value is shown in the below table.

Table 1 Comparison of value of ratio for different pressure difference

S.No.	Average pressure difference $(\Delta P^{0.5})$	From base paper $\left\{\frac{Q}{A\,(2/\rho)^{0.5}}\right\}$	For Numerical analysis $\left\{\frac{Q}{A\,(2/\rho)^{0.5}}\right\}$	Error in %
1	1	0.72	0.7028	2.38
2	2	1.40	1.36	2.85
3	2.5	1.85	1.812	2.05
4	3	2.18	2.124	2.56
5	3.5	2.53	2.493	1.46
6	4	2.8	2.769	1.10

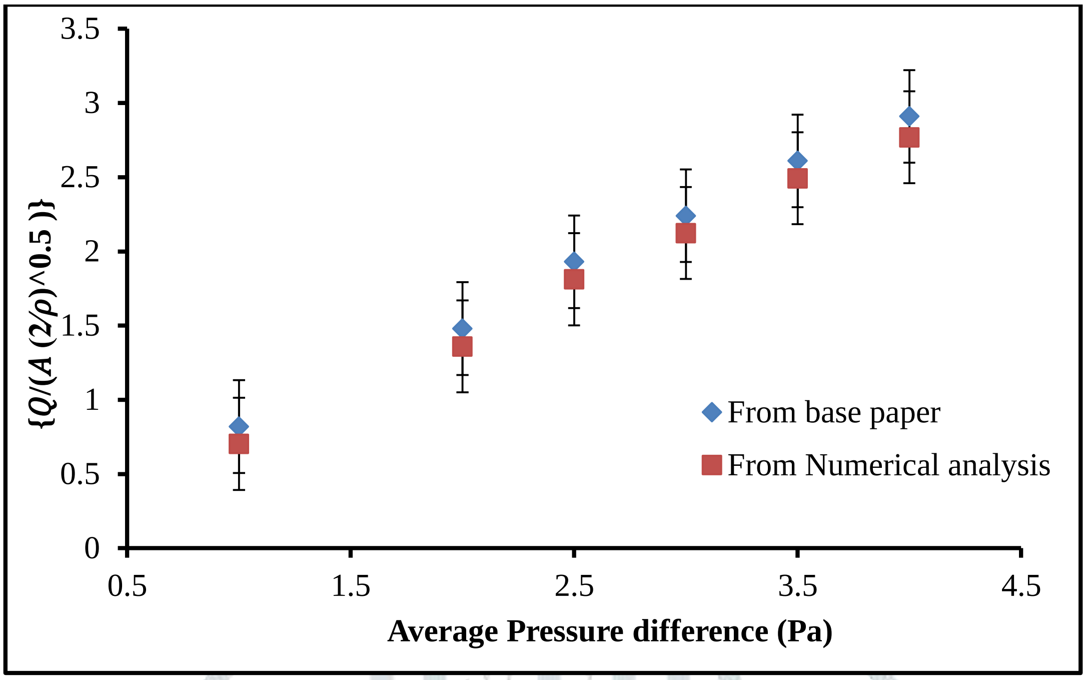

Fig.4 shows the comparison of ratio at different pressure difference

Form the above graph it is found that the value of ratio obtained from the numerical analysis is closer to the value of ratio obtained from the base paper at each pressure difference. There is very small variation in the value of ratio for different pressure difference here the CFD model of air curtain for smoke resistance is correct. So after validating the CFD model of air curtain, here in this work it analysed the effect of different air jet angle and change in velocity of air curtain.

Effect of different air jet angle

For analysing the effect of different air jet angle on air curtain performance here in this work it considered different air jet angle that are 10, 15, 20, 25 and 30 degree angle. During the analysis of different air jet angle, velocity of air jet coming from the air curtain was remaining same for different air jet angle at different pressure difference. For analysing each angle at different pressure difference here in this work it considered six different pressure difference that are 1, 4, 6.25, 9, 12.25 and 16 Pa. For different angle at each different pressure difference here it calculates the value of volume flow rate of smoke at inner outdoor of the system.

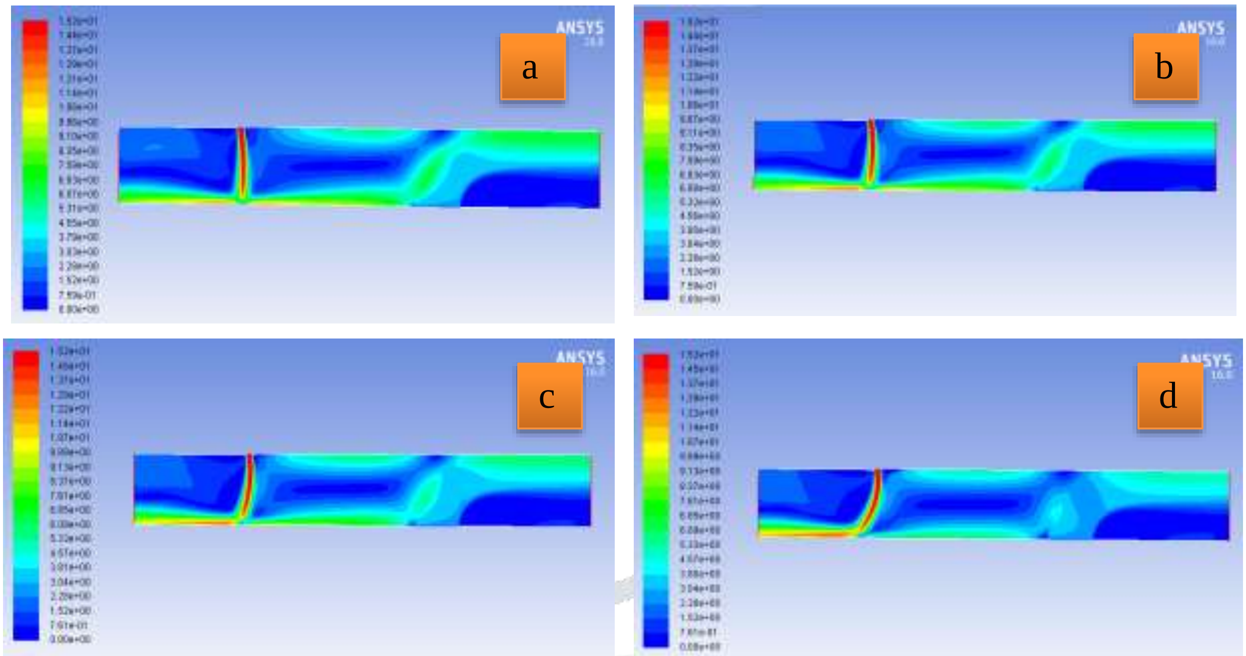

Fig.5 shows the contours of velocity (a) at 10 degree for 1 Pa pressure difference, (b) at 10 degree for 4 Pa pressure difference, (c) at 10 degree for 9 Pa pressure difference and (d) at 10 degree for 16 Pa pressure difference

Comparison of Different air curtain angle

For finding the better angle here in this section it compares the value of volume flow rate of smoke at different pressure difference across the door. The comparison of volume flow rate of smoke is mention in the below table.

Table 2 Comparison of volume flow rate for different air curtain angle

Average pressure difference (Pa) ($\Delta P^{0.5}$)	Volume flow rate (m^3/sec) at 10 degree	Volume flow rate (m^3/sec) at 15 degree	Volume flow rate (m^3/sec) at 20 degree	Volume flow rate (m^3/sec) at 25 degree	Volume flow rate (m^3/sec) at 30 degree
1	2.201	2.0628	1.8522	1.7128	2.2811
2	2.4827	2.3458	2.1593	1.9919	2.5763
2.5	2.6852	2.5323	2.3724	2.2027	2.765
3	2.982	2.8306	2.6371	2.4517	3.114
3.5	3.3425	3.1645	3.0122	2.7715	3.4282
4	3.8287	3.5779	3.3581	3.1642	3.9612

Form the above table it is found that the value of volume flow rate of smoke is decreasing as it move from 10 degree to 25 degree angle of air curtain, but at 30 degree angle it again start increasing. So through analysis it is found that 25 degree air curtain angle shows the minimum volume flow rate of smoke at all the given pressure difference.

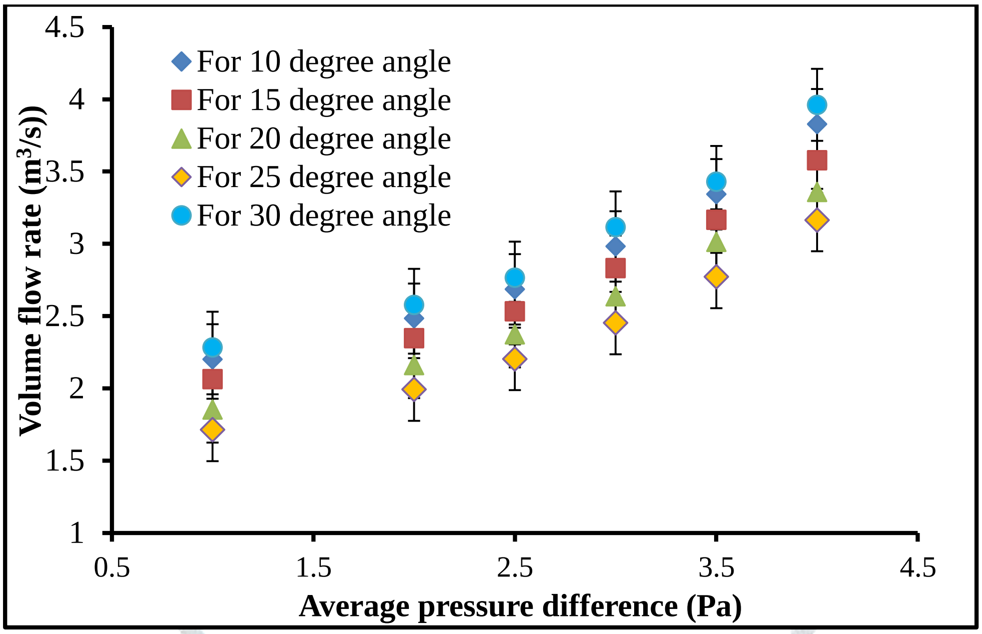

Fig.6 comparison of volume flow rate of smoke at different pressure difference for different angle

Through graph it is found that with 25 degree air jet angle, air curtain can be used up to 16 Pa pressure difference across the door which is much higher pressure difference zone as compared to other zone reported in previous work perform by different researchers. Through analysis it also shows that as the angle increases from 25 to 30 degree there is large increment in volume flow rate of smoke means smoke moving toward the un-fire zone increases frequently as compared to 25 degree angle. So here we can say that 25 degree angle is the best optimize angle for air curtain jet. After analysing the effect of different air jet angle on smoke resistance and thermal insulator, here in this work it also analysed the effect of different air jet velocity on smoke resistance and thermal insulation. The analysis of different air velocity was described in the below section.

Effect of different air jet velocity

For analysing the effect of different air jet velocity on smoke resistance and thermal insulation here in this work it considered four different air jet velocities that are 8, 10, 12 and 13.5 m/s. At each given velocity, it considered the different pressure difference conditions and calculates the value of volume flow rate of air. For analysing the different pressure difference, it considered same pressure difference cases as considered during the analysis of effect of air jet angle that are 1, 4, 6.25, 9, 12.25 and 16 Pa. The analysis of different air jet velocity were performed in the below section. During analysis air jet angle is considered as 25 degree.

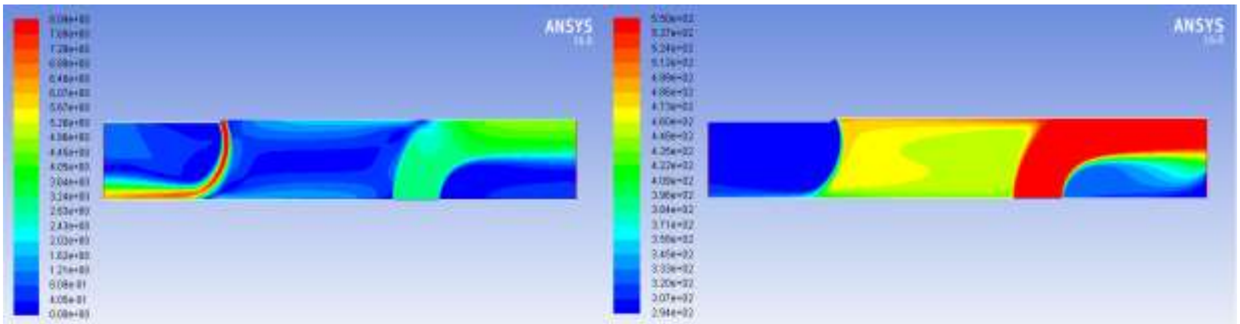

Fig.7 velocity and temperature contour at 1 Pa pressure difference

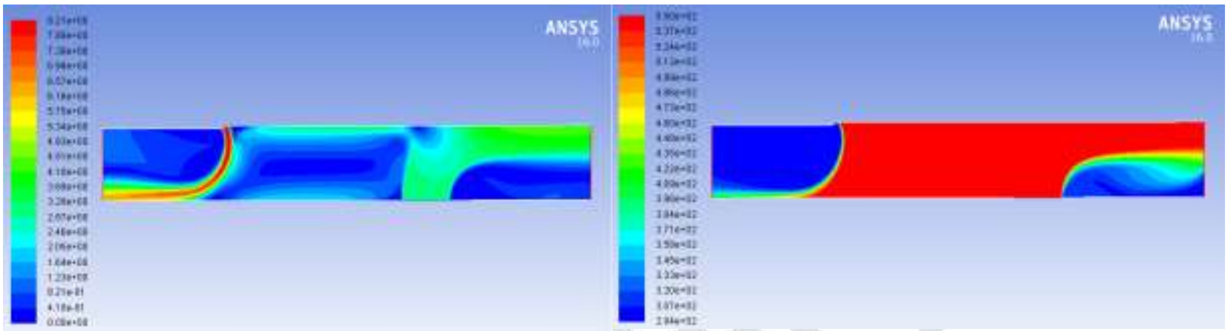

Fig.8 velocity and temperature contour at 4 Pa pressure difference

Comparison of different air jet velocities

After calculating the value of volume flow rate for different velocity of air jet at different pressure difference, here it compares the value of different air jet velocity. The comparison of different volume flow rate at different air jet velocity were shown in the below table.

Table 3 Value of volume flow rate at different velocity of air jet velocity

Average pressure difference (Pa) ($\Delta P^{0.5}$)	Volume flow rate (m^3/sec) at 8 m/s	Volume flow rate (m^3/sec) at 10 m/s	Volume flow rate (m^3/sec) at 12 m/s	Volume flow rate (m^3/sec) at 13.5 m/s
1	2.4005	2.0443	1.8519	1.7729
2	2.9902	2.5133	2.2084	2.0810
2.5	3.3420	2.9435	2.5223	2.3122
3	4.1562	3.3861	2.8540	2.6174
3.5	4.6233	3.8178	3.4556	2.9914
4	5.8134	4.8461	3.9249	3.4596

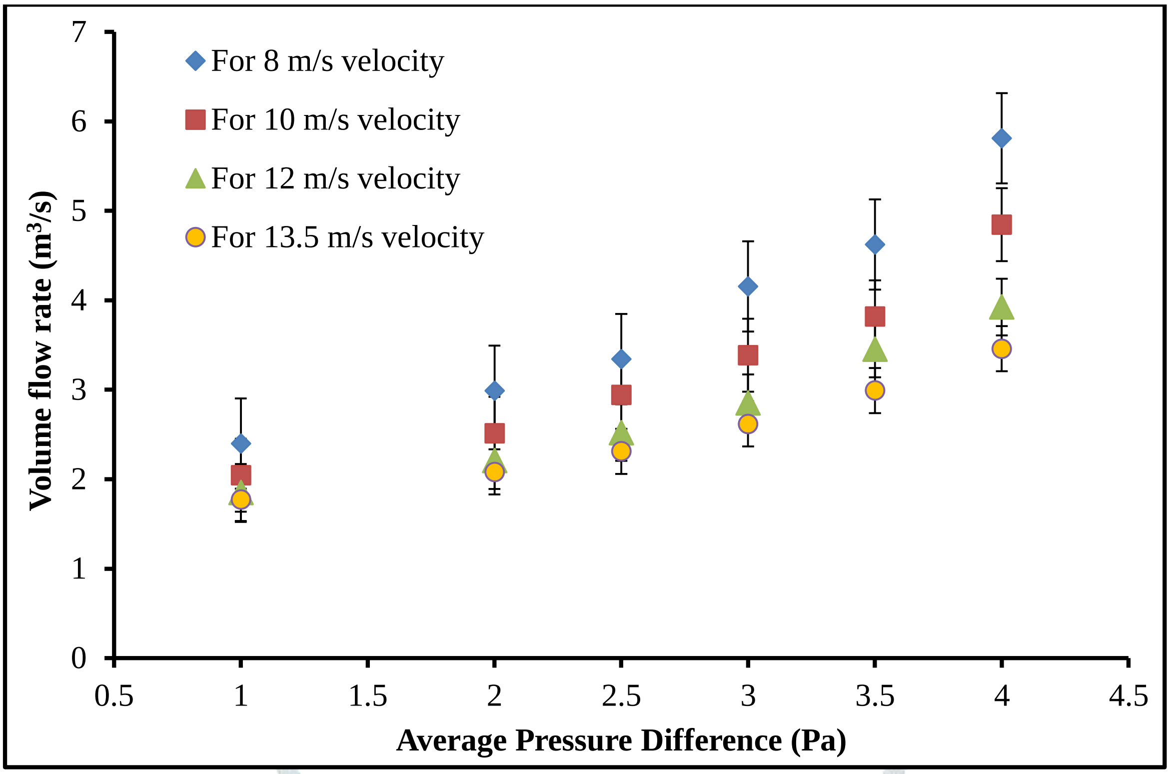

Fig.9 comparison of different velocity of air jet for different pressure difference

Form the above comparison graph it is found that as the velocity of air jet increases the value of volume flow rate of smoke start decreasing at outer outlet and show the stability of air jet at much higher pressure difference as compared to base paper. Through graph it is found that at lower pressure difference the variation in volume flow rate of smoke at different velocity is less, whereas as the pressure difference across the door increases, difference in volume flow rate of smoke for different air velocity at particular pressure difference start increasing with shows the sensitivity of infiltration and exfiltration of smoke at outer outlet. Through analysis it is observed that during higher pressure difference infiltration and exfiltration is more sensitive, so it is necessary for air jet to be more stable at higher pressure difference. Through analysis it found that with 13.5 m/s air jet velocity at 16 Pa pressure difference air jet coming from the air curtain is able to reach the floor and restrict the inflow and outflow of smoke. During fire condition, the pressure start increasing as the temperature and smoke increases, so in order to restrict the flow of smoke in un-fire zone it is necessary to use air curtain which is able to restrict the flow of smoke. With 25 degree air jet and 13.5 m/s velocity here in this work smoke flow is restricted at much higher pressure difference.

Conclusion

- It is found that with 25 degree air jet angle, air curtain can be used up to 16 Pa pressure difference across the door which is much higher zone as compared to other reported work perform by different researchers.
- Air curtain can be used as thermal insulator to restrict the flow of heat from fire zone to un-fire zone.

- Air jet angle also effect the flow of heat from fire zone to un-fire zone, through analysis it is shown that 25 degree air jet restrict the flow heat at much higher pressure difference so 25 degree shows the best angle of air jet.
- As the velocity of air jet increases the volume flow rate of smoke at outer outlet decreases at all particular pressure difference.
- Through analysis it is found that as the 13.5 m/s velocity of air jet air curtain is able to restrict the flow of smoke at 16 Pa pressure difference which is much higher pressure difference as compared to previous reported data.
- At this particular higher pressure difference air curtain also act as a thermal insulator which separates the fire and un-fire zone.
- Air curtain can be used as smoke resistance and thermal separator in high rising buildings to reduce the casualties.

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