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# Effect of Air-Curtain Discharge Speed on the Effectiveness of Vortex-like Air-Curtain Approach for Severe Accident Management

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## 1. Introduction

To prevent spread of radioactive material in the event of containment failure, containment bypass, or a spent fuel accident is one of the outstanding issues in nuclear power plant safety. The issue received considerable attention in the wake of Fukushima accident, and several regulations emerged necessitating nuclear utilities to develop and possess capabilities for minimizing radiological consequences radioactive material release by suppressing the dispersion into the environment [1].

Unfortunately, existing state of the art safety systems are not prepared for mitigating threat of radioactivity released outside reactor containment, though some utilities are considering using spray technology for this purpose. In fact, spray is one of the simplest and easiest technology to use, but certainly, it is not the most effective and clean way to mitigate airborne radioactive material outside reactor containment. The effectiveness of spray to capture airborne particulates is inherently limited and is sensitive to a number operating conditions. Even for the case of in-containment spray systems, where operating conditions are strictly controlled, spray can reduce airborne radioactive content approximately by a factor of two [2]. Therefore, one can expect that spray performance in suppressing airborne radioactive material in open, and uncontrolled environment could be far less, which might not be sufficient for mitigating offsite radiological consequences. Moreover, large quantities of liquid radioactive waste would be generated, which could impose a radioactive threat of its own to emergency workers, and environment by contaminate nearby land, and water resources.

Therefore, there is a requirement to explore alternative ideas, which could be advanced towards development of a rather effective and clean radioactivity mitigation system. For this purpose, we have introduced an approach for preventing spread of radioactive material in the event of containment failure in our earlier work. The approach is based on air-curtain technology integrated with a suction, and a radioactivity treatment system for effective confinement, capture, and treatment of the radioactive material leaking outside reactor containment.

The purpose of air-curtain installation is to isolate reactor containment from outside environment, confine the leaking radioactive material in a localized area, and minimize the impact of outside wind. The wind could blow away airborne radioactive material immediately after discharge leaving little room for effective capturing. Therefore, vortex-like air-curtain plays an important role in this process, and its effectiveness could severely influence the performance of overall system. In this work, we investigate the effectiveness of air-curtain for preventing infiltration wind into the system as a function of air-curtain discharge speed, and discharge angle for given wind conditions.

## 2. Methodology

### *2.1. The air curtain effectiveness*

The usual air-curtain applications involve a linear or planner installation of air-curtains at doors, where at least one side of the air-curtain have controlled environment [3]. However, our application is in the open environment, where conditions on either side of the air-curtain is uncontrollable, and our interest is to prevent air-exchange across the air-curtain, regardless of the direction of infiltration. The peculiar nature of air-curtain utilization in a circular configuration for protecting reactor containment from all sides further makes it difficult to quantify performance of air-curtain.

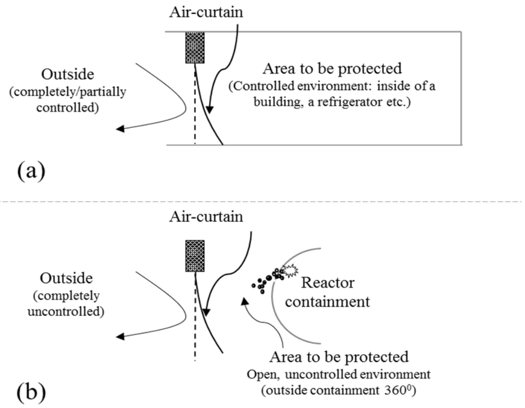


Fig. 1: Comparison of typical air-curtain utilization scenario (a), and current air-curtain utilization scenario.

However, in order to define a parameter, which could at least provide a quantitative insight, and comparison of the air-curtain effectiveness against outside wind, and other atmospheric perturbation, we define air-curtain effectiveness as,

$$\text{Effectiveness (\%)} = \left(1 - \frac{Q_{\text{with A-C}}}{Q_{\text{without A-C}}}\right) \times 100 \qquad (1)$$

$$Q_{\text{with A-C}} = \int_A (V_{\text{without A-C}} . A) dA$$

= net flow through surface area A without air-curtain

$$Q_{\text{with A-C}} = \int_{A} (V_{\text{with A-C}} . A) dA$$

= net flow through surface area A with air-curtain

Where A is the surface area of a cylindrical curved surface patch shown in Fig. 2. While defining this, it was assumed that any changes in net flow across this surface patch would directly measure the effectiveness of the air-curtain.

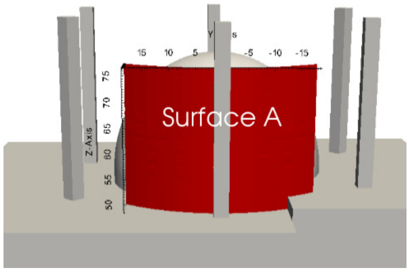


Fig. 2: Surface area used for effectiveness estimation.

### *2.2. Final system configuration*

In our previous work [4], we have provided qualitative analysis using computational fluid dynamics modeling of the system to determine effective configuration, which was configuration C-4 (Fig. 3, Fig. 4), consisting of six air curtain towers, and six suction locations. However, a quantitative analysis was required to substantiate those findings, and gauge air-curtain performance, which is now provided in this work. The final configuration (C-4) is selected for current study. The effectiveness of this configuration is calculated in this work according to above stated formula, and the results are compared with other analyzed configurations.

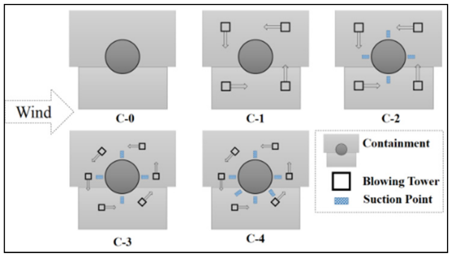
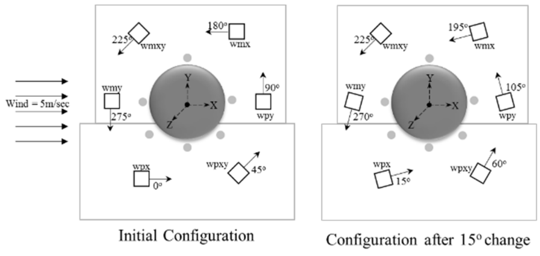


Fig. 3: Analyzed system configurations [4]

### *2.3. Variation of air-curtain discharge speed and angle*

There are six air-curtains installed in our finalized configuration. Each air-curtain can be operated at any given discharged speed. To see the effect of air-curtain discharge speed on system performance, we have changed air-curtains discharged systematically (5m/sec, 10m/sec, and 15m/sec). The wind speed was kept fixed at 5m/sec with 0° angle of attack with respect to the global axis.

In order to study effect of discharge angle, an inward or outward change of 15° was made to the air-curtains discharge direction to increase the impedance of the air-curtain against infiltrating flow. For example, air-curtain '*wmy'* has to prevent infiltration of outside wind that is why; its angle was changed outwards. On the other hand, air-curtain '*wpy,* has to limit the flow going outside from the system, so the change was inwards. The change of discharged angles from initial configuration is shown in Fig. 3.



Initial Configuration

Configuration after 15° change

Fig. 4: Depiction of variations in air-curtain discharge angle.

### *2.4. Analysis approach*

The computational fluid dynamics (CFD) approach using open source CFD toolbox OpenFOAM was utilized to perform current analysis. OpenFOAM framework is based on the control volume approach, and consists of C++ libraries, used primarily to create executable (i.e. applications). The applications are either solvers or utilities. Each solver is designed to solve a specific problem, while utilities are for data manipulations [5].

The computational model is based on steady state incompressible RANS (Reynolds Averaged Navier Stokes) equations of fluid dynamic. The one-equation eddy-viscosity Spalart Allmaras (SA) model is used for the closure of RANS system alongside second order discretization schemes.

## 3. Results and Discussion

In this section, we present calculation results of effectiveness parameter for final system configuration comparing it with other configurations to confirm to analysis results, as well as the effect of air-curtain discharge speed, and angle.

### *3.1. Effectiveness of final system configuration*

The effectiveness of the final configuration in comparison to other configurations is calculated and presented in Fig. 4. It can be easily seen that effectiveness of the final configuration C-4 is much higher (~95%) than that of other configurations, and net infiltration is approximately negligible in this case, confirming previous findings.

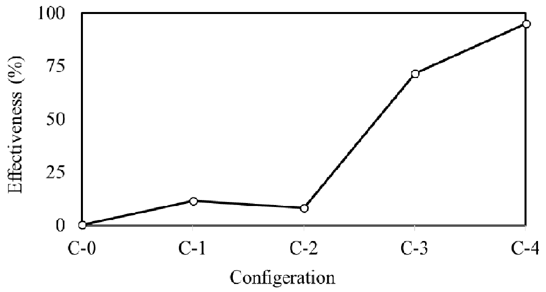


Fig. 5: Effectiveness of the final system configuration (C-4) in comparison to other configurations

### *3.1. Effect of air-curtain speed, and angle*

The results on the effect of air-curtain speed are shown in Fig. 6, in the form of flow streamlines, and effectives of the air-curtain against infiltrating wind. In general, results indicated an improvement in air-curtain effectiveness with increase in air-curtain discharge; however, increase in the leakage of the internal fluid was observed at discharged speed in excess of 10m/sec. Increase in discharge speed, resulted in decrease in system effectiveness, which means an excessive discharge speed could help internal fluid to escape the confinement.

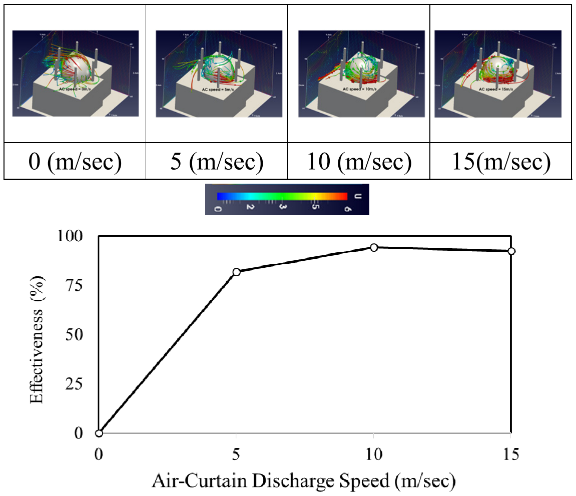

0 (m/sec) | 5 (m/sec) | 10 (m/sec) | 15(m/sec)

Fig. 6: Effect of air-curtain discharge speed (m/sec)

The change in angle as per strategy stated in previous section, resulted in approximately 20% increase in air-curtain effectiveness against infiltration, and the escape of the fluid at the backside was reduced. This showed that keeping a discharge angle at 15° opposite to the flow direction could substantially improve air-curtain performance, and stability.

The results of discharge speed and angle variations implied that a balance between air-curtain and wind speed is vital for effective confinement of the material. Considering the fact that utilization of this system is in open environment having continuous changes in wind speed, and direction, a programmed operation of the system will be required to manage air-curtain discharge speed, and angle accordingly. Therefore, it is suggested to develop a well-defined response function between air-curtain design parameters, and relevant atmospheric parameters.

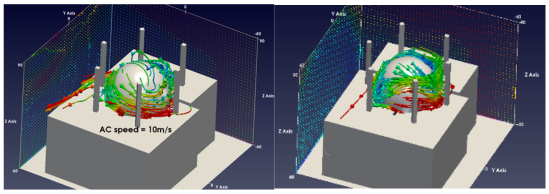


Fig. 7: Effect of air-curtain discharge angle.

## 3. Conclusions

An approach based on vortex-like air-curtain was proposed earlier for preventing spread of radioactive material to the environment and mitigate subsequent radiological consequences.

Effect of air-curtain discharge speed, and discharge angle was studied, and a quantitative account of air-curtain in terms of effectiveness parameter was performed in this work.

It was found that for given wind speed, air-curtain effectiveness would improve with increase in air-curtain discharge speed to an extent, after which any increase in discharge velocity could deteriorate the performance, due to imbalance between discharge and wind speed. Keeping air-curtain discharge at an angle of 15° opposite to the predominant flow direction is devised.

It is suggested to develop an appropriate response function to accommodate any changes in wind speed, and direction in future studies.

## ACKNOWLEDGMENTS

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