NUMERICAL SIMULATION OF SNOW DRIFTING AROUND SNOW FENCES

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The turbulent flow of wind and snow creates a complicated interaction during snow-drifting. To study snowdrift distribution patterns around a snow fence, a two-dimensional model is developed using ANSYS fluent (a commercially available CFD software). K-epsilon and discrete phase model are applied for this multiphase simulation. The model can simulate the dynamic changes as well as snow distribution patterns around a porous snow fence under no concurrent snowfall condition. It also works for different bottom gaps, porosities, and fence surfaces. The numerical result shows that snowdrift accumulation increases on the leeward side of the snow-fence and the snow-phase volume fraction decreases behind the snow fence for a certain time. Results obtained from the numerical model are in good agreement with the experimental measurements. A comparison is also made between the performance of a solar snow fence and a traditional snow fence. Higher snow drifting on the leeward side of the fence is observed for the traditional snow fence; whereas the maximum height of drifting is closer to the fence for the solar snow fence than those of traditional snow fences do. Therefore, the proposed model could be a useful guide for any snow fence design and implementation.

Keywords: K-epsilon, Porosity, Snowdrift height, CFD.

1 INTRODUCTION

Snowdrift is the process of snow mass movement driven by wind. During the winter, uncontrolled snow drifting affects both pedestrian and vehicular movement. Snow particles in the wind reduce the visibility of drivers and may cause traffic accidents (Matsuzawa et al. 2005). Snow fence installation may reduce these kinds of accidents (Tabler 2003). To address this phenomenon, the study of snowdrift distribution characteristics is important.

Snowdrift distribution can be observed through different methods including field measurements and wind or water tunnel experiments. Field experiments have uncontrolled boundary conditions whereas real snow drift scaling is difficult and time-consuming (Tominaga 2018). In wind tunnel experiments, prototype models are required based on similarity criteria which is expensive (Tominaga 2018, Zhou et al. 2019). Computational fluid dynamic (CFD) techniques are powerful tools to analyze fluid flow due to its controlled boundary conditions (Blocken and Gualtieri 2012). Several researchers tried to simulate the snow drifting events numerically and predict their accumulations. Considering saltation and suspension, a numerical model was developed by Uematsu et al. (1991) to measure snowdrift rate. A two dimensional numerical snow drift model is proposed by Sundsbo (1996) based on gas-gas theory and scalar transport equations. Single phase steady state (SPSS) method along with IBM (immersed boundary
method) is used by Wang et al. (2019) for CFD modeling of snowdrift on roofs. Whereas fluid solid coupling effect through Lagrange particle tracking method is proposed by Wang and Huang (2017) to track snow particles over terrain like surroundings. Although several research on snow drift analysis have been performed, numerical simulation of snow accumulation around a snow fence is still limited (Yang et al. 2022).

In this paper, a numerical model is developed to predict snowdrift distributions around 50% porous traditional and solar snow fences based on multiphase turbulent flow theory and erosion and deposition of snowdrifts. The prediction of the model is first validated with the field measurements (Tabler 2003) and then used to estimate the snowdrift profile considering different initial snow cover on the ground. Furthermore, the effect of porosity, mesh size, and time-step sizes on the snow drift simulation process are analyzed. At the end, a comparison is made between the performance of a solar snow fence and a traditional snow fence. The effect of the smooth surface of solar snow fences on snowdrift is summarized for possible field implementations.

2 NUMERICAL MODEL AND SIMULATIONS

2.1 Governing Equations

Snow drift is an event of gas-solid two-phase flow. To model this transportation process, a multiphase turbulent flow theory is used. The governing equations of transport for fluid region are:

$$\frac{\partial (\rho_m \phi)}{\partial t} + \frac{\partial (\rho_m \phi v_{mx})}{\partial x} + \frac{\partial (\rho_m \phi v_{my})}{\partial y} = \frac{\partial}{\partial x} \left( \tau \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left( \tau \frac{\partial \phi}{\partial y} \right) + q \phi$$

$$\rho_m = \rho_a + \rho_s$$

$$v_{mx} = \frac{\rho_m v_{ax} + \rho_s v_{sx}}{\rho_m}$$

$$v_{my} = \frac{\rho_m v_{ay} + \rho_s v_{sy}}{\rho_m}$$

In Eqs. (1-4), $\rho_m$ = mixture density, $v_{mx}$, $v_{my}$ = mixture velocities in $x$, $y$ direction, respectively, $v_{ax}$, $v_{ay}$ = wind velocities in $x$, $y$ direction, respectively, and $v_{sx}$, $v_{sy}$ = snow velocities in $x$, $y$ direction, respectively. The turbulent kinetic energy and turbulent dissipation rate in the inlet boundary are estimated as follows (ANSYS 2019):

$$K = \frac{3}{2} \left( \frac{U}{I} \right)^2$$

In Eq. (5), $K$ = turbulent kinetic energy, $U$ = mean flow velocity, and $I$ = turbulence intensity.

2.2 Computational Settings and Boundary Conditions

In this study, the domain size, fence dimensions, and no. of grid cells are adopted from (Yang et al. 2022). The geometry of the computational domain is shown in Figure 1. A 50% porous snow fence is located at 180 m distance from the left boundary of the model considering the snow storage capacity (Tabler 1994). The snow fence height (H) is 3m with a bottom gap of 0.33 m. Mesh size is controlled by quadrilateral grids along with the proximity size function. Moreover, edge sizing and face meshing tools are applied to reduce the number of grid cells. Around 133 thousand grid elements are used during the computation. It is also assumed that the initial snow depth on the ground is 2m with no slip bottom boundary.

Snowdrift occurs when the threshold velocity of snow particles is less than the wind velocity (Yang et al. 2022). The wind speed and direction remain constant in this model to measure snow drift characteristics around a porous snow fence although these change with time in real life. At the top boundary, no snow falling is considered. In the inlet, a user-defined function is used for an
exponential wind profile. The logarithmic law (Richards and Hoxey 1993, Yang et al. 2022) for wind in inlet boundary is shown in Eq. (6):

$$U(y) = \frac{U_*}{k} \ln \frac{y}{y_0}$$

where, $U_*$, $k$, $y$, and $y_0$ are friction velocity, Von Karman constant, vertical height above snow surface, and snow surface roughness length, respectively. The wind speed is 12 ms$^{-1}$ and snow particle density is 250 kg m$^{-3}$ (Wang et al. 2019). The boundary conditions of this model are shown in Table 1.

Table 1. Boundary conditions.

<table>
<thead>
<tr>
<th>Items</th>
<th>Settings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet boundary</td>
<td>A user-defined function for air velocity</td>
</tr>
<tr>
<td>Outlet boundary</td>
<td>Zero pressure</td>
</tr>
<tr>
<td>Bottom boundary</td>
<td>Wall, No slip</td>
</tr>
<tr>
<td>Top boundary</td>
<td>Wall, Specified shear</td>
</tr>
<tr>
<td>Fence</td>
<td>Wall, No slip</td>
</tr>
</tbody>
</table>

2.3 Impact of Mesh Sizes

In the CFD simulation, result accuracy mostly depends on the mesh size and number of elements (Dutt 2015). As such, mesh sensitivity analysis has been performed in this study (Figure 2). The element size needs to be minimized carefully to reduce computational timing and resolve divergence issues. In this model, mesh element size is selected as 2.2m so that snow drift comes to an equilibrium state at the leeward direction of snow fence and gives an accurate result.

2.4 Impact of Time Step Size

Snows drift rate should be integrated with time step to measure snowdrift height (Uematsu et al. 1991). In this simulation, fixed time step method with step size 0.001s to 0.01s is used. During the calculation, inlet wind velocity needs to be greater than the size ratio of mesh cell and time step for a convergent result whereas the residual of all variables should be less than $10^{-4}$ (Yang et al. 2022). Figure 3 shows the equilibrium snow drift height changes for different time step sizes.
3 MODEL VALIDATION

Snow drift occurs when snow particles fall down on the ground (Tabler 1991). To evaluate the accuracy of model, snow distribution is simulated around a 50% porous snow fence for different levels of initial snow covers on the ground and the results are compared with the field measurement (Tabler 1980, Tabler 2003) (Figure 4).

![Figure 4. Snowdrift accumulation around a porous snow fence for different snow depths on the ground.](image)

The field measurement shows that maximum snow drift height is 1.2 times of snow fence height (H) situating at 6H distance behind the fence. Thus, the extension of snow drift from the fence is 34H in the leeward side. The other lines (Figure 4) represent the numerical results that are in similar trend with the field survey. The simulated snow drift mostly occurs behind the snow fence since wind gets slow at snow fence location (Tabler 1991). Behind the snow fence, the maximum snow drift height is around 0.73H for 1.5m initial snow cover and the snow deposition extends to 40H. Because of a fixed domain, snow drift deposition length in the leeward direction of fence is almost similar for other ground snow cover. Maximum snow drift height increases to 1.79H to 1.8H while snow depth on the ground is increased from 2m to 3m. The distance between the fence and the location of maximum drift height increases from 0.6H to 1.6H, if the initial snow depth on the ground also raises from 1.5m to 3m. The boundary conditions are always variable in the field which is constant during the simulation. Moreover, in the field survey report there are some missing variables such as snow cover rate on the ground and site surrounding conditions. Therefore, some variations might occur in the results between field and numerical study. With this consideration, it can be said that the proposed numerical multi-phase model is in good agreement with the field result and represents the snow accumulation mechanism.

4 PARAMETRIC STUDY

4.1 Effect of Porosity and Bottom Gap

The snow blocking effect of a fence is highly affected by its porosity and height. Snow storage capacity of a snow fence will be reduced if the bottom gap is greater than 15% of its total height (Tabler 1991). Less porosity generates a strong blocking effect, though snow does not create any drifting near a solid snow fence with 11% bottom gap (Figure 5). Maximum drift height ahead of this solid fence is 0.52H and it is around 25H distance in front of the fence location. Simulation result also indicates that a 25% porous snow fence with low percentage of bottom gap creates more snow drifting height than a 50% porous snow fence with high percentage of bottom gap. The maximum snow drift height for 25% and 50% porous snow fence is 1.96H and 1.8H, respectively. Moreover, the location of max drift height comes closer (from 1.96H to 1.8H) to the leeward side of the fence if the porosity is increased from 25% to 50%, respectively.
4.2 Effect of Fence Surface

Snow accumulation around a porous snow fence varies with its surface condition. The proposed simulation model is used to compare the snow drift event between a traditional (wood material) snow fence and a solar (glass material) snow fence. A solar snow fence with slip condition can be considered as a smooth surface having zero specified shear in all the component directions. Wind velocity is zero at the wall point of a traditional (non-slip) snow fence due to fluid viscosity. Results show that a non-slip snow fence creates greater drift height than smooth snow fence. The maximum drift height due to non-slip and smooth snow fence is 1.8H and 1.3H, respectively. Moreover, the peak of snow drifting happens in the leeward side of a traditional snow fence at 1.6H distance from fence due to its greater roughness while this peak point is located at the windward direction (0.4H distance from fence) of the solar snow fence (Figure 6).

![Figure 5. Effect of different porosity and bottom gap of a snow fence (H=snow fence height).](image)

![Figure 6. Snowdrift accumulation around a snow fence of different surface conditions.](image)

4.3 Discussions

Snow fence installation helps to accumulate snow drift in a certain area. Figure 4 shows that under no concurrent snow falling condition, the snow volume fraction decreases behind the snow fence and then starts again to increase. This is due to sudden increase of friction velocity and the jet formation at the fence bottom gap. Thus, the snow cover is blown away by wind and the volume fraction of the snow phase is reduced. After that, the friction velocity decreases but is still greater than the threshold friction velocity. Snow fence leads to assemble large amounts of snow in its leeward side. The same trend is followed by different snow depths on the ground. Moreover, due to the roughness effect, the peak of snow drifting is higher for non-slip fence compared to smooth surface. Numerical simulation uses fixed boundary conditions which is not possible in real life. As such, the deviation observed between numerical and observation results concerning the maximum drift height and the distance between the snow drift peak and fence location. Though characteristics of simulated snow drifting pattern around the snow fence are almost like the field survey.
5 CONCLUSIONS

A two-dimensional multiphase turbulent flow model is proposed to simulate snowdrift distribution around a porous snow fence. Porosity, bottom gap, and fence surface highly influence the snow distribution pattern. Snow fence slows down the wind speed so that more snow accumulates in its leeward direction. It helps to assemble snow drift at a fixed location because after reaching the maximum height at a certain distance, snow drifting comes to an equilibrium state. The peak point of snow accumulation is closer to the fence location in solar fence than the traditional one. Therefore, these numerical results demonstrate that the proposed model of this study could provide a useful tool to evaluate snow fence performance in the future.

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