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Numerical Solution of Fence Performance for Reduction of Sand Deposition on Railway Tracks

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A B S T R A C T

Movement of sand particles in nature creates many problems for humans. One of these problems is deposition of particles on rails that decreases the speed of the train or in some cases hampers the reversal of the train rails. In this paper, the motion of sand particles over railway track embankment, and how these particles settle on railway tracks are investigated. Moreover, the performance of different fences of different heights and distances has been compared. It can be stated that particles velocity is highest on the embankment slope and up to the fence and lowest around the fence. Most of the particles deposition is on the slopes or near the embankment. Fences with different heights, distances (from the railway's longitudinal axis), and porosities are compared. Using the appropriate fence depends on the geographic and environmental factors, but in general the use of a fence with a height of 1 meter positioned at distance of 3 meters from the railway's longitudinal axis, and with 20% porosity is recommended.

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NOMENCLATURE

F_D	Coefficient of Drag force	**Greek Symbols**	
F_D	Drag force	ρ	Density (kg/m^3)
c_k	Discrete lattice velocity in direction (k)	μ	Viscosity
g	Gravity(m/s^2)	**Subscripts**	
u	Horizontal components of velocity (m/s)	g	Gas
d_p	Particle diameter	p	Particle
ρ_p	Particle density		
U_p	Particle velocity		
R_e	Reynold number		
v	Velocity		

1. INTRODUCTION

It is difficult to describe the continuously and accurately of dynamic states of aeolian particles in motion by doing experiments in wind tunnels or measurements in the field. Therefore, numerical simulations are chosen by researchers to study gas–solid two-phase flow of aeolian sand transport and many numerical models have been published in recent years. Movement of sand particles are of three kinds: creep, suspended, and saltation. Wind has the most important influence on sand transport. More empirical work is being done in

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wind tunnels or in the field. In the wind tunnel there have been conducted a variety of tests about the effect of fences and vegetation. Studies are more about movement of small particles and rates of mass transfer but precipitation of particles has been given little attention.

Bangold et al. [1] demonstrated a logarithmic relation between wind speed profiles and altitude. They found that debit of sand particles is related to the cube of their velocity. Donget al. [2] used wind tunnel experiments to demonstrate the effect of particles diameter on their speed. They showed that the rate decreases with increasing particle diameter. Zhang et al. [3] conducted several researches on wind speed profile and came up with a logarithmic model. Shao et al. [4] compared the density and mass flux of seaside sand and desert sand. Wang et al. [5] used the Rossin-Rambler Pattern and Mixture Model to study numerical distribution of particles with different diameters. They showed that the area indicating suspended particles is smaller for non-homogeneous particles compared to homogeneous particles. Kanget et al. [6] used statistical approach and numerical simulation and calculated the probability distribution of particles in different areas. Xie et al. [7] used wind tunnel experiments to demonstrate the impact velocities of sand particles and their take-off speeds. They used high speed cameras to study movements of sand particles at a distance of 1 millimetre above the surface.

Results showed that the probability of particles follows a Gamma distribution model and the Gamma function is dependent on the diameter of particles as well as their velocities and the form of the distribution function changes with changes in the diameter and velocity. Liqiang et al. [8] conducted wind tunnel studies of movement of sand particles and their surface impact angles and velocities. Their results showed a surface impact angle range of 28-39 degrees and a reflection angle range of 30-44 degrees. Reflection velocity was shown to be 0.8-0.9 of the impact velocity. It was also shown that there is a higher probability of moving particles near the surface. Kang and Liu [9] also conducted a numerical study of movement of sand particles within airflow. In their paper they discussed horizontal and vertical velocities of particles in different altitudes. Their studies showed that the probability distribution function of (take-off velocity/impact velocity) is a logarithmic function while that of impact velocities is an exponential function. Probability distribution of particle velocities for each altitude is a unimodal function. Results of this study have been compared with results of wind tunnel experiments.

Zhang et al. [10] investigated the movement of sandy desert and sandy sea while the friction velocity divided friction velocity threshold variation 10%-25%. Bo et al. [11] investigated effect of particle diameter and wind velocity on the movement of sand particles and velocity of deposition and lift off with this method we can capture from particle in the wind tunnel. Several years ago many studied of various diameters and velocities were performed. The result show velocity of wind and particle diameter hasn't influence on the profile of function distribution lift off angle and impact angel. The other hand particles which are faster have the ability of dividing the small particles when they impact the surface. After the collision, the particles have the ability to come up to the height of 10 to move to its diameter.

Bitog et al. [12] investigated movement of sand particle from classified fence. They studied the fence which had 2, 4 and 6 meter distance from together and the height was 0.6, 0.8 and 1 meter and porosity variation was 0, 0.2, 0.4 and 0.6. The fence with porosity of 0.2 had optimal effect (the fence with less porosity than 0.2 vortex are the problem and for the fence with more than 0.4 the permeability is problem). When the porosity is zero (means the solid fence) with increase in the height, the particle velocity reduces more but in another porosity, variation of porosity hasn't effect and when the distances between fences are increased the velocity is little.

Safi [13] investigated fence with variation porosity and fence that they are have 2 or 3 porosity then compared them together. In this paper, used numerical simulation and use experimentally for validation data. In this investigated the best efficiency is when we use fence that the down side is 20% and the upper side is 40% porosity. Huang et al. [14] use a fence with different porosity so that the upper and down of fence have different porosity and indicate if the upper part of fence porosity is zero and down side of fence porosity is 30%, the fence is optimal. In this paper, the numerical model of sand particles over a railway track embankment, and how these particles settle on railway tracks are investigated (see Figure 1). Also, the performance of different fences has been compared. In this analysis, the effect of height, porosity and distance from railways for different fences have investigated.

Figure 1. Deposition particle on rail way in desert

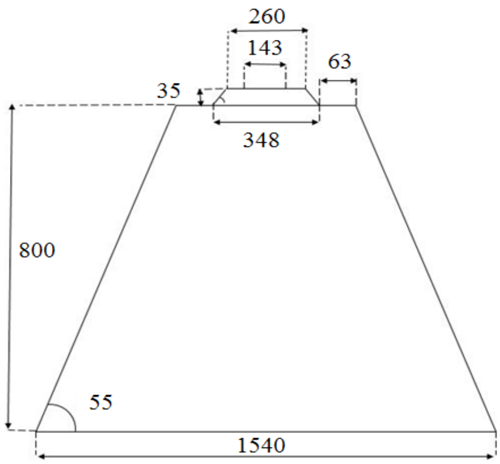

Figure 2. Grid geometry

2. NUMERICAL SIMULATION

Some experimental data related to natural movement of particles for designing a fence which will kept sand from coating train rails have been used. 2D model of injection of particles in a medium of air for studying behaviour of sand particles is used. Navier-Stokes equations with discrete fuzzy type are solved. In order to gain the amount of settlement of sand particles, we have to gain velocity of particles in every time. The DPM method has this ability to calculate the velocity of particles in every time. In this model, sand particles are injected into the air; Eulerian and Lagrangian approximations are used for sand particles and air respectively also "Rng k" model is used for turbulence model because in this model the equation of ε have better performance near the walls. The height of roughness is 0.02 and coefficient of roughness is 0.01.

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff}\frac{\partial k}{\partial x_j}\right) +G_k+G_b-\rho\varepsilon-Y_M+S_k \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \varepsilon)+\frac{\partial}{\partial x_i}(\rho \varepsilon u_i)=\frac{\partial}{\partial x_j}\left(\alpha_\varepsilon \mu_{eff}\frac{\partial \varepsilon}{\partial x_j}\right) +C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}-R_\varepsilon+S \tag{2}$$

Computational grid of this study is presented in Figure 2. In order to get better result, the real dimensions are used. The solution domain is 110 meters long and 20 meters wide with 124000 cells in it. The number of cells is different, because the distances of fence from railways are different. In this paper, we increase the number of mesh to 349320, but the increasing the number of mesh from this value does not change the results. The fence is 10 meter height and the embankment has a slope of 34 degrees.

The distance between two lines of rails is 1.5 meters and smaller mesh is used near the rails.

Boundary conditions of input velocity, symmetry, output pressure, and barricading on the right, left, above, and below should be obtained. The sand inlet to the model through velocity inlet surface.

Particle diameter assumed to be in range of 200-500 micrometres and the Rosin-Rammler particle dissipation model to be in place. Also, particle density assumed to be 2650 kg/m^3. Other assumptions including dry wall fence surface and fixed roughness coefficient. Random statistical approach and the "k" turbulence model with the turbulence coefficient being 10% is used. In such conditions, particle dissipation is achieved through the Brownian force, resulting from bombardment of particles by the molecules of the fluid.

To solve this problem, first the single phase model should be solved and then particles should be added to the continuous environment, then characteristics of each particle at any moment in time can be obtained. It is expected that particles inside the boundary conditions whose velocities are lower than the boundary velocity will deposit within the boundary layer. Using the precipitation conditions, the probability distribution function of particle precipitation can be calculated. As pointed out before, particles which deposit may later rise from the surface. The probability distribution function of particle precipitation and particle rising is calculated and then time dependence of their movement is studied. Eventually, the final precipitation profile of these particles is calculated. Particle take-off force is calculated by using the Li and Ahmadi theory [15] which it is a modified form of Saffman correlation [16].

The input values of CFD model is presented in Table1 and the governing equations are as follow:

$$\frac{\partial u_p}{\partial t} = F_d(u - u_p) + \frac{g_x(\rho_p - \rho)}{\rho_p} + F_x \quad (3)$$

$$F_D = \frac{18\mu}{\rho_{p\,d_p}{}^2}\frac{C_D Re}{24} \quad (4)$$

$$Re = \frac{\rho d_p |u_p - u|}{\mu} \quad (5)$$

$$F = \frac{2k\,\vartheta^{1/2}\rho\, d_{ij}}{\rho_p d_p (d_{IK} d_{kl})^{1/4}} \quad (6)$$

$$\Delta p = -(\frac{\mu}{\alpha}\vartheta + C_2\frac{1}{2}\rho v^2)\Delta m \quad (7)$$

The fence is optimized by modifying key fence parameters such as height, porosity, distance from the axis of the rails, and the precipitation volume of sand set on the rails. Darcy equation is used to calculate the pressure difference resulted from the porous medium; where μ is the viscosity of the fluid, α is the permeability coefficient of the fluid, C_2 is the dispersion coefficient of the porous medium, and Δm is the thickness of the filter [17].

To solve the problem, the geometry designed and meshed in Gambit 2.4.6. Then, the particles inject in the model with helping DPM method in Fluent Software. For analysing the velocity of particles depend on their time, we used to Matlab Software. SIMPLE method is used for solving pressure-velocity coupling. To isolate and solve the spatial equations, second Order, upwind standard, quick, second Order up wind are used to solve governing equations of pressure, momentum, turbulent Kinetic energy, and turbulent dissipation rate, respectively.

TABLE 1. Input values of CFD model

Parameter	Value
Air density(kg/m^3)	1.225
Sand density(kg/m^3)	3650
Air viscosity (kg/m-s)	1.7894e-05
Air temperature(k)	298.15
Wind Velocity (m/s)	3,6,10
Cmu	0.0845
C1-Epsilon	1.42
C2-Epsilon	1.68
Counningham correction	0.5
Spread Parameter	2.6
Atmospheric Pressure (pa)	101325

3. RESULT AND DISCUSSION

First, the profile deposition of particle for the fence with porosity of 50% and height of 1 meter is compared with experimental data. Alhajraf et al. [18] presented the profile of sand deposition around fence numerically and compared their results with experimental data of Iversen [19] tested by using a wind tunnel and tabler tested in the field. Figure 3 represents the numerical profile of sand particle deposition on the flat surface with porosity of 50%. Figure 4 shows that the difference between results of present study and work of tabler is about 13.6%.

The magnitudes of turbulent intensity are different, and depend on the input parameters. However, when the air passes through the fence the turbulent intensity increase in upstream of the fluid. Since, the ground is desert effects, the intensity of turbulent is 0.15 [17].

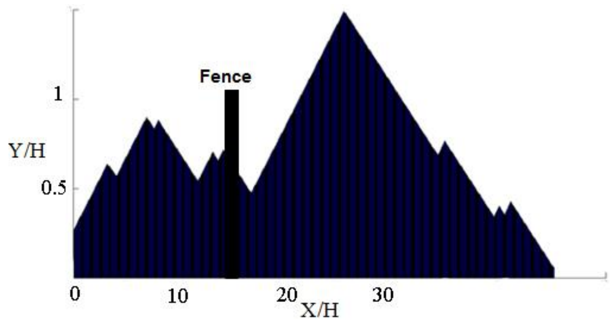

Figure 3. Deposition profile around the fence porosity 50 percent

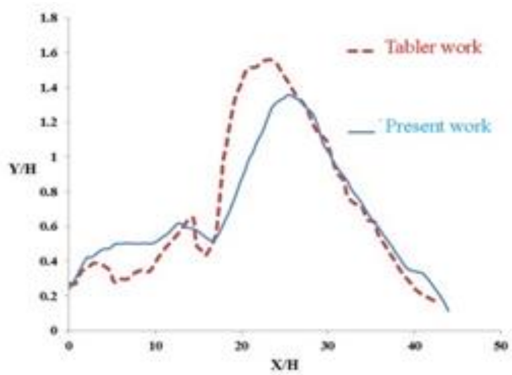

Figure 4. Comparing deposition profile with Tabler experimental

Wall roughness increases the wall shear stress and breaks up the viscous sublayer in turbulent flows. A technical roughness has peaks and valleys of different shape and size, can be described by an equivalent sand-grain roughness. As we know, the quantity of Y+ must be less than 100 [18]. In this analysis, the quantity of Y+ is less than 83. Deposition profile depends on wind velocity, when particles are moving slower than the threshold velocity, these particles will not be able to jump from the ground and take off. As indicated in Figure 5 (a) when wind velocity is 2 m/s, particles are not able to go through the embankment and when the wind velocity increases the particles are able to go through the embankment and then there is little particle deposition upwind of ramp. Probability of deposition particles near the ramp on the ground is highest (Figure 5-(b)). It can be concluded that the wind velocity is the key factor for the design of the fence which depends on the geographic area and the wind speed profile. Figure 6 indicates the velocity contour in longitudinal and transverse direction. It is clear from Figure 6a and Figure 6c that the minimum longitudinal speed is in downwind on ramp. Also, Figures 6b and 6d indicate that particle have tendency to move up in upwind flow before arrive railway and have the tendency to deposition in downwind flow. Increasing the wind velocity caused the velocity near the boundary layer to increase and particles are less able for deposition on the surface.

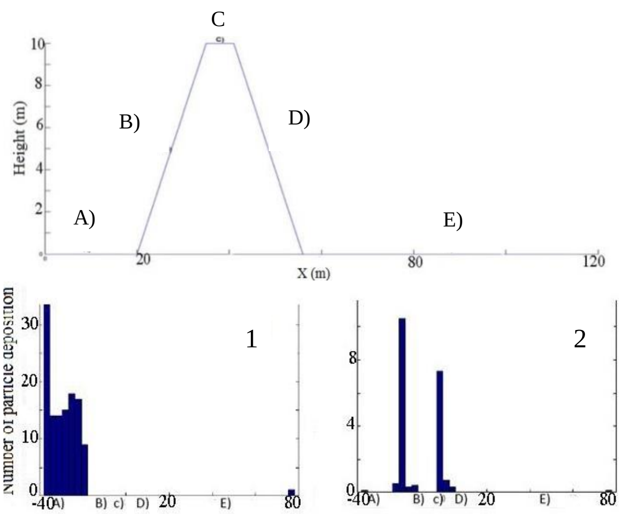

Figure 5. Histogram of probability absent of fence (1)-deposition particle velocity is 2 (m/s) (2)-deposition particle velocity is 3 (m/s)

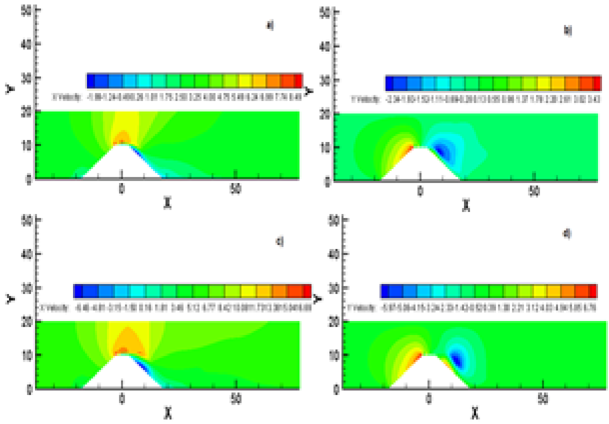

Figure 6. contour velocity in a) direction longitudinal and velocity is 3 (m/s), b) direction vertical and velocity is 3 (m/s), c) direction longitudinal and velocity is 6 (m/s), d) direction vertical and velocity is 6(m/s)

Actually, this figure shows when wind velocity is 3 (m/s) particles have more tendency for deposition compared to wind velocity of 6 (m/s).

Fences have been applied to reduce precipitation of particles on rails. As it was shown in Figure 7, when fences are used, horizontal wind speed over the fence is higher than when there is no fence. It is worth noting that changes in wind speed have little effect on the form of sort gradient. Using a fence with a porosity of 20% instead of a zero porosity (rigid) fence would result in less reduction of down wind speed near the boundary layer.

A good fence's performance is dependent on the velocity of the wind the least and it provides for the lowest probability of precipitation of particles. It is clear from Figure 8 that increasing the fence height from 1 to 1.5 meter has little effect on the probability of particles precipitating while it drastically increases the drag force borne by the fence. Thus, it can be noticed that 1 meter is the optimal height. When a rigid fence is used still less particles are let in at higher wind speeds compared with porous fences but higher wind speeds imposes stronger drag force on such fences, leading to their destruction over time. For rigid fences, optimal distance from the railway's longitudinal axis is 3 meters at low wind speed and 4 meters at high wind speed.

Using a fence with a porosity of 50% reduces the downwind speed of particles. For such a fence, increasing the distance from the railway's longitudinal axis reduces precipitation in low wind speeds, while in high wind speeds, better results are obtained when the said distance is reduced.

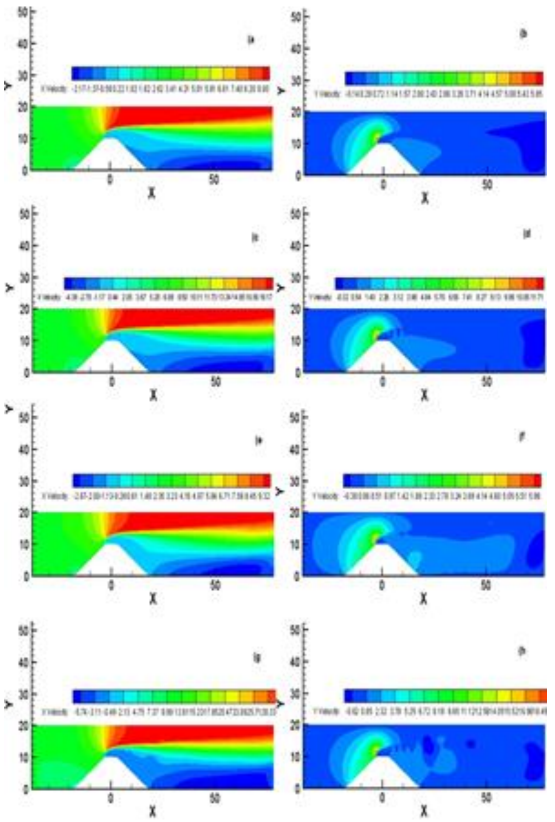

Figure 7. Velocity contour when we use solid fence with height of 1 meter and distance form center rail is 3 meter a) direction longitudinal and velocity is 3 (m/s), b) direction vertical and velocity is 3 (m/s), c) direction longitudinal and velocity is 6 (m/s), d) direction vertical and velocity is 6 (m/s) –Velocity contoure when we use fence with porosity of 20% and height is 1 meter and distance from center rail is 3 meter a) direction longitudinal and velocity is 3 (m/s), b) direction vertical and velocity is 3 (m/s), c) direction longitudinal and velocity is 6 (m/s), d) direction vertical and velocity is 6 (m/s)

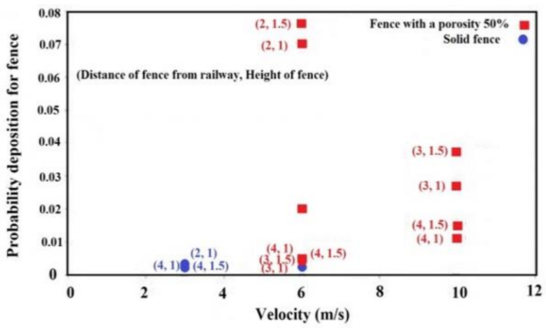

Figure 8. Probability deposition for fence (porosity zero and 50%)

Compared with a rigid fence, a fence with 20% of porosity reduces the drag force considerably; and compared with a fence with 50% of porosity it lets much fewer particles in. The probability of particles precipitating inside the fence is near zero for a fence with 20% porosity which means very few particles would get through. For the optimal distance from the railway's longitudinal axis, the time profile of precipitation at different wind speeds for the situation when the fence is positioned at a distance of 3 meters is given. These profiles can be easily obtained if the particle diameter range and the number of precipitated particles as well as the number of those which took off again are known.

As it was shown in Figure 9, most particles deposition are at the foot of the embankment. The same fence with a porosity of 20% gives better results when positioned at a distance of 3 meters to the railway's longitudinal axis compared to when it is positioned at a distance of 4 meters. When the fence is positioned farther from the rail, particles are suddenly opposed to without being first encumbered by the upward slope of the embankment. Here, they still retain enough energy to climb upwind and up the slope. If they are of a large diameter, their weight will soon overcome their upward movement; smaller particles though can overcome gravity and move up until precipitating on the rails. We can see that from Figure 10, by increasing the number of mesh, the amount of deposition of sand particles for the fence with porosity of 20% in distance 20 meter after 9 hours approximately are the same.

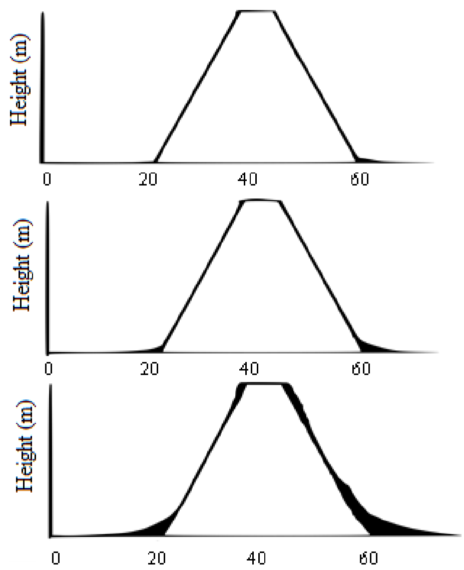

Figure 9. Deposition profile of sand when fence is 3 meter distance from central of railway by time-a) 3 hour b) 9 hour c) 24 hour

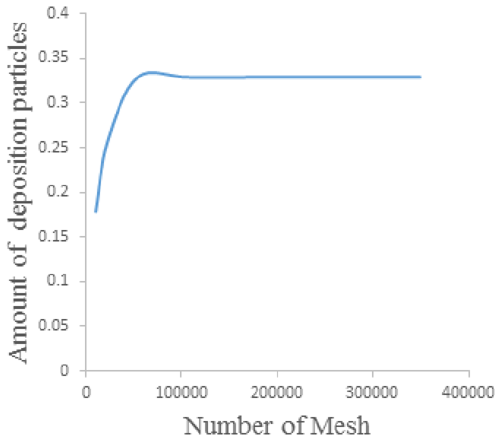

Figure 10. Amount of deposition of particles for 20% porosity fence in 20 meter distance from railway

4. CONCLUSIONS

Movement of sand particles in nature creates many problems for humans. In this paper, using fences for reduction of deposition of particles on rail surfaces have been discussed. Most of these particles deposition is on the ground near the slopes of the embankment. Fences with different heights and distance and porosity are compared. Geographic and environmental factors determine the type of fence which should be set up. It is concluded that increasing the height from 1 meter to 1.5 meter and using rigid fences did little to reduce precipitation but highly increased the drag force imposed on the fence. Furthermore, using a fence with a porosity of 50% lets more particles in compared to a fence with a porosity of 20%. It was shown that positioning the fence on the slope enables the particles to climb upwind and to deposition on the rails. Using a 1 meter high fence with a porosity of 20% positioned at a distance of 3 meters from the railway's longitudinal axis is recommended.

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Numerical Solution of Fence for Deposition Reduction Sand on Railway Tracks

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چکیده

حرکت ریزگردها در طبیعت مشکلات فراوانی را برای انسان ها ایجاد می کند. یکی از این مشکلات ایجاد شده نشست این ذرات بر روی ریل قطار می باشد که باعث کاهش سرعت قطار و در مواردی واژگونی آن می شود. در این مقاله، حرکت ریزگردها بر روی ریل قطار و نحوه نشست آن بررسی شده است. همچنین تاثیر ارتفاع، پروسیتی و فاصله حصار تا ریل حصار بررسی شده است. نتایح نشان می دهد سرعت ذرات شن در اطراف حصار کمترین مقدار و بر روی سطح شیب دار بیشترین مقدار را دارا می باشد. در اطراف سطح شیب دار و بر روی خاکریز بیشترین میزان نشست ریزگرد می باشد. استفاده از حصار مناسب وابسته به شرایط جغرافیایی و محیطی می باشد ولی به طور کلی استفاده از حصاری با ارتفاع ۱ متر و در فاصله ۳ متری از مرکز ریل قطار با پروسیتی ۲۰٪ توصیه می شود.

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