WIND TUNNEL SIMULATIONS OF THE EFFECTS OF POROUS FENCE ON THE AERODYNAMICS OF MINERAL PILES

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Abstract. *The knowledge of the effects of wind fence on wind field is important for undertanding of wind erosion mechanism around mineral piles. Wind tunnel simulations of mean velocity field characteristics of the air flow upwind and winward of the wind fences were investigated. The experiments were performed in a simulated neutral boundary layer wind tunnel which the oncoming flow representing the suburbun site. The Reynolds number was based on the heigth of the scale model material pile and free stream velociyt was aboub* $Re = 3,86 \times 10^4$ *. Wind fences scale models with different porosities (36%, 57%, 63% and 81%), materials and height were installed upwind of the mineral piles.The wind fences with porosities 36% and 57% seems to be effective for reducing the wind velocity.*

Keywords*: wind fence, mineral piles, wind tunnel experiments.*

1. INTRODUCTION

The steel and mining industries represent an important economic activity in Vitória, ES, Brazil. Among the important emission sources from these facilities are open storage mineral and coal piles. The impacts of dust emission from open storage mineral piles are serious environmental problem due to this process have been let the human health deteriorated and causes degradation of the air quality (Cong *et al*., 2011). Wind erosion depends on the effects of wind flow on the surface of the piles, such as wind velocity, pressure and wall shear stress (Park and Lee, 2001). The ejection of the dust particle from piles results in three movements: rolling, saltation and dispersion. Theses mechanisms are due to lift force that depends on the magnitude of oncoming flow velocity and the friction velocity on the pile's surface (Park and Lee, 2001).

Several works were conducted to investigate the windbreak in the reduction of wind erosion (Lee and Park, 1999). In this case, porous wind fence have been used as an artificial barrier for abating the wind erosion over material piles.

Lee and Park (2000) studied in a wind tunnel the shelter effect of porous wind fence on surface pressures and wall shear stress on the coal piles scale models (1/800) of POSCO open storage. The wind fence of porosity ε = 40% had an effective decrease of both mean and fluctuations pressures on the scale models coal piles. They found that occurred a decrease of wall shear stress on the windward surface of coal piles. The decrease was more than a half comparing with another situation that had no fence presence.

Loredo-Souza *et al*. (2005) carried out wind tunnel experiments to investigate the flow characteristics around an isolated coal pile scale model of the Vale mining industry in the city of Vitoria, ES, Brazil. The results showed that the mean wind speeds were higher next to the top of the pile and that porous wind fence to reduce the wind velocity in the crucial region of wind erosion. In addition, it was observed that wind fences with porosities in the range of 53% to 68% were the most effective in reducing wind erosion.

Dong *et al*. (2007) used wind tunnel simulation to study the mean flow regime behind porous fence with different porosities at different wind velocities. The mean velocity fields were measured using the particle image velocimetry. The mean velocity fields were similar to different wind velocities and revealed seven typical flow regions behind the porous fence. They found that the optimal porosity used to be around 0.2 or 0.3. The authors reported that this corresponds a critical porosity above which bleed flow dominates and below reversed flow becomes significant. The main objective of this study was to simulate experimentally the velocity fields in order to identify the optimal porosity of the porous wind fence in the reduction of wind erosion.

Zhang *et al*. (2010) investigated experimentally the shelter effect of a porous wind fence on saltating sand. They used a wind fence with porosity of 38.5% that was installed on a flat bed of sand collected from a beach (d = 200 – 300 μm). The capture of images of saltating sand particles around the fence was obtained by using a high-speed digital camera at frame rate of 4000 frames per second. The particle tracking velocimetry (PTV) method was employed to extract the instantaneous velocity fields of saltating sand particles. The results showed that the mean velocities decrease on the leeward side of the fence and a high-velocity region occurred in the shear layer above the fence. In the leeward region was observed that both particle concentration and mass flux have been decay largely.

The main objective of this study was to simulate experimentally the velocity and turbulence fields in order to identify the optimal porosity of the scale model porous wind fence in the reduction of wind erosion around a scale model open storage material piles.

2. MATERIAL AND METHODS

The experiments were performed in an open-return subsonic wind tunnel with a test section of 2.0 m long, 0.5 m wide and 0.5 m high. In order to generate the neutrally atmospheric boundary layer, wood spires (0.37 m) and roughness elements (cubical wooden blocks of 0.018 m) were installed upstream the test section of the wind tunnel according to the theory proposed by Irwin (1981). The scale model material pile has a triangular prism configuration and it was scaled-down of 1/100 of the prototype coal pile of Vale Mining Company (Malcum, 2006). The mean streamwise velocity has the following power law profile:

$$\frac{U(z)}{U_\delta} = \left(\frac{y}{\delta}\right)^p \tag{1}$$

where δ = 0.30 m is the atmospheric boundary layer thickness. The velocity profile was fit with p = 0.25, which corresponds to the velocity profile over suburban terrain. The experimental set-up and coordinate system used in this work are show in Fig. 1. The mean vertical velocity profiles of the simulated atmospheric boundary layer were measured by a Pitot tube with probe of 3 mm diameter coupled to micromanometer (TSI, model EBT720), Fig. 1. The free stream mean velocity was fixed at U_δ = 7.42 m/s and the corresponding Reynolds number (Re) based on the scale model material pile height (h_p = 0.08 m) was about Re = 3.86 × 10^4.

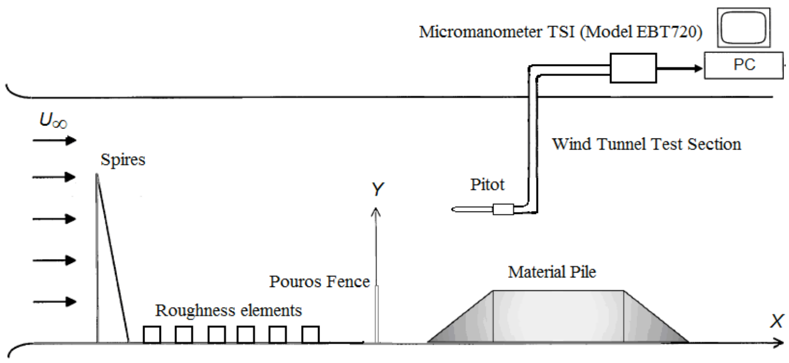

Figure 1. Sketch of the wind tunnel test section, measurement system and porous fence localization.

In this study, porous fences of porosities ε = 36%, 57%, 63% and 81% were selected to the investigated shelter from the material piles. Two types of porous fences scale models with different height of y = 1.0 h_p and y = 1.5 h_p (where h_p was the material pile height) were installed windward of material piles. Table 1 shows the physical proprieties of WF configurations used in this work.

Table 1. Physical proprieties of WF configurations used in this work.

Wind Fence	Porosity (%)	Height	Hole diameter (mm)	Material
WTWF1	36	1.0 h_p	0.2	Polyester
WTWF2	36	1.5 h_p	0.2	Polyester
WTWF3	57	1.0 h_p	0.2	Polyester
WTWF4	57	1.5 h_p	0.2	Polyester
WTWF5	63	1.0 h_p	0.2	Polyester
WTWF6	63	1.5 h_p	0.2	Polyester
WTWF7	81	1.0 h_p	0.3	Steel
WTWF8	81	1.5 h_p	0.3	Steel

3.RESULTS

In this work, the shelter effect of a porous wind fence on a triangular material piles scale model, located behind the WF, was investigated experimentally for various porosities (36%, 57%, 63% and 81%). Vertical mean wind velocity profiles were obtained upstream and downstream the scale model pile

Figure 2 shows the mean vertical velocity profile of the wind for measurements at x = 0.5 h_p downstream of the porous wind fence of 1.0 h_p. With the presence of porous fence of 1.0 h_p, the wind velocity decreases to WTWF1 and WTWF3 in the range 0.0 $\leq y < 0.08$ m. For the WTWF5 the reduction of the wind velocity occurred only between 0.03 m $\leq y < 0.08$ m. For the WTWF7, with higher porosity (81%), occurred an increase in the wind velocity in the range 0.0 $\leq y < 0.08$ m. On the top and above of the pile height was observed an acceleration of the flow for all scale model wind fences that were used.

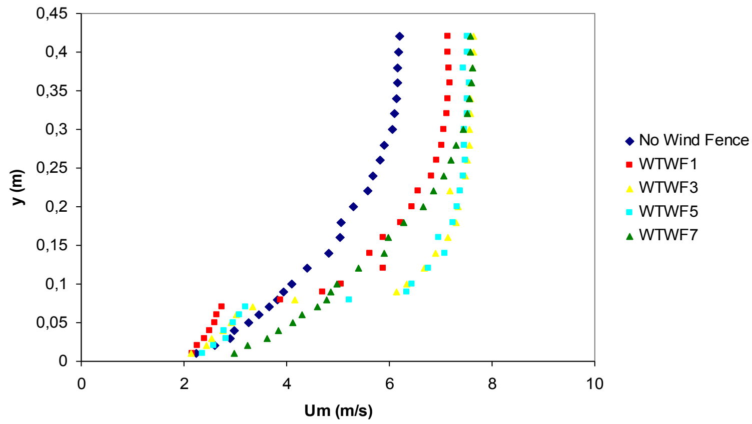

Figure 2. Results of measurements in x = 0.5 h_p downstream of material piles for wind fence with y = 1.0 h_p.

Figure 3 shows the mean vertical velocity profile of the wind for measurements at x = 1.0 h_p downstream of the porous wind fence of 1.0 h_p. With the presence of porous fence of 1.0 h_p the wind velocity decreases only for the WTWF1 in the range of 0.0 $\leq y < 0.08$ m. On the top and above of the pile height was observed an acceleration of the flow for all scale model wind fences that were used.

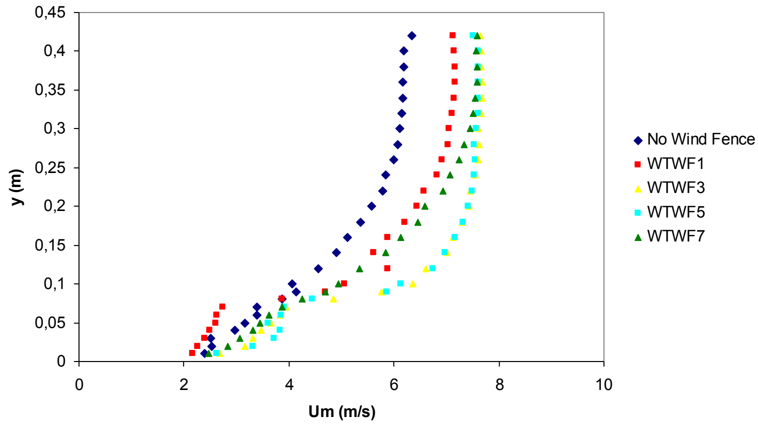

Figure 3. Results of measurements in x = 1.0 h_p downstream of material piles for wind fence with y = 1.0 h_p.

Figure 4 shows the mean vertical velocity profile of the wind for measurements at x = 1.5 h_p downstream of the porous wind fence of 1.0 h_p. The measurements were realized to greater heights that 0.03 m due to presence pile material base. The results showed a decrease of the wind velocity in this region for all wind fences used for 0.03 $\leq y \leq$ 0.08 m. These results suggest that the reduction of mean wind velocity may be due to the presence of the pile.

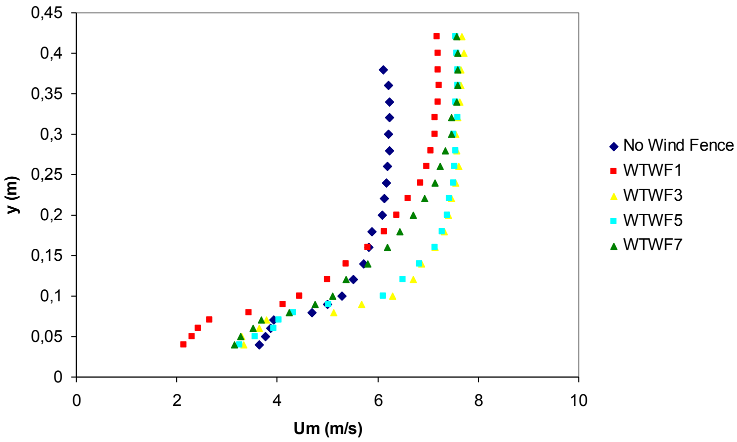

Figure 4. Results of measurements in $x = 1.5\ h_p$ downstream of material piles for wind fence with $y = 1.0\ h_p$.

Figure 5 shows the mean vertical velocity profile of the wind for measurements at $x = 13.0\ h_p$ downstream of the porous wind fence with 1.0 h_p. With the presence of porous fence of 1.0 h_p the wind velocity decreases only for the WTWF1 in the range of $0.0 \leq y < 0.08$ m. On the top and above of the pile height was observed an acceleration of the flow for all scale model wind fences that were used.

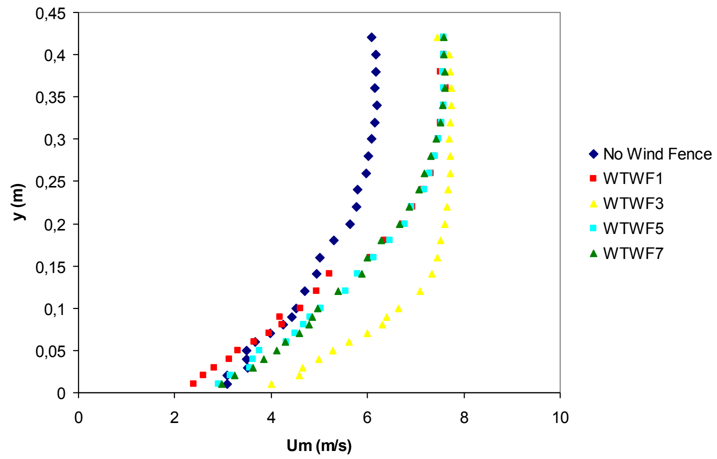

Figure 5. Results of measurements in $x = 13.0\ h_p$ downstream of the porous wind fence with $y = 1.0\ h_p$.

Figure 6 shows the wind mean velocity for wind fence of $y = 1.5\ h_p$ at the position $x = 0.5\ h_p$, downstream of the porous wind fence. The results showed that wind velocity decreases for the WTWF2, WTWF4 and WTWF6 in the range of $0 \leq y < 0.12$ m (the wind fence height). Above this range, $y > 0.12$ m, it was observed an acceleration of the flow for all scale model wind fences that were used.

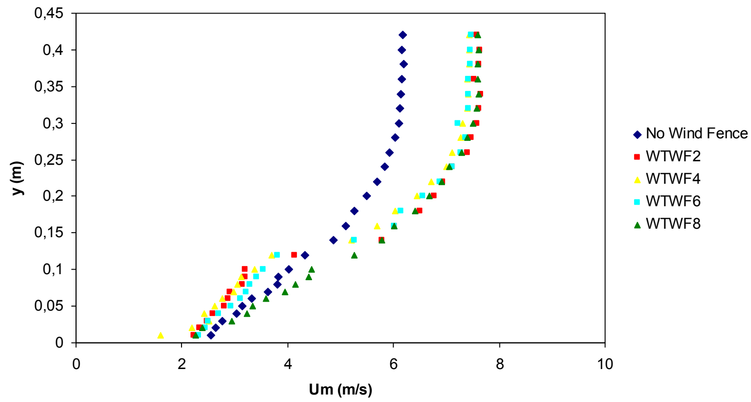

Figure 6. Results of measurements in $x = 0.5\ h_p$ downstream of material piles for wind fence with $y = 1.5\ h_p$.

Figure 7 shows the mean vertical velocity profile of the wind for measurements at x = 1.0 h_p downstream of the porous wind fence of 1.5 h_p. The measurements were realized in heights greater than 0.06 m due to presence pile material base. With the presence of porous fence of 1.5 h_p, the wind velocity decrease for the WTWF2, WTWF4 and WTWF 6 in the range of 0.06 m ≤ y ≤ 0.12 m. Above this range, y > 0.12 m, it was observed an acceleration of the flow for all scale model wind fences that were used.

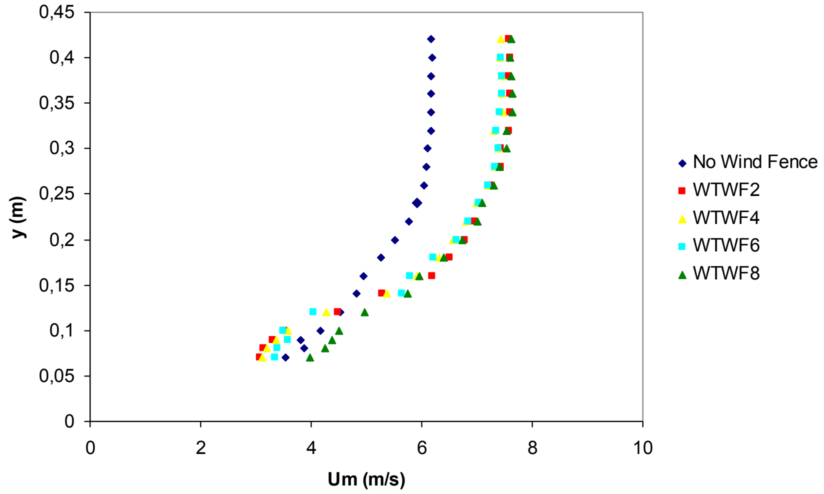

Figure 7. Results of measurements in x = 1.0 h_p downstream of material piles for wind fence with y = 1.5 h_p.

Figure 8 shows the mean vertical velocity profile of the wind for measurements at x = 1.5 h_p downstream of the porous wind fence of 1.5 h_p. The measurements were realized to greater heights that 0.08 m due to presence pile material. With the presence of porous fence of 1.5 h_p, the wind velocity decrease for the WTWF2, WTWF4 and WTWF 6 in the range of 0.06 m ≤ y ≤ 0.12 m. Above this range, y > 0.12 m, it was observed an acceleration of the flow for all scale model wind fences that were used.

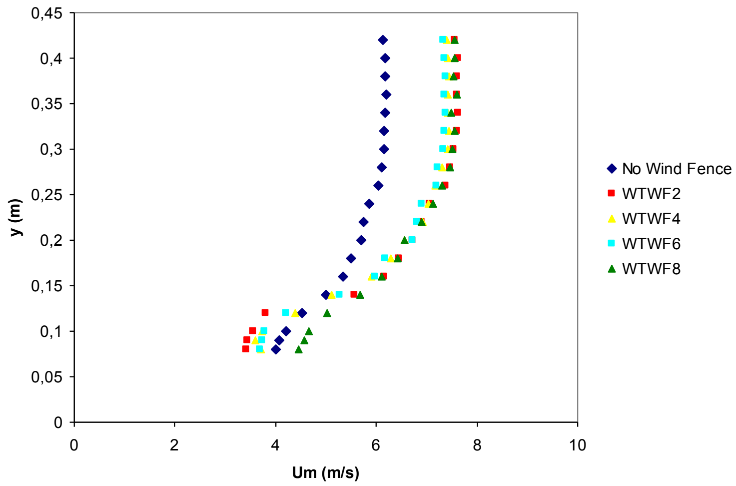

Figure 8. Results of measurements in x = 1.5 h_p downstream of material piles for wind fence with y = 1.5 h_p.

Figure 9 shows the mean vertical velocity profile of the wind for measurements at x = 13.0 h_p downstream of the porous wind fence with 1.5 h_p. With the presence of porous fence of 1.5 h_p, the wind velocity decreases for the WTWF2, WTWF4 and WTWF 6 in the range of 0.0 m ≤ y ≤ 0.08 m. Above this range, y > 0.08 m, it was observed an acceleration of the flow for all scale model wind fences that were used. These results suggest that the reduction of mean wind velocity may be due to the presence of the pile.

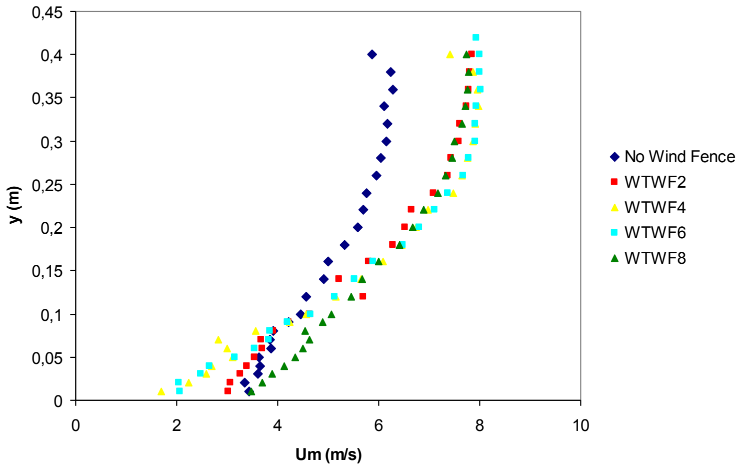

Figure 9. Results of measurements in x = 13.0 h_p downstream of the porous wind fence with y = 1.5 h_p.

Table 2 shows the mean performance of wind fence of y = 1.0 h_p in reducing the wind velocity around mineral piles. When there was fence in front of the material pile (x = 0.5 h_p), the oncoming flow was decelerated slightly when it approaches to the prism. The flow was accelerated downstream of the wind fence (y/h_p > 1.0) due to it was not observed a reduction of the wind velocity. For the wind fence with height of 1.0 h_p the optimal porosity was found to be 36 %, with slight reduction of the wind velocity.

Table 2. Mean performance of wind fences of y = 1.0 h_p for reducing the wind velocity around mineral piles.

	WTWF1	**WTWF3**	**WTWF5**	**WTWF7**
		x = 0.5 h_p		
$0 < y/h_p \leq 0.5$	13.15	8.07	1.94	
$0.5 < y/h_p < 1.0$	0.22	9.57	11.03	
$y/h_p = 1.0$				
$1.0 < y/h_p \leq 1.5$				
		x = 1.0 h_p		
$0 < y/h_p \leq 0.5$	12.79			
$0.5 < y/h_p < 1.0$	18.53			
$y/h_p = 1.0$				
$1.0 < y/h_p \leq 1.5$				
		x = 1.5 h_p		
$0.375 < y/h_p \leq 0.5$	41.02	8.10	10.73	13.15
$0.5 < y/h_p < 1.0$	35.51	7.56	1.30	9.73
$y/h_p = 1.0$	26.93		7.84	9.89
$1.0 < y/h_p \leq 1.5$	13.38			0.5
		x = 13.0 h_p		
$0 < y/h_p \leq 0.5$	17.08			
$0.5 < y/h_p \leq 1.0$	2.71			
$y/h_p = 1.0$				
$1.0 < y/h_p \leq 1.5$				

Table 3 shows the performance of wind fence of y = 1.5 h_p in reducing the wind velocity around mineral piles. When there was fence in front of the material pile (x = 0.5 h_p), the oncoming flow was decelerated slightly when it approaches to the prism. The flow was accelerated downstream of the wind fence (y/h_p > 1.0) due to it was not observed a reduction of the wind velocity. For the wind fence with height of 1.5 h_p the optimal porosity was found to be 57%, with slight reduction of the wind velocity.

Table 3. Performance (%) of wind fences of $y = 1.5\ h_p$ for reducing the wind velocity around mineral piles.

	WTWF2	WTWF4	WTWF6	WTWF8
		$x = 0.5\ h_p$		
$0 < y/h_p \leq 0.5$	13.84	27.81	9.94	1.49
$0.5 < y/h_p \leq 1.0$	15.12	18.08	10.61	
$1.0 < y/h_p \leq 1.5$	9.77	16.24	11.47	
		$x = 1.0\ h_p$		
$0.5 < y/h_p \leq 1.0$	16.10	14.62	9.04	
$1.0 < y/h_p \leq 1.5$	6.77	8.40	8.83	
		$x = 1.5\ h_p$		
$y/h_p = 1$	14.98	7.49	8.03	
$1.0 < y/h_p \leq 1.5$	15.48	6.82	7.52	
		$x = 13.0\ h_p$		
$0 < y/h_p \leq 0.5$	9.30	34.27	34.22	
$0.5 < y/h_p \leq 1.0$	2.8	18.00	5.78	
$1.0 < y/h_p \leq 1.5$				

4. CONCLUSIONS

The wind fences with porosities 36% and 57% and height of 1.5 h_p seems to be effective for attenuating the wind velocity around scale model material piles, this suggested that the reduction of the porosity implies in a reduction of the wind speed. For seven WF was observed that the wind reduction occurred a shortened shelter distance upstream of the wind fence. For all the cases with the presence of the porous screen the average wind velocities above to the pile were higher than the equivalent average velocities for the case no wind fence.

5. REFERENCES

Cong, X.C., Cao, S.Q., Chen, Z.L., Peng, S.T. and Yang, S.L., 2011. "Impact of the installation scenario of porous fences on wind-blow particle emission in open coal yards". Atmospheric Environmental, Vol. 45, pp. 5247-5253.

Dong, Z., Luo, W., Qian, G. and Wang H., 2007. "A wind tunnel simulation of the mean velocity fields behind upright porous fence." Agricultural and Forest Meteorology, Vol. 146, pp. 82-93.

Irwin, H.P., 1981. "The Design of Spires for Wind Simulation". Journal of Wind Engineering and Industrial Aerodynamics, Vol. 7, pp. 361-366.

Lee, S.J. and Park, C.W., 1999. "Surface pressure characteristics on a triangular prism located behind a porous fence." Journal of Wind Engineering and Industrial Aerodynamics, Vol. 80, pp. 69-83.

Loredo-Souza, A.M.; Schettini, E.B.C., Guimarães, A.F., Pimentel, J.L. and Ignácio, L.R., 2005. "Wind Tunnel Testing of a Coal Pile Model of the CVRD – Vitória, Brazil and Efecctes Caused by Porous Fence". In: 10 th ACWE – Americas Conference on Wind Engineering, Baton Rouge, Louisiana, USA.

Malcum, K.C., 2006. Avaliação dos efeitos de telas porosas sobre a aerodinâmica de pilhas de carvão. Dissertação de Mestrado – Programa de Pós-Graduação em Engenharia Civil, UFRGS, Porto Alegre, R.S., Brazil.

Park, C.W. and Lee, S.J., 2001. "The effects of a bottom gap and non-uniform porosity in a wind fence on the surface pressure of a triangular prism located behind the fence". Journal of Wind Engineering and Industrial Aerodynamics, Vol. 89, pp. 1137-1154.

Zhang, N., Kang, J-H. and Lee, S-H., 2010. "Wind tunnel observation on the effect of a porous wind fence on shelter of saltating sand particles". Geomorphology, Vol. 120, pp. 224-232.

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