Computers and Electronics in Agriculture xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Design of a windbreak fence to reduce fugitive dust in open areas

Rack-woo Kim [a], In-bok Lee [a,b,*], Kyeong-seok Kwon [c], Uk-hyeon Yeo [a], Sang-yeon Lee [a], Min-hyung Lee [a]

[a] Department of Rural Systems Engineering, Research Institute for Agriculture and Life Sciences, College of Agriculture and Life Sciences, Seoul National University, 599, Gwanakno, Gwanakgu, Seoul 08826, Republic of Korea
[b] Research Institute of Green Eco Engineering, Institute of Green Bio Science and Technology, Seoul National University, 1447 Pyeongchang-daero, Daehaw-myeon, Pyeongchang-gun, Gangwon-do 25354, Republic of Korea
[c] Animal Environment Division, Department of Animal Biotechnology & Environment, National Institute of Animal Science, Rural Development Administration, Wanju-Gun, Jeollabuk-Do 55365, Republic of Korea

ARTICLE INFO

Article history:
Received 10 January 2017
Received in revised form 5 June 2017
Accepted 15 August 2017
Available online xxxx

Keywords:
Computational fluid dynamics
Saemangeum reclaimed land
Saltating dust
Suspended dust
Windbreak fence

ABSTRACT

The wind characteristics of the Saemangeum reclaimed land are quite different from those of inland because of the prevalence of strong wind environments near the seashore. Thus, the probability of fugitive dust dispersion would be higher under these wind environmental conditions, and civil complaints regarding fugitive dust have increased in the residential area. Therefore, we must establish countermeasures to reduce fugitive dust. In this study, the dispersion behavior of fugitive dust at the Saemangeum reclaimed land was simulated by using a two-dimensional CFD simulation. A CFD model was simulated by considering the wind velocity and the design properties of the windbreak fences, such as their height, installation interval and number of layer. The percent of upstream velocity (PUV) is applied in this study to quantitatively evaluate the reduction in the wind velocity by a windbreak fence. The behavior of saltating dust was analyzed by comparing the simulation results with the threshold wind velocity, which is the wind velocity at which the soil particulates come off the surface and erosion starts. The behavior of suspended dust was analyzed by using the reduction rate of dust concentration according to the installation conditions of the windbreak fence. A strategy for installing windbreak fences was suggested according to these results to reduce fugitive dust in the Saemangeum reclaimed land.

© 2017 Elsevier B.V. All rights reserved.

1. Introduction

The Saemangeum reclaimed land is one of the largest reclaimed lands in the world, with a total area as large as 40,100 ha. Since the completion of its 4 seawalls in 2006, the salt concentration in the area has increased, accelerating the drying of its surface. Its arid open area has low vegetation coverage and thus is prone to wind erosion, resulting in problems with fugitive dust.

The wind environment of a reclaimed land is different from that of inland areas because of the influence of sea-land breezes, which exhibit higher wind velocity in a constant direction and are strongly influenced by turbulence because of convection from the seashore (Korea Metrological Administration, 2014). The arid conditions in the Saemangeum reclaimed land continue in spring, during which the precipitation and relative humidity are low. Most of the soil consists of sand soil with low clay content or silt soil, so the probability of fugitive dust dispersion would be higher when the maximum wind velocity is 25–39 $m\,s^{-1}$ at a reclaimed land (Rural Research Institute in Korea Agricultural and Rural Infrastructure Corporation, 2004). Fugitive dust negatively affects ecological systems by reducing visibility, creating aesthetic displeasure, causing respiratory diseases in humans and animals, and hindering the assimilation, breathing and evaporation of plants by blocking the stomata when deposited on leaves (Jeong, 2012; Kang and Lee, 2005; Kim et al., 2005). Civil complaints regarding fugitive dust have increased in the residential area and the country club around the Saemangeum reclaimed land, so we must establish countermeasures to reduce fugitive dust.

Studies have examined the optimal installation and reduction performance of windbreak facilities, such as fences, obstacles, halophyte covers, windbreak forests, and tillage, on fugitive dust in an open area (Dong et al., 2007; Grantz et al., 1998; Kim et al., 2005; You et al., 2006). The roots and stems of halophytes prevent surface erosion by promoting the solidification and stabilization of the sediment and reduce the concentration of fugitive dust by collecting suspended dust (Choi, 1998; Hwang et al., 2009; Shin et al., 2013). A windbreak fence is one method to prevent sand erosion and its dispersion in open spaces and deserts, resulting in wind

* Corresponding author at: 599, Gwanakno, Gwanakgu, Seoul 08826, Republic of Korea.
E-mail address: iblee@snu.ac.kr (I.-b. Lee).

http://dx.doi.org/10.1016/j.compag.2017.08.014
0168-1699/© 2017 Elsevier B.V. All rights reserved.

ARTICLE IN PRESS

Nomenclature

AED	Aerodynamic equivalent diameter
ABL	atmospheric boundary layer
C_2	inertial resistance factor (m^{-1})
C_μ	model fitting parameter (0.09)
CFD	computational fluid dynamics
$D_{m,j}$	mass diffusion coefficient for species j ($m^2\ s^{-1}$)
$D_{T,j}$	thermal diffusion coefficient for species j ($kg\ m^{-1}\ s^{-1}$)
EL	elevation level (m)
ESDU	Engineering Sciences Data Unit
FVM	finite volume method
J_j	diffusion flux of specie j ($kg\ m^{-2}\ s^{-1}$)
k	turbulent kinetic energy ($m^2\ s^{-2}$)
PM10	particle matter under 10 μm
PM2.5	particle matter under 2.5 μm
PUV	percent of upstream velocity (%)
R^2	coefficient of determination
RANS	Reynolds-averaged Navier-Stokes
Re	Reynold number
RNG	Re-Normalization Group
Sc_t	Turbulent Schmidt number
SIMPLE	semi-implicit method for pressure-linked equations
T	temperature (K)
TAC	technical advisory committee
UDF	user-defined functions
u	wind velocity ($m\ s^{-1}$)
u^*	wall friction velocity ($m\ s^{-1}$)
u_{ref}	design wind velocity ($m\ s^{-1}$)
u_t	threshold wind velocity ($m\ s^{-1}$)
Velocity field$_{\text{with fence}}$	wind velocity with a windbreak fence ($m\ s^{-1}$)
Velocity field$_{\text{without fence}}$	wind velocity without a windbreak fence ($m\ s^{-1}$)
Y_j	mass fraction of species j
y^+	dimensionless distance from the wall
z	height in the atmospheric boundary layer (m)
z_0	aerodynamic roughness length (m)
α	permeability (m^2)
Δn	thickness of porous media (m)
ΔP	static pressure difference (Pa)
ϵ	turbulent energy dissipation ($m^2\ s^{-3}$)
κ	Von Karman constant
μ	viscosity coefficient ($kg\ m^{-1}\ s^{-1}$)
μ_t	turbulent viscosity ($kg\ m^{-1}\ s^{-1}$)
ρ	air density ($kg\ m^{-3}$)

velocity reduction and sedimentation around the fence (Dong et al., 2007; Hong et al., 2015; Kim et al., 2006; Perera, 1981; Santiago et al., 2007; Song et al., 2007; You et al., 2006). Windbreak forests are planted to prevent wind damage, salt damage, odors and fugitive dust (Alhajraf, 2004; McAneney et al., 1990; Mercer, 2009; Plate, 1971; Santiago et al., 2007). Obstacles or tillage can also increase the surface roughness and reduce the wind velocity (Grantz et al., 1998; Tatarko, 2004).

A method that can be installed in a short time in the Saemangeum reclaimed land is required because this region is rapidly exposed to wind erosion in a strong wind environment. The use of halophytes to prevent fugitive dust has maintenance problems: maintaining an optimal growth environment for halophytes is difficult because of the continuous desiccation. Given many aspects such as the economy, maintenance and the wind reduction effect, many studies have therefore suggested that the installation of windbreak fences is a proper method to manage the dispersion of fugitive dust in the Saemangeum reclaimed land. However limited studies, which have investigated the installation cost, the optimal reduction effect on fugitive dust and applicability to an open area, have been conducted regarding the optimal installation of a windbreak fence.

Studies regarding the dispersion of fugitive dust and the reduction efficiency of a windbreak fence can be classified into three categories: field tests, wind tunnel tests and numerical analyses. Raine and Stevenson (1977) used hot-wire anemometers to measure the average velocity at the wake of windbreak fences and investigated the flow characteristics. Perera (1981) suggested that a porosity value of more than 0.3 for a windbreak fence is appropriate based on a flow analysis of windbreak fences with an anemometer. Cornelis and Gabriels (2005) conducted a wind tunnel test to optimize the installation of a screen for a windbreak fence and found that the most efficient wind velocity reduction was achieved when the porosity ranged from 0.2 to 0.35. Santiago et al. (2007) proposed an optimal porosity of 0.35 for a windbreak fence after a wind tunnel test and numerical analysis based on the Reynolds-averaged Navier-Stokes equations (RANS). Lim and Lee (2000) conducted a numerical analysis in the wake of windbreak fences and compared these results to the results from a wind tunnel test to evaluate the accuracy of the model. Kim et al. (2006) reported that the wind velocity reduction from a wind tunnel test was the highest when the distance between the windbreak fences was 4–7 times the height of the fence, when the porosity of circular and vertical windbreak fences was 0.4, and when the porosity of a horizontal windbreak fence was 0.2. Based on a wind tunnel test and numerical analysis, Bitog et al. (2009) analyzed the wind velocity reduction rather than dust behaviors according to the porosity of a windbreak fence and its arrangement in the Saemangeum reclaimed land and suggested that the highest wind velocity reduction was obtained when the porosity was 0.2, regardless of the height or the distance of the windbreak fences. Kim et al. (2013) conducted an experiment regarding the aerodynamic resistance of commercially available windbreak screens based on the number of screen layers and the arrangement by using a small wind tunnel. Hong et al. (2015) used a small wind tunnel to measure the aerodynamic resistance of windbreak screens with various arrangements, and their results were applied to a computational fluid dynamics (CFD) simulation. In particular, Hong et al. (2015) verified this CFD simulation by comparing it with the results from a field test and analyzed the wind velocity reduction of the windbreak fence to suggest optimal parameters for wind velocity reduction. Field tests are a reliable method that uses a full-scale model. In a very wide space such as the Saemangeum reclaimed land, however, understanding all the phenomena in a qualitative and quantitative manner by relying on point-by-point measurements becomes more difficult, while the cost and time for such measurements remain, as with other obstacles. Furthermore, separating the contribution from the climate conditions to the results is difficult because the wind environmental conditions change during the measurements. For a wind tunnel test, it is possible to control the condition and to acquire quantitative data, while it is sensitive to the similarity law with the cost of time and money.

In this study, the dispersion behavior of fugitive dust at the Saemangeum reclaimed land was simulated by using numerical analyses such as CFD, from which the optimal installation of a windbreak fence was suggested to efficiently reduce fugitive dust dispersion. A two-dimensional simulation model in which the

Please cite this article in press as: Kim, R.-w., et al. Design of a windbreak fence to reduce fugitive dust in open areas. Comput. Electron. Agric. (2017), http://dx.doi.org/10.1016/j.compag.2017.08.014

Download English Version:

https://daneshyari.com/en/article/6539492

Download Persian Version:

https://daneshyari.com/article/6539492

Daneshyari.com