A NUMERICAL STUDY ON THE EFFECTS OF METEOROLOGICAL AND RECLAIMING CONDITIONS ON REDUCTION OF SUSPENDED PARTICLES

Ju-Hyun Lee, Jae-Jin Kim*
Pukyong National University, South Korea

Abstract

The effects of meteorological and reclaiming conditions on the reduction of suspended particles are investigated using a computational fluid dynamics (CFD) model with the *k*-*ε* turbulence closure scheme based on the renormalization group (RNG) theory. Sixteen numerical experiments with different meteorological and reclaiming conditions are analyzed. Total amounts of suspended particles are calculated using the frictional and threshold frictional velocities, erosion potential function, and the number of surface disturbance. In the case of a 10 m-reclaiming and northerly wind, the amount of suspended particles is largest. The Lagrangian particle dispersion model (LPDM) which can consider the particle deposition is developed to investigate the range of dispersion and the deposition amount of the suspended particles.

1. INTRODUCTION

Particles such as coal dust, lime powder, and sand which are suspended from the storage piles to adjacent region by wind can cause severe atmospheric pollution problems. The formation of suspended particles is largely affected by meteorological condition (ambient wind speed and direction) and reclaiming condition (reclaiming height and area, existence of windbreaks). During the last decades, many studies (U.S. EPA, 1995; Kim, 2005) are performed to investigate the effects of meteorological conditions on occurrence of suspended particles. However, they focused on meteorological condition only. In this study, the effects of meteorological and reclaiming conditions on reduction of suspended particles are investigated using a computational fluid dynamics (CFD) model.

2. NUMERICAL MODEL

The numerical model used in this study is the same as that of Kim (2007). In this study, a three-dimensional, non-hydrostatic, non-rotating and incompressible airflow system is considered. The governing equations include Reynolds averaged momentum equation, mass continuity equation and transport equation for passive scalar. In the present CFD model, the RNG *k*-*ε* turbulence scheme presented by Yakhot et al. (1992) is used. This scheme differs from the standard *k*-*ε* turbulence scheme in that it includes an additional sink term in the turbulence dissipation equation to account for non-equilibrium strain rates and it employs different values for the model coefficients. The governing equation set is numerically solved on a staggered grid system using a finite volume method with the semi-implicit method for pressure-linked equation (SIMPLE) algorithm (Patankar, 1980).

The CFD model used in this study is validated against the wind tunnel data of Brown et al. (2000). The dispersion model is validated against the wind tunnel data of Pavageau and Schatzmann (1999) and the large eddy simulation data of Liu and Barth (2002).

The CFD model reproduced the mean flow structures perfectly (Fig. 1a) and even the intensity of the vortex in the second street canyon very well (Fig. 1b). The CFD model underestimated slightly the concentration in lower layer of street canyon, but it simulated the distribution pattern very well (Fig. 2).

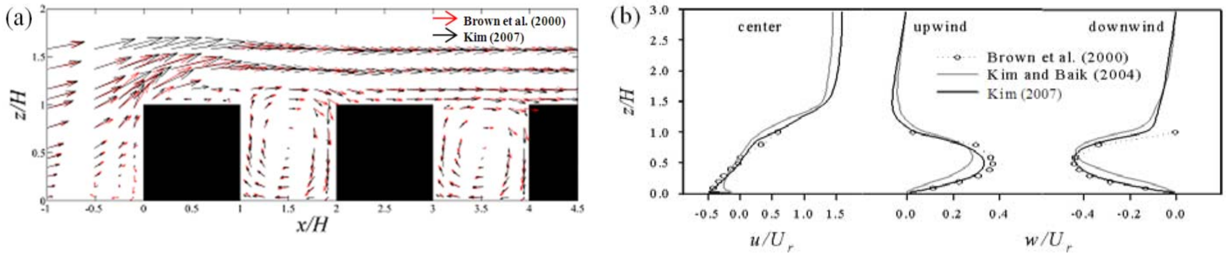

Fig. 1. (a) Wind vector field [wind vectors in red – Brown et al. (2000)] and (b) vertical profiles of velocity components in the 2nd street canyon

*corresponding author: Prof. Jae-Jin Kim. Tel.: +82-51-629-6645, jjkim@pknu.ac.kr

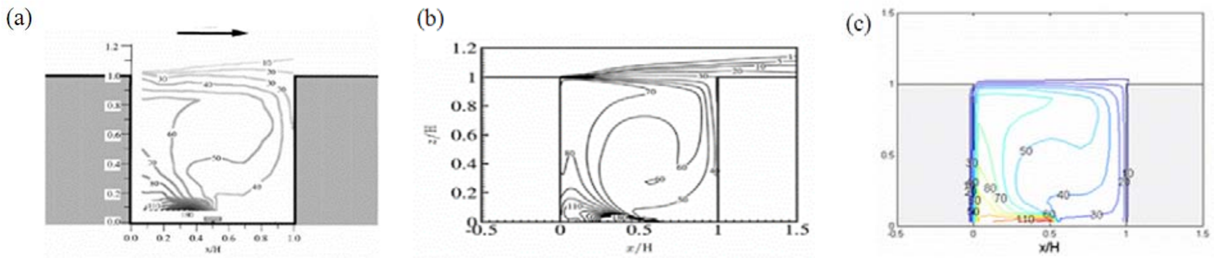

Fig. 2. Distribution fields of passive pollutants emitted from the point source (a) measured by Pavagear and Schatzmann (1999), (b) simulated (LES) by Liu and Barth (2002), and (c) simulated (RANS) in this study

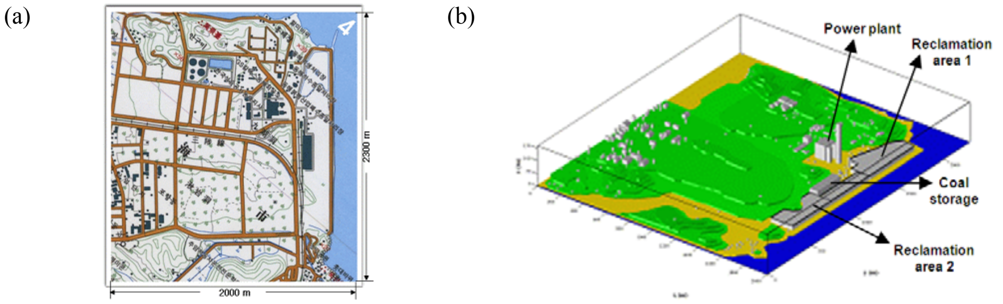

Fig. 3. The (a) map for the simulation region and (b) configuration of the topography and buildings constructed in the CFD model

Table. 1. The summary of the numerical experiments

Case	Category			Wind Direction		
	Reclamation height	Reclamation area	Windbreak	0°	31.75°	58.5°
F1010	10m	1	No	q243	q211	q185
F1210	10m	1, 2	No			
F1215	15m	1, 2	No			
F12WB	15m	1, 2	Yes			

The first two digits after ‘F’ indicate whether the area 1 and area 2 are reclaimed or not and the last two digits indicate the reclamation height. The q243, q211, q185 stand for the northerly, north-north-easterly, and east-north-easterly, respectively

3. EXPERIMENTAL SETUP

Fig. 3a represents the map for the simulation region and Fig. 3b indicates the configuration of topography and buildings constructed in the CFD model. The horizontal domain size is 2000 m and 2300 m in x- and y-direction, respectively. The number of cells is 200, 200, and 60 in x-, y- and z-direction, respectively. The horizontal grid size is uniform (10 m and 11.5 m in x- and y-direction) The vertical grid size is uniform (2.5 m) up to the 21th layer and it increases up to the 39th layer with the expansion ratio of 1.1. From the 40th layer, the vertical grid size is uniform as 13.9 m.

The numerical model is integrated for 3600 s. The time step is 1 s. The predictive emission factor equation (U.S. EPA, 1995) is used to calculate the total amount of suspended particles at each grid point. Four reclaiming conditions for three ambient wind directions are considered (12 numerical experiments) (Table 1).

4. RESULTS AND DISCUSSION

4.1. FLOW FIELD

Flow patterns are very complicated due to the existence of the small hills and buildings. In the F1010 case, the wind speed decreases rapidly due to cavity region formed in the leeward side of the reclamation area 1 (Fig. 4a). Wind speed is also very weak in the area between the reclamation area and the power plant (Fig. 4c). In the F12WB case, the wind speed decreases and the flow distortion deepens at the surface of the reclamation area 1 and 2 by the windbreak (Figs. 4d and 4e). Behind the windbreak, a reverse flow appears as the recirculation zone is formed (Fig. 4f).

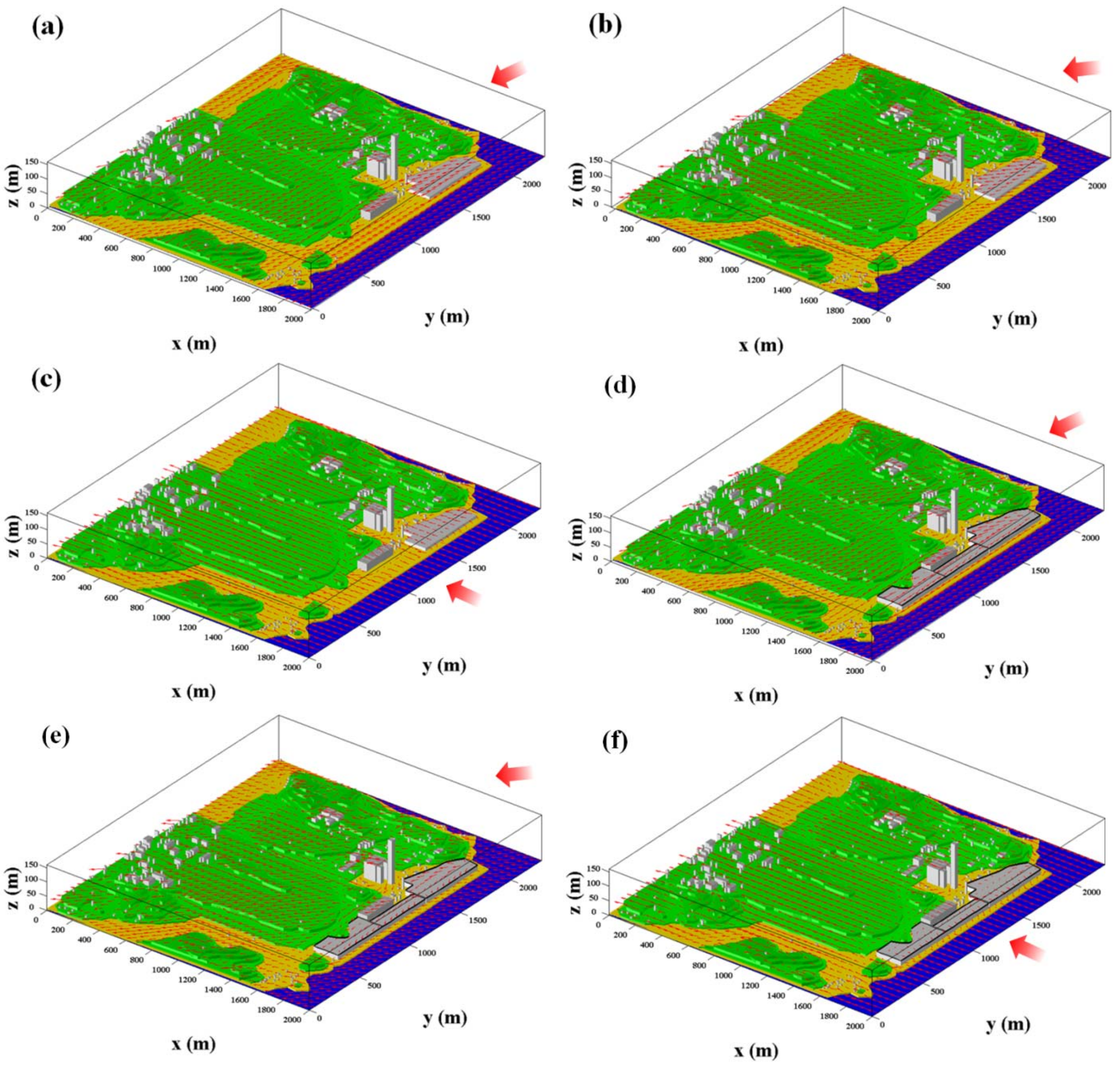

Fig. 4. The wind-vector fields in the F1010 [upper] and F12WB [lower] cases for the northerly [(a) and (d)], north-north-easterly [(b) and (e)], and east-north-easterly [(c) and (f)] at z = 2.5 m from the ground surface

4.2. CONCENTRATION FIELD

Total amount of suspended particles per year is calculated by the predictive emission factor equation (U. S. EPA, 1995). In this study, it is assumed that the reclamation area is reclaimed entirely and evenly and that particle suspension occurs only at the upper side of the reclamation area. The emission rate in the model is calculated using the total amount of the suspended particles per year. The predictive emission factor equation can evaluate the total amount of suspended particles per year by size (e.g. PM30, PM15, PM10, PM2.5). In this study, the PM10 concentration is focused on.

In the F1010_q243 case (Fig. 5a), concentration is high near the reclamation area 1 and it rapidly decreases as going to the downwind region. The maximum concentration (524.9 μg m^{-3}) appears near the downwind edge of the reclamation area 1. In the case, PM10 concentration near the reclamation zone and coal storage exceeds 50 μg m^{-3} which is the permitted annual average concentration of PM10 by the standard of natural environment of the Ministry of Environment, Korea. In the F12WB_q243, as in the F1010_q243, concentration is high near the reclamation areas 1 and 2 and it rapidly decreases as going to the downwind region. The maximum concentration (394.4 μg m^{-3}) near the downwind edge of the reclamation area 1 is lower than that in the F1010_q243. Near the reclamation area 2, concentration is overall lower than that in the F1215 case (not shown). In the case, PM10 concentration is lower than 50 μg m^{-3} everywhere except over the reclamation areas.

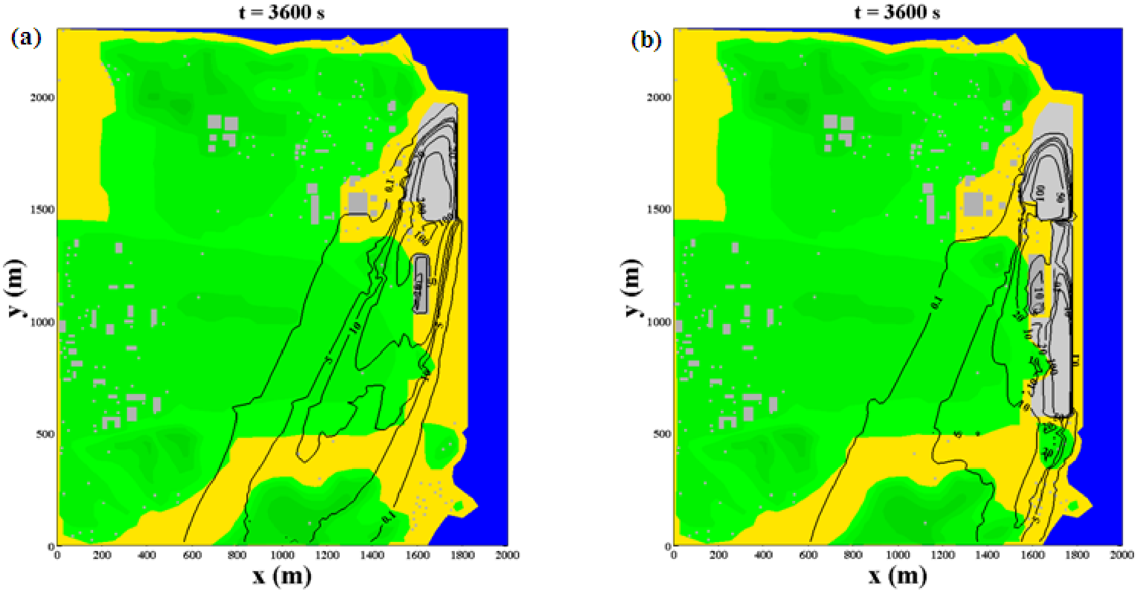

Fig. 5. The concentration fields of PM10 in the (a) F1010_q243 and (b) F12WB_q243 cases for the northerly at t = 3600 s

5. SUMMARY AND CONCLUSION

The effects of meteorological and reclaiming conditions on reduction of suspended particles are investigated using a computational fluid dynamics model. A complicated flow pattern such as flow distortion, horse-shoe vortex, recirculation zone, and channelling flow appeared due to the topography and buildings. Specially, the flow characteristics around the reclamation area are affected by the reclaiming height, reclaiming area and windbreak. When the reclaiming condition is same, the amount of the suspended particles is maximized in the northerly case. In the F12WB case, the amount of the suspended particles is smallest due to the decrease in the friction velocity above the reclamation area by the windbreak.

Acknowledgement

This work was funded by the Korea Meteorological administration Research and Development Program under Grant CATER 2007-3307

References

Brown, M. J., R. E. Lawson Jr., D. S. DeCroix, and R. L. Lee, 2000. Mean flow and turbulence measurements around a 2-D array of buildings in a wind tunnel. *11th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA*, Long Beach, CA, U.S.A., 35-40.

Kim, J.-J., and J.-J. Baik, 2004. A numerical study of the effects of ambient wind direction on flow and dispersion in urban street canyons. *Atmospheric Environment*, 38, 3039-3048.

Kim, H.-G., 2005. Optimization of Fugitive Dust Control System for Meteorological Conditions. *Journal of Korean Society for Atmospheric Environment*, 21, 573-583.

Liu, C.-H., and M. C. Barth, 2002. Large-eddy simulation of flow and scalar transport in a modeled street canyon, *Journal of Applied Meteorology*, 43, 1410-1424.

Patankar, S. V., 1980. Numerical Heat Transfer and Fluid Flow, *McGraw-Hill, New York*, 126-131.

Pavagear, M., and M. Schatzmann, 1999. Wind tunnel measurements of concentration fluctuations in urban street canyon. *Atmospheric Environment*, 33, 3961-3971.

Yakhot, V., Orszag, S. A., Thangam, S., Gatski, T. B., Speziale, C. G., 1992. Development of turbulence models for shear flows by a double expansion technique, *Phys. Fluids A4*, 1510-1520