Impact of Open-cut Coal Mine Terrain Complexity on Atmospheric Dispersion

S. Nosek[a], *Z. Janour*[a], *L. Kukacka*[a,b], *K. Jurcakova*[a], *R. Kellnerova*[a,b], *E. Gulikova*[c],

[a] Institute of Thermomechanics, Academy of Sciences of the Czech Republic, Prague, Czech Republic, nosek@it.cas.cz
[b] Charles University in Prague, Faculty of Mathematics and Physics, The Department of Meteorology and Environment Protection, Prague, Czech Republic
[c] Ecoprogress, Most, Czech Republic

ABSTRACT: The open-cut coal mine situated in the north-west of Czech Republic represents a pit of huge dimensions (approx. 5km long, 4km wide and 115m deep). In order to predict air quality at surrounding villages and town Chomutov, with population of almost fifty thousand inhabitants, the wind-tunnel measurements of neutrally stratified flow and concentration fields were performed simultaneously over a model. The model including a necessary part of the coal mine and surrounding topography with respect to future mine expansion was designed at scale ratio 1:3300. The gaseous pollutant was simulated as a source point (representing mining machine) at the bottom of the mine. For one prevailing wind direction simultaneous measurements of velocity components and concentrations at specified planes above the model were performed by two-dimensional Laser Doppler Anemometry (LDA) and Fast-Response Flame Ionization Detector (FFID), respectively. The impact of the complex terrain on passive pollutant dispersion was observed and the assessment of the air quality at populated areas is discussed.

1 INTRODUCTION

To date, wind-tunnel modelling of dispersion and deposition of fugitive coal dust from open-cut coal mine doesn’t have such a rich history as modelling of gaseous pollutants in urban models. Essentially, there are two main objects concerning of modelling of coal dust dispersion in wind-tunnels: open mines and stock piles. The main goal of „open mines” studies was to understand the airflow patterns within the mine with respect to its shape and dimensions in order to improve air quality for mine workers. Due to big dimensions of coal mines excavations and thus small model scales the dispersion of particulate matter was not performed. Much work was done in this field by Russian scientists during the seventies and eighties (e.g. Nikitin & Bitkolov, 1975). In nineties it was followed by Peng (Peng & Lu, 1995) and Meroney (Meroney & Grainger, 1992) who simulated stably stratified flow over Australian open-cut coal mine by inverted floor.

The studies done on second object, stockpiles, involve wind-tunnel modelling of real coal powder dispersion because of bigger model scale possibilities (Xuan & Robins 1994; Lee &

Park 2000). The work of Xuan and Robins (1994) revealed important relations between complex terrain (storage area with many buildings) and particulate matter dispersion: turbulence enhanced by terrain complexity reduces threshold wind speeds and increases emission and mean deposition of coal dust.

In this study we present approach used only by Meroney (Meroney & Grainger, 1992) so far where the atmospheric dispersion of gaseous pollutant above the open-cut mine was simulated by helium/air tracer gas mixtures in the stratified flow. The combination of residual coal and oil shale, caused by mining processes, with moisture resulting in dangerous fumes and smokes was main justification of the study. We decided to model neutrally stratified flow instead and simulate the point source representing mining machine at the bottom of the mine for which we used ethane as a tracer gas. Because of better diffusivity and lower density of ethane contrary to coal dust, we assume that we also modelled the worst case of atmospheric dispersion from possible pollutants.

2 EYPERIMENTAL SET-UP

2.1 Wind tunnel

For experiment an open low-speed wind tunnel of Institute of Thermomechanics Academy of Sciences of the Czech Republic in Nový Knín was used. The tunnel is 1.5m wide and 1.5m high and consists of two main sections: 20m long section for development of appropriate boundary layer and 2m long test section where the measurements above the model are performed. For our case of small scale ratio (1:3300) the development section was kept empty, without any roughness elements and spires. Only 1.5m of special inclination smoothly connected to model relief was kept in development section. This special inclination reproduces topography of coal mine situated in front of the modelled area and was roughen by sand grains (size of the grains was smaller than 0.5mm) in order to achieve aerodynamically rough flow and appropriate characteristics of modelled atmospheric boundary layer.

2.2 Model

The modelled area was designed according to wind-tunnel dimensions and results from previous study (Nosek et al., 2013) on model scale 1:9000. A qualitative method based on laminar-turbulent analogy (Cermak, 1984) revealed the main flow field over the entire coal mine excavation and its importing surrounding topography. In Figure 1 is depicted the new model selection including a necessary part of the coal mine topography with respect to future coal mine expansion and surrounding populated areas (south part of town Chomutov, Droužkovice village). This selection resulted in total squared area of aprox. 5 x 5km and scale of 1:3300 according to win-tunnel dimensions.

The model was made of extruded polyurethane and manufactured by computer numerically controlled (CNC) machine with precision of 0.5mm. The special roughness of 0.5mm was applied by CNC machine for model surface as well as all necessary vegetatitions and urban areas were made manually for completeness (Fig. 2) in order to fullfill the aerodynamic roughness of moderatelly rough terrain. As a input data for CNC the geographic information system (GIS) was used.

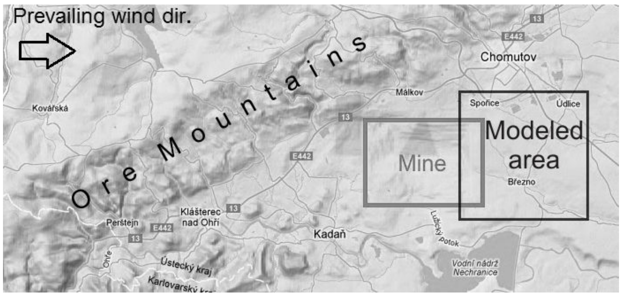

Figure 1: Selected modeled area (5 x 5km) with highlighted open-cut coal mine and characteristic orography of north-west part of Czech Republic. The prevailing wind direction is from west.

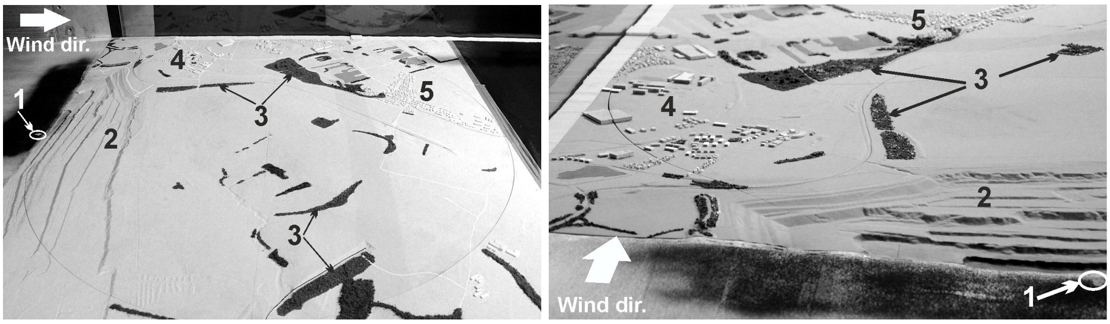

Figure 2: Left: entire model of scale ratio 1:3300 positioned at wind-tunnel including point source of pollutant (1) integrated at the bottom of special inclination smoothly connected to east end of coal mine (2), necessary vegetation (3), south part of town Chomutov (4) and village Droužkovice (5). Right: detail (taken from the wind direction) of the model and special inclination connetcted to model relief.

2.3 Measurement techniques

We used unique simultaneous point measurements of two velocity components and concentrations (see more in Kukačka et al. (2012)) by two-dimensional optical fibre Laser Doppler Anemometry (LDA) and Fast-response Flame Ionization Detector (FFID), respectively. Ethane was used as a tracer gas simulating passive pollutant for concentration measurements by FFID. The wind-tunnel free stream velocity was measured by Prandtl tube at fixed position in the centre of wind-tunnel 3m in front of the model and was used as a reference velocity (u_{ref}) for point measurements.

2.3 Boundary layer

As mentioned above in section 2.1 the boundary layer was simulated in 19.5m long development section without any roughness elements and vortex generators. Two–dimensional LDA measurements in vertical profile was performed above the centre of the special inclination 10cm in front of the model connection using a reference wind speed 5.2m/s. The vertical profile of dimensionless mean longitudinal velocity u/u_{ref}, turbulence profiles and turbulence spectra of u are compared with VDI profiles for moderately rough terrain (VDI, 2000) in Figure 3. Mean roughness length z_0 = 0.04m was obtained from the log fitting and power exponent α = 0.13 from power fitting. According to VDI (2000) for moderately rough terrain the z_0 should be from 5.10^{-3} to 10^{-1} m and α from 0.12 to 0.18. Thus, according to these parameters and Figure 3 we conclude that characteristic boundary layer for moderately rough type of terrain was modelled appropriately. Furthermore, the Reynolds number, averaging time and source strength independence was fulfilled as well.

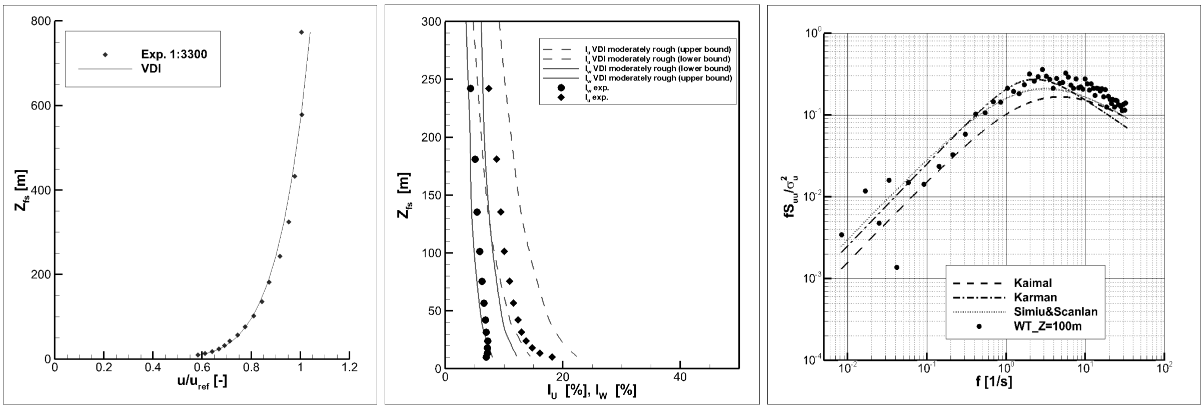

Figure 3: The vertical profile of dimensionless longitudal velocity u/u_{ref} (left), vertical profiles of turbulence intensities I_u, I_w (middle) and turbulence spectra of u at full scale height 100m above the terrrain (right) of modelled boundary layer.

3 RESULTS

There are displayed five measured vertical planes *yz* and one vertical plane *xz* on the model contour map in Figure 4 at dimensionless coordinates *x/h* and *y/h*, respectively, where *h* is a coal mine depth (*h* = 35mm, corresponding to 115m at full scale). The coordinate *x* is in parallel with wind direction and *z* is the height.

In following sections are presented only selected results from velocity (no figures) and concentration fileds (Fig. 6 and 7).

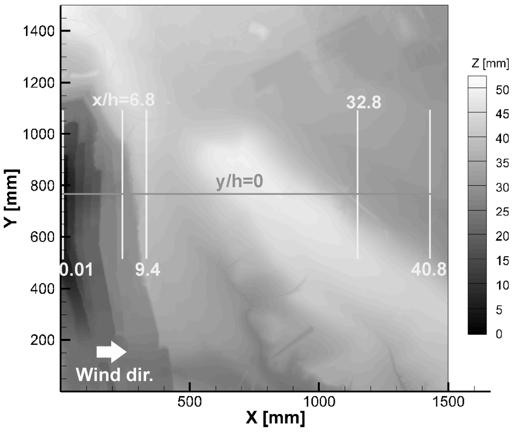

Figure 4: Measured vertical planes *yz* (vertical lines) and vertical plane *xz* (horizontal line). Note the elongated hill in the middle of the model (white contours).

2.1 Velocity field

Mean dimensionless longitudinal u/u_{ref} and vertical w/u_{ref} velocity field were measured at six vertical planes *yz* and one vertical plane *xz*. The impact of mine escarpments, hill in the middle of the model and surface roughness (vegetation and urban areas) on both mean velocity fields was observed. The speed up of dimensionless longitudinal velocity was evident at the edges of mine escarpments and top of the hill. Even the magnitude of dimensionless vertical velocity w/u_{ref} was rather low the ascending effects was found near by the mine escarpments (position *x/h* = 6.8 in Fig.4), upstream the slope of the hill and vegetation and urban areas (Fig. 2). The biggest descending effect occurs downstream the hill (position *x/h* 32.8 in Fig. 4).

Both longitudinal I_u and vertical I_w turbulence intensity higher than 20% correlated with topographic features of the model (e.g. mine escarpments) and with model surface roughness (vegetation, urban areas).

2.2 Concentration field

The dimensionless tracer gas concentration $C^* = (Cu_{ref}H^2)/Q$ (where C is measured volume concentration, H is a vertical difference between the lowest and highest point in the model and Q is source emission volume flow) at vertical planes *xz* and vertical plane *yz* is presented in Figure 6 and 7, respectively. Form this figures we can see that the highest values of C^* ($C^* > 4$) are kept within the coal mine excavation (*x/h* < 10, Fig. 6) and behind the hill (*x/h* > 30, Fig. 6, and *x/h* = 32.8, Fig. 7) the values of C^* are at least four times ($C^* < 1$) lower than those in mine. Figure 7 for vertical planes *x/h* = 32.8 and 40.8 demonstrates the shift of the plume centre from the contaminant source origin to the north direction (to populated area – Droužkovice village) by magnitude of *y/h* = 1. This can be explained mainly by effect of the flow around the hill.

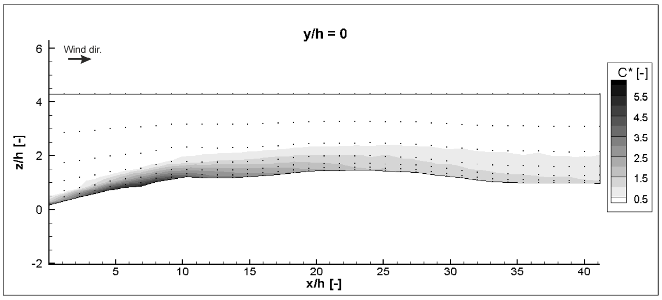

Figure 6: Mean dimensionless tracer gas concentrations C^* at vertical plane *xz*.

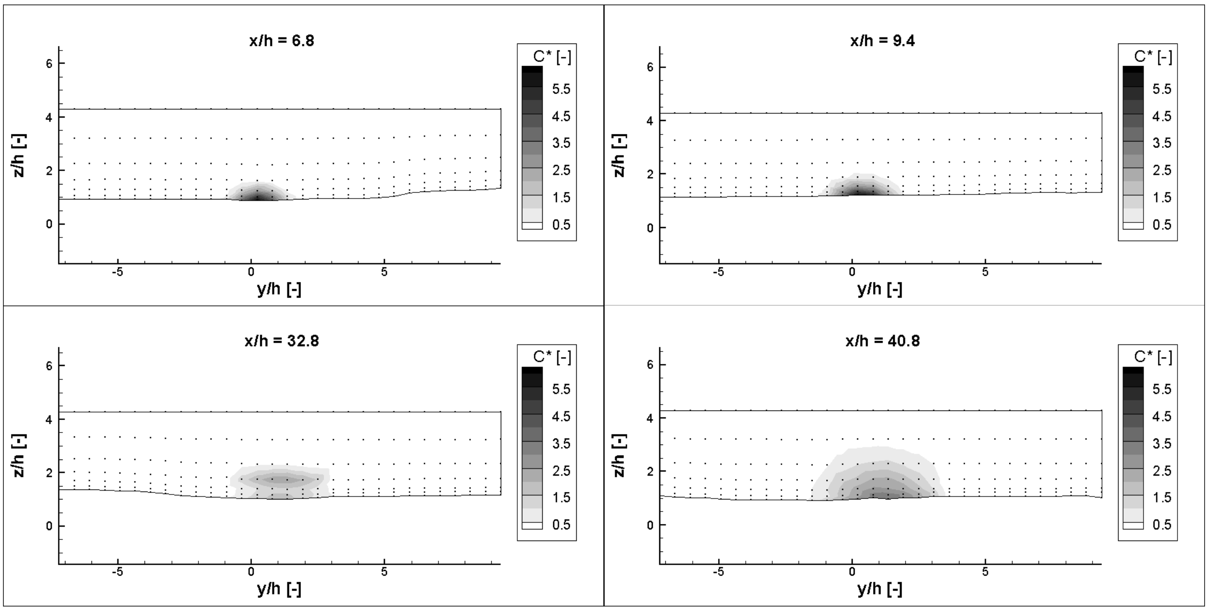

Figure 7: Mean dimensionless tracer gas concentrations C^* at vertical planes *yz* (upstream view).

4 CONCLUSION

The modelling of neutrally stratified flow over small scale model of complex terrain, including part of open-cut coal mine, was successfully performed. The simultaneous point measurements of two velocity components and concentrations revealed that the magnitude of lateral and vertical velocity components was not large enough to influence the passive pollutant dispersion. The plume direction gone along to simulated prevailing wind direction, thus the terrain complexity has little effect on pollutant dispersion. Shallow elongated mine excavation shape with moderate slopes, where the flow retention is weak comparing to deep closed mines, and moderate relief of surrounding topography could be main explanations. In future work the neutrally stratified flow over the model concerning of planned mine expansion (the excavation should reach the middle part of recent simulated area - hill) will be simulated as well as gaseous pollutant positioned at the bottom of newly emerged mine. Hence, the impact of excavation transformation on pollutant dispersion can be observed.

5 ACKNOWLEDGEMENT

The authors kindly thank for the financial support of the Technology Agency of the Czech Republic (project number: TA01020428). This work was carried out with institutional support RVO: 6138899.

6 REFERENCES

Cermak, J., 1984. Physical modelling of flow and dispersion over complex terrain. Boundary Layer Meteorology, 30, pp.261–292.

Kukačka, L. et al., 2012. Wind tunnel measurement of turbulent and advective scalar fluxes: a case study on intersection ventilation. TheScientificWorldJournal, 2012, p.13.

Lee, S. & Park, C., 2000. The shelter effect of porous wind fences on coal piles in POSCO open storage yard. Journal of Wind Engineering and Industrial Aerodynamics 84, pp.101–118.

Meroney, R.N. & Grainger, C., 1992. Nightime flow and dispersion over large basins or mining pits, in: Symposium on Measurement and Modeling of Environmental Flows, ASME Winter Annual Meeting, Anaheim, California.

Nosek, S. et al., 2013. Neutrally stratified flow modelling over complex terrain at meso-scale: open-cut coal mine study, EPJ Web of Conferences, 45, 01070 (2013).

Peng, X. & Lu, G.R., 1995. Physical modelling of natural wind and its guide in a large open pit mine. Journal of Wind Engineering and Industrial Aerodynamics, 54-55, pp.473–481.

VDI Verein Deutcher Ingenieure ed., 2000. Physical modelling of flow and dispersion processes in the atmospheric boundary layer - application of wind tunnels, VDI Verein Deutcher Ingenieure, Düsseldorf.

Xuan, J. & Robins, A., 1994. The effects of turbulence and complex terrain on dust emissions and depositions from coal stockpiles. Atmospheric Environment, 28(11), pp.1951–1960.