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Adaptation of the Czech regulatory dispersion model for odour dispersion calculation, its validation and critical evaluation

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After elimination of the most serious problems caused by the substances, deteriorating air quality in Czech Republic (except for suspended particles), odorants also came into focus of public and legislators. Similarly as in case of “classical” pollutants, besides the olfactometric measurements or surveys based on questionnaires, odour dispersion models application are also demanded, especially for the estimates of newly planned facilities impacts. The Czech dispersion model SYMOS’97 designated for calculations of dispersion of passive (non-reactive) buoyant, continuous release from single or multiple sources has been adapted for the assessment of dispersion of odorous substances. Because odour subjective perception by humans is proportional to the instantaneous peak concentration of the odorant rather than to mean values, the SYMOS model, which is set for the calculation of hourly mean concentrations, had to be modified in this way. Widely used peak-to-mean ratio (P/M ratio) approach has been selected as suitable. The main advantage of the proposed approach inheres in the fact that most input data management and calculation procedures included in the original SYMOS modelling system could be maintained.

On the other hand, such simplified approach might result in discrepancy of model results with the measured data, however uncertain the odour concentration measurements might be. Results of validation of modified model SYMOS, based on comparison with the experimental data, showed that despite of relative simplicity of adaptation procedure the model provides reasonable results applicable in the practice. A critical evaluation of the modified SYMOS model in comparison with the ADMS model showed that ground level peak odour concentrations are mostly underestimated by SYMOS approach, in comparison with the ADMS model results and the size of the domain where odour could be perceived is underestimated by SYMOS against the ADMS.

1. The SYMOS´97 dispersion model adaptation for odour modelling

The SYMOS’97 (Bubnik et al.) dispersion model is designated for calculations of dispersion of non-reactive buoyant, continuous release from single or multiple sources which may be point, area or line sources. Five stability classes according to Czech national stability classification scheme based on routine observations from synoptic meteorological stations are applied within the model. Therefrom three classes describe stable stratification, the residuary ones cover neutral and convective state of the atmosphere. The modelling system enables the calculation of annual mean pollutants concentrations, maximal possible hourly concentration and annual dust fall-out. Pollutant removal from the atmosphere due to deposition or chemical transformation is involved through the decay term. Complex terrain corrections based on digital terrain model are included as a routine part of model calculations. The model is not applicable for the calm and light wind conditions.

It is well known that the odour subjective perception by humans is proportional to the instantaneous peak concentration of the odorant rather then to mean values averaged over longer periods. Because the SYMOS model, similarly as other dispersion models of this class, is tailored for calculation of hourly mean concentrations, the basic procedure how to modify the SYMOS for odour concentration consisted in recalculation of hourly means reached in particular hours into corresponding peak values which might occur during these hours. Widely used peak-to-mean ratio (P/M ratio) approach has been selected as suitable solution of this task, as described by Keder et al. (2006).

The utilized approach enabled that most input data management and calculation procedures included in the primary SYMOS modelling system could be maintained. The substantial difference of the model adapted for odorous substances is that, because owing to complicated and specific nature of odour perception it is not possible to simply sum the concentration contributions from different sources, modelling of odorant concentration field originated from only one source is recommended. The procedure is as follows: fields of maximum possible hourly concentrations are calculated from the input data on source parameters and meteorology. The corresponding stability category is recorded for each grid value. The output concentration field is subsequently recalculated into peak values using the set of peak-to-mean ratio coefficients. The coefficients value depends on the source type, stability class and on the distance of the reference point to the source. The set of P/M ratios, derived by Katestone Scientific (Freeman and Cudmore, 2002), has been selected and incorporated into model.

2. The data set used for adapted model validation

Bächlin et al. (2002) published a comprehensive report on the field experiment in the surrounding of the pig farm in Germany. The site was located in the flat terrain and all experiments were performed during time with neutral stratification. A unique collection of data resulted from this perfectly executed experiment. It consists of 14 data subsets corresponding to measurements series marked from B till O. For each 10 minutes-long series a complete data on source parameters, meteorology and concentration data of odour and passive tracer are available. The concentration data were collected at the traverses in the lee of the source. Besides the concentration measurement, subjective odour intensity assessment in 6 point scale has been conducted by the panel of 12 trained persons, allocated at the testing point along the traverses. During the 10 minutes-long series the panellist recorded their estimate of odour intensity each 10 second. Thus, 60 values of the odour intensity estimates were gathered for each testing point and each series. Maximum estimated odour intensity value has been found for each testing point and used in subsequent analysis.

Using source and meteorology input data reported for each series, the hourly mean odour concentrations were calculated by the SYMOS model at each testing point and transformed into corresponding peak values. The paired measured and model data for series B,C and E till O were analysed and compared.

3. Results of comparison with the experimental data

Comparison of odour concentration calculated by the adapted SYMOS model and odour intensity levels reported by panellists is shown at Fig. 1. Areas of high peak concentrations correspond with the higher odour intensity level assessed subjectively. According to panellist' assessment, the odour plume is wider then estimated by model.

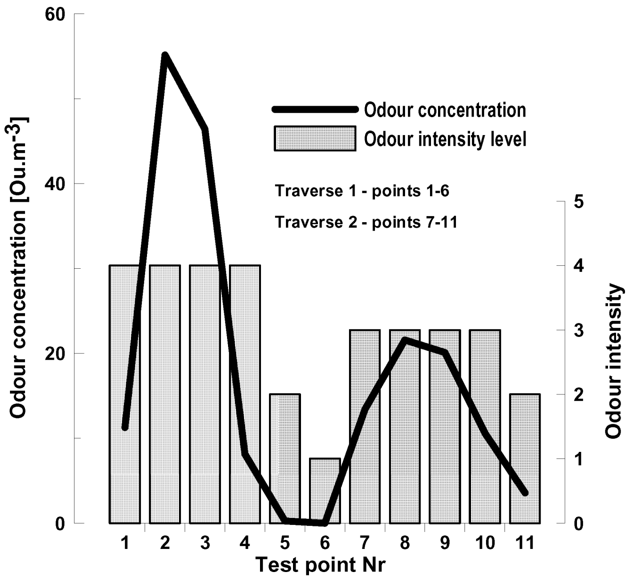

Fig. 1: Comparison of modelled odour concentrations and estimated odour intensity for series G

With the aim to enable comparison of modelled and estimated odour intensities, function relationship among modelled peak concentrations and maximum odour intensity values reported by panellists at testing points has been found. The corresponding data pairs for all above mentioned series were grouped into 6 classes according to intensity level value. Medians of modelled odour concentrations were estimated for each class marked 0 till 5. The data fit curve

$$I_{od} = 1.068 C_{od}^{0.4641} \tag{1}$$

where I_{od} reads for odour intensity and C_{od} means modelled odour concentration, follows the widely used Stevens law equation.

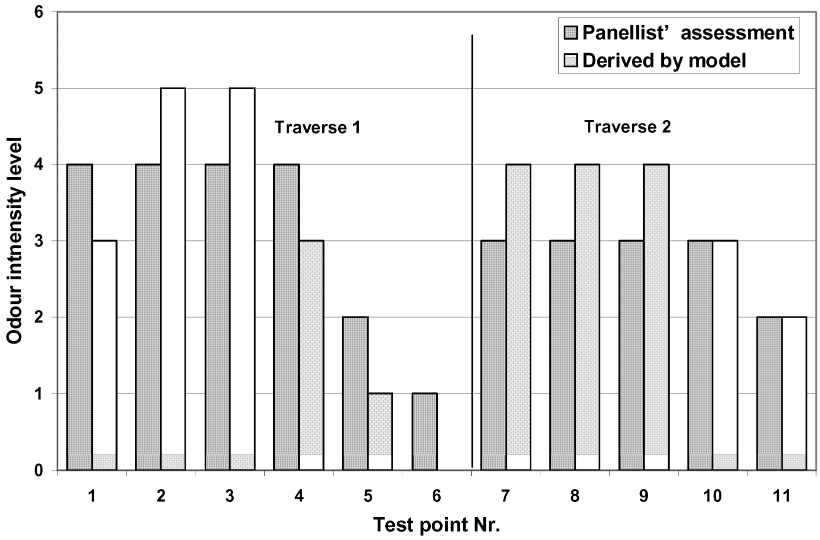

Fig. 2: Comparison of observed and modelled odour intensity level for series G

The peak odour concentrations were transformed into odour intensity levels by means of equation (1) and compared with those estimated by panellists in the field. Fig.2 shows odour concentration intensities, estimated by panellists at test points during the series G, compared with intensities derived from model calculation. A satisfactory agreement of model and experimental data are apparent from the picture. The model slightly overestimates intensity classes near the plume centreline.

4. Results of comparison with more sophisticated model

A critical evaluation of the modified SYMOS model in comparison with the ADMS model version 3.3 (CERC, 2004) has been provided. This is the Gaussian model with concentration fluctuation module included. The model computes concentration standard deviations, probability density functions and percentiles. These features enable an advanced modelling, among others modelling of transport and dispersion of odorous substances.

The basic features of comparison procedure were as follows. Model calculations were provided for a flat terrain, agricultural area with surface roughness 0.3 m, in middle latitudes. The modelling domain extent was 1500 x 1000 m. Dispersion from elevated point and ground-based area source was modelled under stable, neutral and convective conditions. Westerly wind of velocity 2 m/s for stable and convective, 5 m/s for neutral stratification was assumed. The mixing height of 900m for convective, 800m for neutral and 100m for stable conditions was supposed in calculations. The source emission rate amounted 25 000 OUe/s.

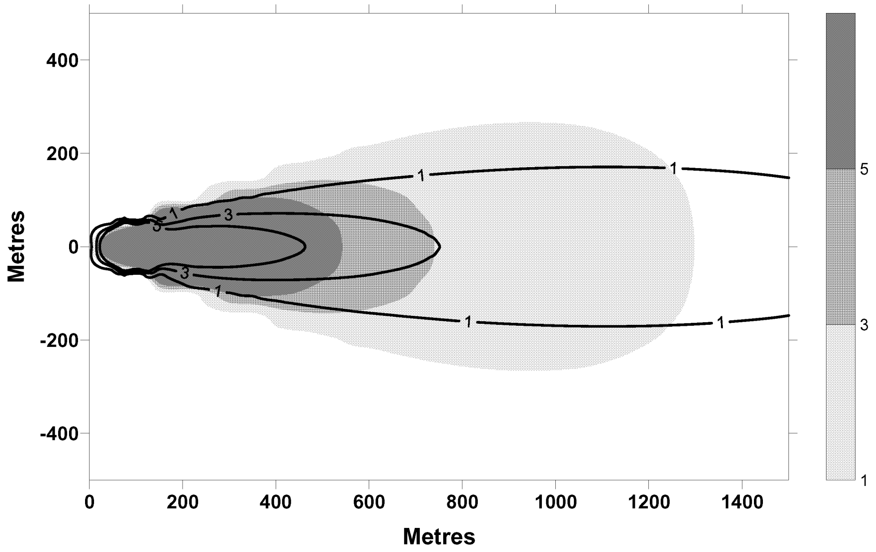

Fig. 3: Comparison of ADMS (grey scale) and SYMOS (isolines) maximum ground level concentration fields for point source, stable conditions

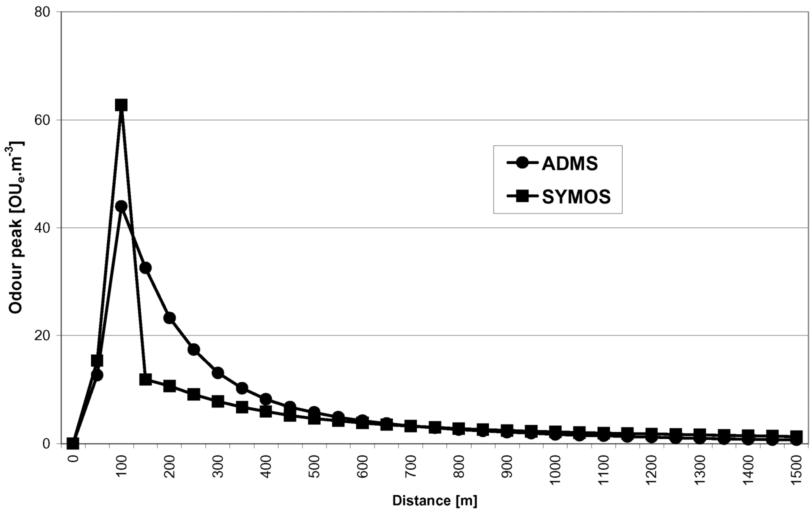

Fig. 4: Comparison of ADMS and SYMOS maximum ground level concentration under plume axis for point source, stable conditions

The following model output data were compared:

- Maximum peak odour concentrations recalculated from hourly means by P/M ratio coefficients (SYMOS approach)

- Percentile 99% taken as maximum peak concentration estimate provided by ADMS
- Odour concentration 2D fields and ground concentrations profiles under plume axis calculated by both models

Figures 3 and 4 show examples of results of comparison of maximum ground level concentrations of odorants calculated by the ADMS and adopted SYMOS model. Similar comparisons were provided for other combinations of input parameters listed above. It became obvious that namely for area sources noticeable differences among both models results exist and that the area size where odour could be perceived is underestimated by SYMOS approach against ADMS.

5. Conclusions and scope for future work

Results of validation of modified model SYMOS based on comparison with the experimental data showed that despite of relative simplicity of adaptation procedure the model provides reasonable results applicable in the practice. However, in comparison with ADMS model which has been considered as more advanced one, SYMOS model seems to underestimate the area size where odour could be perceived, especially for ground area sources. Moreover, ground level peak odour concentrations were mostly underestimated by SYMOS approach, in comparison with the ADMS model results. An odour concentration profile resulted from SYMOS calculations shows an abrupt discontinuity in comparison with smooth course of ADMS profile. An appropriate change of peak-to-mean ratios set used in SYMOS calculation might be a possible remedy of these faults. There is still an acute need for experimental data sets appropriate for testing and validation of odour dispersion models.

6. References

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