ATMOSPHERIC DISPERSION MODELING WITHIN WATER VAPOUR PLUMES OF COOLING TOWERS

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INTRODUCTION

In the last years, the release of emissions of power plants by use of the cooling towers has become a kind of a state-of-the-art technique. The advantages are a remarkable "stack" height and the chance to use the powerful flow dynamics within the tower, which persists considerable time after the release in the water vapour plume.

Those plume dynamic effects have been examined with wind tunnels long ago (e.g. Schatzmann et al, 1986, Lohmeyer and Nester, 1987), but have not been incorporated into routinely applicable dispersion modelling, which most of all was due to a lack of computer power and the necessity to program a complex software scheme.

The authors have developed a method to incorporate the water vapour plume dynamics of cooling towers into 3dimensional wind fields with the aim to considerate those dynamics within dispersion modelling. This contribution shows first results for a single meteorological case, the expansion on a whole year cycle simulation with hourly changing meteorological input data (8.760 situations) is currently work in progress.

PHENOMENON

The plume of a cooling tower consists of two counter-rotating vortexes with an updraft region in the centre and downdrafts on both sides (Fig. 1 left). In reality, the plume will develop in many different ways, according to wind speed, change of wind direction with height and turbulence structure in the lower atmosphere. Additionally, with the thermal energy provided by the heat content of the saturated air, the whole plume will rise by its own while being shifted downwind (Fig. 1 right).

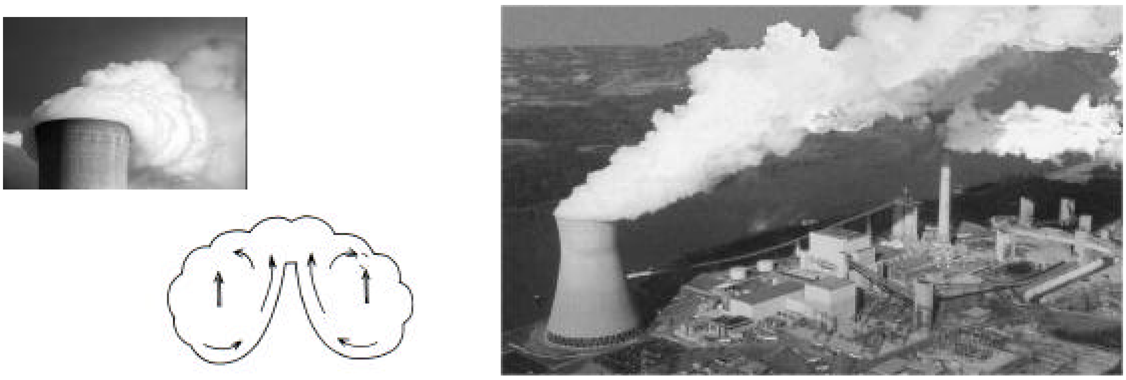


Fig. 1: Cross-section of plume and plume-dynamics perpendicular to the flow direction (left), picture of a typical plume shape (right).

Air pollutants mixed in the plume are incorporated in this flow, hence it can be expected that, compared to a simulation without plume dynamics, the near-surface-concentration in certain distances to the plant are decreasing beneath the centre of the plume and are intensified at the lateral areas.

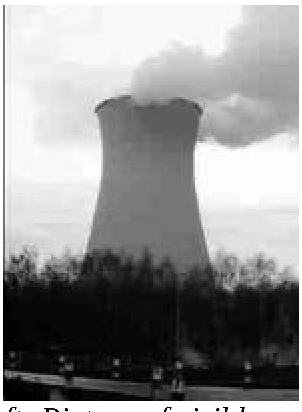
PRE-CONDITION: SIMULATION WITH COOLING TOWERS AS AN OBSTACLE

Until a few years ago, cooling tower effects on dispersion could only be quantified by wind tunnel studies. Usually, a certain number of flow cases were selected and applied on a model of a power plant. Tracer gas was released at the source (stack or cooling tower), and concentrations were measured downwind. By comparison of measurements with and without the cooling tower as an obstacle within the wind tunnel, intensification factors for concentration could be derived. Those intensification factors then were applied on results of dispersion models.

In 2002, German legislation introduced a lagrangian particle model as standard procedure in dispersion modelling (TA Luft, 2002). This model has the ability to activate a module which calculates the influence of obstacles on flow and turbulence. In 2005/2006, a group of power suppliers in Germany financed a study, where a vast number of wind tunnel studies were compared to model results using the standard model mentioned above (Bahmann and Schmonsees, 2006).

As a result, the authors of the study concluded that the model results and the wind tunnel measurements were in good agreement. By following some model-operation technical advices, the use of the standard dispersion model is recommended as a replacement for wind tunnel studies. Nevertheless, this study only considered obstacle-related effects. Plume dynamics were not included.

Fig 2 shows an interesting and method-convincing modelling detail out of calculations similar to those performed in the study mentioned above. On the left, a picture of plume vortexes with visible downwash areas at the edges of the cooling tower is displayed, whereas on the right, a model result of concentrations on a level *5 m beneath the top rim* of the cooling tower is shown.



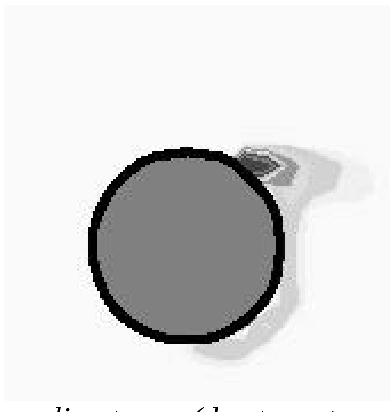


Fig. 2: Left: Picture of visible vortexes downwind of a cooling tower (due to water vapour) Please note the downdrafts at the outer edges of the cooling tower.
Right: Results of model calculation with explicitly considering the cooling tower as an obstacle: Concentration 5 m beneath the top rim of the cooling tower.

DESCRIPTION OF PLUME DYNAMICS: COUNTER-ROTATING VORTEX

Due to observations, measurements and theoretical approaches, Janicke 1992 published a simplified mathematical description of plume dynamics. The plume is described as a

combination of two counter-rotating vortexes. Essential parameters are wind speed at top level of the cooling tower, the diameter at the top, the distance between the centres of the vortexes and the height of the vortex axis above ground level. The two latter are functions of the downwind distance. The approach needs some constant values, which have been derived by the use of wind tunnel measurements (for details see Janicke 1992).
Fig.2 shows a 3D-view of the resulting flow structure with special focus on the vertical wind.

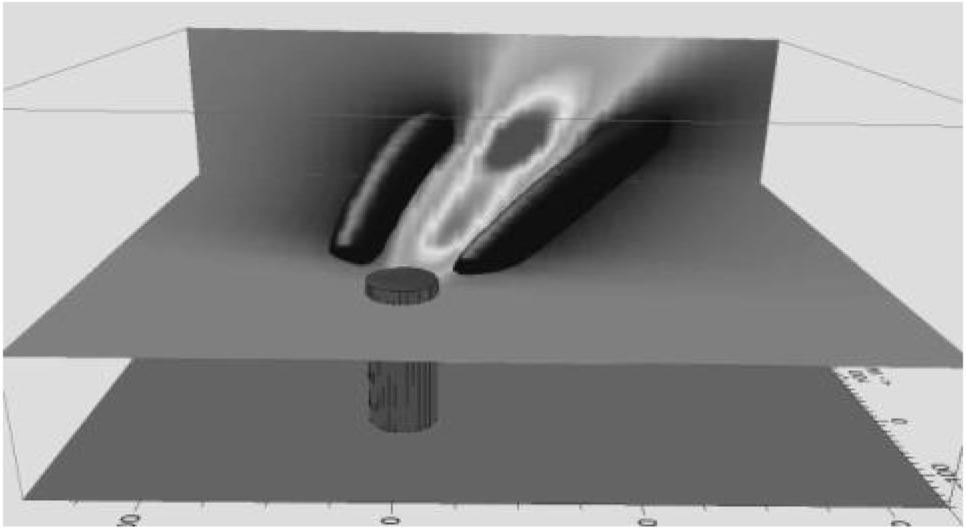


Fig. 3: Downwind view of the flow structure of water-vapour plume of a cooling tower. Dark "tubes": Downdraft areas. Horizontal and vertical cross-sections show the updraft at the centre of the plume. Result of wind field modelling with added counter-rotating vortexes.

IMPLEMENTATION INTO DISPERSION MODELLING

To incorporate the plume dynamics into dispersion modelling, 3 steps have to be performed:

1) Simulation of 3D wind field(s) with a flow model. Buildings and especially the cooling tower should be explicitly considered as obstacles.
2) Calculation of the 3D wind field(s) of the plume as counter-rotating vortexes using geometrical (height, diameter of cooling tower) and meteorological (wind speed, direction) input data.
3) Superposition of wind field(s) from step 1) and 2). If necessary, scaling of wind-field 1) to current wind speed in advance. Mass-consistency should be assured for the resulting field.

After that, dispersion modelling can be performed using field 3) instead of field 1).

This procedure still neglects atmospheric stability. Since cooling tower plume dynamics mainly become important to surface concentrations in situations of higher wind speed, this simplification might be acceptable.

It also doesn't calculate interactions between surrounding flow and vortex on base of a physical equation system. A kind of interaction is incorporated when calculating mass consistency of the added wind fields.

RESULTS OF A CASE STUDY

The case study was calculated for a strong wind event (wind speed 12 m/s in 10 m above ground, which means 23 m/s at the top rim of the cooling tower). The cooling tower was 62 m in diameter (top rim) and reached 136 m above ground level.

The initial wind field (step 1)) was calculated with the diagnostic flow model “lprwnd”, which is implemented in the model system LASAT. This model fulfils the demands of the standard dispersion model according to German legislation (TA Luft, 2002). One of the main features of this standard procedure is a significant clockwise wind rotation with height (Ekman Layer). Wind from west in 10 m is thus coupled with wind from WNW directions above the top rim of the cooling tower.

The counter-rotating vortexes were calculated using the approach of Janicke 1992. Since this is an analytical solution, wind components upwind and besides the cooling tower were generally set to zero. The height of the vortex axes as function of the downwind distance was determined with a special programme module “VDISP”, which goes back to the work of Schatzmann et al 1986.

Due to circumstances which are not part of this contribution, a set of buildings with decreasing height was installed downwind straight next to the cooling tower.

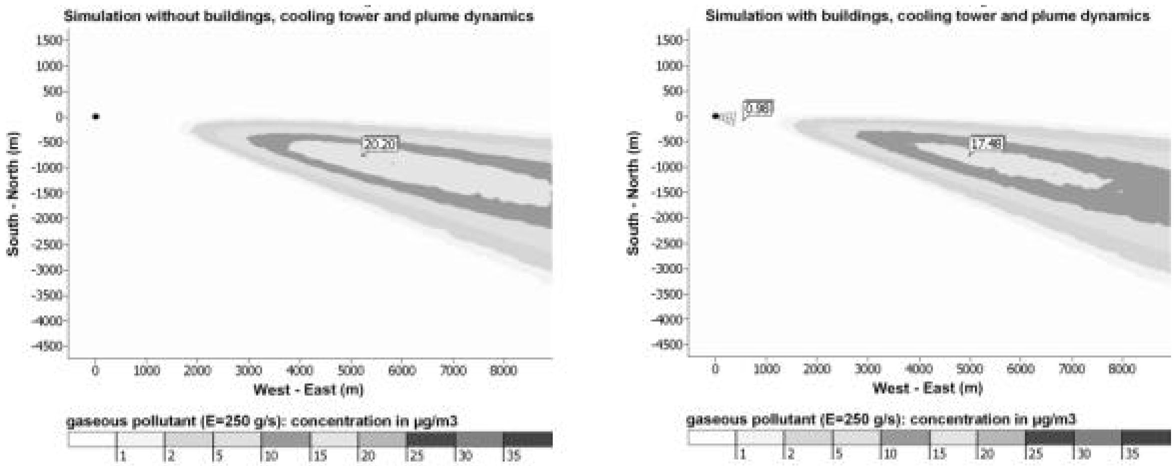


Fig. 4: Surface concentration field of simulation without any buildings and without plume dynamics (left) and with explicit consideration of both effects in wind field and dispersion calculation (right).

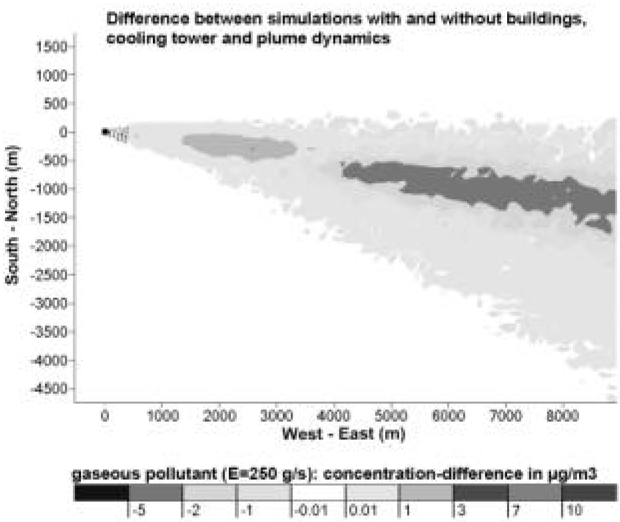


Fig. 5: Difference in surface concentration between simulation with buildings, cooling tower and plume dynamics and a calculation without those effects. Explanation see text.

In Fig. 4, results for surface concentrations of a gaseous pollutant (release with 250 g/s) are shown. The left picture shows surface concentrations calculated without any buildings and without plume dynamics, the right picture provides concentrations calculated by considering building-effects and plume dynamics within the wind field-calculation.

Most descriptive is the difference between those two concentration fields (Fig 5). Due to downwash effects of both, cooling tower and buildings, a significant rise of surface concentrations is calculated downwind in an area proximate to source and obstacles.
In further distances, a decrease of concentration in the centre of the surface plume is calculated, which is an effect of plume dynamics (see Fig. 3). Correspondingly, at the lateral boundaries of the surface plume, a slight increase of concentration occurs. The asymmetric shape of this latter phenomenon is caused by the wind-rotation with height.

CONCLUSIONS AND FUTURE PROSPECTS

The incorporation of water vapour plume dynamics into dispersion modelling is possible and leads to realistic results. The calculated effects are consistent with structures which can be expected out of a physically inspired view. Nevertheless, no measured data set is available yet to validate those results.
Neglecting the plume dynamics leads to an overestimation of the maximum surface concentrations, which puts the operator on a "safe side" when it comes to licensing procedure. But for a more realistic modelling, we recommend a consideration of those dynamics into dispersion modelling whenever wind speed exceeds a value of approximately two times the release speed of the plume.
At the present time, the plume dynamics and the counter-rotating vortexes are incorporated into a dispersion calculation for a whole year cycle.

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