An enhanced nozzle alignment to cause spray overlapping in FGD plants

M. Feldkamp* R. Kaesemann* J. Neumann* H. Fahlenkamp*
m.feldkamp@ct.uni-dortmund.de
**University of Dortmund*
Chemical Engineering Department
Chair of Environmental Technology
Emil-Figge-Str. 70
D - 44221 Dortmund
Phone ++49 (0) 231 755 3418
Fax ++49 (0) 231 755 6194
http://utwww.chemietechnik.uni-dortmund.de/

1 Introduction

In power plant technology modern gas scrubbers are used in the flue-gas desulphurization of coal-fired plants to absorb sulfur dioxide in aqueous solution. For this several nozzles sputter the washing liquid. Potential of optimization is given by in the fluid dynamics. By a purposeful arrangement of nozzles in several spraying levels it is possible, that the sprays of the nozzles penetrate themselves mutually. The effect of the secondary dispersion, which appears with intersection and penetration of sprays during atomization in the flue-gas scrubber, can be effectively used for the improvement of atomization efficiency and mass exchange at absorption of the noxious gases in a flue-gas desulphurization plant (FGD). The drop collision can be used as an effective mechanism for the enlargement of the specific surface of the dispersed phase, i.e. the wash suspension drops.
So far secondary dispersion was neglected in the modeling of flue-gas scrubbers and could not be used in practice purposefully [1], [2]. A starting point offers the three-dimensional simulation of the spray-overlap in a wet scrubber with the help of suitable CFD simulations (Computational fluid Dynamics) and purposeful consideration of the drop collision [3], [4], [5].

Figure 1: View into the FGD-scrubber

With help of the simulations described here, two nozzle locations in a FGD-scrubber, which are shown in fig. 1, should be examined. For the simulation of the two-phase flow of gas and liquid drops in the regarded FGD-scrubber a simulation algorithm, developed at the chair of environmental technology at the University of Dortmund called sIMPACT©, is used. The simulation algorithm is able to compute single nozzles or nozzle cluster with or without view on drop collision in three dimensions.

2 Structure of the simulation algorithm

In previous work concerning the numeric simulation of two-phase flows [6], [7] the fundamental preservation equations could be solved and phase change effects could be considered. There numerous simplifications were made and additional effects such as drop-collision, drop-wall-interaction, drop-oscillation and aerodynamic collapse were always neglected. GRUß [7] regarded the flow as more or less two-dimensional, for example. This does not correspond to real conditions in flue-gas scrubbers, in which a pronounced three-dimensional flow profile is present.

Models for consideration of drop-collisions are implemented into commercial CFD products either not, or only for certain special cases. In particular models are used, which exclusively consider the coalescence (combination) colliding drops, but regard the drop-collapse and thus the secondary dispersion. In older work in the area of the CFD simulation of flue-gas scrubbers [8], [9] this important effect remains likewise unconsidered.

Work concerning drop-collision was also accomplished in the field of the meteorology to clarify the spectrum of rain drops [10]. The models developed thereby cannot generally be transferred to technical applications, since special boundary conditions were presupposed.

For flue-gas scrubbers the cooperation of nozzles and the associated change in [11], [12] the drop spectra was only partly scientifically examined so far [13], [14], [15]. Experimental work in this area exists only partly [16].

The simulation algorithm [17], developed at the chair of environmental technology at the University of Dortmund, uses a statistic model due to the high number of drops in the scrubber. This model accomplishes a statistic averaging per control volume of the dispersed phase, instead of regarding individual collisions purposefully. Thereby the two-phase flow is computed in the EULER-LAGRANGE-method. The EULER-valuation of the continuous phase is based on the continuity equation, the NAVIER-STOKES-equation and turbulent transport equations. Additionally the gas-flow is regarded as incompressible and isothermal.

The dispersed phase is described in the LAGRANGE-method to be able to describe the reaction on the continuous phase and the interactions between the drops as accurately as possible. The model of the dispersed phase works with a MONTE-CARLO-simulation. Here, a drop is simulated representatively of a physical drop quantity. Particle pursuit takes place simultaneously, i.e. all drops and the gaseous phase are moved at the same time.

Collision detection takes place with a modified collision model according to DOHMANN [16]. It works with a stochastic formulation of the collision detection and for this reason it is better suitable for the high drop numbers in the simulation of wet scrubbers than models, which regard individual collisions.

The simulation algorithm works with simplified geometries, i.e. no installations or detailed scrubbers are modeled. The shape of the simulation areas is limited to simple geometrical forms such as rectangular parallelepipeds or cylinders. The simulation areas are divided into an orthogonal equidistant mesh. This mesh is doubly put on, once for the continuous phase (gaseous phase) and once for the dispersed phase (liquid drops). The turbulence modeling in the simulator routine is made by a k-ε-model.

3 Simulation

The simulated FGD-scrubber is a rectangular shaped scrubber, which is equipped with 270 helix full cone nozzles on five planes (fig. 2, left). Each level again consists of six nozzle lances with eight nozzles on each lance. Particularly at the simulated scrubber is the location of the nozzles and lances. Both the lances in the individual planes and the nozzles on each lance are vertically directly arranged one above the other (fig. 2, right).

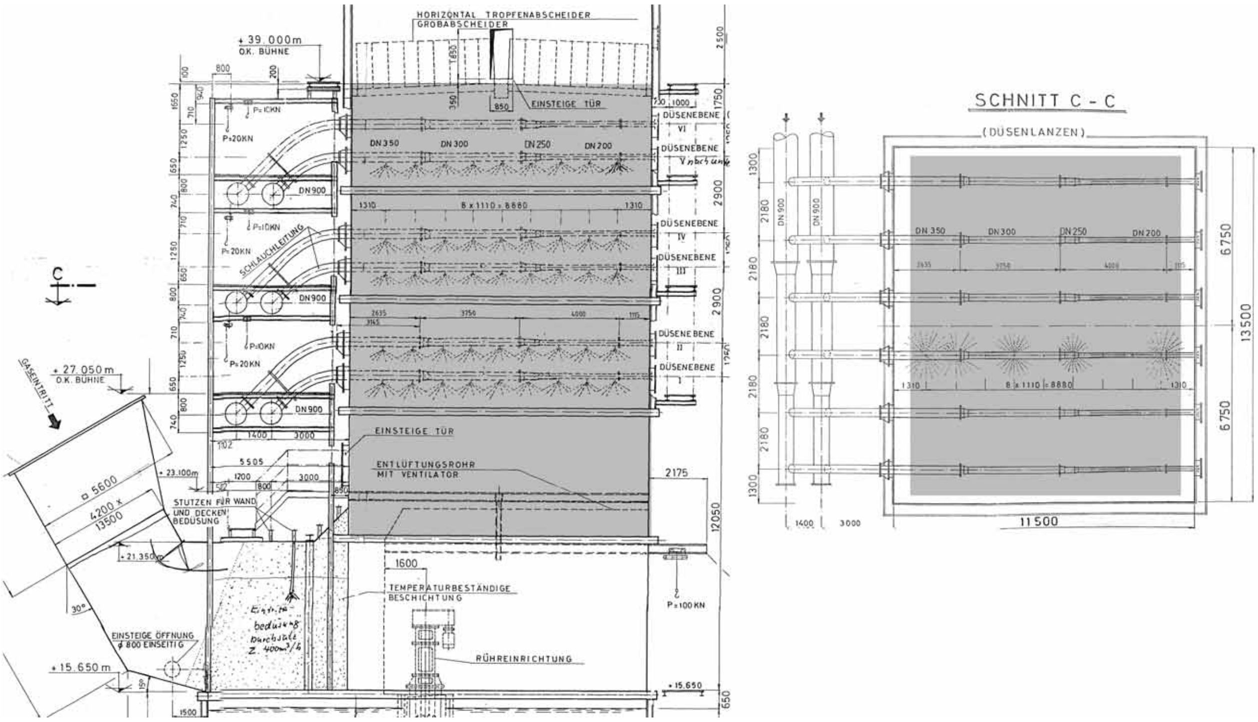

Figure 2: scrubber with the simulated area (gray)

Because of that the scrubber can be divided into 4.5 × 3 identical rectangular simulation areas with the dimensions (w × h × d) of 2.22 m × 4.36 m × 8.3 m. Thus a surface area of 9.68 m^2 and a volume of 152.93 m^3 per simulation area result. The simulation areas are divided in approx. 122000 cells and contain 20 helix full cone nozzles on five planes in each case. All nozzles have a spray angle of 120° and a flow rate of 1151 l/min.

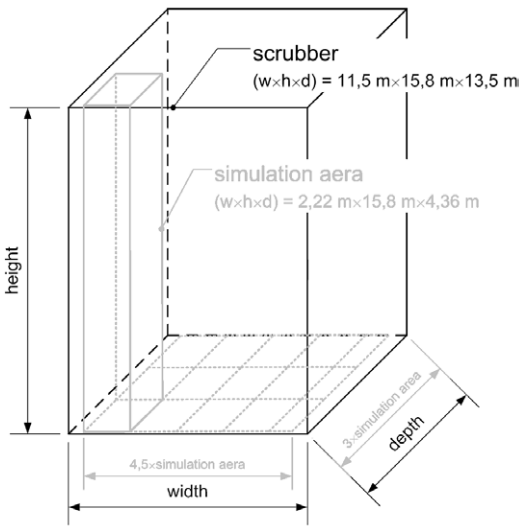

Figure 3: division in simulation areas

In the following comparatively two cases should be regarded:

1. simulation A (actual state)
2. simulation B (turned nozzle levels)

The difference in the simulations A and B is in the location and the spray direction of the nozzles, shown in fig. 4. Simulation B results from simulation A by the turning the nozzles of the levels 1+2 and 3+4 towards each other, whereby the distance of the nozzles is reduced to approx. 1/5.

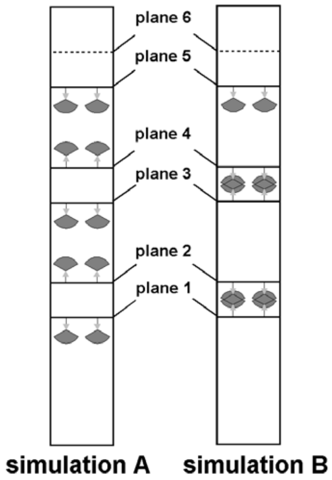

Figure 4: location of nozzles in the simulations A and B

The size of the simulation area and all scrubber-specific inputs remain unchanged in both cases, only the location and the spraying direction of the nozzles are changed.

4 Results

The drop diameter in the scrubber is to be discussed first. The presented drop diameter is not the real diameter of each drop in the specific simulation cell, but the mean diameter of all drops in the specific simulation cell. Thus it applies:

$$\bar{d}_T = \frac{1}{n}\sum_{i=1}^{n} d_{T_i} \tag{1}$$

One reports on the drop diameter in the following, the middle drop diameter per cell is actually meant, computed according to formula (1). Fig. 5 shows the mean drop diameter in simulation A and B on vertical cut along the scrubber axis. Comparing simulation A and B, it appears, that by turning the nozzles in simulation B, the locations of the collision areas are shifted. Now they are between the planes 1 + 2 and 3 + 4 (see fig. 4). At the same time the drop diameter in simulation B and the number of cells with high mean drop diameter (> 400 µm) decreases.

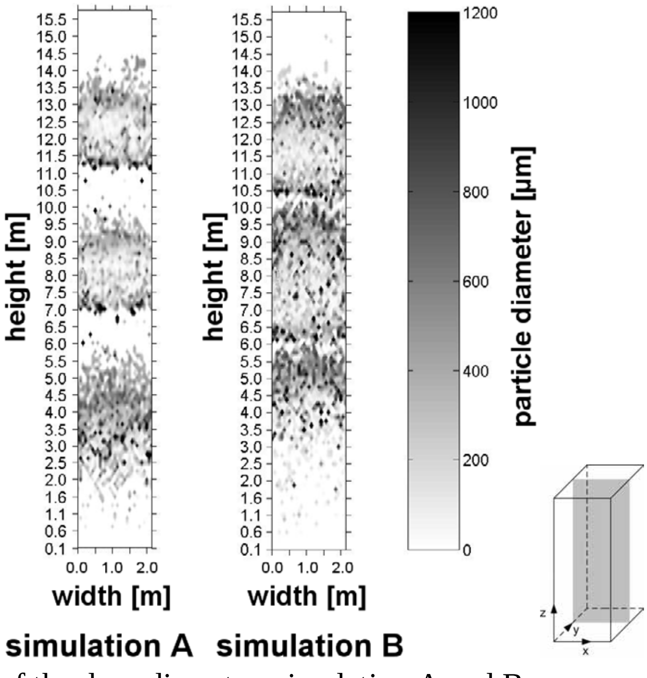

Figure 5: comparison of the drop diameter, simulation A and B

This clarifies also the number distribution of cells with the same drop diameter, presented in fig. 6. Here the shift towards smaller drop diameters in simulation B is clearly recognized, as it has been described with fig. 5, too.

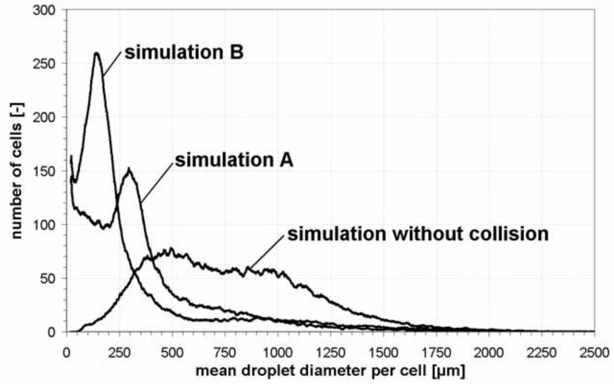

Figure 6: distribution of the drop diameter per cell, simulation A and B

To clarify the general influence of the drop collision, fig. 6 shows the distribution without view of collision additionally. This illustrates the drop spectrum, as the manufacturer at an individual nozzle measured it. The collision influence becomes also clear with view of the drop density in fig. 7. It is computed from the number of drops per volume.

$$\bar{\rho}_{T_i} = \frac{1}{V_i}\sum_{i=1}^{n} n_{T_i} \tag{2}$$

In simulation A the particle density is about 10^6 - 10^{12} drops/m^3. By turning the nozzles as in simulation B, peak values up to 10^{13} drops/m^3 are reached. At the same time fig. 7 shows for simulation B an smoother and more compact distribution of the drops than simulation A. However, the carryout of small drops by the gas-flow is not affected by the nozzle location of simulation B. In both simulations drops are hardly available above the plane 5 in fig. 7. An aspect that can be shown with more exact view to the drop surface (fig. 9).

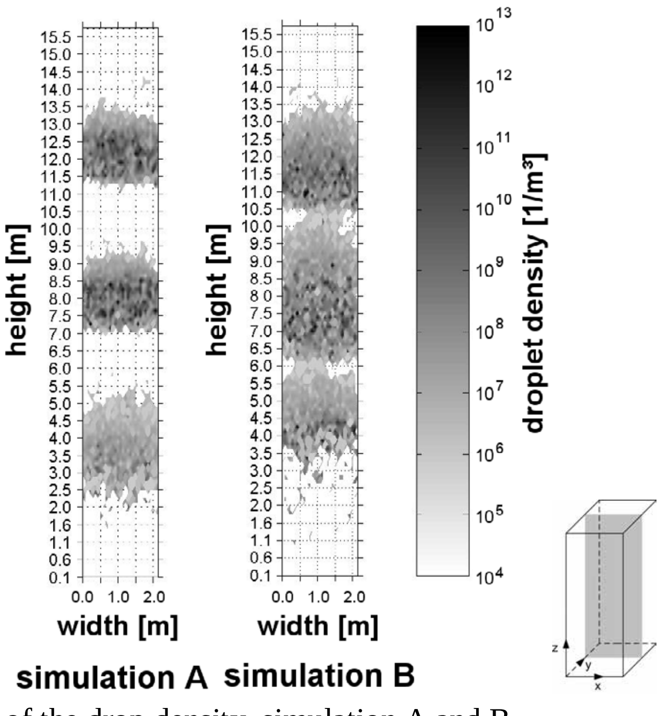

Figure 7: comparison of the drop density, simulation A and B

The SAUTER MEAN DIAMETER (SMD) represents an important dimension at the design of scrubbers in power plant technology.

Usually average drop diameters are defined by the following equation:

$$d_{mn} = \left[\frac{\sum_i n_i \cdot d_{p_i}^{\ m}}{\sum_i n_i \cdot d_{p_i}^{\ n}} \right]^{1/(m-n)} \qquad mit\ m = 1,2,3 \quad n = 0,1,2 \quad und \quad m > n \tag{3}$$

Thus the arithmetic diameter d_{10}, the surface diameter d_{20}, the volume diameter d_{30} and the SMD d_{32} result. In fig. 8 the progress of the SMD for the two regarded simulations A and B is presented over the time.

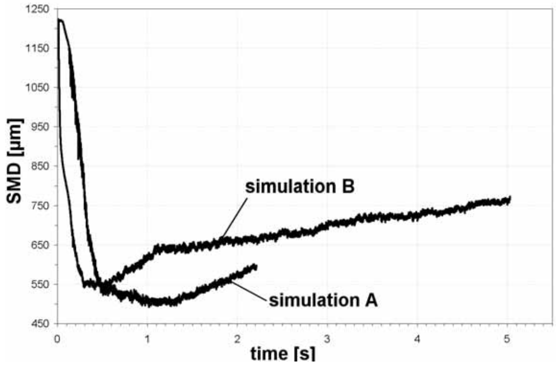

Figure 8: comparison of the SMD

As consequence of collision the SMD drops strongly in both simulations in comparison to a single nozzle (d_{32} = 1820 µm). That the SMD of simulation A in the regarded time interval is smaller than that of simulation B goes back to the definition of the SMD (formula 3). It considers large drops more strongly. The overall drop surface is likewise a relevant design parameter for industrial wet scrubbers (FGD-scrubbers), since over the overall drop surface can be concluded on the degree of separation of sulfur dioxide from the flue-gas. Similarly to the SMD the overall drop surface shows a dependence on location of the nozzles. For the simulation A with 3715 m^2 a smaller surface results. Turning the nozzles as in simulation B, then the overall drop surface with 4405 m^2 becomes larger again.

More interesting than the pure numerical value for the drop surface in the scrubber (fig. 9) is the distribution of the volume specific surface along the scrubber height. In simulation A (fig. 9, left) the surface is concentrated between plane 2 + 3 and 4 + 5 and below the first nozzle plane. Against it, between plane 1 + 2 and 3 + 4 is hardly surface is in the scrubber. Same applies above plane 5, which suggests on a low drop flow in direction mist eliminator. Generally it shows up that the drop surface is distributed quite inhomogeneous in the scrubber.

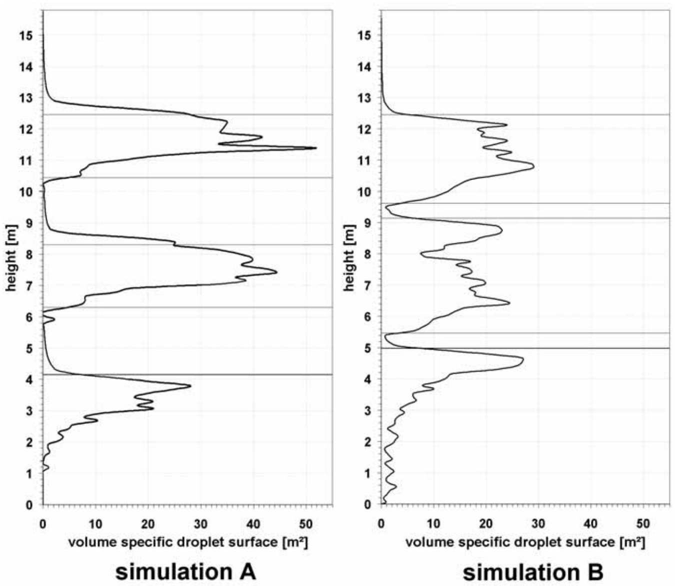

Figure 9: comparison of the volume specific drop surface, simulation A and B

In simulation B with turned nozzles the drop surface is more evenly distributed along the scrubber height. At the same time areas with low surface between plane 1 + 2 and plane 3 + 4 are reduced. Similarly to simulation A there is hardly surface above plane 5, i.e. the drop flow towards the separator remains constant.

5 Meaning of the results for practice

The accomplished simulations show that by an optimization of the nozzle location and the nozzle selection in a scrubber, the mass exchange surface can again be increased, like in comparison of simulation A and B.

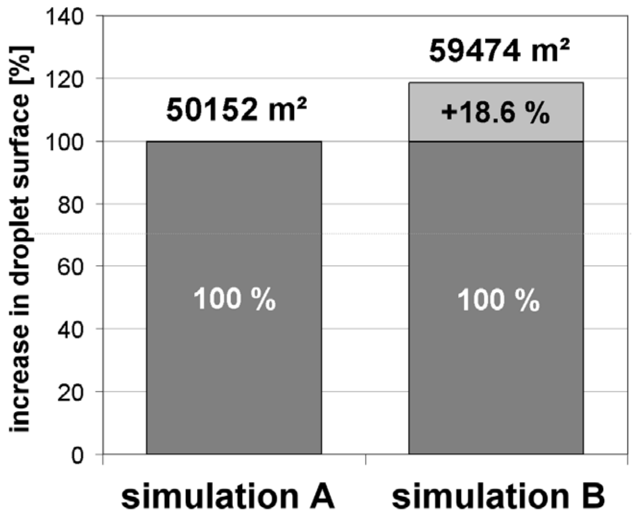

Figure 10: comparison of the overall drop surface

For simulation B the potential in drop surface increase is at 18,6 % surface increase in the comparison to simulation A, like in Abb. 10 presented. Whereby simulation B does not show the maximal possible optimization degree, but it represents only a simple and fictitious variation of the nozzle location.

A purposeful optimization of existing scrubbers and a consideration of drop collision effects during the design of scrubbers make it possible to reduce consumption at wash suspension and pump energy (self-power requirement) with a continuously high desulphurization degree. Alternatively it appears possible to increase the desulphurization degree with same pump energy expenditure.

6 Preview

The necessity for optimization can become necessary because of the employment of heat value-poor and/or sulfur-rich fuels as also by intensified legal guidelines, e.g. by the novella of the GROSSFEUERUNGSANLAGEN-VERORDNUNG (GFA-VO) (engl.: large fired plant guideline) (88/609/EWG) from 23.Oct.2001 (guideline 2001/80/EG) recently entered into force. It prescribes a limit value of 200 mg/Nm^3 SO_2 in the exhaust gas for new installations. This value applies likewise to the exhaust part of the coal in old facilities, which burn sulfur contenting spare fuels from the refuse economy as well. For the exhaust part of the waste 50 mg/Nm³ SO_2 are to be kept. The mixing limit value lies thereby between 150 and 185 mg/Nm³ SO_2. Simultaneously the power station operating company is forced to decrease operating costs due to the liberalization of the current market. Therefore in the future the optimization of the spray areas in flue-gas scrubbers move increasingly in the field of vision of the power plant operators.

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