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INFLUENCE OF AIR HUMIDITY ON THE SUPPRESSION OF FUGITIVE DUST BY USING A WATER-SPRAYING SYSTEM

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Abstract One of the main origins of fugitive dust emission arises from bulk handling in quarries or mines, in particular, from bulk materials falling from a hopper or a conveyor belt. Water-spraying systems, using two-phase nozzles, are one of the methods to suppress such dust emission. In this work we tried to develop a mathematical model to correlate air humidity, water flux through the nozzle and the dust (in particular PM10) emission, in order to improve the application and efficiency of these systems. Sand from the Yellow River in China was dropped from a conveyor belt into a dust chamber at 1 kg·min^{-1}, wherefrom the emitted dust was sucked off and quantified via a cascade impactor. A two-phase nozzle was installed in the dust chamber with a water flux through the nozzle of 1.2 to 3 L·h^{-1}, whereas the relative air humidity changed between 55 and 73%. Dust emission was found to be linearly dependent on relative air humidity. Furthermore model equations were developed to describe the dependence of PM10 emission on water flux and relative air humidity.

Keywords dust suppression, spraying system, air humidity, water flux, bulk solids, fugitive dust emission

1. Introduction

Investigations in the 1990's on sources of dust emission revealed an increase of emission from fugitive sources as compared to point sources (VDI 3790 Blatt 3, 1999). One of the main origins of fugitive dust emission arises from bulk handling in quarries or mines, in particular, from bulk materials falling from a hopper or a conveyor belt (Höflinger, n.d.). Reducing dust emission of falling bulk materials by using water has engendered much interest for scientific investigation, such as moistening the particles before dropping (Plinke et al., 1991 & 1995; Visser, 1991; Trenker & Höflinger, 2001) or using one-phase nozzles to produce a water spray that agglomerates the fine dust particles (Brabec, 1990).

A water spray consisting of a larger number of small droplets presents larger surface area than a water spray of equal liquid volume but with large droplets, thus capable of contacting and removing dust with greater efficiency (Gaunt, 2003). One often uses two-phase water-air nozzles to create such a spray of fine droplets, which require, however, low air pressure (1/10 that for one-phase nozzles) and low water consumption (generally less than 1 litre per hour per nozzle), and possess several further advantages:

- low pressure - lighter equipment and less energy
- low water flux - less moisture in the material
  - less costs for fresh and waste water
  - easier application in the laboratory
- variation of droplet size without changing the water flux
- small droplets for low water flux

Exposed to the environment, the performance and efficiency of dust removal by using water spraying is affected by temperature and relative humidity. But unfortunately no methods and no calculation equations are yet available for the optimal design of a spraying device for dust reduction. To develop such methods it is necessary to clarify the basic relationship between the dust reduction achieved and the design and operation parameters of the nozzle equipment, their appropriate position inside the enclosed dust area of the falling bulk solids and the volume of the air stream being sucked off. For a given nozzle with a fixed position in an enclosed dust area and a constant air stream, the influence of the water flux through the nozzle and the relative humidity should first be investigated and model equations to describe these relationships should be derived. For this purpose a laboratory bulk falling test apparatus was built for the necessary experimental investigations.

2. Laboratory Bulk Falling Apparatus and Measurement Equipment

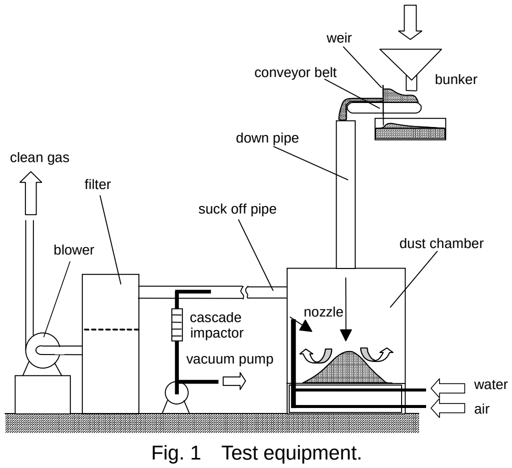

Fig. 1 Test equipment.

The bulk solids (sand from Yellow River) are stored in a bunker above a conveyer belt. In order to obtain constant material feed to the down pipe the bulk solids have to pass a weir, where they are piled up (see Fig. 1). Upon reaching a certain height above the weir excess sand drops into a box below the bin.

The sand passing the weir falls through the down pipe into a dust chamber, where the generated dust is sucked off and the particle concentration and size distribution are measured isokinetically in the suck-off pipe using a cascade impactor (VDI 2066 Blatt 5, 1994) of Chinese manufacture.

To minimize dust emission a two-phase water-air nozzle is installed in the dust chamber. This nozzle is characterised by low air pressure and low water flux while delivering fine droplets.

The design of the nozzle (Düse 1005, VSR Industrietechnik, Germany), is shown in Fig. 2. The air streaming through the centre of the nozzle causes sufficient resonance to mix with the surrounding water. Both, the resonance and the pressure drop from the inside of the nozzle to the outside, reduce the water droplet size.

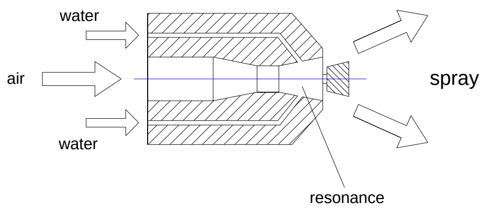

Fig. 2 Two phase water-air nozzle.

Figure 3 shows the position of the spraying nozzle in the dust chamber, inclined to the path of the dropping sand by 7° and 87 cm above the sand drop plate. The centre of the spray on the drop plate coincides with the centre of the falling sand.

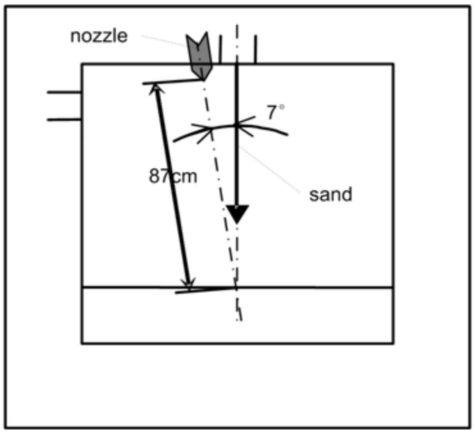

Fig. 3 Position of the spraying nozzle.

Both the mass flow of sand to the dust chamber and the water flux through the nozzle must be adjusted in the range of right proportions, particularly to avoid too much sand flow to lead to too high dust emission to be properly measured by the cascade impactor. The optimal combination was as follows:

Sand mass flow - 1 kg·min^{-1}
Water flux - 1.2 to 3 L·h^{-1}

The limited capacity of the cascade impactor limited the running time for one test to 5 to 10 minutes (corresponding to 5 to 10 kg of sand dropped into the dust chamber). The air pressure for the two-phase nozzle was 3 bars. Table 1 shows the droplet size distribution under these conditions (VSR Industrietechnik, 2006).

Table 1 Droplet size distribution of the two-phase nozzle

Water flux / L·h^{-1}	$x_{10,3}$ / µm	$x_{50,3}$ / µm	$x_{90,3}$ / µm
1.2	11	19	32
3	11	21	37

3. Bulk Material

The bulk material, sand from Yellow River, with a characteristically high amount of particles below 10 µm, was first dried down to ~0.8 m% water content, and then stored in 14 airtight barrels. For each test, a mixture of sand from all barrels was used to prevent varying particle size distribution and varying moisture content. Fig. 4 shows the cumulative mass particle size distribution of the Yellow River sand used in the experiments.

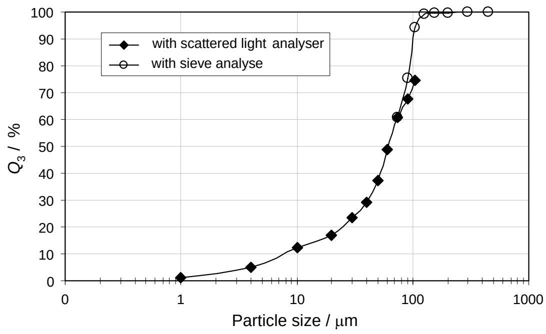

Fig. 4 Cumulative mass particle size distribution Q_3 of Yellow River sand.

4. Experimental Investigations

The falling bulk mass flow was kept constant at 1 kg·min^{-1}, and the water flux was varied between 1.2 to 3 L·h^{-1}.

As the air entering the dust chamber was not air conditioned, the relative air humidity depended on the local weather condition. The temperature remained almost constant at 20° ± 1°C. After a certain test time to measure the dust mass using the cascade impactor, the PM10 value was calculated, to relate the collected dust mass below an aerodynamic diameter of 10 µm to the fallen sand mass (mg dust·kg^{-1} sand). Fig. 5 shows that the dust emission can obviously be reduced by increasing the water flux as well as by raising the air humidity. Noticeable is the linear dependence of dust emission on relative air humidity. These data were further used for interpolation to get emission/water flux curves for fixed relative humidities as

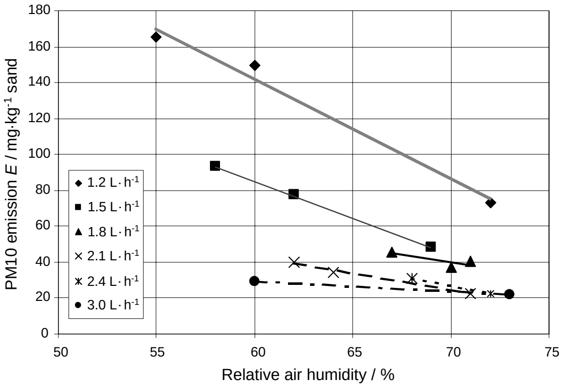

Fig. 5 PM10 emission E versus relative air humidity for different water flux.

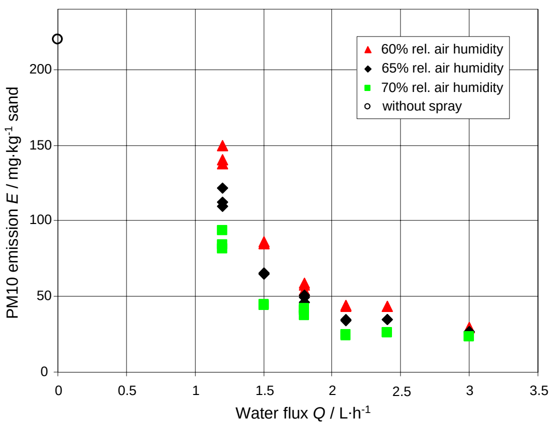

Fig. 6 PM10 emission E versus water flux Q for different relative air humidities.

shown in Fig. 6, inclusive of the PM10 value without water spraying for comparison.

As some water droplets, coming out of the nozzle, were consumed through evaporation before reaching the falling sand, actual dust reduction started only thereafter. For higher air humidity water evaporates slower, causing less such initial loss of water. Thereafter increasing the water flux further reduced the dust emission. The reducing effect versus water flux added is stronger for higher than for lower dust emission concentrations. As the dust emission decreases further, water flux increase has no additional

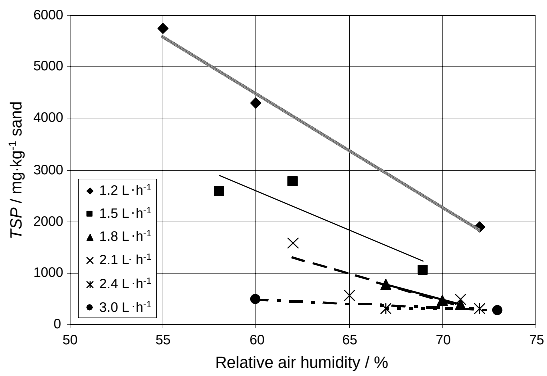

Fig. 7 *TSP* versus relative air humidity.

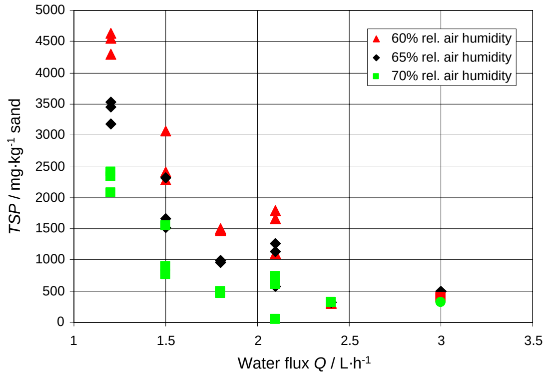

Fig. 8 *TSP* versus water flux Q.

dust suppression effect. Above a certain water flow further increase has no effect on dust suppression and the dust emission remains constant. This remaining residual dust emission comes from dust areas in the chamber which are not reached by the water spray. In Figs. 7 and 8 analogous measurements are shown for *TSP* (Total Suspended Particulates) concentrations and the experimental results confirm the above considerations also for *TSP*.

5. Development of Model Equations

To provide a tool for optimising the necessary water flux, the emission-*versus*-water flux data in Fig. 6 were formulated into a mathematical model. Following the modelling of deep-bed filtration (Luckert, 2004) the following kinetic equation is proposed to describe the reduction of particle concentration *dc* over the thickness *dz* of the filter cake (the larger the thickness the better the concentration reduction):

$$\frac{dc}{dz} = -\lambda_d \cdot c \,, \tag{1}$$

where the proportional factor λ_d means that particle reduction is proportional to its concentration *c*. This mathematical relationship can be interpreted alternately as the dust particle reduction mechanism caused by water spray. The number of filter grains which form the deep bed filter layer has a similar function to the particle separation as the stationary mass of water dispersed in the dust chamber generated by the water spray. If the water spray flow *Q* is increased the stationary mass of dispersed water in the dust chamber will be increased too. Therefore the filter layer thickness *z* in Eq. (1) can be replaced by the water flow *Q*, and the particle concentration *c* is replaced by the PM10 emission *E*.

Starting with E_0 for the emission without water spray, E_{res} for the residual emission for high water flux, *Q* for the water flux and Q_0 for the initial water flux which is necessary to start the reduction of the PM10 emission, Eq. (1) can be modified into the following model:

$$\frac{d(E - E_{res})}{dQ} = -\lambda \cdot (E - E_{res}) \,. \tag{2}$$

Integration yields

$$\ln(E - E_{\mathrm{res}}) = -\lambda \cdot Q + \mathrm{C}\,. \tag{3}$$

From the initial conditions, Q_0 and E_0, the value of the constant C can be derived:

$$Q = Q_0 \rightarrow \mathrm{C} = \ln(E_0 - E_{\mathrm{res}}) + \lambda \cdot Q_0\,. \tag{4}$$

Substitution of C gives the two alternate forms of the final model:

$$\ln\left(\frac{E - E_{\mathrm{res}}}{E_0 - E_{\mathrm{res}}}\right) = -\lambda \cdot (Q - Q_0)\,, \tag{5}$$

$$E = E_{\mathrm{res}} + (E_0 - E_{\mathrm{res}}) \cdot e^{-\lambda \cdot (Q - Q_0)}\,, \tag{6}$$

where λ is an empirical factor which controls the emission reduction. While in deep-bed filtration λ_d depends on the filter material (grain size, porosity, etc.), for our present case λ denotes the influence of the water spray (droplet size, dispersion of the droplets in the dust chamber, etc.).

Figure 9 shows schematically the above model considerations in terms of three curves representing different relative air humidities, which need different initial water mass and therefore have different starting points for their dust suppression.

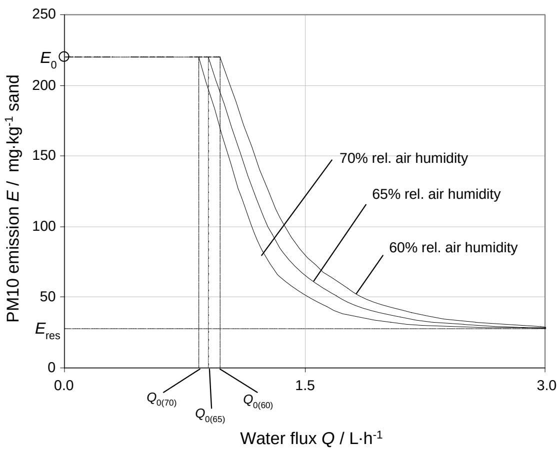

Fig. 9 Parameters of the mathematical model.

By reading out the values for the emission without water spray E_0 and the residual emission E_{res} from the experimental data in Fig. 6, the parameters λ and Q_0 can be found by regression of the experimental data using Eq. (5), as shown in Table 2 and Fig. 10. It can be seen that the model fits the experimental values well.

Table 2 Values of model parameters, determined by regression

E_{res} / mg·kg^{-1} sand	E_0 / mg·kg^{-1} sand	rel. air humidity / %	Q_0 / L·h^{-1}	λ / L^{-1}·h
27.9	220	60	0.97	2.4
		65	0.89	2.6
		70	0.84	3.1

Equation (6) together with the process specific parameters can be used to estimate the dust suppression effect for different water fluxes. In further scientific investigations the influence of different nozzle parameters (resulting in different droplet sizes, droplet dispersion grade, etc.) and the position of the nozzle in the chamber on λ and Q_0 will be further clarified.

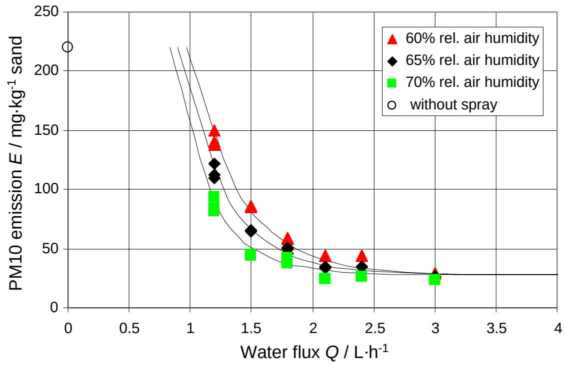

Fig. 10 PM10 emission E versus water flux Q including model equations.

6. Conclusion

For dust suppression using fine water spray, e.g., dust emitted from falling bulk materials in an enclosed dust chamber, the influence of water spraying flux and relative humidity of the surrounding air on dust emission were investigated. It was found the higher the relative humidity, the lower the needed water flux to reach equal dust suppression. For each relative humidity a certain initial water flux is needed to start the dust suppression. The higher the humidity, the lower the initial water flux, and therefore the overall water consumption. By increasing the water flux, dust suppression starts with higher effect which diminishes with further water flux increase. Above a certain maximum water flux no further dust suppression can be achieved. These relationships were modelled by a mathematical equation which can be used to calculate the dust suppression for different water fluxes and relative humidities.

Nomenclature

C	constant, -
c	particle concentration, kg·m^{-3}
E	PM10 emission, mg·kg^{-1} sand
E_0	PM10 emission without water spraying, mg·kg^{-1} sand
E_{res}	residual PM10 emission, mg·kg^{-1} sand
PM10	particulate matter 10 microns, mass of particles with an aerodynamic diameter of less than 10 microns, mg·kg^{-1} sand
Q	water flux, L·h^{-1}
Q_0	initial water flux to start the dust reduction, L·h^{-1}
Q_3	cumulative particle mass, %
TSP	total suspended particulates, mg·kg^{-1} sand
λ	emission reduction factor, L^{-1}·h
λ_d	proportional factor for deep bed filtration, m^{-1}
z	filter layer thickness, m

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