Elimination of dust production from stables for dairy cows

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ABSTRACT: Three experiments with dairy cows were conducted in an air-conditioned stable under controlled conditions. The objective of the study was to determine the effect of the regulated ionic microclimate on the emission of dust particles (aerosol) up to the diameter of 10 µm (PM_{10}). Four dairy cows were housed in common straw-bedded boxes and the stable was equipped with a vacuum ventilation system. To regulate the ionic microclimate, the apparatus Agri 1 000 (maximum voltage 7 kV, current 25 µA) was used. Thus the airborne dust concentration in the stable (42–132 µg/m^3) was reduced by 12.7–26.2%. In experiments B and C statistical significance $P \leq 0.05$ was reached. The emissive flow from the stable was decreased from 7.41–8.63 mg/h to 5.30–6.55 mg/h per one animal, i.e. by 24.1–31.3%. Owing to ionisation the ratio of n^+ to n^- ions was changed. A unipolarity coefficient (P) was changed from 1.65–1.93 to 0.82–0.89, i.e. superiority of n^- ions.

Keywords: dairy cows; housing; air ionisation; dust emission PM_{10}; ion ratio

Aerial pollution has been of concern since the world industrial development started to introduce new extraneous materials into the natural composition of air. There is a strong evidence that the air pollution negatively affects human health. A number of different ill-effects can be ranked among them, e.g. increased incidence of subjective difficulties, changed parameters of the respiratory system or increased mortality of persons attenuated by chronic respiratory and cardiovascular diseases. The effect of dust particles on the organism is dependent on their composition, shape and size. The particles of the size above 10 µm in diameter are either totally prohibited from getting into the respiratory system or they are retained in the upper part of the respiratory system. Smaller particles (below 10 µm), however, may reach the lower part of the respiratory system and have negative implications on the self-cleaning mechanisms of the lungs.

Based on current scientific knowledge (van Leeuwen, 1997), it is not possible to determine a safe threshold concentration for dust aerosol with no ill-effects on human health below it. According to the conclusions of the World Health Organisation (WHO), dust aerosol is the substance with non-threshold effects. While Hůnová and Šantrocha (2000) confirmed that the effects on health are associated with aerosols of the particle size given in nm, in most European countries samples of Total Suspended Particulate (TSP) are still collected regardless of the particle size. The results of epidemiological studies (Krzyzanowski et al., 1998) suggest that health effects are more closely associated with the concentration of the dust fraction up to 10 µm (PM_{10}) than with the concentration of TSP. Emissions of aerosol particles PM_{10} in outside air are involved in the European Standard 12341 – Air quality – determination of the PM_{10} fraction of aerosol particles.

Emissions of dust particles from farm animal facilities are most important for the vicinity of stables. It is often the subject of growing disagreements between farmers and their neighbours. Dust sources in farm animal facilities are above all feeds (fine particles of processed cereals and dried plants), parts of animal skin, urine crystals and solid parts

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of faeces. However, the concentration of these dust particles is not constant but it varies between years and seasons (Chardon, 1999). The highest concentration is reached in spring while the lowest in summer and winter. A high variability (65 to 96%) is found in monthly averages. The production of the aerosol fraction PM_{10} was monitored by Dolejš et al. (2004) under common conditions in farm animal operations. Net emissions of these dust particles from facilities for dairy cows, fattened bulls, pigs and broilers were 69.9, 30.5, 37.4 and 34.2 g/year per one animal, respectively.

Regarding the risk to the health of people and farm animals, reduction of the dust concentration in stables and elimination of the dust emission into the environment are the permanent objectives. With these aims in view, different physical principles were investigated e.g. moistening of the bedding (also in combination with oil), adjustments of ventilation systems, biological filters, etc. The results suggest that air ionisation might be the optimum technique for dust elimination. In addition, other positive effects are associated with this technique such as elimination of ammonia, improvement of animal performance or microbiological quality of milk from dairy cows. With respect to the fact that dust participates in the mechanism of the aerial transport of disease, air ionisation effects were examined in closed space (Mitchell et al., 2000). Dust was generated artificially and its concentration was reduced by air ionisation by 72 to 91% depending on its initial level.

The study was primarily focused on dust concentration. Particularly the possibilities to influence the concentration of dust particles of the size up to 10 μm (PM_{10}) in the stable and the emission of these particles into the environment (net production associated with farm animals) were investigated.

MATERIAL AND METHODS

Experiments were conducted in an air-conditioned stable with the loose bedded type of housing. The animals were fed a TMR diet *ad libitum* and milked twice a day. They were fixated at a feeding trough during the milking period. Four Holstein cows were used in each experiment with a potential milk production of 9.000 kg of milk (experiment A) and 9.500 kg of milk (experiments B and C). Regarding specific methods of dust concentration measurements, the system of vacuum ventilation was used. The stable temperature was not regulated but the air flow volume was controlled. The stable was equipped with the air ionisation apparatus Agri 1000. The basic parts of the apparatus are a high-voltage generator (approximately 7 kV, max. 25 μA) and a high-voltage line with emitters located 0.8 m from each other.

The experimental design required that dust concentrations had to be continually measured for the period of 24 h so that the effect of the used housing technology was taken into account. Only one apparatus could be used. To be able to measure both parameters (stable dust concentration and dust net production), it was necessary to record the dust concentration (PM_{10}) for three days in both experimental periods (referential = with and experimental = without ionisation). During this period the apparatus was located as follows:

Day 1: at the air inlet, i.e. recording of the outdoor concentration

Day 2: at the air outlet (at the discharge ventilator), i.e. recording of the gross concentration

Day 3: at the living zone of animals, i.e. 0.9 m from the floor level

It is evident that the dust production inside the stable was recorded for the first 2 days while the dust concentration was measured on day 3. The measuring of PM_{10} and ion count started on the 31st day of dairy cow housing in experiment A, on the 26th day in experiment B and on the 78th day in experiment C. Air ionisation of the experimental period was applied only in this period.

Dust concentration was measured with Dusttrak (USA), a laser analyser with memory recording. Air flow volume was measured with a common anemometer placed on an exhaust ventilator (product of air flow velocity and known aperture area). By means of its corporate software the Dusttrak device provides a summary protocol including measured data, table and graphical outputs. The values of PM_{10} particle concentration were integrated into average concentration per hour and these data were calculated as average per period. Net dust production (PM_{10}) is calculated as a difference (k_{dif}) in dust particle concentration at the air outlet (gross concentration) and at the air inlet (outdoor concentration):

$$k_{dif} = k_{out} - k_{in} \text{ (mg/m}^3\text{)}$$

Dust production (E) is calculated:

$$E = k_{dif} \times Q \text{ (mg/m}^3\text{)}$$

where: Q = air flow volume (m^3/h)

Table 1. Survey of measured parameters

Parameter	Indication	Unit	Method and frequency of measurements
Dust concentration (PM10)	k	μg/m^3	k – 5 min
Dust concentration – inlet	k_{in}	μg/m^3	k – 5 min
Dust concentration – outlet	k_{out}	μg/m^3	k – 5 min
Concentration difference	k_{dif}	μg/m^3	k – 5 min
Air flow volume	Q	m^3/h	a – 3 times a day
Dust (PM10) flux	E	mg/h	re-calculation
Outside temperature	t_e	°C	k – 10 min
Inside temperature	t_i	°C	k – 10 min
Rel. humidity – outside	RH_e	%	k – 10 min
Rel. humidity – inside	RH_i	%	k – 10 min
Ion count – inside	n	n$^+$, n$^-$	a – 3 times a day
Unipolarity coefficient	P	n$^+$/n$^-$	re-calculation
Air flow velocity	v_a	m/s	a – 3 times a day

k = continuous measurement
a = discontinuous measurement

Table 2. Thermal-humidity conditions of experiments

Experiment date	Period	External		Internal		
		t_e (°C)	RH_e (%)	t_i (°C)	RH_i (%)	v_a (m/s)
A	ref.	19.5	47.7	20.5	55.3	0.34
14.–20.6. 2003	exp.	18.9	50.7	20.4	57.2	0.38
B	ref.	16.1	60.8	21.8	58.8	0.40
2.–8.5. 2004	exp.	15.8	68.1	21.6	54.5	0.35
C	ref.	16.8	61.6	20.9	56.8	0.43
23.–30.6. 2004	exp.	15.7	69.7	20.6	58.1	0.42

The values of ion microclimate were determined with the digital ionmeter T-2000. The count of n$^+$ and n$^-$ ions per 1 cm^3 of air is shown in a separate experiment and its regimes. The ratio of n$^+$ to n$^-$ ions is expressed as a unipolarity coefficient P (Spurný, 1985):

$$P = \frac{n^+}{n^-}$$

In each period 9 measurements of the ion count of both polarities were realised in total (three times a day in three days).

Thermal-humidity microclimate parameters were measured with a Commeter, model 4 130 and 3 120 with memory recording. The other parameters (microclimate conditions) given in Table 2 were measured three times a day and their mean values were used.

The integrated values of PM_{10} concentration at the air inlet and outlet from the measured stable were calculated as average per given experimental period. The statistical significance of differences in inlet-outlet concentrations in the respective periods was determined. Total index of this difference (k_{dif}), which serves as one of the components for the calculation of net emission from the stable, was integrated into average value per hour and the value difference between the normal and experimental period was tested by t-test. The statistical significance of the change in PM_{10} particle concentration in the animal living space owing to air ionisation was evaluated by t-test. Changes

Table 3. Concentration of dust particles of size up to 10 μm (PM_{10}) at the outlet and inlet of the stable (μg/m^3)

Experiment n = 24	Period	Outlet		Inlet		Statistical significance
		$\bar{x}$	SD	$\bar{x}$	SD	P
A	ref.	135	52.46	106	46.14	NS
	exp.	130	41.59	106	32.18	0.05
B	ref.	57	22.32	29	21.45	0.05
	exp.	40	15.12	21	14.32	0.05
C	ref.	89	45.16	62	44.87	NS
	exp.	82	35.47	61	34.69	0.05

NS = not significant

in the ion count (n^+ and n^-) were tested in the same way.

RESULTS AND DISCUSSION

Changes in dust particle emission (PM_{10})

The analysis of realised measurements (Table 3) revealed that the outlet concentration PM_{10} (k_{out}) was particularly affected by the dust concentration at the air inlet to the stable (k_{in}). With regard to the development of weather conditions the measured absolute values of concentration (k_{in}) ranged from 3 to 1 330 μg/m^3 while the daily averages ranged from 21 to 106 μg/m^3. The increased concentrations in experiment A can be explained by heavy traffic on the road near the stable. This situation is explained in Table 3. The differences between the inlet and outlet concentration (k_{dif}) in normal periods in experiments A and C were statistically insignificant owing to a high variability of particle concentrations in the time of measurements. Similarly, a high variation was also found for the dust concentration measured inside the stable. The other measured parameter – k_{dif} had lower variability as it was directly influenced by the experimental animals and housing technology. The differences were 27.3–29.3 and 19.1–23.9 μg/m^3 for normal and experimental periods. Statistical significance of difference k_{dif} between the normal and experimental period was $P \leq 0.05$ in experiment A, in experiments B and C statistical significance was even higher – $P \leq 0.01$ (Table 4). The production of PM_{10} particles was 711.6–828.2 mg per day and stable, i.e. 177.8–207.1 mg per day and cow in normal periods, in experimental periods it was 508.8 to 629.0 mg per day and stable, i.e. 127.2–157.0 mg per day and cow. The emission of PM_{10} particles decreased to 70.6–74.9% owing to ionisation. The result is shown in Table 4.

The emission of dust particles mentioned above is only related to the given experimental facility (air-conditioned stable). It is difficult to compare the obtained results with other studies to a certain extent because different methods of dust fraction measurement (mostly TSP) were used or a different method of data evaluation (gross emission is used, i.e. outlet concentration of dust fraction) was applied. In addition, similar studies were conducted for poultry and pig facilities only. The only source of information concerning cattle (fattening) is

Table 4. Statistical significance of the (PM_{10}) concentration difference and emission of dust particles (PM_{10}) from the stable

Experiment n = 24	Period	k_{dif} (μg/m^3)		P	Air flow rate	Emission	Index
		$\bar{x}$	SD		(m^3/h)	(mg/day)	ref. = 1.000
A	ref.	29.3	9.65	0.05	1 190.0	836.8	0.749
	exp.	23.9	6.36		1 092.0	626.4	
B	ref.	27.7	9.15	0.01	1 125.8	748.4	0.706
	exp.	19.3	5.78		1 140.1	528.1	
C	ref.	27.3	8.71	0.01	1 098.1	719.0	0.721
	exp.	21.4	5.34		1 009.4	518.4	

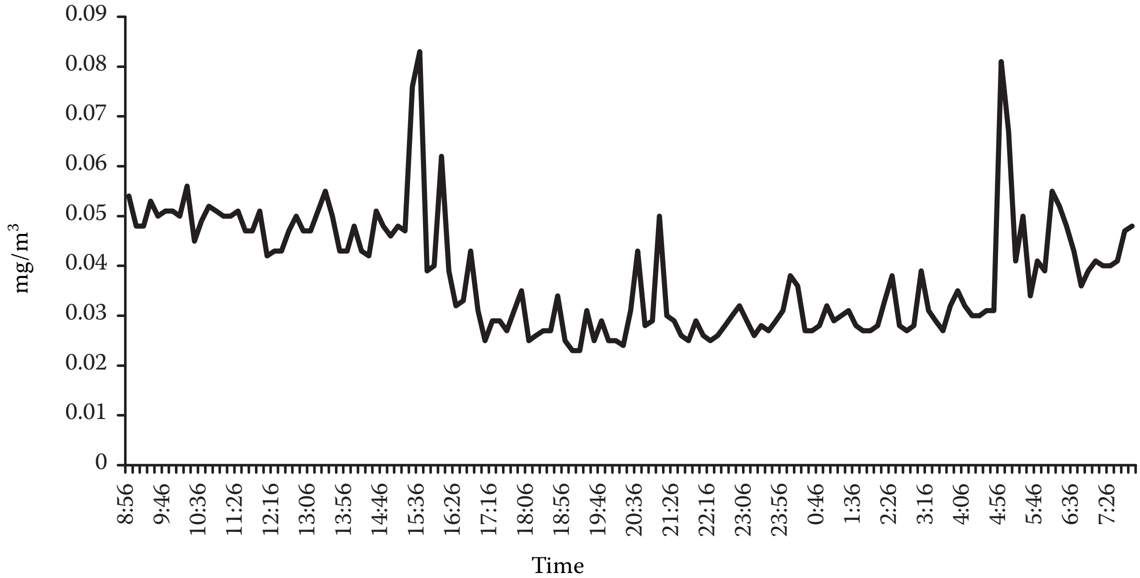

Figure 1. Aerosol PM_{10} – input

Seedorf (2000), who reported dust emission for TSP and the fraction up to 5 μm 145 and 24 mg/h/LU, respectively. When using a similar way of calculation (product of k_{out} and Q), our results of gross production of PM_{10} fraction will range from 10.25 to 33.33 mg/h/LU.

Dust particle (PM_{10}) concentration inside the stable

The dust particle content of inlet air affected dustiness inside the stable directly. Its daily averages during normal periods were 42–132 μg/m^3 and in experimental periods 31–112 μg/m^3. The dust originating by the activity indoors in the stable (outlet – inlet difference) participated in the dust content in the stable. In experiments B and C it participated 34.2–66.7% during normal periods and 30.4–48.7% in experimental periods. In experiment A its part in both periods was app. 22%. The efficiency of air-ionisation in decreasing dust particles (PM_{10}) was 84.8% in experiment A, 73.8% experiment B and 87.3% experiment C. In experiments B and C statistical significance $P \leq 0.05$ was reached. The summary of results is shown in Table 5. Air ionisation efficiency for reduction of dust particles was investigated in several other studies. Dolejš et al. (2002) reported that dust concentrations in stables for pigs and cattle were reduced from 20.6 to 28.4%.

Treatment with high voltage field

The n^+ ion counts inside and outside the experimental facility were similar but the n^- ion count was considerably reduced below the level of 170 n^-/cm^3. In some cases even the decrease below the level of 100 n^-/cm^3 was recorded. It corresponded with the unipolarity coefficient (P) that was in the range of 1.65–1.93. Due to air ionisation induced by the high voltage (up to 7 kV) the n^- ion count was increased and ranged from 320 to 350 n^-/cm^3. This was reflected in a unipolarity coefficient (in the range of 0.82–0.89). The ion counts

Table 5. Concentrations of dust particles (PM_{10}) in the living space of animals (μg/m^3)

Experiment	ref.		exp.		Index	Statistical significance
n = 24	$\bar{x}$	SD	$\bar{x}$	SD		P
A	132	41.26	112	25.32	0.848	NS
B	42	21.18	31	12.35	0.738	0.05
C	79	19.64	69	12.49	0.873	0.05

NS = not significant

Table 6. The ion microclimate during experiments – count n^+/cm^3, n^-/cm^3

Experiment $n = 9$	Period	n^+/cm^3			n^-/cm^3			Unipolarity coefficient P
		$\bar{x}$	SD	P	$\bar{x}$	SD	P	
A	ref.	339.6	44.04	NS	175.7	39.92	0.01	1.933
	exp.	303.2	19.30		339.1	40.61		0.894
B	ref.	280.1	24.37	NS	169.7	27.49	0.01	1.631
	exp.	295.6	29.05		342.8	59.05		0.862
C	ref.	303.4	31.86	0.05	171.4	36.17	0.01	1.770
	exp.	271.4	23.07		329.9	43.13		0.823

NS = not significant

are shown in detail in Table 6. It follows from it that changes in n^- ions were statistically significant first of all. Statistical significance was $P \leq 0.01$ in all experiments, while of the n^+ count was significant only in experiment C ($P \leq 0.05$). The changes were statistically insignificant in experiments A and B.

Dust particles were charged as a result of the development of the electrostatic field with a high vertical gradient in the stable associated with the production of free ions. Due to mutual integration the conglomerates increased their weight and by the action of the gravitation force they settle more quickly than under normal conditions. This fact is directly responsible for a reduction of the dust concentration in the stable and the decreased dust emission into the environment. The process of dust settling depends on a number of factors. Except for the electrostatic potential gradient they are above all the original electrostatic charge of each dust particle, air flow velocity and turbulence in the stable and triboelectric potential of different stable component surfaces.

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