# Effect of floor design in a dairy cow house on ammonia emission - Design, test and preliminary results with an experimental set-up for run off experiments

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Design characteristics, dirtiness and wetness of the floor in cow houses influence emissions of ammonia and the behaviour and claw health of dairy cows in cubicle houses. Besides, the manure surplus in the Netherlands increasingly forces dairy farmers to treat slurry at farm level. Experimental research with ten different floor elements and water as model urine liquid, was carried out to explore the run off of urine towards a slurry pit. Remaining water on different floor types varied strongly from 0.154 kg for newly developed floors up to 0.432 kg for the traditional slatted floor. The reduction effect of the manure scraper was small for floors with low remainder (about 0.020 kg less) but high for the slatted floor (about 0.300 kg less). Potential emission reduction of the newly developed floors would be more than 40% as compared to the slatted floors, which is about 4.231 kg ammonia per cow per year.

Keywords: Ammonia emission, floor design, dairy cow house, urine transport

### 1 Introduction

The emission of ammonia from animal husbandry systems, especially from dairy cow houses, is the main cause of environmental acidification in the Netherlands (NL). Dairy farming contributed about 60% in 1990 (Groot Koerkamp et al., 1998) of which approximately 20% originated from cow houses. Ammonia volatilizes from the cow house (floor and slurry pit), slurry storage outside the house, slurry application and the pasture (grazing). This research focussed on the emission of ammonia from the floor only in the cow house. Design characteristics, dirtiness and wetness of the floor in cow houses influence emissions of ammonia, and also the behaviour and claw health of dairy cows. Besides, the manure surplus in the NL increasingly forces dairy farmers to treat the slurry, that is collected in the pit underneath the slatted floors, at farm level. The general treatment is to separate solids in the slurry from the liquid by means of special separators. Alternatively, faeces and urine can also be kept separate in the house directly after excretion, whereby urine drains off the floor to a gutter or pit, and faeces are collected by a traditional manure scraper or otherwise (e.g. a robot) and stored elsewhere. Based on a system analysis of processes involved in the emission of ammonia and welfare and hygiene of dairy cows, the focus was set on the urine puddle left on the walking floor in these houses. To assess the effect of the design of a floor in cow houses, the following objectives were formulated. (1) Develop a measurement set-up able to test floor elements, (2) within this set-up, develop and test a urine supplier and its accuracy, 3) get insight in the repeatability of the set-up, and 4) get insight in the dynamic behaviour in time and space of the water run-off from the floor elements. Objective 3) and 4) were carried out with twelve different floor elements, both traditional and recently developed floor types for cubicle cow houses.

### 2 Materials and Methods

A measurement set-up was designed and constructed and is described in section 2.1, details about the simulation liquid in section 2.2, and the floor elements are described in 2.3. With this set-up, three experiments were carried out to answer the questions related to objective 2 - 4. In experiment one, the accuracy of two devices for urine supply were assessed and compared; in experiment two the repeatability of the set-up was determined and in experiment three the dynamic run off, the formation of a pool and possible effect of spatters were determined.

#### 2.1 Measurement set-up

The goal was to assess the remainder of urine on a floor element after a simulated urination with a model liquid. A floor element transport the fluid horizontally, towards the sides, slats or holes, and then vertically downwards off the floor. The liquid drained into a collection tray underneath the floor element. A simplified mass balance was used to determine the amount of liquid on the floor.

Figure 1 shows two cross-sections (A and B) and top-view (C) of the measurement set-up. A framework (Figure1, no. 9) was equipped with four points (3) to support the floor element (5). These points of support were adjustable in height (4) to level the floor element exactly horizontally. The points of support were positioned opposite each other so that the other two sides of the floor element were free of obstructions (Figure 1C). An urination of a dairy cow was simulated (both in volume and deposition) with two types of a liquid dispenser, a cistern (8 in Fig. 1B) and a pipe with overflow (7 and 11 in Fig. 1A), connected with a funnel (7), resulting in a trickle (5) and leaving a puddle (6) on the floor. The trickle caused spatters from the floor, which were drained into the collection tray (2) by means of flaps (12) in the set-up of Fig 1B.



Figure 1, Side-view of the two version of the measurement set-up (A and B) and top-view of the floor element (C). Legend: 1. balance, 2. collection tray, 3. points of support, 4. adjust height of support, 5. floor element, 6. trickle and puddle, 7. (collection) pipe with funnel, 8. cistern, 9. construction of steel, 10. plateau, 11. water collection overflow, 12. side flaps, 13. possible movement in x- and y- direction.

Underneath the points of support a horizontally levelled balance (1) was positioned, with a collection tray (2) on top. The balance was placed on a plateau (10). The plateau was needed to lift the balance and the tray to collect the water just underneath the floor element. Besides, the plateau was used to place the balance in the middle underneath the floor element and the tray. The plateau was fixed to the experimental setup. The balance had an accuracy of 0.001 kg, which was confirmed by the last calibration report. The weight of the balance was automatically read by a software program, written in National Instruments Labview, and produced readings of the weight together with the time in milliseconds. The weight of the collection tray (aluminium, ca. 20 kg) plus twelve urine simulations (ca. 3.3 kg each) summed up to the measurement range of the balance (60 kg).

### 2.2 Simulation liquid

Table 1 shows typical values for the excretion of urine and N in the urine by dairy cows. According to (Whitehead, 1995) there is a wide variation in volume between breeds, individual animals and, for an individual animal, from day to day. Daily urine production is influenced by diet. The large volumes are typical of breeds such as Frysian. We choose an amount of about 3.3 L for the simulation of one urination, which urinate in the upper range of the variation as shown in Table 1.

Table 1, Typical values for the excretion of N in urine by dairy cows (Whitehead, 1995) and calculations to determine the urea N concentration (LEI).

Description	Minimum	Maximum
Urine volume per day [L]	10	40
Urination frequency [#]	8	12
Volume per urination [L]	1.5	3.5
Dry matter in urine [g*L <sup>-1</sup> ]	60	120
urea N concentration in urine [g*L <sup>-1</sup> ]	2	20
Average urea N concentration in urine [g*L <sup>-1</sup> ]	8	10
N excreted in urine [g N day <sup>-1</sup> ]	80	320
N excreted in urine [kg N year <sup>-1</sup> ]	30	120

According to (Monteny & Erisman, 1998) a urine puddle is  $0.8 \text{ m}^2$  on a slatted floor and is  $1.2 \text{ m}^2$  on a solid floor. Because the floor elements in our experiments had different surface areas, ranging from 0.8 to  $1.2 \text{ m}^2$ , the trickle was positioned at or near the centre of a floor element at a leveled area to simulate the puddle size as good as possible. Positioning at a leveled area also reduced or prevented spatters.

Water was used as a model fluid to simulate the urine of dairy cows. According to (Hall & Hoff, 2002), (Arts *et al.*, 1991), (ASG, 1993) and (Koriath, 1975) physical properties of urine and water, like density and viscosity, do not differ much. Surface tension and vapour pressure are also of interest, but are unknown for cattle urine. According to (Perryman & Selous, 1935) the surface tension of biological fluids changes in time, for example the surface tension of human urines becomes smaller. With the use of water we overcame the problem of variation in practical urine properties and hygiene (smell, emissions, dirtiness).

### 2.3 Floor elements

In experiment two and three, 12 floor elements were used that differed in design (especially the top layer), size, weight and/or in composition of concrete (Table 2). The floors were developed, produced and supplied by four different Dutch companies that produce concrete floor elements for dairy cow houses.

All floor elements were 1,00 m. wide. The length and thickness differed, caused by the standard production sizes of the manufacturers. Among the elements there were seven prefab elements. Prefab elements are cast in a mould. After one day the dry concrete is taken out and the element is finished. The other elements (indicated as non-prefab) were made in series production, whereby concrete is casted in a mould and taken out immediately after casting. The composition of this concrete differs from prefab because it has a higher dry matter content to dry outside the mould. The prefab floor elements are smoother at the top layer and have a higher compactness compared to elements made in series production.

Floor	Size w*l*h [m]	Description	Groove depth
Slatted floor (non prefab)	1.00*1.20*0.16	No grooves, leveled slats	-
Welfare floor 1 (non prefab)	1.00*1.00*0.10	Leveled grooves, rectangles (0.08*0.03m)	3 mm
Welfare floor 2 (prefab)	1.00*1.20*0.10	Sloped main grooves (1%) middle to sides, crossing grooves, rectangles (0.08*0.03m)	5 - 12 mm; 5 mm
Welfare floor 3 (prefab)	1.00*1.20*0.10	Sloped main grooves (1%) middle to sides, crossing grooves, rectangles (0.08*0.03m), H	5 - 12 mm; 5 mm
Welfare floor 4 (prefab)	1.00*1.20*0.10	Sloped main grooves (1%) middle to sides, crossing grooves, rectangles (0.08*0.03m), HE	5 - 12 mm; 5 mm
Welfare floor 5 (prefab)	1.00*1.20*0.10	Sloped main grooves (2.5%) middle and side to hole, crossing grooves, rectangles (0.08*0.03m)	3 - 12 mm; 3, 4, 8 mm
Welfare floor 6 (prefab)	1.00*1.20*0.10	Sloped main grooves (2.5%) middle and side to hole, crossing grooves, rectangles (0.08*0.03m), HE	3 - 12 mm; 3, 4, 8 mm
Welfare floor 7 (prefab)	1.20*0.80*0.14	Sloped main grooves (2.5%) side to side, parallel and crossing grooves, varying design	5 - 15 mm; 1 mm; 2 mm
Welfare floor 8 (non prefab)	1.20*0.80*0.14	Sloped main grooves (2.5%) side to side, parallel and crossing grooves, varying design	5 - 15 mm; 1 mm; 2 mm
Welfare floor 9 (non prefab)	1.00*0.80*0.16	Leveled grooves crossing, diamonds and on top	10 mm; 3 mm
Grooved floor (non prefab)	1.00*1.10*0.16	Leveled grooves side to side, slats pattern	30 mm
Welfare floor 10 (prefab)	1.00*1.20*0.12	Leveled main grooves, zigzag line and crossing grooves, hexagons	30mm; 5mm

Table 2. Different floor elements with fabrication method (prefab; non prefab), description and groove depth. H - special ingredient added to the concrete; E - extra.

#### 2.4 Experiments and measurements

Three experiments were carried out. In experiment one the accuracy of the two devices for urine supply, a cistern and a pipe with overflow, were assessed and compared. The water of one urination as supplied by the cistern or pipe was caught in a bucket, and the net amount of water was measured with mass balance. For the cistern, a total of 57 measurement were taken on 6 days (not equally distributed), for the pipe with overflow a total of 12 measurements were taken on 6 consecutive days. Mean, standard deviation and standard errors were calculated per day and per device.

In experiment two the repeatability of the set-up was determined. Since the floor elements were all new, it was possible that they could absorb water during the experiments. To overcome this problem, each floor element was completely drowned in a water reservoir for at least seven days. Each floor element was pre-wetted before measurements took place.

The experimental set-up of figure 1A was used for this experiment (the pipe with overflow). For each floor element 10 runs of water supply were carried out, directly after each other within a time interval of approximately three quarters of a hour. After each run the floor elements were 'dried' by means of pressurizes air (a preliminary test with a squeegee resulted in a dry floor surface, but all grooves remained full with water). This air was blown over the floor elements with a pipe with small holes under air pressure. This pipe was slowly moved over the floor element and blew the water from both the floor surface as well as from the grooves.

In experiment three the dynamic run off, the formation of a pool and possible effects of spatters were determined. The dynamic run off was determined with the continuous measurements of the weight of the balance. The formation of pools on the floor elements and the presence and amount of spatters were visually determined.

### 2.5 Data analysis

To check the distribution of data skewness and kurtosis were assessed according to (Kenney & Keeping, 1951) and (Kenney & Keeping, 1962). To test equality of variances Levene's test was applied (Levene, 1960). Based on Levene's test and according to (Garson) was chosen to use Games-Howell test for multiple comparison.

To calculate the remainder of water at floor level the collected water was subtracted from the applied water (equation 1) To determine  $NH_3$ -N production a calculation according to (Monteny *et al.*, 1998) was performed (equation 2.

$$W_{floor} = W_{urination} - W_{collected} \tag{1}$$

 $W_{floor}$  = Weight of remainder of water at floor level [kg]

 $W_{urination}$  = Weight of water applied [kg]

 $W_{collected}$  = Weight of water collected [kg]

$$\mu_{urea} = \frac{\mu_{\max} * [U_t]}{K + [U_t]}$$
(Monteny & Erisman, 1998) (2)

 $\mu_{urea}$  = Rate of NH<sub>3</sub>-N production per cow [kg\*m<sup>-3</sup>\*s<sup>-1</sup>]

 $\mu_{\text{max}}$  = Maximal rate of urea nitrogen conversion [kg\*m<sup>-3</sup>\*s<sup>-1</sup>] = 2.70\*10<sup>-3</sup>

 $[U_t] =$  Concentration of urea nitrogen in the urine at time t (=0) [kg\*m<sup>-3</sup>] = 9

 $\mathcal{K}$  = Michaelis-Menten constant for urea conversion [kg\*m<sup>-3</sup>] = 56\*10<sup>-3</sup>

 $\mu_{urea}$  is coupled to  $W_{floor}$  and extrapolated to a day and a year (365 days) based on the urination frequency and the average urea N concentration in urine per cow.

### 3 Results and discussion

### 3.1 Accuracy of the urine supply

Table 3 show the mass of water as supplied by the cistern. The overall mean was 3.292 kg, with a standard deviation (SD) of 0.066.

Day	Time	W <sub>cistern</sub> (kg)	Ν	S.d. (kg)	S.e. (kg)
1	Random	3.263	5	0.030	0.013
2	Random	3.379	5	0.034	0.015
3	Random	3.381	5	0.051	0.023
4	Afternoon	3.292	13	0.062	0.017
5	Morning	3.296	11	0.053	0.016
	Afternoon	3.256	6	0.031	0.013
6_	Afternoon	3.244	12	0.050	0.014
	Total	3.292	57	0.066	0.009

Table 3. The mass of water (mean, standard deviation and standard error in kg as supplied by the cistern (W<sub>cistern</sub>) on 6 days at various moments during the day.

Table 4 show the mass of water as supplied by the pipe wit overflow. The overall mean was 3.370 kg, with a s.e. of 0.005 kg. The accuracy of the pipe with overflow was with 5 g much lower than that of the cistern (66 g).

Day	Time	W <sub>overflow</sub> (kg)	Ν	S.d. (kg)	S.e. (kg)
1	Morning	3.372	10	0.005	0.002
	Afternoon	3.371	10	0.008	0.002
2	Morning	3.370	10	0.006	0.002
	Afternoon	3.369	10	0.003	0.001
3	Morning	3.370	10	0.003	0.001
	Afternoon	3.370	10	0.006	0.002
4	Morning	3.369	10	0.003	0.001
	Afternoon	3.370	10	0.005	0.001
5	Morning	3.371	10	0.005	0.002
	Afternoon	3.370	10	0.005	0.002
6	Morning	3.370	10	0.004	0.001
	Afternoon	3.368	10	0.004	0.001
	Total	3.370	120	0.005	0.000

Table 4. The mass of water (mean, standard deviation and standard error in kg) as supplied by the pipe with overflow (W<sub>overflow</sub>) on 6 days.

#### 3.2 The repeatability of the experimental set-up

Table 5 show the absolute and relative amount of water that remained on the floor in kg ( $W_{floor}$ ) at t = 120 seconds from the start of simulation. Floor elements in the upper part were equally sized and ranked with increasing amount of water. Floor elements in the lower half had different sizes, and were for that reason not really comparable.

Table 5, The absolute (kg; mean and se) and relative (% of total urination) remaining amount of water on the floor ( $W_{floor}$ ) for 12 floor elements. Means in the upper part of the table with corresponding superscripts did not differ significantly. The floor elements in the lower half of the table had different sizes. The potential emission of ammonia (µ-urea; kg NH<sub>3</sub> / yr per cow) from the remaining urine is also given. \*The result of this floor was influenced by the points of support.

Floor type	W <sub>floor</sub>	W <sub>floor</sub>	μ <sub>urea</sub>
(code)	Mean and SE (kg)	(%)	(kg/yr per cow)
Welfare floor 6	0.245 (0.008) <sup>1</sup>	7.3	2.400
Welfare floor 5	0.273 (0.012) <sup>2</sup>	8.1	2.674
Welfare floor 3	0.277 (0.015) <sup>2</sup>	8.2	2.713
Welfare floor 4	$0.363 (0.007)^3$	10.8	3.555
Welfare floor 2	0.364 (0.012) <sup>3</sup>	10.8	3.565
Slatted floor	0.432 (0.053)4	12.8	4.231
Grooved floor	0.154 (0.012)	4.6	1.508
Welfare floor 7	0.180 (0.100)	5.3	1.763
Welfare floor 8	0.197 (0.034)	5.8	1.929
Welfare floor 10	0.260 (0.017)	7.7	2.546
Welfare floor 9*	0.327 (0.018)	9.7	3.203
Welfare floor 1	0.338 (0.019)	10.0	3.310

There were four significant groups, indicated by the superscripts. The welfare floor 6 showed the best result of only 0.245 kg water remaining which is 7.3% of the applied volume and corresponded to 2.400 kg ammonia per year per cow. Compared to a slatted floor of 4.231 kg per year per cow this was a reduction of about 43%. The other sized floor elements showed better results ranging from 0.154 kg remaining at the grooved floor to 0.338 for welfare floor 1.

The variation between the 10 runs of supply of water for the same floor element was expressed as the standard error of the mean. The s.e. ranged generally between 7 and 19 g water, with some higher values like 34, 53 and 100 g. So, in general the variation was small as compared to the amount of water remaining on the floor. Also the variation in the water supply with the water pipe with overflow (s.e. 5 g) was low as compared to the variation between runs.

#### 3.3 The dynamic run off, pools and spatters

Figure 2 shows a graph of the flow down curve for five floor elements, just to indicate the difference between floor elements. This curve was derived from a separate, constantly measured simulation of 290 seconds for each floor element. The first 30 seconds from start were not shown because of scaling. From the figure can be seen that the slatted floor was transporting the highest volume at t = 290 sec. The welfare floor 8 transported within 60 seconds a lot of water (3.079kg) but over the next 230 seconds only 0.092kg water was drained. The grooved floor was also fast until 60 seconds (3.075kg) but this floor continued a rather fast transportation of 0.209kg over the next 230 seconds.



Figure 2, Flow down curve of remaining water at floor level for five floor elements.

When the trickle fell in or at the edge of a groove, a lot of spatters originated and fell aside the collection tray. This influenced the accuracy of the measurement. A groove-position experiment was performed for every floor element.

The size of a puddle differed per floor element. Figure 3 indicates the size of the puddle for the slatted floor and the grooved floor. Since the grooves are wide (35 mm at top level) the puddle remain small at the grooved floor while on the slatted floor the puddle flow towards all sides. So the design of a floor influences puddle size.



Figure 3, Sketch of the slatted (left) and grooved (right) floor elements with a light gray spot which indicates the place of the trickle. The black spots indicates the puddle which originate form the trickle (based on observations during the experiments).

Three different types of spatters were determined, type 1, 2 and 3 in Figure 4. Spatters fell 1) aside the tray, 2) fell directly in the tray and 3) fall on top of the floor element. The total volume of category 1 spatters per floor element was neglected for the first experiment. To collect these spatters a flap was mounted for the second experiment (Figure 4C). In practice spatters just fall on the next floor element. They fall nearby or far away, depending on the velocity of spatters. Besides spatters, puddle size depends on floor type and distance to drain point (Braam & van den Hoorn, 1996).



Figure 4. Three situations of a floor element above the collection tray; (A) floor element with large side (B) floor element with small side (C) with a flap. Numbers 1, 2 and 3 indicate the different spatters, originated from the water trickle at the floor element.

#### 3.4 Measurement set-up

There are different methods to determine the remaining fluid at a floor element. Within this research we chose to subtract the weight of the water in the collection tray from the weight applied by the urine simulation. This method is easy to use and fast to calculate the remainder. Disadvantage of this method is that both  $W_{collected}$  and  $W_{urination}$  had a mean with variation (standard error), so there are two sources of variation. Another method to determine  $W_{floor}$  is to collect the water at floor level. This might be possible with a kind of sponge or vacuum cleaner. Big disadvantage of such a method is the tolerance, it is difficult to collect exactly all the water. Besides it is a time consuming method.

There was the possibility that the points of support interfere with the experiments, but only the welfare floor 9 floor element transported the fluid to all four sides, so also to the points of support. All the other floor elements transported water only in two opposite directions as indicated in Figure 1C.

# 4 Conclusions

A measurement instrument was developed which can repeat urine simulations with a high accuracy, within a short period of time.

The design and composition of a floor element does influence the urine transportation on and from the floor element. The best results at t = 120 seconds were shown by the grooved floor,  $W_{floor}$  was 0.154 kg, but this floor element had other dimensions than the six equal sized floor elements. From this series the welfare floor 6 showed the best results,  $W_{floor}$  was 0.245 kg.

From the continuously measured simulations can be concluded that after 290 seconds all the floor elements were still transporting water. But there were differences. The slatted floor element still transported a considerably amount of water while the welfare floor 8 was almost finished.

The design of a floor element could lead to a considerably high reduction of ammonia emission from the floor. Where a currently used slatted floor result in 4.2 kg  $NH_3$  per cow per year, the grooved floor element result in 1.5 kg  $NH_3$  per cow per year. This was a reduction of 64%.

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