

GROOVED FLOOR SYSTEM FOR CATTLE HOUSING: AMMONIA EMISSION REDUCTION AND GOOD SLIP RESISTANCE

D. Swierstra, C. R. Braam, M. C. Smits

ABSTRACT. To improve the slip resistance of solid floors in dairy cow houses and to achieve the ammonia emission reduction prescribed by the Dutch government, precast concrete floors with grooves and a dung scraper were investigated. The grooves parallel to the alley had 160 mm center-to-center spacing and were 35 mm wide and 30 mm deep. The urine could drain along the grooves. Perforations in the grooves were spaced 1.1 m apart and could be open or closed. When the perforations were open, urine could be drained directly into a slurry pit below. In case of closed perforations, draining of urine was only possible at one alley end. The feces were dragged to one end of the alley using a scraper, provided with facilities, that also cleaned the grooves.

The floor system was constructed in a compartment of a mechanically ventilated experimental cow house. In another compartment a traditional slotted floor served as a reference. Ammonia emissions from both compartments were recorded continuously. The effects on ammonia emission and the performance of the perforations in the floor were determined. The floor system was also implemented into various practical farms and some practical experiences were gathered.

Ammonia emission from the compartment with the grooved solid floor operating with open perforations was reduced by 46% compared with the reference compartment. Closing of the perforations resulted in an ammonia emission reduction of 35% compared to the reference compartment.

Keywords. Cow, Cow housing, Grooved concrete floor elements, Ammonia emission, Slip resistance.

In the Netherlands, ammonia emission from animal husbandry is one of the main factors causing environmental acidification (Heij and Schneider, 1995). The contribution to the total national ammonia emission was approximately 20% in 1990. The Dutch government has set ammonia emission reduction goals for the year 2000 and the year 2005 of, respectively, 50% and 70% relative to the year 1980 (Anonymous, 1995). In various areas in the Netherlands, a reduction in ammonia emission by 50% is already prescribed for newly-built animal houses. The percentage of reduction is compared with traditional housing systems with a slotted floor.

In the Netherlands nearly 90% of the dairy cows are kept in free-stall houses with cubicles. The walking alleys mainly consist of precast concrete slotted elements, covering a slurry pit. The feces and urine excreted by the animals are collected in an underfloor slurry pit. The factory-made concrete elements are cast in steel molds and the top surface is finished with a plastic float trowel. Concrete slats with the obtained surface texture are relatively slip-resistant, which supports the animals' movement. Slip resistance in the

direction perpendicular to the axis of the slats is further assured by the gaps.

Ammonia is formed by the breakdown of excreted urea in the urine of the animals. This reaction is catalyzed by the enzyme urease, present in the feces and surfaces regularly fouled with feces and urine (production phase) (Ketelaars and Rap, 1994). The ammonium ions produced in the liquid layer (slurry or urine pool) are released at the air-liquid layer boundary (volatilization phase). Emission of ammonia takes place as the inside air of a building, and thus the volatilized ammonia, is exchanged by ventilation and replaced by outside air (emission phase). According to Kroodsma et al. (1993), ammonia volatilizes at regularly fouled surfaces, at the slotted floor surface (60% of total volatilization), and the slurry pit (40%). The air velocity above the slurry in the slurry pit and the exchange of air between the house and the pit influence the total ammonia volatilization in the cow house. Earlier research showed possibilities to reduce ammonia emission by using sloping solid floors (Braamet et al., 1997a,b; Swierstra et al., 1995).

The function of alley floors is to provide a stable surface for the animals to walk on and to collect the slurry. These floors should not be slippery and not cause hoof disorders. In general, the type of floor finishing can influence the health of the animals' hooves, the behavior of the animals, and most of all, their locomotion (Albutt and Cermak, 1985). A study on the locomotion of sloping concrete floors in practice showed more slipperiness for the animals on this type of floor (Van Eert and Smits, 1996).

To improve slip resistance on solid floors, a floor with grooves and perforations was developed and tested (Figure 1). The ammonia emission from a free-stall house with a grooved floor and the performance of the perforations in the grooves are reported here.

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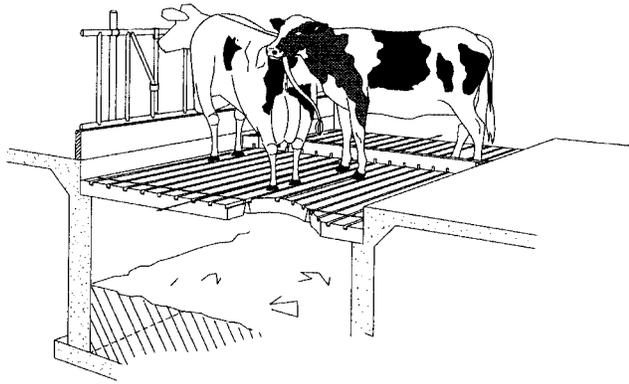


Figure 1. Concrete grooved floor elements in an alley with slurry scraper in a free-stall house for cows.

MATERIALS AND METHODS

ACCOMMODATION AND ANIMALS

Experiments were carried out in a cow house on an experimental farm. This free-stall type of cow house with cubicles represents the most common type of cow housing used in the Netherlands (Smits et al., 1993). The cow house was divided into three compartments. Figure 2 shows the plan and a cross-section of the cow house. Compartment 2 was provided with the experimental grooved floor and compartment 3 with the reference slotted floor, thus enabling direct comparison between the results obtained with the experimental floor and the reference floor. Compartment 1 was not used in this experiment.

In each compartment a row of 10 cubicles was situated against the side-wall. Next to the feed rack there was a 3.0 m wide loafing alley for the animals. Underneath the floors of each compartment there was a pit 1.65 m deep. The pits under the loafing alley and the feeding alley were used for slurry storage. To obtain similar conditions underneath the floors, the slurry in the storage pit was mixed with an electric mixer twice a day. The compartments were mechanically ventilated to carry out measurements to determine the ammonia emission and to ensure equal climatic conditions in all compartments. In each compartment a ventilation shaft was constructed in the roof, in which a fan was mounted to exhaust the air from the compartment. The air entered the building through an inlet in one side-wall and was conducted by a two-layer ceiling.

In each compartment 10 Holstein-Friesian cows were housed day and night. Due to the absence of a milking parlor the cows were not lactating. The cows were housed at least three weeks before the trial for adaptation and had a similar total live weight per group. The daily ration for the cows was a mixture of grass silage, beet pulp, straw, and concentrate (total 200 g N cow⁻¹ day⁻¹).

GROOVED FLOOR SYSTEM

The grooved floor system consisted of solid leveled prefabricated concrete elements covering a slurry pit. The span length of the elements was 3.0 m, the width 1.1 m, and the thickness 160 mm (Figure 3).

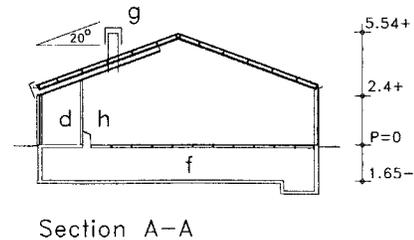
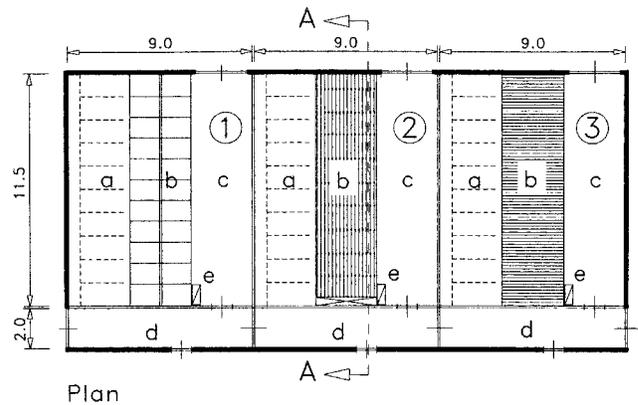


Figure 2. Plan and section of cow house with three identical compartments for 10 cows each, with a slotted floor as reference in compartment 3 and the grooved floor in compartment 2. Compartment 1 was not used (dimensions in m): a: lying area; b: loafing alley; c: feeding alley; d: control passage; e: drinking bowl; f: slurry pit; g: exhaust shaft; h: slurry discharge opening.

The total area of perforations of the floor elements was less than 0.5% of the total floor area.

The prefabricated concrete floor slabs were manufactured by Den Boer Beton B.V. at Nieuw-Lekkerland (NL). The feces were removed every two hours by a mechanical scraper and were dumped into the pit through a floor opening at the end of the alley. To clean the grooves and to prevent them from becoming clogged, the blade of the slurry scraper was equipped with a tooth-shaped rubber strip. The discharge opening at the end of the alley was 0.2 m wide and enclosed to prevent air exchange between the slurry pit and the cow house. The scraper was manufactured by Brouwers Stalinrichtingen B.V. at Leeuwarden (NL). The grooved floor system has been patented (Swierstra, 1998).

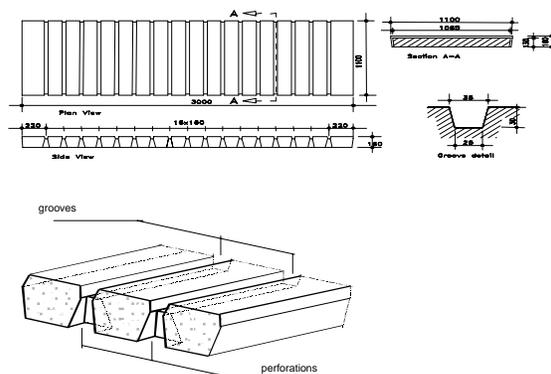


Figure 3. Grooved concrete floor element (dimensions in mm).

REFERENCE FLOOR

The reference floor was a concrete slotted floor. The slotted floor elements were 1.1 m wide and had a span of 3.0 m. On top, the separate slats were 120 mm wide. The slots between two adjacent slats were 37 mm wide (Figure 4). The total area of gap openings of the slotted floor elements was 20% of the total floor area. The slats were manufactured according to the Dutch Standard NEN 3873 (1989). In the factory the surface of the slats was smoothed and burrs on the edges were removed. The reference floor in compartment 3 was in use already for more than one year. This floor was not provided with a dung removing system.

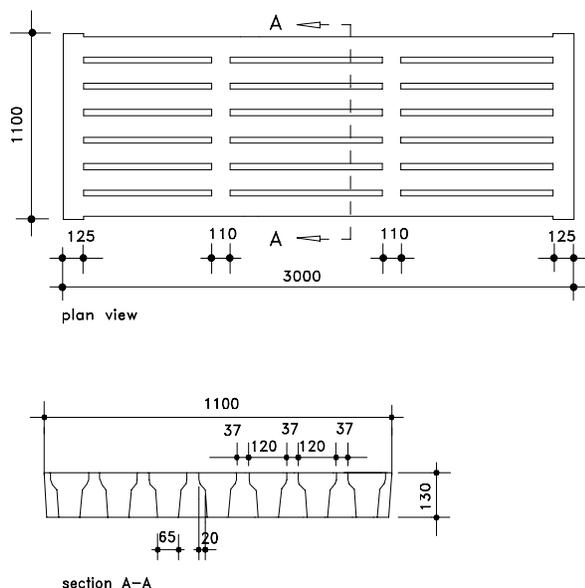


Figure 4. Slotted concrete floor element of reference floor (dimensions in mm).

EXPERIMENTS

The compartment with the grooved floor elements with perforations was put into use in October 1996. During the experiment two floor types were tested and compared with a slotted floor as reference (Ref):

- Grooved floor with open perforations (GFO);
- Grooved floor with closed perforations (GFC).

The experiment with the grooved floor versus the reference floor lasted five periods of 10 days, three periods with open perforations (GFO) and two periods with closed perforations.

The closed perforations were tightened by filling up the perforations with a polyurethane foam (GFC), thus simulating floor performance if all the perforations were clogged. After the periods with the closed perforations, they were opened by removing the foam manually. Table 1 lists the test periods with the open and closed perforations.

During the first weeks of 1997, the capacity of the mechanical ventilation was set at 10% of the maximum capacity to prevent freezing in the compartments because of the low outside temperature. The results obtained during this period were left out of the analyses and period V was moved up two weeks.

Table 1. Test periods of grooved floor with open (GFO) and closed (GFC) perforations.

Period	Floor system	Date
I	GFO	8 Nov 96 – 18 Nov 96
II	GFC	22 Nov 96 – 2 Dec 96
III	GFO	6 Dec 96 – 16 Dec 96
IV	GFC	20 Dec 96 – 30 Dec 96
V	GFO	17 Jan 97 – 27 Jan 97

AMMONIA EMISSION

To determine ammonia emission from the compartments, each compartment was provided with a mechanical ventilation system. The ammonia emission was defined by the amount of ammonia released from a compartment of the house per unit of time and was calculated by multiplying the amount of outgoing air by the difference between the ammonia concentration in the exhaust and incoming air. Anemometers situated in the ventilation outlet shafts recorded the airflow.

The ammonia concentration in the outgoing air was measured in air samples taken automatically approximately 10 times an hour in the exhaust shaft. Outside the cow house at a distance of about 50 m the ammonia concentration was also recorded, defining the concentration of the incoming air. In a converter, the NH_3 in the air samples was oxidized to NO . The NO concentration was measured in a NO_x analyzer. In the center of each compartment the ambient temperature and the relative humidity were also measured. The average values of the data collected were stored on an hourly basis. Scholtens (1990) has described in more detail the aspects of measuring of the ammonia emission from a mechanically ventilated housing system.

PERFORATIONS

The perforations between the solid floor elements were essential for draining the grooved floor system. In each groove at each joint between two adjacent floor elements, there was a perforation, resulting in a total of 170 perforations. Clogging of the perforations with solid manure or feed could reduce the draining effect of the perforations. During the experiments with the open perforations (GFO) the performance of the perforations in the floor was tested. Perforations were identified as clogged when a stick with a diameter of 12 mm, mass 40 g, dropped 200 mm, would not fall through the perforation by gravity. When the experiments with the closed perforations were carried out, all the perforations were checked to be actually closed. During all periods no ventilation of the pit underneath of the floor elements with outside air took place.

STATISTICAL ANALYSIS

The ratio between mean daily ammonia emission from the compartment with the grooved floor and the reference compartment was calculated.

Preliminary analyses showed that there was no significant overall temperature effect. With open perforations, ammonia emission reduction tended to increase with temperature. With closed perforations, there was no such tendency. Because these temperature effects were not significant, in the final model temperature was excluded. The logarithm of the ratio was explained by the model:

$$\text{Log} (E_{\text{exp}} / E_{\text{ref}})_{(t)} = C + P + v_{(t)} \quad (1)$$

where

- $E_{(i)}$ =daily mean ammonia emission from compartment (i = exp, ref)
- t = day number
- C = the expected reduction in case of grooved floor with open perforations (GFO)
- P = effect of the floor with closed perforations (GFC) relative to GFO
- $v_{(t)}$ = the stochastic contribution at day t

The relationship between the successive error components was described by a first-order autoregressive model (Box and Jenkins, 1976):

$$v_{(t)} = bv_{(t-1)} + a_{(t)} \quad (2)$$

where b is the autoregression coefficient and $a_{(t)}$ the independently distributed errors with mean zero.

Ammonia emission reduction (%) was calculated as $(1 - \text{ratio of emission}) \times 100$ with ratio = $E_{\text{exp}} / E_{\text{ref}}$. The results have been based on 10 days of measuring per test period. The results of two days of the first and third test periods and four days of the second test period were not included in the analysis. These values were missing due to technical problems with the measuring device.

RESULTS AND DISCUSSION

AMMONIA EMISSION

Figure 5 shows the daily mean ammonia emission rate ($\text{g h}^{-1} \text{NH}_3$) from the compartment with the grooved floor and the reference compartment with the slotted floor during the five test periods. Figure 6 shows the mean daily inside temperatures in the test compartment with the grooved floor and the outdoor temperatures. The mean daily temperature in the compartment with the slotted floor was equal to the mean daily temperature in the compartment with the grooved floor. The results of the measurements in the compartment with the grooved floor and the compartment with the reference slotted floor are presented in tables 2 and 3. The results are the daily mean measured values. Table 2 contains the results of the three testing periods of the grooved floor with the open perforations (GFO). The results in table 3 concern the two periods with the grooved floor with closed perforations (GFC). The data in tables 2 and 3 show that the mean climatic conditions in the experimental and the reference compartment were almost identical during all testing periods.

By covering the slurry pit with the solid grooved concrete elements and by draining the urine via the grooves and perforations, a substantial reduction in ammonia emission was obtained. The ammonia emission from the compartment with the open grooved floor (GFO) was reduced 46% compared with the emission from the compartment with the slotted floor. The 95% confidence interval was 40% to 52%. The reduction of ammonia emission from the compartment with the grooved floor with closed perforations (GFC) was 35% compared with the emission from the compartment with the slotted floor. The 95% confidence interval was 24% to 42%. The ammonia emission of a grooved floor without perforations shows a decline of the reduction of 24% in comparison with the floor with perforations.

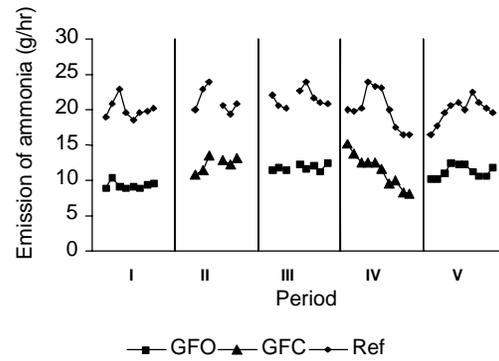


Figure 5. Mean emission of ammonia (g/hr) from a compartment with a grooved floor with open perforations (GFO) and with closed perforations (GFC) compared with the reference compartment with a slotted floor (Ref) during five test periods.

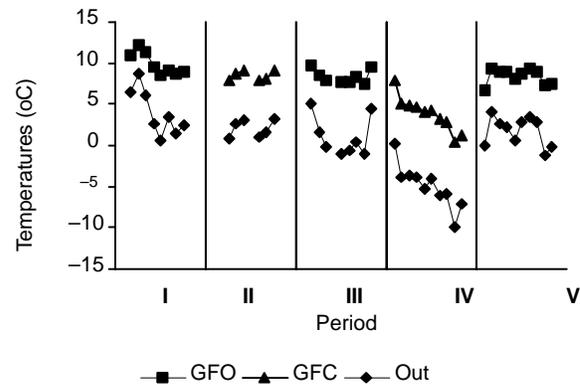


Figure 6. Mean daily temperatures in the test compartment with the grooved floor with open perforations (GFO) and with closed perforations (GFC) and the outside temperature (Out) during five test periods.

Table 2. Mean climate conditions and ammonia emission from grooved floor with open perforations (GFO) in comparison with reference floor (Ref).

Item	Period I		Period III		Period V	
	GFO	Ref	GFO	Ref	GFO	Ref
Number of measuring days	8	8	8	8	10	10
Temperature T_{in} (°C)	10.1	11.2	8.9	9.7	8.2	8.7
Temperature T_{out} (°C)	4.2	4.2	2.5	2.5	1.3	1.3
Relative Humidity (%)	75	78	81	82	81	84
Ventilation flow (m^3/h)	3360	3450	2820	2900	2580	2660
Ammonia concentration (g/m^3)	3.0	6.4	4.8	8.1	4.9	8.0
Ammonia emission ($\text{NH}_3 \text{ g/h}$)	9.7	21.1	13.1	22.9	12.4	20.8

Table 3. Mean climate conditions and ammonia emission from grooved floor with closed perforations (GFC) in comparison with reference floor (Ref).

Item	Period II		Period IV	
	GFC	Ref	GFC	Ref
Number of measuring days	6	6	10	10
Temperature T_{in} (°C)	8.4	9.4	4.0	4.4
Temperature T_{out} (°C)	1.6	1.6	-4.7	-4.7
Relative Humidity (%)	78	81	71	76
Ventilation flow (m ³ /h)	2620	2700	2275	2390
Ammonia concentration (g/m ³)	5.1	8.0	5.5	7.7
Ammonia emission (NH ₃ g/h)	13.1	21.4	12.5	18.4

Ammonia volatilization from a grooved floor with closed perforations was expected to be higher than from the floor with open perforations. This was because the urine could not drain away as easily as on the floor with open perforations. The maximum drainage distance of urine on the floor with perforations was 0.55 m (half of the 1.1 m spacing between perforations in a groove). On the floor without perforations, the maximum drainage distance in the test compartment was more than 11.0 m (length of the loafing alley). The longer the drainage distance, the larger the area covered by a urination of a cow and the larger the amount of urea not drained to the underfloor slurry pit and thus present on the floor surface. Monteny et al. (1998) demonstrated that the amount of urine had a substantial influence on ammonia emission from a floor surface. Reduction of drainage distance of a urine puddle is essential.

Ammonia emission from a naturally ventilated farm in practice with a grooved floor was measured by Huis in 't Veld and Scholtens (1998). The measurement period was January–April 1998. This farm had 97 cow places in a free-stall system with two rows of cubicles on each side of a central feeding alley. The mean inside temperature during the test was 12.2°C. On the base of 190 housing days, ammonia emission was 4.4 kg per cow. The reference ammonia emission rate as used in Dutch regulations of a dairy cow house with a slotted floor is 8.8 kg NH₃ per cow per 190 days (Anonymous, 1998). The measured ammonia emission was equal to a reduction of 50% when compared with the reference and is in accordance with the results of the experiments described here.

PERFORATIONS

Figure 7 shows the percentage of clogged perforations at eight observations spread over the experiments with the open perforations (GFO). The results show that the percentage of clogged perforations overall never exceeded 10% of the total number of perforations present in the floor ($n = 170$). Probably the pyramidal profile of the perforations in combination with the supply of fresh urine on the floor resulted in spontaneous unclogging of most of the blocked perforations. It appeared that the location of the clogged perforations varied. Figure 8 shows the percentage of clogged perforations per groove widthwise of the passage. Most of the clogged perforations were observed directly behind the feed rack. At this place, the perforations were least needed due to less urinating of the cows.

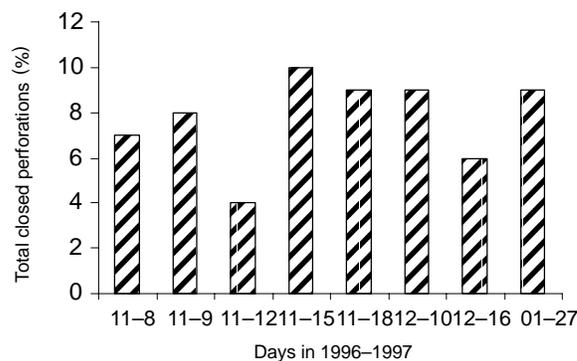


Figure 7. Number of clogged perforations in percentages of the total number of perforations (100% = 170) in the grooved floor during 8 measurements.

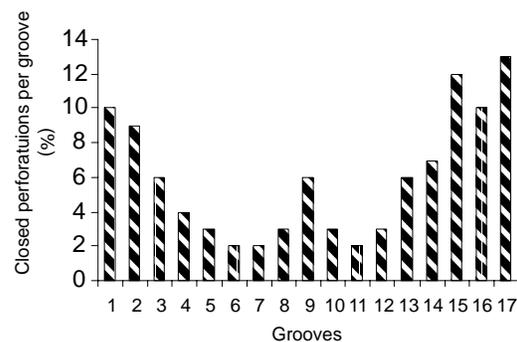


Figure 8. Total number of clogged perforations per groove in percentages in relation to the total number (100% = $8 \times 170 = 1360$) of measured perforations widthwise of the floor during 8 measurements (stalls next to groove 1; feed rack next to groove 17).

An inquiry was held during winter 1998–1999 on 10 Dutch practical farms with a grooved floor system (Goetstouwers, 1999). In this inquiry the performance of the perforations was also an item. No problems with perforation clogging were reported.

SLIPPERINESS

The locomotion of the cows on the grooved floor was not studied in this experiment. Before the grooved floor was put in use by the cows, the slip-resistance was measured. According to the Dutch standard NEN 3873 (1989), the slip-resistance was measured with a Leroux apparatus. The standard demands a mean Leroux value of 63 with a minimum of 58. In the experiment the measured mean value was 65 with a minimum of 61 and thus met the standard. Because the profile of the grooved floor (single beams and grooves) is equal to that of the slotted floor and because the slip-resistance meets the standard, it can be supposed that there is no significant difference in locomotion of the cows on the grooved floor in comparison with the slotted floor. Also, the inquiry of Goetstouwers (1999) reported overall positive experiences concerning the locomotion of the animals on this type of floor.

SAFETY

It is well known that slurry pits covered with slotted floors can contain gases toxic to cattle as well as to humans. When using grooved floors with a total floor opening less than 1% of the total floor area, the toxicity of air in the pit will be expected to be increased compared with the slotted floor. Therefore it is very important not to enter the slurry pit before the pit has been adequately ventilated.

APPLICATIONS

The grooved concrete floor elements can be constructed over a slurry pit in a cow house in the same way as slotted concrete elements. The additional investment costs of constructing a grooved floor compared with a slotted floor are approximately Euro 13 per m² (Swierstra et al., 1997). In a cubicle house for 90 cows, the total extra investments of the grooved floor and the scraper are approximately Euro 150 to 170 per cow place. This is approximately 5% additional to the total investment of a cow house of Euro 3300 per cow place (Braam and Van den Hoorn, 1996). The investment costs of a slurry scraper vary from Euro 87 to 130 per cow place. The annual running cost of the grooved floor system is approximately Euro 24 to 26 per cow place. With a reduction in ammonia emission on the standard of 8.8 kg NH₃ per cow by 4 kg (46%) per cow per housing period of 190 d, the annual costs are Euro 6.0 to 6.5 per kg ammonia emission reduction.

CONCLUSIONS

During a winter period, a grooved concrete floor with perforations and a scraper, in an experimental free-stall type of cow house, demonstrated a reduction of 46% of the ammonia emission when compared with an identical compartment with a slotted floor. The grooved floor without perforations gave a reduction of ammonia emission of 35%.

During the experiments, no more than 10% of the perforations became clogged. The locations of the clogged perforations varied. The highest percentage of perforations clogged up was behind the feed rack where least urination took place.

Results indicated that the slip resistance of the concrete grooved floor was not less than the slip resistance of slotted floors and it can be assumed that the locomotion of cattle was at least similar to locomotion on the slotted floor.

The additional investments required by the grooved floor system vary from Euro 150 to 170 per cow place. This is about 5% of the total investment of a cow house.

REFERENCES

Albutt, R., and J. Cermak. 1985. An approach to the development of improved floor surfaces for dairy cows. *Farm Buildings & Eng.* 2(2): 21–23.

Anonymous. 1995. Integral report on manure and ammonia policy (in Dutch). Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer en Ministerie van Landbouw, Natuurbeheer en Visserij, The Hague, The Netherlands.

_____. 1998. Wijziging Uitvoeringsregeling ammoniak en veehouderij. Interimwet ammoniak en veehouderij — Ministerie van Volkshuisvesting, Ruimtelijke Ordening en

Milieubeheer en Ministerie van Landbouw, Natuurbeheer en Visserij. Uit: Staatscourant 1998, nr. 245, 's-Gravenhage, p. 20.

Box, G. E. P., and G. M. Jenkins. 1976. *Time Series Analysis, Forecasting and Control*. San Francisco, Calif.: Holden-Day.

Braam, C. R., and C. J. Van den Hoorn. 1996. Concrete floors for animal houses with low ammonia emission (in Dutch, with English summary). *IMAD-DLO Rapport 96-12*. Wageningen, The Netherlands

Braam, C. R., M. C. J. Smits, H. Gunnink, and D. Swierstra. 1997a. Ammonia emission from a double-sloped floor in a cubicle house for dairy cows. *J. Agric. Eng. Res.* 68(4): 375–386.

Braam, C. R., J. J. M. H. Ketelaars, and M. C. J. Smits. 1997b. Effects of floor design and floor cleaning on ammonia emission from cubicle houses for dairy cows. *Netherlands J. Agric. Sci.* 45(1): 49–64.

Goetstouwers, S. 1999. Sleufvloer functioneert naar behoren. *Agrabeton* 9(4):18–19.

Heij, G. J., and T. Schneider. 1995. Dutch priority programme on acidification. Final report third phase Dutch priority programme on acidification. *RIVM Report No. 300-05*. Bilthoven, The Netherlands.

Huis in 't Veld, J. W. H., and R. Scholtens. 1998. Praktijkonderzoek naar de ammoniakemissie van stallen XXXXII – Natuurlijk geventileerde ligboxenstal met sleufvloer voor melkvee. *Dienst Landbouwkundig Onderzoek Rapport 98-1006*. Wageningen, The Netherlands.

Ketelaars, J. J. M. and H. Rap. 1994. Ammonia volatilization from urine applied to the floor of a dairy cow barn. In *Proc. 15th General Meeting of the European Grassland Federation*, 413–417, ed. L. 't Mannetje and J. Frame. Wageningen, The Netherlands: European Grassland Federation.

Kroodsmma, W., J. W. H. Huis in 't Veld, and R. Scholtens. 1993. Ammonia emission and its reduction from cubicle houses by flushing. *Livestock Prod. Sci.* 35(3–4): 293–302.

Monteny, G. J., D. D. Schulte, A. Elzing, and E. J. J. Lamaker. 1998. A conceptual mechanistic model for the ammonia emissions from free stall cubicle dairy cow houses. *Trans. ASAE* 41(1): 193–201.

NEN 3873. 1989. *Reinforced Concrete Slatted Floors in Livestock Housing Systems* (in Dutch). Delft/Gouda: Nederlands Normalisatie-instituut and CUR.

Scholtens, R. 1990. Ammoniakemissionsmessungen in zwangbelüfteten Ställe (Measurements of ammonia emission in animal housing with forced ventilation). In *Proc. Ammoniak in der Umwelt*, 20.1–20.9, ed. H. Döhler und H. Van den Weghe. Braunschweig, Darmstadt: Kuratorium für Technik und Bauwesen in der Landwirtschaft.

Smits, M. C. J., W. Kroodsmma, D. Swierstra, and W. J. De Boer. 1993. Framework of ammonia emission reduction research in the new IMAG-DLO experimental building for cattle (in Dutch, with English summary). *IMAG-DLO Rapport 93-8*. Wageningen, The Netherlands.

Swierstra, D., M. C. J. Smits, and W. Kroodsmma. 1995. Ammonia emission from cubicle houses for cattle with slatted and solid floors. *J. Agric. Eng. Res.* 62(2): 127–132.

Swierstra, D., M. C. J. Smits, and C. R. Braam. 1997. Grooved concrete floor elements to reduce ammonia emission and to prevent slipperiness in a loose house for cows. In *Proc. Concrete for a Sustainable Agriculture: Agro-, Aqua- and Community Applications*, 263–269, ed. E. Berge, H. Mageroey, and K. R. Berg. Oslo, Norway: Norwegian Concrete Association.

Swierstra, D. 1998. Stalvloer alsmede vloerelement voor toepassing in een dergelijke vloer. Patent No. NL1003271.

Van Eert, J. W. H., and M. C. J. Smits. 1996. Belloopbaarheid van hellende, dichte vloeren voor melkvee. In *IMAG-DLO Nota P 96-42*. Wageningen, The Netherlands.