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25/2025

Final report

Information about Techniques to consider in the Determination of BAT for the Intensive Rearing of Cattles

by:

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Abstract: Information about Techniques to consider in the Determination of BAT for the Intensive Rearing of Cattles

This document serves as the basis for the exchange of relevant information in order to determine the "Best Available Technique" in cattle farming. The techniques to be considered when determining the BAT are presented using a set structure. The document reports on a selection of potential techniques that could be selected as the BAT, including emerging techniques. The techniques considered (reduction techniques) are briefly described and a summary of their main impacts on the environment, other media and animal welfare are provided. The economic impact of the techniques is also described. Other criteria include statements about the usage of the techniques in practice (including example plants) and the driving force for the application of the techniques. The reduction techniques considered as the potential BAT can be implemented in the following types of production: dairy cows, calf rearing (up to 6 months of age), young cattle, beef cattle, calf fattening and suckler cows with their offspring. The reduction techniques relate to feeding and techniques used in the barn as well as to the storage, landspreading and handling of manure. The basis is the level of knowledge from 2021.

Kurzbeschreibung: Informationen über Minderungstechniken bei der Festlegung der BVT zu berücksichtigenden Techniken in der Intensiv-Rinderhaltung

Dieses Dokument dient als Grundlage für den Informationsaustausch zur Festlegung der „Besten Verfügbaren Technik“ in der Rinderhaltung. Die bei der Festlegung der BVT zu berücksichtigenden Techniken werden nach einem einheitlichen Schema dargestellt und stellen eine Auswahl der BVT-Kandidaten dar. Techniken in der Entwicklung („emerging techniques“) werden ebenso betrachtet. Die berücksichtigen Techniken (Minderungstechniken) werden kurz beschrieben sowie die wichtigsten Auswirkungen auf Umwelt, andere Medien, Tierwohl und Ökonomie zusammengefasst. Weitere Kriterien sind Aussagen über den praktischen Einsatz (inkl. Musteranlagen) und die Triebkraft für die Anwendung der Techniken. Bei der Festlegung der BVT zu berücksichtigende Minderungstechniken werden die Produktionsrichtungen Milchkühe, Kälberaufzucht (bis zum 6. Lebensmonat), Jungrinder, Mastrinder, Kälbermast sowie Mutterkühe mit deren Nachzucht betrachtet. Die Minderungstechniken beziehen sich auf die Fütterung, Techniken im Stall sowie auf die Wirtschaftsdüngerlagerung, -ausbringung und -behandlung. Grundlage ist der Kenntnisstand von 2021.

Table of content

List of tables ... 9

List of abbreviations ... 11

Summary ... 14

Zusammenfassung ... 16

1 Reduction techniques ... 18

1.1 Techniques to consider in the determination of Best Available Techniques (BAT) ... 18

1.1.1 Feeding ... 19

1.1.1.1 Nitrogen ... 19

1.1.2 Methane ... 24

1.1.2.1 Measures for determining ration composition ... 24

1.1.2.2 Feed supplements ... 28

1.1.3 In the barn ... 31

1.1.3.1 Low-emission floors in cattle farming ... 32

1.1.3.2 Cleaning devices for barn floors ... 62

1.1.3.3 Elevated feeding stalls with partitions separating feeding stations ... 69

1.1.3.4 Slurry acidification in the barn ... 74

1.1.3.5 Exhaust air treatment for reducing emissions in beddingless housing in calf fattening ... 80

1.1.4 In storage facilities ... 87

1.1.4.1 Slurry acidification in storage tanks ... 87

1.1.4.2 Covered storage of solid manure ... 91

1.1.4.3 Covered storage of liquid manure ... 93

1.1.5 During landspreading ... 96

1.1.5.1 Slurry application ... 96

1.1.6 Manure treatment ... 109

1.1.6.1 Separation of liquid manure ... 109

1.1.6.2 Anaerobic digestion of manure (biogas with gas-tight digestate storage) ... 113

1.1.7 Overview of the basic application possibilities and the techniques in the barn ... 120

2 Emerging techniques ... 122

2.1 Urease inhibitor (UI) ... 122

2.2 Urine catchment and collection device ... 125

3 List of references ... 129

List of Figures

Figure 1: Possible applications of low-emission floors in individual types of production ... 33
Figure 2: Emission of ammonia from excrements on the walkway and from the slurry channel below for a conventional perforated floor without sealing flaps ... 34
Figure 3: Perforated floors with sealing flaps to reduce air exchange and ammonia emissions in barns ... 34
Figure 4: Perforated, profiled floor with a reduced number of slits and sealing flaps in the slits; lateral view ... 35
Figure 5: Perforated, profiled floor with slits at larger, regular intervals and sealing flaps in the slits; view from above ... 35
Figure 6: Perforated, profiled floor with slits at larger, regular intervals and sealing flaps in the slits; lateral view ... 35
Figure 7: Lateral view of floor element with a close-up of the sealing flap which reduces gas exchange with the slurry channel ... 36
Figure 8: Perforated, profiled floor with sealing flaps ... 40
Figure 9: Surface properties of the low-emission, profiled barn floor with sealing flaps ... 40
Figure 10: Lateral view of floor element with a close-up of the sealing flap which reduces gas exchange with the slurry channel ... 40
Figure 11: Rubber mat with a reduced number of slits for perforated floors ... 45
Figure 12: Rubber mat with a reduced number of slits for a perforated floor, detailed view ... 45
Figure 13: Rubber mat with convex curvature towards the slits for a perforated floor, top view ... 50
Figure 14: Rubber mat with convex curvature towards the slits for a perforated floor, lateral view ... 50
Figure 15: Rubber mat with convex curvature towards the slits for a perforated floor, detailed view ... 51
Figure 16: Solid barn floor with a cross slope and urine-collection channel, view from above ... 54
Figure 17: Solid barn floor with a cross slope and urine-collection channel, front view ... 55
Figure 18: Solid, profiled floor with grooves, view from above ... 59
Figure 19: Solid, profiled floor with grooves, detailed view ... 59
Figure 20: Sketch of a robotic manure scraper on a solid barn floor ... 63
Figure 21: Sketch of a robotic manure scraper for perforated barn floors ... 65
Figure 22: Stationary scraper system with a chain ... 67
Figure 23: Elevated feeding stall with flexible partitions between each feeding station, lateral view from the front ... 70

Figure 24: Elevated feeding stall with flexible partitions between each feeding station, lateral view from the back 70
Figure 25: Elevated feeding stall with slanted feeding fence, lateral view 71
Figure 26: Use and application possibilities of elevated feeding stalls with partitions separating feeding stations, according to the individual types of production........ 72
Figure 27: Schematic diagram of slurry acidification in the barn........ 75
Figure 28: Use of slurry acidification in the barn, according to the individual types of production........ 77
Figure 29: Schematic diagram of a two-stage exhaust air treatment system in beddingless housing for calf fattening 82
Figure 30: Possibility of using exhaust air treatment systems with forced-air ventilation, according to the individual type of production 85
Figure 31: Schematic diagram of slurry acidification in a storage tank; arrows indicate adjustable height 88
Figure 32: Sketch of solid manure storage with permanent roofing 92
Figure 33: Solid manure storage with permanent roofing........ 92
Figure 34: Round tank with a fixed cover to prevent entry of rainwater and ensure a low-emission rate 94
Figure 35: Trailing hose distributor 97
Figure 36: Trailing shoe distributor 100
Figure 37: Slot injector........ 103
Figure 38: Arable injector 105
Figure 39: Schematic diagram of a vehicle used for slurry acidification during landspreading........ 108
Figure 40: Schematic diagram of a press screw separator (a) and a decanter centrifuge (b)........ 110
Figure 41: Schematic diagram of an agricultural biogas plant with the main plant components........ 115
Figure 42: Greenhouse gas emissions from biogas electricity for a 150 kW_{el} biogas plant (rated capacity) operated with 100 % cattle slurry; external heat use: 20 % of the heat produced; digester heating: 25 % of heat produced; reference for heat credit: natural gas heat; German electricity mix and fossil mix substituted by biogas for comparison. 118
Figure 43: Basic application possibilities and limitations of the reduction techniques to be considered in the determination of BAT in individual types of production in the barn 121
Figure 44: Formation of ammonia........ 122
Figure 45: Schematic representation of the mode of action of a urease inhibitor 122
Figure 46: Sketch of a urine catchment and collection device........ 126
Figure 47: Possible applications of a urine catchment and collection device, according to the types of production........ 127

List of tables

Table 1: Criteria for describing the techniques to be considered in the determination of BAT (reduction techniques) 18
Table 2: Indicative target values for the (utilizable) crude protein content in dry matter (DM) of the ration for cattle 20
Table 3: Mean N excretion of cattle per cubicle and year or per animal, taking into account the basic feed ration and animal productivity 21
Table 4: Calculation of N excretion of dairy cows (per cow and year) as well as excretion reduction in case of needs-adjusted N supply in comparison with standard values, taking into account animal productivity 22
Table 5: N excretion with faeces, urine and milk with different ruminal N balances (RNB) 23
Table 6: Effective emission-reduction measures related to ration composition and their impact on methane emissions 26
Table 7: Effective emission-reduction measures related to ration composition and their impact on animal productivity 26
Table 8: Effective reduction measures through feed supplements and their impact on methane (CH_4) emissions 29
Table 9: Effective emission-reduction measures through feed supplements and their impact on animal productivity 29
Table 10: Prices and emission factors for purchased feeds 31
Table 11: Overview of low-emission floor types currently available on the market 32
Table 12: Economic parameters of the perforated, profiled floor with a reduced number of slits and sealing flaps 38
Table 13: Economic parameters of the profiled, perforated floor with sealing flaps 43
Table 14: Economic parameters of a rubber mat with a reduced number of slits for a perforated floor 47
Table 15: Economic parameters for rubber mat with convex curvature towards the slits for a perforated floor 53
Table 16 Economic parameters of the solid floor with a cross slope and a urine-collection channel 56
Table 17: Economic parameters of the solid, profiled floor with grooves 60
Table 18: Overview of the possible use of robotic manure scrapers and collectors and stationary manure removal systems for different floor types with solid- or liquid-manure processes 62
Table 19: Fixed and variable costs as well as consumption of operating materials for a folding scraper 68
Table 20: Economic parameters of elevated feeding stalls with partitions separating feeding stations 73

Table 21: Economic parameters of slurry acidification in the barn 79
Table 22: Economic parameters of slurry acidification in a storage tank 89
Table 23: Investment related to the covering of solid manure storage 93
Table 24: Emission reduction potential of different covers for slurry tanks.......................... 95
Table 25: Investments and annual costs for different covers of slurry tank (manufacturer prices without VAT) 96
Table 26: Application costs and emission reduction costs for landspreading liquid manure with trailing hose distributors 99
Table 27: Application costs and emission reduction costs for landspreading liquid manure with trailing shoe distributors 102
Table 28: Application costs and emission reduction costs for landspreading liquid manure with slot injector 104
Table 29: Application costs and emission reduction costs for landspreading liquid manure with an arable injector 107
Table 30: Process engineering and economic parameters of separators 113
Table 31: Methane production and climate-relevant emissions in the form of NH_3, N_2O and CH_4 during the storage of cattle slurry in comparison to biogas utilisation 117
Table 32: Economic guideline values for exemplary new plants 119
Table 33: Economic guideline values for use of the urease inhibitor (UI) 124

List of abbreviations

3-NOP	3-Nitrooxypropanol
a	Year
AFP	German Federal Programme for the Promotion of Agricultural Investment (Agrarinvestitionsförderungsprogramm)
AP	Animal place
AwSV	Ordinance on Installations for Handling Water-Polluting Substances (Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen)
BAT	Best Available Technique (Beste verfügbare Technik)
BImSchG	Federal Immission Control Act (Bundesimmissionsschutzgesetz)
BREF	Best Available Techniques (BAT) reference documents (BVT-Merkblätter, Dokumente zu den besten verfügbaren Techniken)
CH_4	Methane
CHP	Combined heat and power
CO_2	Carbon dioxide
CO_2-eq.	CO_2-equivalent
CP	Crude protein
d	Day
DM	Dry Matter
DüV	Fertiliser Ordiance (Düngeverordnung)
EC	Energy crops
ECM	Energy-corrected milk
EEG	German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
EFSA	European Food Safety Authority (Europäische Behörde für Lebensmittelsicherheit)
EIP-Cattle	European Innovation Partnership Cattle - Construction in cattle farming - emission reductive, animal- and eco-friendly
el.	Electricity
EmiMin	Emission Reduction in Farm Animal Husbandry (Verbundvorhaben Emissionsminderung Nutztierhaltung)
eq.	Equivalent
EU	European Union
FM	Farm manure
g	Gram
GHG	Greenhouse gas emissions
IE	Industrial Emissions
IRPP	Intensive Rearing of Poultry or Pigs (Intensivtierhaltung von Geflügel und Schweinen)

JGS facilities	Storage of slurry, dung water and silage effluent (Jauche-Gülle-Silagesickersaft-Anlagen)
kg	Kilogram
KTBL	Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V.
kWh	Kilowatt hour
8	Liter
LAVES	Lower Saxony State Office for Consumer Protection and Food Safety (Niedersächsische Landesamt für Verbraucherschutz und Lebensmittelsicherheit)
IenW	Ministry of Infrastructure and Water Management (Ministerie van Infrastructuur en Waterstaat), Den Haag
LW	Live weight
m^2	Square meter
m^3	Cubic meter
ME	Metabolize energy
mg	Milligram
mS	Millisiemens
N	Nitrogen
n. a.	Not available
n. e.	No effect
N_2O	Nitrous oxide
NH_3	Ammonia
NO_{3-}	Nitrate
PP	Phosphorus
PraxREDUCE	Collaborative project: Implementation of urea inhibitor formulation for ammonia mitigation as well as sustainable, animal and environmental friendly cattle husbandry (Praktische Anwendung einer Ureaseinhibitor-Formulierung zur Minderung von Ammoniakemissionen in Ställen für eine nachhaltige, tier- und umweltgerechte Rinderhaltung)
PT	Pump tanker truck
R	Ruminants
Rav	Regeling ammoniak en veehouderij (Regulation on ammonia and livestock farming)
RGP	Residual gas potential
RNB	Ruminal N balance
s	Second
SCoPAFF	Standing Committee on Plants, Animals, Food and Feed (Ständiger Ausschuss für Pflanzen, Tiere, Lebensmittel und Futtermittel)
SIUK	Specific investment in environmental and climate protection (Spezifische Investitionen in Umwelt- und Klimaschutz)
SP	Self-propelled truck

TA Luft	German Technical Instructions on Air Quality Control (Technische Anleitung zur Reinhaltung der Luft)
TierSchNutztV	Animal Protection Keeping of Production Animals Ordinance (Tierschutznutztierhaltungsverordnung)
TMR	Total mixed ration
UBA	German Environment Agency (Umweltbundesamt)
uCP	Utilizable crude protein
UI	Urease inhibitor
UVP	Umweltverträglichkeitsprüfung
VDI	Association of German Engineers (Verein Deutscher Ingenieure)
VERA	Verification of Environmental Technologies for Agricultural Production

Summary

This document serves as the basis for the exchange of relevant information in order to determine the "Best Available Technique" in cattle farming. The Commission's implementing decision of February 10, 2012 on the guidelines for collecting data and drawing up BAT reference documents and their quality assurance defines the term "best" as the technique that is the most effective in achieving a good general level of protection of the environment. The term "available" implies that the technique is an economically viable option that can be implemented in the relevant sector under technically acceptable conditions, and that there is practical experience with the technique that goes beyond testing in pilot plants. The term "technique" includes the technology used and, in particular, the way in which a livestock facility is maintained and operated (management of the facility, proper professional practices).

The techniques to be considered when determining the BAT are presented using a set structure. The document reports on a selection of potential techniques that could be selected as the BAT, including emerging techniques. The techniques considered (reduction techniques) are briefly described and a summary of their main impacts on the environment, other media and animal welfare are provided. The economic impact of the techniques is also described. Other criteria include statements about the usage of the techniques in practice (including example plants) and the driving force for the application of the techniques. The reduction techniques considered as the potential BAT can be implemented in the following types of production: dairy cows, calf rearing (up to 6 months of age), young cattle, beef cattle, calf fattening and suckler cows with their offspring. The reduction techniques relate to feeding and techniques used in the barn as well as to the storage, landspreading and handling of manure. Specifically, the techniques are as follows:

- Feeding
  - Nitrogen-adapted feeding
  - Optimal energy-protein ratio of the ration
  - Measures for determining ration composition
  - Feed supplements
- In the barn
  - Low-emission floors
  - Cleaning devices for barn floors
  - Elevated feeding stalls with flexible partitions between feeding stations
  - Slurry acidification in the barn
  - Exhaust air treatment
- In storage
  - Slurry acidification in storage
  - Covered storage of solid manure
  - Covered storage of liquid manure
- During landspreading
  - Slurry acidification during landspreading

Landspreading of liquid manure

- Manure treatment

  Separation of liquid manure

  Anaerobic digestion of manure (biogas with gas-tight digestate storage)

- Emerging techniques

  Urease inhibitor

  Urine-collection device

The document presents the potential applications in cattle farming facilities of the BAT techniques under consideration and outlines any limitations regarding their use which need to be taken into account.

The basis is the level of knowledge from 2021.

Zusammenfassung

Dieses Dokument dient als Grundlage für den Informationsaustausch zur Festlegung der „Besten Verfügbaren Technik“ in der Rinderhaltung. Gemäß dem Durchführungsbeschluss der Kommission vom 10. Februar 2012 über die Leitlinien für die Erhebung von Daten sowie für die Ausarbeitung der BVT-Merkblätter und die entsprechenden Qualitätssicherungsmaßnahmen bezeichnet der Begriff „beste“ die Technik, die am wirksamsten zur Erreichung eines allgemeinen Schutzniveaus für die Umwelt erreicht werden kann. Der Begriff „verfügbar“ setzt voraus, dass die Technik im jeweiligen Sektor unter technisch vertretbaren Verhältnissen wirtschaftlich einsetzbar ist und praktische Erfahrungen vorliegen, die über den Status von Versuchsanlagen hinausgehen. Der Begriff „Technik“ umfasst neben der angewandten Technologie insbesondere auch die Art und Weise, wie eine Tierhaltungsanlage gewartet und betrieben wird (Management einer Anlage, gute fachliche Praxis).

Die bei der Festlegung der BVT zu berücksichtigenden Techniken werden nach einem einheitlichen Schema dargestellt und stellen eine Auswahl der BVT-Kandidaten dar. Techniken in der Entwicklung („emerging techniques“) werden ebenso betrachtet. Die berücksichtigen Techniken (Minderungstechniken) werden kurz beschrieben sowie die wichtigsten Auswirkungen auf Umwelt, andere Medien, Tierwohl und Ökonomie zusammengefasst. Weitere Kriterien sind Aussagen über den praktischen Einsatz (inkl. Musteranlagen) und die Triebkraft für die Anwendung der Techniken. Bei der Festlegung der BVT zu berücksichtigende Minderungstechniken werden die Produktionsrichtungen Milchkühe, Kälberaufzucht (bis zum 6. Lebensmonat), Jungrinder, Mastrinder, Kälbermast sowie Mutterkühe mit deren Nachzucht betrachtet. Die Minderungstechniken beziehen sich auf die Fütterung, Techniken im Stall sowie auf die Wirtschaftsdüngerlagerung, -ausbringung und -behandlung. Im Einzelnen handelt es sich um folgende Techniken:

- Fütterung
  - Stickstoff angepasste Fütterung
  - Rationen mit optimalen Energie-Protein-Verhältnis
  - Maßnahmen der Rationsgestaltung
  - Futterzusatzstoffe
- Im Stall
  - Emissionsmindernde Stallböden
  - Reinigungsvorrichtungen für Stallböden
  - Erhöhte Fressstände mit Fressplatzabtrennungen
  - Gülleansäuerung im Stall
  - Abluftreinigung
- Im Lager
  - Gülleansäuerung im Lager

Abdeckung fester Wirtschaftsdünger

Abdeckung flüssiger Wirtschaftsdünger

- Während der Ausbringung

  Gülleansäuerung während der Ausbringung

  Flüssigmistausbringung

- Wirtschaftsdüngerbehandlung

  Separation flüssiger Wirtschaftsdünger

  Güllevergärung (Biogas mit gasdichter Gärrestlagerung)

- Techniken in der Entwicklung („emerging techniques")

  Ureaseinhibitor

  Harnauffang- und Sammeleinrichtung

Für die festzulegenden BVT-Techniken werden die Einsatzmöglichkeiten in den Produktionsrichtung der Rinderhaltung dargestellt und die Einschränkungen beim Einsatz aufgezeigt, die zu berücksichtigen sind.

Grundlage ist der Kenntnisstand von 2021.

1 Reduction techniques

1.1 Techniques to consider in the determination of Best Available Techniques (BAT)

This report describes reduction techniques used in cattle farming which could potentially be selected as BAT in cattle farming. These reduction techniques cannot be combined with every housing system or applied to every type of production. Possible applications for these techniques are presented in Chapter 1.1.7 (from p.120).

The description of the techniques that are potential BAT is based on the following aspects:

Table 1: Criteria for describing the techniques to be considered in the determination of BAT (reduction techniques)

Term	Definition
Brief description	
Technical description	Technical description incl. brief explanation of plant technology
Achieved environmental benefits	Most important environmental effects, potentially achievable main benefits (e.g. emission reduction, energy consumption reduction) (e.g. ammonia, odour, methane, nitrogen oxides (NO_X), energy, process water, noise)
Environmental performance and operational data	Plant-specific performance data (including emission values, operating values, consumption values - for raw materials, water and energy) Vulnerability/stability of the technique, accident prevention Control capability for regular operation (e.g. pH value measurement)
Cross-media effects	Description of the side effects caused by the use of the technique and effects on other media. (e.g. ammonia, odour, methane, nitrogen oxides (NO_X), energy, process water, noise)
Animal welfare	Description of animal welfare issues: effects on animal behaviour and health
Technical considerations relevant to applicability	Consideration of implementation in practice and possible usage restrictions
Economics	Information on costs (annual investment and operating costs, reduction costs), cost-saving opportunities (e.g. regarding consumption, waste charges)
Driving force for implementation	Conditions promoting the use of the technique (guidelines, incentives, subsidies, etc.) in addition to environmental aspects Local conditions or requirements for introducing the technique Information on non-environment-related reasons for introducing the technique (e.g. consumer preferences, market research, animal welfare, incentive programmes, etc.)
Example plants	Plants in Germany, Europe or in an EU member state that are already implementing the technique. If the technique is not yet implemented in this area in Europe or elsewhere, a brief explanation is provided

The techniques that could potentially be selected as BAT are related to the following areas: feeding (Chapter 0), techniques used in the barn (Chapter 1.1.3), storage (Chapter 1.1.4), landspreading (Chapter 1.1.5), manure treatment (Chapter 1.1.5.1.5) and emerging techniques (Chapter 2).

Feeding

1.1.1 Nitrogen

In addition to affecting animal productivity in terms of milk and meat, the nitrogen supply to cattle also influences the level of N excretion in faeces and urine. The potential of animals to use the N they ingest to produce milk and live weight is limited by their biological conditions. Between 5% and 35% of the ingested N is used efficiently (Chase 2003, Powell et al. 2010). The unused N which they excrete (in the case of excess intake, mainly via urine) (Castillo et al. 2000, 2001) significantly contributes to the formation of ammonia in addition to nitrous oxide. Hence, a reduction in the N compounds in faeces decreases the potential of NH_3 and N_2O emission generation.

The N metabolism of cattle is subject to several factors. For this reason, it is crucial that the forestomach is supplied with microbes as efficiently as possible and that the small intestine is provided with usable crude protein (uXP).

The feeding measures described below can be used to mitigate unwanted N emissions.

1.1.1.1 N-adapted feeding

Brief description

By adjusting the N supply to the lactation and growth curves of animals, it is possible to reduce the share of unused, excreted N in faeces and urine (Arriaga et al. 2009, Firkins and Reynolds 2005). This N share is quantified using nutrient balancing:

Intake (N) - Animal products (N) = Excretion (N).

Technical description

To correctly adjust the N content to demand, knowledge about animal productivity, specifically regarding live weight gains and milk yield, is necessary. The amount of nutrients ingested must be determined through analyses, in particular of the basic feed. In addition, the relevant declaration of purchased feed must be taken into account.

The N supply can be adjusted, for example by forming productivity groups, deploying automatic feeding and milking systems, and in the future, by introducing practical technical implementations in addition to monitoring the animals' access to the feeding table (Denißen 2021). Performance-adapted allocation of feed can be facilitated by equipping feed mixer with control elements and weighing devices or comparable technology. The animals' actual feed intake can be estimated by additionally determining the feed residues. It is also necessary to record the harvest volumes, taking into account losses during the silage process of grass and corn.

To determine the N supply in dairy cows, the milk urea content can be a useful parameter. Various influencing factors are taken into account, such as the lactation stage, milk yield, live weight, water intake and level of protein supply (Flachowsky and Lebzien 2007, Spek et al. 2013). Milk urea concentrations should be between 150 - 250 mg/l, although values > 250 mg/l milk may occur when the ration contains larger proportions of pasture grass or protein-rich grass silage (Glatz-Hoppe et al. 2019).

Unlike monogastric animals, ruminants have rumen microbes that can synthesize essential amino acids. N use efficiency can be improved in lactating dairy cattle by using protected lysine and methionine, parallel to reducing crude protein intake (Schuba and Südekum 2012).

Achieved environmental benefits

Performance-adapted N intake by animals reduces the amount of N excreted through urine and faeces. Sajeev et al. (2018) showed that for every percentage point of reduction in crude protein (CP) in the ration, up to 17% (± 6%) less NH_3 emissions were produced in the barn, storage and during landspreading.

The possibility of adjusting N intake, and thus reducing environmental impact, depends on the original supply situation and the productivity level of the animals.

Environmental performance and operational data

In addition to monitoring the N supply via the milk urea content, additional data can be obtained from the CP content or the utilizable CP content (uCP) in the ration (Table 2).

Table 3 shows the mean N excretions of cattle from different types of production.

Table 4 compares the mean N excretions with the N excretions with needs-adjusted supply, for dairy cows as an example.

Table 2: Indicative target values for the (utilizable) crude protein content in dry matter (DM) of the ration for cattle

Type of production	CP (% DM)	uCP (% DM)	Source
Dairy cattle (early lactation, by milk yield)	14.5 - 16	15 - 16.5	Frank et al. 2002 Bonsels et al. 2020
Dairy cattle (late lactation, by milk yield)	12.5 - 14	13 - 14.5	Frank et al. 2002 Bonsels et al. 2020
Dry cattle	11.5 - 12	12	Bonsels et al. 2020
Rearing cattle (up to 400 kg LW)	10 - 13		GfE 2001
Rearing cattle (from 400 kg LW)	9 - 13		GfE 2001
Feeders (depending on daily gain and LW)	13 - 20		LfL 2020b
Fattening bulls (200-400 kg LW, depending on daily gain)	13 - 14		LfL 2020b
Fattening bulls (400-750 kg LW, depending on daily gain)	12 - 12.5		LfL 2020b
Fattening calves	16 - 19		Averbeck et al. 2021
Suckler cows (depending on LW and stage of lactation)	8 - 13		Brändle et al. 2009

LW = live weight, CP = crude protein, uCP = utilizable crude protein; DM = dry matter

Table 3: Mean N excretion of cattle per cubicle and year or per animal, taking into account the basic feed ration and animal productivity

	Grassland based **farm**		**Arable** based **farm**	
		Dairy cows (per cow and year)		
6,000 kg ECM	109 kg N	18.2 g N/kg ECM	100 kg N	16.7 g N/kg ECM
8,000 kg ECM	124 kg N	15.5 g N/kg ECM	115 kg N	14.4 g N/kg ECM
10,000 kg ECM	141 kg N	14.1 g N/kg ECM	133 kg N	13.3 g N/kg ECM
12,000 kg ECM	-	-	152 kg N	12.7 g N/kg ECM
		Young cattle rearing, first calving age 27 months (per animal)		
605 kg gain	129 kg N [1]	213.2 g N/kg gain	102 kg N	168.6 g N/kg gain
		Suckler cow husbandry, 700 kg LW (per cow and year)		
6 months suckling, 230 kg weaning weight	105 [1]	456.5 g N/kg gain	-	-
9 months suckling, 340 kg weaning weight	114 [1]	335.3 g N/kg gain	-	-
		Cattle fattening, from 45 kg LW (per animal)		
Bull, up to 675 kg LW	-	-	58 kg N	92.1 g N/kg gain
Bull, up to 750 kg LW	-	-	62 kg N	87.9 g N/kg gain

ECM = Energy-corrected milk (4.0% fat and 3.4% protein); LW = live weight; grassland farm = quantity of roughage consumed-DM with more than 75% from grass products
1 with pasture

Source: DLG 2014

Table 4: Calculation of N excretion of dairy cows (per cow and year) as well as excretion reduction in case of needs-adjusted N supply in comparison with standard values, taking into account animal productivity

	Arable based **farm**				
	mean N intake (kg)	**mean N excretion (kg)**	**needs-adjusted N intake (kg)**	**Needs-adjusted N excretion (kg)**	**Reduction (%)**
6,000 kg ECM	132	100	125	92	7
8,000 kg ECM	159	115	149	105	9
10,000 kg ECM	187	133	169	115	13
12,000 kg ECM	216	152	194	129	15

ECM = Energy-corrected milk (4.0% fat and 3.4% protein)

Source: DLG 2014, Bonsels et al. 2020

Cross-media effects

No information available.

Animal welfare

No information available.

Technical considerations relevant to applicability

This feeding measure can be applied to farms with indoor housing systems, provided that the parameters specified under "Technical Description" are taken into account. However, the necessary equipment and technology are not available on every cattle farm, often due to the sometimes-high economic investment required to purchase them. In extensive farming systems with a low supply of additional feed or in farms where the animals have access to pasture, on the other hand, it is very difficult to control feed intake which depends essentially on plant growth in the pastures.

Economics

Knowledge of the amounts of nutrients ingested via the basic feed allows curbing of the use of cost-intensive concentrates.

Driving force for implementation

Controlling the N intake and, in turn, N excretion has become especially important for farms in nitrate-polluted areas since the new Fertiliser Ordinance (DüV 2017) and the obligatory documentation of fertilisation measures came into effect.

Example plants

N-adjusted feeding is already practised by agricultural holdings. At present, however, it is not (technically) possible to collect evidence on the extent to which N-adjusted feeding is practised across the entire farm. To ensure comprehensible documentation, it is essential to carry out farm-specific feed analyses, implement performance-oriented calculation of rations and compare these findings with the practical feeding situation several times a year. To achieve this, automatic feeding systems, which are used in dairy cow husbandry and also in cattle fattening in several 100 farms, offer good conditions (Oberschätzl-Kopp and Haidn 2014).

1.1.1.1.1 Optimal energy-protein ratio of the ration

Brief description

A balanced energy-protein ratio in the ration optimises ruminal protein synthesis and thus reduces the excreted amount of N.

Technical description

The supply of carbohydrates and the availability of N are both critical for the growth of microbes in the rumen, which enable protein synthesis and the provision of essential amino acids. In addition to meeting the energy and N requirements of the animal, it is necessary to ensure that the animal produces the required microbes, and that surpluses are avoided (Flachowsky and Lebzien 2007, Castillo et al. 2001). The amount of utilizable crude protein in the duodenum (uCP) required by the animals must also be considered.

The ruminal N balance (RNB) represents a measure of the supply of rumen microbes and is calculated according to the German protein evaluation system (GfE 2001) as follows:

$$(\text{CP intake} - \text{uCP intake})/6.25 = \text{RNB}$$

A balanced RNB is achieved by combining feed with positive and negative RNB as appropriate.

Achieved environmental benefits

If the ration has a positive RNB, this indicates an excess of N in the rumen. Thus, the ability of the micro-organisms in the rumen to use recycled urea to meet the protein requirements by means of enterohepatic circulation is not utilised. The excess urea is excreted in urine, resulting in avoidable NH_3 emissions. When nitrogen, rather than energy, limits microbial synthesis in the rumen, much of the N is excreted in the faeces as indigestible microbial N (Kebreab et al. 2002).

Environmental performance and operational data

Table 5 shows the relationship between the ruminal N balance and the excretion via milk, urine and faeces. In this context, the N available in the rumen ranging between +0.3 and-0.6 g RNB/MJ ME shows a significant decrease in the amount of N excreted in the urine.

Table 5: N excretion with faeces, urine and milk with different ruminal N balances (RNB)

RNB (g/MJ ME)	N urea (g/d)	N faeces (g/d)	Milk urea N (mg/dl)
-0.6	67	89	3.2
-0.3	81	96	4.8
0	153	110	10.1
0.3	262	104	15.2

Source: Riemeier 2004

Cross-media effects

No information available.

Animal welfare

No information available.

Technical considerations relevant to applicability

Achieving a favourable energy-protein ratio is especially challenging in pasture-based systems. If most of the roughage is produced on permanent pastures because of the farm's location, there is also only limited scope for action. However, balancing the energy-protein ratio can be partially accomplished by supplementing with feed that is rich in energy- but contains relatively low crude protein, such as corn silage or cereals, while providing adequate fibre.

Economics

The costs of the above-mentioned measure depend on a farm's location, its available grassland and arable fodder growth. The decisive factor is the extent to which additional feed must be purchased to ensure an optimal energy-protein ratio in the feed ration.

Driving force for implementation

Ensuring a balanced RNB and, in turn, controlling N-excretion is especially important for farms in nitrate-polluted areas since the new Fertiliser Ordinance (DüV 2017) and the obligatory documentation of actual fertilisation measures came into effect.

Example plants

Determination of the optimal energy-protein ratios is already practised by agricultural consultants and, therefore, by agricultural holdings.

1.1.2 Methane

In addition to being produced during manure storage, methane (CH_4) emissions result from cattle digestion – enteric fermentation – and have a measurable impact on CH_4 emissions from agriculture.

CH_4 is produced during digestion when the cell-wall components of plants are broken down by methane-forming micro-organisms in the rumen. It is thus biologically linked to the possibility of utilising fibre components and, in turn, producing food. The microbial population of the rumen is influenced by the composition and amount of feed ingested, thus affecting the amount of methane produced. The leakage of CH_4 constitutes a loss, not only for the environment, but also for the animal's energy balance. There are various measures for reducing such leakages which involve adjusting animal feed.

When evaluating such measures, it is important to keep in mind that methane production is associated with the conversion of plant components that are not digestible for humans into animal protein. Often, the measures listed below involve inhibiting this biological process in order to mitigate enteric methane emissions.

To date, research has yielded insufficient scientific evidence regarding the duration of action, food quality and dosage of feed supplements that pose an economic burden. Furthermore, the measures are not equally suitable for every cattle farm.

1.1.2.1 Measures for determining ration composition

Brief description

The CH_4 emissions from digestion can be influenced by the following ration formulation measures:

1. Increased feeding of non-structural carbohydrates
2. Increasing feed intake and decreasing grass maturity

Technical description

1. Increased feeding of non-structural carbohydrates

Through chewing and re-chewing, high-fibre plant material in the ration is crushed, promoting salivation. The formation of saliva, which occurs mainly in the parotid gland, leads to the secretion of sodium, potassium, phosphate and bicarbonate, among others. The high concentration of mineral ions results in a pH of the rumen juice that is only weakly acidic. This in turn affects the population of methanogenic microbes in the rumen and, at the same time, the resulting pattern of fatty acids. Acetate is predominantly produced. At the same time, hydrogen is produced, which is reduced to CH_4 via CO_2. An increased intake of rations high in sugar and starch, on the other hand, decreases the pH value in the rumen as a result of a faster feed intake and a high passage rate. This favours the growth of micro-organisms that form a higher quantity of propionate and butyrate, producing either no hydrogen at all or a smaller amount (van Soest 1994). However, it should be taken into account that the degree of CH_4 reduction depends on other factors, such as the type of concentrated feedstuffs and composition of the total ration.

2. Increasing feed intake and decreasing grass maturity

Various authors (e.g. Ellis et al. 2007) have shown that CH_4 emissions from digestion rise with an increasing intake of dry matter. Arndt et al. (2021) point out, however, that increasing feed intake represents an emission reduction strategy, especially for animals in certain climatic regions where there is an insufficient supply of feed containing sufficient nutrients. As a result, daily CH_4 emissions increase, but emissions per unit of animal product decrease.

In general, reduced CH_4 emissions are correlated with higher nutrient quality and digestibility. Note that the degree of maturity of the basic feed can be an indicator of these two characteristics (Hristov et al. 2013).

Achieved environmental benefits

Based on an extensive literature review, Arndt et al. (2021) found that the CH_4 emissions per unit of feed ingested could be reduced by 13% by **increasing the amount of concentrate in the ration**. They did not detect an increase in daily CH_4 emissions, despite increasing feed intake. At the same time, they reported a positive effect on both live-weight gain (+21%) and milk yield (+17%).

Although higher feed intake and the **use of early-cut green forage** increase daily CH_4 emissions by 18% on average, productivity rises (live-weight gain + 162% and milk yield + 17%), thus reducing CH_4 emissions per unit of product by 17% (milk). Likewise, the fattening period can be shortened.

For lactating animals, no reduction in daily CH_4 emissions was found when using early-cut forage in the ration. However, due to the higher digestible energy and protein content, milk yield increased (+ 9%) and, as a result, CH_4 emissions per unit of product were 13% lower (Arndt et al. 2021).

Environmental performance and operational data

The two above-mentioned measures for reducing enteric CH_4 emissions have an effect depending on the composition of the ration, the amount of feed consumed and animal productivity, among other factors. Table 6 and Table 7 show the effects on CH_4 emissions and animal productivity.

Table 6: Effective emission-reduction measures related to ration composition and their impact on methane emissions

Reduction measure	Potential CH_4 emission reduction per day (%)	Potential CH_4 emission reduction per unit of feed intake (%)	Potential CH_4 emission reduction per unit of live-weight increase (%)	Potential CH_4 emission reduction per unit of milk volume (%)	Relevant production systems	Relevant ruminant species
Reduction of the fibrous feed-concentrate ratio	-	-	-9	-9	Indoor housing system	Cattle, small R, other R
Increase in feeding quantity	-	-	n. a.	-17	Barn and pasture keeping system	Cattle, small R, other R
Reduction of grass maturity	-	-	n. a.	-13	Barn and pasture keeping system	Lactating cattle, sheep

n. a. = not available; n. e. = no effect; R = ruminants

Source: Arndt et al. 2021

Table 7: Effective emission-reduction measures related to ration composition and their impact on animal productivity

Reduction measure	Feed intake (%)	Digestibility (%)	Gain (%)	Milk yield (%)
Reduction of the fibrous feed-concentrate ratio	9	n. e.	21	17
Increase in feeding quantity	58	-7	162	17
Reduction of grass maturity	n. e.	15	n. a.	9

n. a. = not available; n. e. = no effect

Source: Arndt et al. 2021

Cross-media effects

A **reduction of roughage** in ruminant rations is offset by other ecological factors, such as excellent grassland utilisation, which is the only form of agricultural use for farms in many locations. In addition, the use of grassland for feed production and grazing preserves the cultivated landscape. Furthermore, the cultivation, production and transport of concentrates usually incurs a higher use of fossil energy than the exploitation of basic fodder, which results in higher CO_2 emissions (KTBL 2017b, Brade and Wimmers 2016). The thus increasing competition between feed and food can be mitigated by the use of co-products from the food industry (Arndt et al. 2021).

The IPCC (2006) has identified additional potential for reducing CH_4 emissions from slurry by **using early-cut forage** due to the increased fibre digestibility. However, animal intake of N in excess to their requirements can lead to increased NH_3 emissions from husbandry and N_2O emissions from manure storage.

Animal welfare

Increasing the **feeding of concentrates** above a certain level is not a suitable diet for ruminants. The latter should contain an appropriate share of structured fibre depending on the dry matter intake and starch content of the ration (Zebeli and Humer 2016) in order to maintain normal rumen function and reduce the risk of diet-related disease.

Technical considerations relevant to applicability

Both of the above feeding measures can be applied in farms with indoor housing systems, taking into account the productivity level, existing feed intake and animal health.

In extensive farming systems with a low supply of additional feed or in farms where the animals have access to pasture, on the other hand, it is very difficult to control feed intake which depends essentially on plant growth in the pastures.

Economics

The cost-effectiveness of the strategy of **increasing the use of concentrate** depends on the costs of feed and concentrate as well as on the resulting increases in animal production and the price of animal products (meat and milk) (Arndt et al. 2021).

Although it increases the nutrient efficiency of milk production, the measure of using **early-cut green forage** has been evaluated as not cost-effective (Arndt et al. 2021).

Research by van Middelaar et al. (2014) estimated this strategy to cost € 57/t CO_2 equivalent and thus to be more efficient than the addition of oilseeds (flaxseed) and nitrate.

Driving force for implementation

There is currently no legal regulation to reduce CH_4 emissions from animal husbandry. Given that some of the above-mentioned measures require high financial outlays and do not yield a monetary return or raise animal productivity, that is, raise the price obtained for the animal product, their use in practice is unlikely.

Example plants

No information available.

1.1.2.2 Feed supplements

Brief description

The CH_4 emissions from digestion can be influenced by the following feed supplements, amongst others:

1. 3-Nitrooxypropanol (3-NOP)
2. Oils, fats and oilseeds
3. Nitrate
4. Tannins

Technical description

The synthetic feed supplement 3-NOP inhibits methane. It has an analogous structure to the methyl coenzyme-M. 3-NOP binds to the enzyme methyl-coenzyme-M reductase, a key enzyme in the pathway of the methanogenesis of archaea and makes them inactive. This interrupts the last step of methanogenesis, the reduction of CO_2 to CH_4.

By adding more **oils, fats or oilseeds** to the ration, a greater amount of non-fermentable, highly digestible energy can be made available to the animal. At the same time, however, feed intake (-6%) and fibre digestibility (-4%) are reduced, and unsaturated or medium-chain saturated fats inhibit methanogenesis.

Nitrate acts as an electron acceptor. In this process, the intake of hydrogen reduces NO_3- in the rumen to NH_3. From an energy perspective, this is preferable to reducing CO_2 to CH_4.

Tannins can inhibit the growth or activity of methanogens and protozoa in the rumen through bactericidal or bacteriostatic activities.

Achieved environmental benefits

Supplementing feed with **3-NOP** reduces daily CH_4 emissions by 39% on average (Arndt et al. 2021). Neither feed intake nor milk yield are negatively affected.

The inhibition of methanogenesis by adding **oils, fats or oilseeds** reduces daily CH_4 emissions by about 20%, while animal productivity remains stable. Vegetable oils and oilseeds that effectively reduce daily CH_4 emissions are: coconut oil (-28%), rapeseed oil (-22%) and rape seeds (-13%), flax oil (-22%) and flax seeds (-17%), sunflower oil (-17%) and sunflower seeds (-39%) as well as cotton seeds (-19%) (Arndt et al. 2021).

Through use of the electron acceptor **nitrate**, daily CH_4 emissions can be reduced by about 17%. Nitrate use slightly decreases feed intake and milk yield (Arndt et al. 2021).

When **basic fodder containing tannin** is used, daily CH_4 emissions have been found to decrease by 12% without affecting feed intake or animal productivity. Bush clover*(Lespedeza cuneata*) reduced the daily CH_4 emissions from goats by 32%, also without affecting their feed intake (Arndt et al. 2021).

Environmental performance and operational data

Melgar et al. (2021) report a 26% reduction in daily CH_4emissions when **3-NOP** is added to the ration of dairy cows with a dose of 60 mg **3-NOP/kg** of dry matter in the feed.

For cattle, a 10 g/kg increase in the **fat content of** the ration reduces CH_4 emissions by 1 g/kg of the dry matter intake. Note that the relationship between the fat concentration in the feed and CH_4 emissions from digestion is not dependent on the form of added fat (i.e. oil or oilseed), the major fatty acids in the added fat (i.e. C12:0 and C:14, C18:1, C18:2, and C18:3) or the fat source (i.e. rapeseed, coconut, fatty acid, flaxseed, soy bean, sunflower, basic staple diet with no added fat) (Grainger and Beauchemin 2011). Hristov et al. (2013) show in a literature analysis that research has yielded inconsistent results on the duration of the effect of using oils, fats and oilseeds in the ration on CH_4 emissions from digestion.

Table 8: Effective reduction measures through feed supplements and their impact on methane (CH_4) emissions

Reduction measure	Potential CH_4 emission reduction per day (%)	Potential CH_4 emission reduction per unit of feed intake (%)	Potential CH_4 emission reduction per unit of live-weight increase (%)	Potential CH_4 emission reduction per unit of milk volume (%)	Relevant production systems	Relevant ruminant species
CH_4 inhibitors	-35	-34	n. a.	-32	Indoor housing system	Cattle, small R
Oils and fats	-19	-15	-22	-12	Indoor housing system	Cattle, sheep
Oilseeds	-20	-14	n. a.	-12	Indoor housing system	Lactating cattle
Electron sinks	-17	-15	-12	-13	Indoor housing system	Cattle, small R
Tannins	-12	-10	n. a.	-18	Barn and pasture keeping system	Cattle, sheep

n. a. = not available; n. e. = no effect; R = ruminants

Source: Arndt et al. 2021

Table 9: Effective emission-reduction measures through feed supplements and their impact on animal productivity

Reduction measure	Feed intake (%)	Digestibility (%)	Gain (%)	Milk yield (%)
CH_4 inhibitors	n. e.	n. e.	n. e.	n. e.
Oils and fats	-6	-4	n. e.	n. e.
Oilseeds	n. e.	-8	-13	n. e.
Electron sinks	-2	n. e.	n. e.	3
Tannins	n. e.	-7	n. e.	n. e.

n. e. = no effect

Source: Arndt et al. 2021

Tannins can only be expected to have reliable and noticeable effects if their concentration exceeds 20 g/kg of dry matter in the feed (Jayanegara et al. 2012). Although a meta-analysis by

Arndt et al. (2021) found that tannin-containing diets had no effect on feed intake, such diets are associated with lower palatability and decreasing feed intake. Table 8 and Table 9 show their effect on CH_4 emissions and animal productivity.

Cross-media effects

Tannins can decrease protein digestibility, which can reduce the N excreted in urine if combined with protein intake in excess of animal requirements or with amounts of highly digestible protein. This decrease in N excretion is beneficial as it reduces NH_3 emissions.

In the case of feed supplements that reduce fibre digestibility (**tannins, oils and oilseeds**), it is necessary to evaluate the extent to which CH_4 emissions from manure storage increase (IPCC 2006).

Hypotheses that the use of **nitrate supplements** increases N_2O emissions from the digestive tract have not been confirmed. The amount of N_2O produced in the rumen is negligible, but it is likely that the amount of N_2O emissions from manure increases due to nitrification and denitrification (Lee and Beauchemin 2014). Petersen et al. (2015) reported N_2O emissions between 0.7 and 1.0% when dairy cows ingested nitrate in different doses, thus lowering the total reduction effect on greenhouse gases by 2 and 7%, respectively. However, supplementing the ration with nitrate can lead to increased N excretion by the animal and, in turn, to a rise in NH_3 emissions.

Animal welfare

The use of **nitrate** can have a toxic effect on the animal. A potential problem is that the rumen ecosystem adapts to the supplement. However, there have been no long-term animal studies on the effect of this adaptation. Furthermore, the total nitrate content of the ration should be considered when supplementing with nitrate (Hristov et al. 2013).

The amount of **oils and fats** ingested by ruminants should be limited to allow healthy rumen fermentation. An overdose has a negative effect on the health and performance of animals which can, for example, lead to milk fat depression.

Technical considerations relevant to applicability

This feeding measure can be used in farms with indoor housing systems; however, knowledge about the amount of feed supplement to be added is essential.

If extensive farming systems with low supplementary feeding and access to pasture are implemented, it is very difficult to control feed intake and there are very few opportunities for administering feed supplements.

Economics

There is no information available on the cost of using **3-NOP** in rations.

Vegetable fats are often expensive and are also required for human diets and biodiesel production. For this reason, the benefit of reducing enteric CH_4 emissions by adding vegetable oils and fats to the ration to improve production efficiency often does not offset the costs incurred by the measure. The use of by-products from bioethanol production, which often still contain 8 - 12% fat, in ruminant feed is therefore a more economic approach (McAllister et al. 2011). van Middelaar et al. (2014) estimate the cost of CH_4 reduction through the addition of flaxseed to the ration of dairy cows to be € 2,594/t CO_2 equivalent.

(2014) found that supplementing the ration of dairy cows with **nitrate** was not cost-effective, at a cost of € 241/t CO_2 equivalent.

The prices and emission factors for purchased feed presented in The cost-benefit ratio of supplementing feed with **tannins** has not yet been evaluated.

Table 10 are based on assumptions.

The cost-benefit ratio of supplementing feed with **tannins** has not yet been evaluated.

Table 10: Prices and emission factors for purchased feeds

Feed	Price (€/t DM)	Emission factor (kg CO_2 equiv./t DM)
Regularly used feed		
Maize silage	148	182
Concentrated feed		
Normal protein	244	748
Medium protein content	261	768
High protein content	322	801
Urea	528	1,650
Feed supplements to reduce CH_4 emissions		
Extruded linseeds	674	1,174
Nitrate source	1,200	727

DM = dry matter; equiv. = equivalent

Source: according to van Middelaar et al. 2014

Driving force for implementation

There is currently no legal regulation to reduce CH_4 emissions from animal husbandry. Given that some of the above measures require high financial outlays and do not yield a monetary return or raise animal productivity, their use in practice is unlikely.

Furthermore, the feed supplements (3-NOP, nitrate, tannins) would have to be approved by the authorities before they could be used. In this respect, an important step was recently taken for 3-NOP. In the Standing Committee on Plants, Animals, Food and Feed (SCoPAFF), the Member States voted in favour of including it in the list of supplements that are authorised for use in animal feed. Final adoption by the Commission is still pending.

Example plants

The measures are not currently applied in agricultural practice for the above-mentioned reasons.

1.1.3 In the barn

This chapter describes reduction techniques which can be applied in the barn and should be considered when determining BAT.

1.1.3.1 Low-emission floors in cattle farming

In the excreted urine of cattle, ammonia is produced by the hydrolysis of urea which is catalysed by the enzyme urease, which is present in the faeces. Urea hydrolysis starts about half an hour after urine is deposited and is complete after a few hours (Monteny and Erisman 1998). Therefore, freshly deposited urine should be separated from the faeces as soon as possible. For this purpose, low-emission floors– with a variety of designs – are used in cattle farming especially in Belgium and the Netherlands, but increasingly also in Germany.

These low-emission barn floors only effectively reduce emissions when a cleaning device that is adapted to the floor is used in combination with humidification. The use of cleaning technology is essential for effectively reducing emissions.

The most important floor types currently available on the market (Table 11) are described below. Figure 1 shows the application possibilities of low-emission floors, combined with cleaning devices, with regard to the individual types of production.

Table 11: Overview of low-emission floor types currently available on the market

Floor type	Brief description	No.	Reduction potential for NH_3 (%)	Investment costs for the measure	
				(€/m²)	(€/cow place (CP)) (1 CP= 5 m²)
Perforated	Perforated, profiled floor with a reduced number of slits and sealing flaps	1 A	46	70 – 75	350 – 375
	Perforated, profiled floor with sealing flaps	1 B	45 – 53	140	700
	Rubber mat with a reduced number of slits for perforated floors	1 C	40 – 50	136	680
	Rubber mat with convex curvature towards the slits for perforated floors	1 D	38	75	375
Solid	Solid barn floor with a cross slope and urine-collection channel	2 A	20 – 38	100 – 120	500 – 600
	Solid, profiled floor with grooves	2 B	31 – 35	75 – 110	375 – 550

Source: own calculation, KTBL

Low-emission floors are currently still only available for housing systems with no or little bedding in dairy cow husbandry and are in practice only used in this type of production. In principle, they could be used in all types of production, provided that the requirements set out for floors in the Animal Welfare Livestock Husbandry Ordinance (TierSchNutztV 2021) are met and the floors are used in housing systems with no or little bedding with slurry systems. However, such floors are not yet offered on the market for other types of production and are therefore not available (Figure 1). There are restrictions regarding the usability of perforated floors, for example, regarding the slot widths for calves and younger animals (up to the end of the 6th month of life). Slot widths therefore have to be adapted to the animals' needs and the requirements of TierSchNutztV. Low-emission floors cannot be deployed if long-stalk straw is used.

It is not possible to use the cleaning techniques required to reduce emissions in all types of production without restrictions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, on the other hand, may be injured by the cleaning equipment. Especially in bull fattening, larger bulls can hinder or even damage mobile cleaning technology. Stationary dung removal systems, on the other hand, function without any problems. Cleaning devices are not used with fully perforated floors in single-room housing for bull fattening because the animals do not have the possibility to move out of the way. Thus, it is not possible to implement low-emission floors in this housing system.

Figure 1: Possible applications of low-emission floors in individual types of production

Type of production		Perforated low-emission floors [1]	Solid low-emission floors [1]
Dairy cows		**Applicable**	**Applicable**
Calf rearing (until the end of 6th month of life)		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)
Young cattle [2]		**Applicable to a limited extent from 7th month of life**	**Applicable in principle** (currently not available)
Cattle for fattening [2]	**Heifers/oxen**	**Applicable to a limited extent from 7th month of life**	**Applicable in principle** (currently not available)
	Bulls	**Applicable to a limited extent from 7th month of life**	**Applicable in principle** (currently not available)
Calves for fattening		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)
Suckler cows with offspring		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)

1 Emission reduction only in combination with cleaning equipment. Use of long-stalk straw is not possible.
2 In systems with separate walkways

Source: own illustration, KTBL

Applicable
Applicable to a limited extent
Applicable in principle (currently not available)

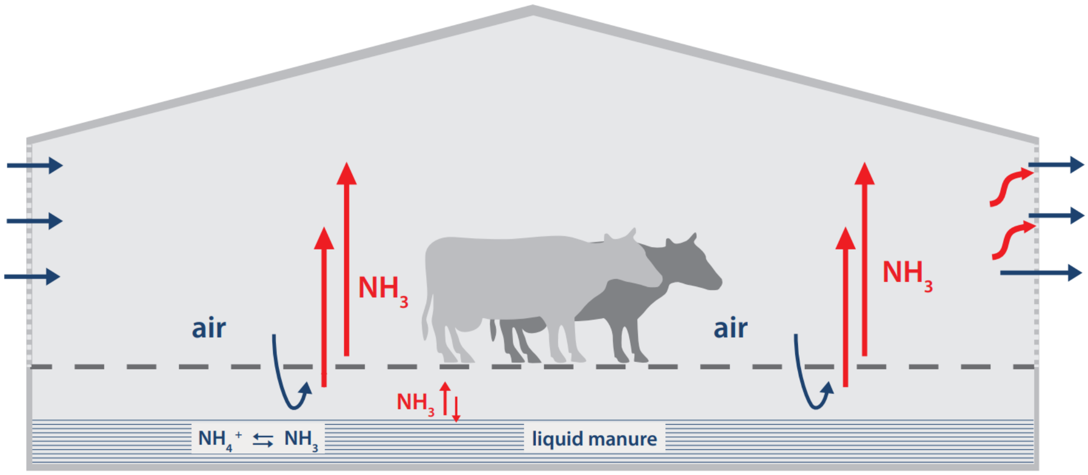
1.1.3.1.1 Perforated barn floors

In housing with perforated walkways, ammonia is emitted both from the excrement on the walkways and from the slurry channel below. This is because the air moves freely between the air space in the barn and the air space above the slurry channel (Figure 2).

Floors for reducing emissions are used in dairy cattle farming especially in Belgium and the Netherlands, but increasingly also in Germany.

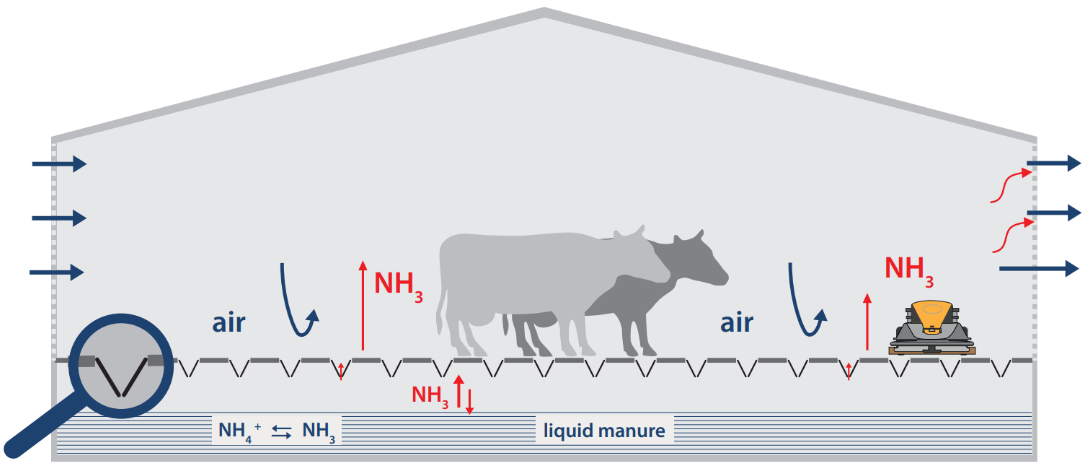
If there are fewer slits and if there are sealing flaps in the slits, the gas exchange is reduced. In this way, by sealing the slurry channel, emissions can be mitigated (Figure 3). These low-emission barn floors only reduce emissions when they are combined with a cleaning device and humidification. They can only be used in housing systems without bedding or with little bedding and without long-stalk straw, as bedding can clog the slats and prevent the floor system from functioning.

Figure 2: Emission of ammonia from excrements on the walkway and from the slurry channel below for a conventional perforated floor without sealing flaps



Source: own illustration, KTBL

Figure 3: Perforated floors with sealing flaps to reduce air exchange and ammonia emissions in barns



Source: own illustration, KTBL

Floor 1 A:

Perforated, profiled floor with a reduced number of slits and sealing flaps

Brief description

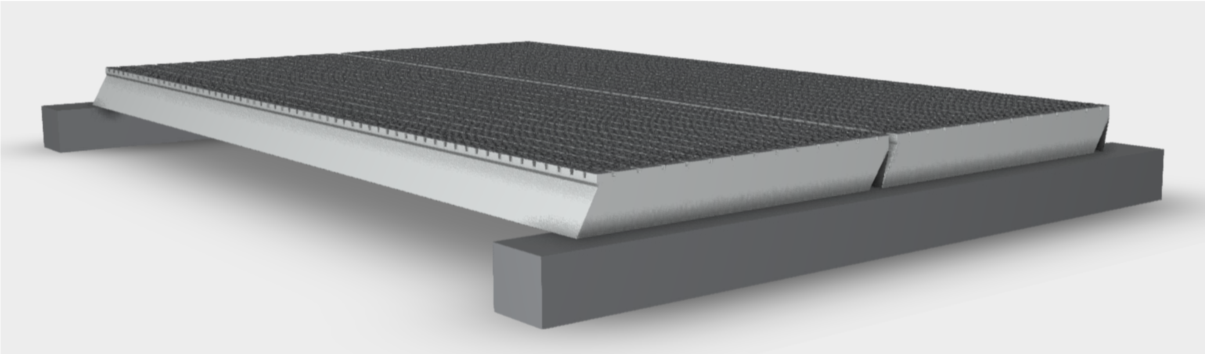
Perforated, profiled floor with slits at larger, regular intervals and sealing flaps in the slits to reduce the potential for ammonia and methane emissions or odour in the barn.

Technical description

Structural design

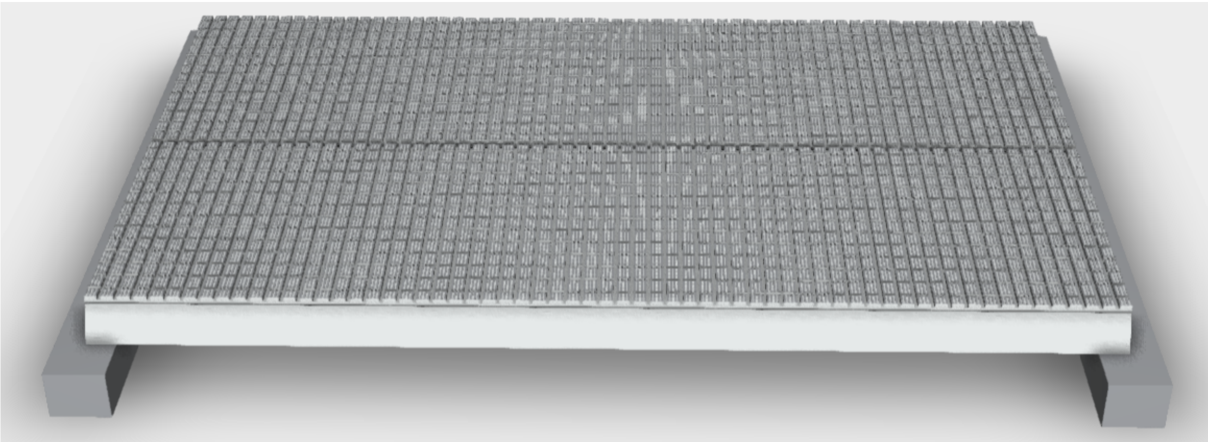
The individual profiled concrete elements of the floor must be mounted on an abutment (Figure 4 and Figure 5). The slurry channel is located beneath it. The concrete elements of the floor are fitted with slits into the slurry channel at regular intervals. Sealing flaps made of plastic (Figure 7) are positioned in these slits, which open to allow faeces to pass through and then close again.

Figure 4: Perforated, profiled floor with a reduced number of slits and sealing flaps in the slits; lateral view



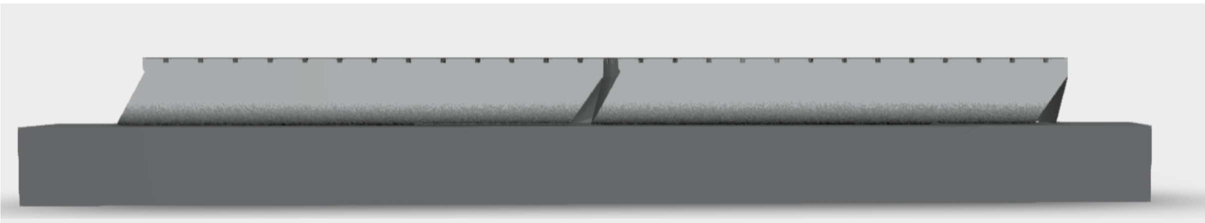
Source: own illustration, KTBL

Figure 5: Perforated, profiled floor with slits at larger, regular intervals and sealing flaps in the slits; view from above



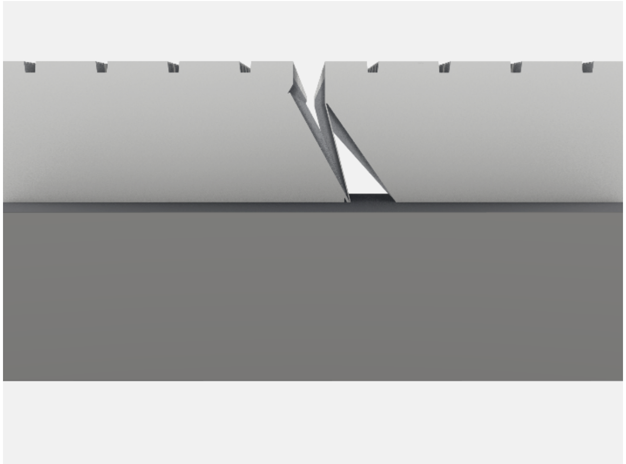
Source: own illustration, KTBL

Figure 6: Perforated, profiled floor with slits at larger, regular intervals and sealing flaps in the slits; lateral view



Source: own illustration, KTBL

Figure 7: Lateral view of floor element with a close-up of the sealing flap which reduces gas exchange with the slurry channel



Source: own illustration, KTBL

Operating principle

Due to the profile on the floor surface, liquids are drained away quickly. Thus, the faeces and urine are separated instantaneously, which reduces ammonia emissions from the walkway in particular. Emissions from the slurry channel are reduced through the use of sealing flaps which restrict the exchange of gases between the air space above the slurry channel and the air space in the barn. These flaps open when faeces pass through and then close again. The faeces remaining on the surface of the floor are regularly pushed off by mobile or stationary scrapers. To ensure the functionality of the flaps and achieve a good cleaning result, the floor is humidified using a water-spraying device.

Achieved environmental benefits

The reduction of the gas exchange between the slurry channel and the barn is expected to decrease ammonia, odour and methane emissions. No other positive environmental effects are currently known.

Environmental performance and operational data

According to the measurements, ammonia emissions in the barn are reduced by approx. 46% (emission factor: 7.0 kg NH_3 per animal place per year) (IenW 2021a) This reduction effect is achieved only in combination with regular cleaning (at least every 2 hours). The reduction potential was measured under laboratory conditions in the Netherlands. A cubicle house with a perforarted floor (dairy cow husbandry) was considered as the reference method.

The floor has to be cleaned regularly with a stationary scraper that is adapted to the floor or a manure removal robot (at least every 2 hours). To prevent the faeces from drying and clogging the slats, the walkway has to be humidified. Regular inspection and, if necessary, replacement of the sealing flaps is needed.

Additional humidification is necessary for the sealing flaps to function smoothly. This is likely to increase the use of process water. In addition, regular cleaning raises energy requirements.

Cross-media effects

There are no cross-media effects.

Animal welfare

Due to the profiled floor surface, the animals show increased sure-footedness (manufacturer's statement 2020). In addition to facilitating natural animal movement (LAVES 2007) , the dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008).

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. For example, manure removal should be avoided during the main feeding phase (Buck et al. 2012, KTBL 2016a). Sensors preventing collisions with animals are particularly important.

The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

The barn floor is suitable for new buildings and reconstructions. A slurry channel is a prerequisite. In housing systems with bedding and a perforated walkway, there is a risk that the slats become clogged. This floor is therefore only suitable for housing systems with no or very little bedding. Long-stalk straw is not suitable for use with such floors. The function of the sealing flaps is not guaranteed in frosty conditions.

In principle, such low-emission floors could be used in all types of production, but so far are only available for dairy cow housing. There are restrictions regarding the width of slats for calves and younger animals (up to the end of the 6th month of life). Slat widths should be adapted to the requirements of the animals and to the specifications set out in TierSchNutztV 2021. Since the emission reduction potential is only achieved in combination with regular cleaning, this floor is of limited use for fattening cattle and young cattle, e.g. in housing systems with separate walkways and perforated floors.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by the cleaning devices. Especially in bull fattening, in particular larger bulls can hinder or even damage the mobile cleaning technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

These floors are installed in new buildings instead of conventional concrete floor elements. At € 70 - 75/m², these prefabricated components are 80 - 100% more expensive than conventional floors. With 5 m² of perforated surface area per animal, investments of € 350 - 375 per animal place can be expected (Table 12).

In the case of reconstructions, the existing surface elements are removed and disposed of. The new elements are mounted on the existing abutments. It is estimated that the deconstruction and disposal of old components and the preparation of channels for new flooring costs € 25 - 50 per animal place. During reconstruction, the barn cannot be fully used, which can decrease animal performance and, thus, lower revenues.

For further consideration of the costs, the investment required for the emission-reduced perforated floor is assumed. The annual building costs (depreciation, interest costs, repairs, insurance) range between € 52 and € 55 per animal place and year (source: own surveys).

A higher control and maintenance workload is expected to ensure the regular inspection and, if necessary, replacement of sealing flaps. As there is currently no experience in this area, the additional workload has not been included in the repair costs.

The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 and € 117 per animal place for 100 and 600 animal places, respectively. The fixed costs (depreciation, interest costs, housing) are therefore between about € 20.90 and € 5.30 per animal place and year (KTBL 2020). The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 and € 117 per animal place for 100 and 600 animal places, respectively. The fixed costs (depreciation, interest costs, housing) are therefore between about € 20.90 and € 5.30 per animal place and year (KTBL 2020).

The operation of the cleaning devices incurs ongoing costs for operating materials (electricity) and repairs, depending on the operating times. For 18 hours of cleaning and 6 hours of charging, the electricity demand is approximately 131 kWh per animal place per year for 100 animal places and 88 kWh for 600 animal places.

Table 12: Economic parameters of the perforated, profiled floor with a reduced number of slits and sealing flaps

Investment and costs	**Animal places (AP)**	
	100	**600**
	€/AP	
Investment		
Buildings and structural equipment	375.00	350.00
Technology and technical system	175.00	117.00
Total investment	**550.00**	**467.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**55.20**	**51.50**
Depreciation	37.50	35.00
Interest costs	5.60	5.30
Building maintenance	11.30	10.50
Insurance	0.80	0.70
Technology and technical system	**20.90**	**5.30**
Depreciation	17.50	4.00
Interest costs	3.20	1.10
Housing	0.20	0.20
Total fixed costs	**76.10**	**56.80**
Variable costs		
Technology and technical system	**91.42**	**62.02**
Repairs	57.80	38.50
Electricity	30.20	20.10
Other inputs		
Water	3.42	3.42
Total variable costs	**94.84**	**65.44**
Total costs	**170.94**	**122.24**

Source: own calculation, KTBL

The variable costs for the cleaning equipment amount to approx. € 88 per animal place and year for 100 animal places. For 600 animal places, these costs are € 58.60 per animal place and year. In addition, costs are incurred for water to keep the surface wet. The devices spray the area with about 1 l of water per m^2 per day. Approximately 1.8 m^3 of water is required per animal place per year, regardless of the herd size. At a price of € 1.90/m^3, the water costs amount to € 3.42 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

In the case of a 46 % reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 25.51. These costs comprise € 8.24 for annual building costs, € 3.12 for fixed engineering costs and € 14.16 for ongoing engineering costs. For 600 cow places, the costs are € 18.23 per animal place per year with annual building costs of € 7.69, fixed costs of € 0.78 and operating costs of € 9.77.

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of approval procedures for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (Agrarinvestitionsförderprogramm; AFP) as a so-called "specific investment in environmental and climate protection" (Spezifische Investionen in Umwelt- und Klimaschutz; SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In addition, the animals' health is expected to improve due to increased sure-footedness and the positive influence on udder and hoof health.

Example plants

Low-emission floors have been used in the Netherlands since 2009. According to data from the Dutch Agricultural Emissions Inventory, about 2% of dairy cows in the Netherlands (about 35,000 dairy cows) are housed in facilities with this type of flooring (CBS 2022). No information is available on the geographical distribution.

Floor 1 B:

Perforated, profiled floor with sealing flaps

Brief description

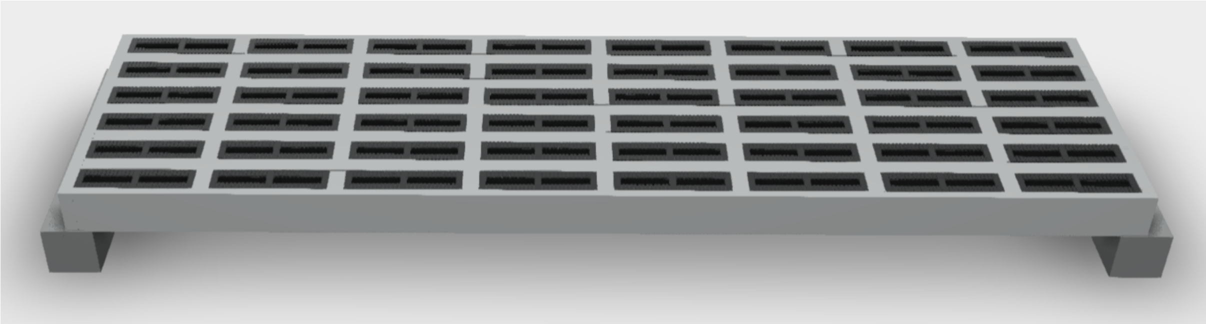
Perforated, profiled floor with sealing flaps to reduce the potential for ammonia and methane emissions or odour in the barn.

Technical description

Structural design

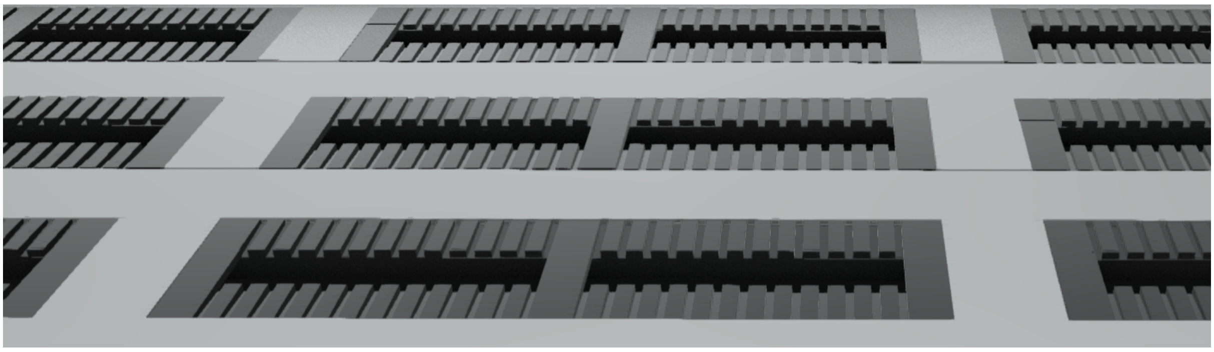
The perforated concrete floor is fitted with rubber inserts (Figure 8). The concrete floor and rubber inserts are profiled with grooves (Figure 9). In addition, the rubber inserts slope down towards the slits. Plastic sealing flaps (Figure 10) are fitted below the rubber inserts in the slits connecting to the slurry channel.

Figure 8: Perforated, profiled floor with sealing flaps



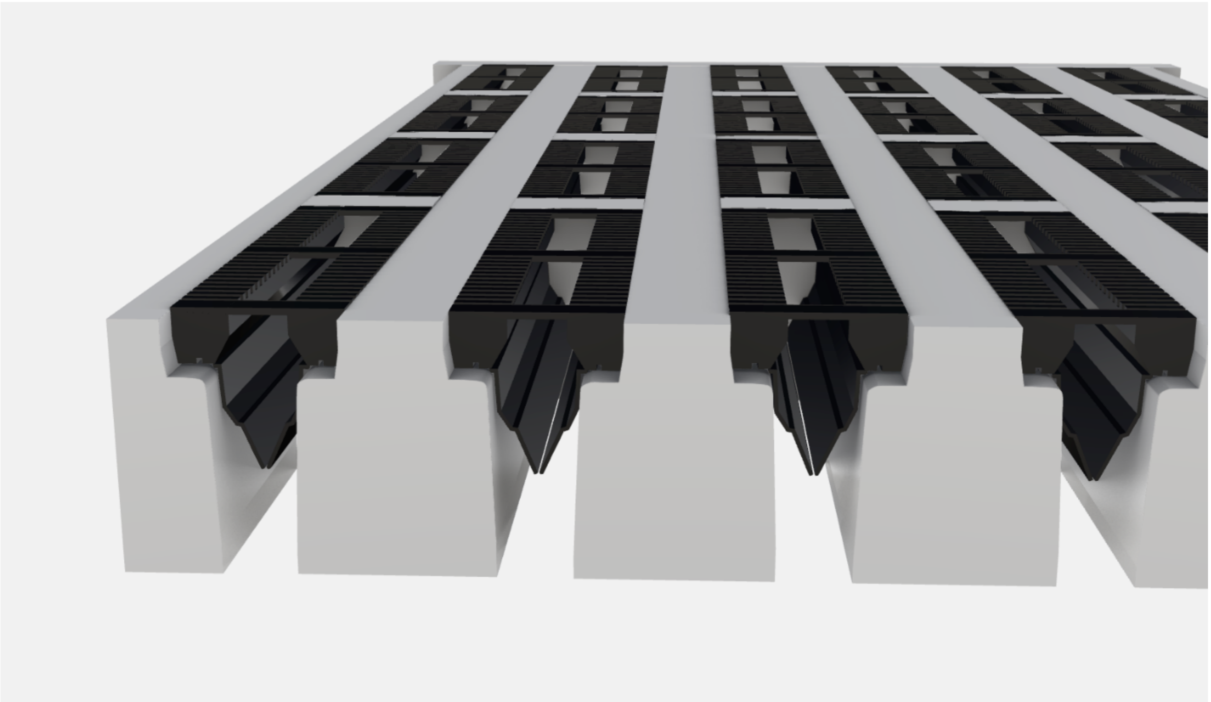
Source: own illustration, KTBL

Figure 9: Surface properties of the low-emission, profiled barn floor with sealing flaps



Source: own illustration, KTBL

Figure 10: Lateral view of floor element with a close-up of the sealing flap which reduces gas exchange with the slurry channel



Source: own illustration, KTBL

Operating principle

Due to the profile on the floor surface, liquids are drained away quickly. Thus, the faeces and urine are separated instantaneously, which reduces ammonia emissions from the walkway in particular. Emissions from the slurry channel are reduced through the use of sealing flaps which restrict the exchange of gases between the air space above the slurry channel and the air space in the barn. These flaps open when faeces pass through and then close again. The faeces remaining on the surface of the floor are regularly pushed off by mobile or stationary scrapers.

Achieved environmental benefits

The reduction of the gas exchange between the slurry channel and the barn is expected to decrease ammonia, odour and methane emissions. No other positive environmental effects are currently known.

Environmental performance and operational data

Emission measurements in cubicle houses with natural ventilation indicate that ammonia emissions are reduced by approx. 45 - 53% (emission factor: 6.0 - 7.9kg NH_3 per animal place per year) compared to a conventional perforated floor (IenW 2021b, VERA 2021).

Emission reduction is achieved when the floor is cleaned regularly (at least every 2 hours) with a manure removal robot. Additional humidification is necessary for the sealing flaps to function smoothly. This is likely to increase the use of process water. In addition, regular cleaning raises energy requirements. The sealing flaps must be checked regularly to verify that they are functioning correctly and replaced if necessary.

Cross-media effects

There are no cross-media effects.

Animal welfare

Due to the profiled surface and the rubber inserts, the animals show increased sure-footedness (manufacturer's statement 2020). In addition to facilitating natural animal movement (LAVES 2007), dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008).

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. Manure removal should be avoided during the main feeding phase (Buck et al. 2012, KTBL 2016a).

Sensors preventing collisions with animals are particularly important. The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

The barn floor is suitable for new buildings and reconstructions. However, reconstructions require higher technical outlays. A slurry channel is a prerequisite. In housing systems with bedding and a perforated walkway, there is a risk that the slats become clogged. This floor is therefore only suitable for housing systems with no or very little bedding. Long-stalk straw is not suitable for use with such floors. The function of the sealing flaps is not guaranteed in frosty conditions.

In principle, such low-emission floors could be used in all types of production, but so far are only available for dairy cow housing. There are restrictions regarding the width of slats for calves and younger animals (up to the end of the 6th month of life). Slat widths should be adapted to the requirements of the animals and to the specifications set out in TierSchNutztV 2021. Since the emission reduction potential is only achieved in combination with regular cleaning, this floor is of limited use for fattening cattle and young cattle, e.g. in housing systems with separate walkways and perforated floors.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by the cleaning devices. Especially in bull fattening, larger in particular bulls can hinder or even damage the mobile cleaning technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

These floors are installed in new buildings instead of conventional concrete floor elements. At around € 140/m², the prefabricated components cost 2.5 times as much as conventional floors. As each animal requires 5 m² of perforated surface, investments of € 700 per animal place can be expected (In addition, costs are incurred for water to keep the surface wet. The equipment sprays the area with about 1 l of water per m² per day. Approximately 1.8 m³ of water is required per animal place per year. At a price of € 1.90/m³, the water costs amount to € 3.42 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

In the case of a 53% reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 28.39. These costs comprise € 13.36 for annual building costs, € 2.71 for fixed engineering costs and € 12.32 for ongoing engineering costs. For 600 animal places, the total costs are € 22.64 per animal place and year; these costs comprise € 13.36 annual building costs, € 0.78 fixed engineering costs and € 8.50 variable costs.

Table 13).

In the case of reconstructions, the existing surface elements are removed and disposed of. The new elements are mounted on the existing abutments. It is estimated that the deconstruction and disposal of old components as well as the preparation of channels for the new floor costs € 25 - 50 per animal place. During reconstruction, the barn cannot be fully used, which can decrease animal performance and, thus, lower revenues.

For further consideration of the costs, the investment required for the emission-reduced perforated floor is assumed. The annual building costs (depreciation, interest costs, repairs, insurance) amount to approx. € 103 per animal place and year (source: own surveys).

A higher control and maintenance workload is expected to ensure the regular inspection and, if necessary, replacement of sealing flaps. As there is currently no experience in this area, this additional workload is only partially included in the repair costs.

The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 per animal place for 100 animal places and € 117 for 600 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 20.88 and € 13.92 per animal place and year (KTBL 2016b). The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 per animal place for 100 animal places and € 117 for 600 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 20.90 and € 14.00 per animal place and year (KTBL 2016b).

The operation of the cleaning devices incurs ongoing costs for operating materials (electricity) and repairs, depending on the operating times. For 18 hours of cleaning and 6 hours of charging, the electricity demand is approximately 131 kWh per animal place per year for 100 animal places and 88 kWh for 600 animal places.

In addition, costs are incurred for water to keep the surface wet. The equipment sprays the area with about 1 l of water per m^2 per day. Approximately 1.8 m^3 of water is required per animal place per year. At a price of € 1.90/m^3, the water costs amount to € 3.42 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

In the case of a 53% reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 28.39. These costs comprise € 13.36 for annual building costs, € 2.71 for fixed engineering costs and € 12.32 for ongoing engineering costs. For 600 animal places, the total costs are € 22.64 per animal place and year; these costs comprise € 13.36 annual building costs, € 0.78 fixed engineering costs and € 8.50 variable costs.

Table 13: Economic parameters of the profiled, perforated floor with sealing flaps

Investment and costs	**Animal places (AP)**	
	100	**600**
	€/AP	
Investment		
Buildings and structural equipment	700.00	700,00
Technology and technical system	175.00	117.00
Total investment	**875.00**	**817.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**102.90**	**102.90**
Depreciation	70.00	70.00
Interest costs	10.50	10.50
Building maintenance	21.00	21.00
Insurance	1.40	1.40
Technology and technical system	**20.90**	**14.00**
Depreciation	17.50	11.70
Interest costs	3.20	2.10
Housing	0.20	0.20
Total fixed costs	**123.80**	**116.90**
Variable costs		
Technology and technical system	**91.42**	**62.02**
Repairs	57.80	38.50
Electrical energy	30.20	20.10
Other inputs		
Water	3.42	3.42
Total variable costs	**94.84**	**65.44**
Total costs	**218.64**	**182.34**

Source: own calculation, KTBL

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of approval procedures for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (AFP) as a so-called "specific investment in environmental and climate protection" (SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In addition, the animals' health is expected to improve due to increased sure-footedness and the positive influence on udder and hoof health.

Example plants

Low-emission floors have been used in the Netherlands since 2009. According to data from the Dutch Agricultural Emissions Inventory, about 4% of dairy cows in the Netherlands (about 65,000 dairy cows) are housed in facilities with this type of flooring (CBS 2022). No information is available on the geographical distribution.

This type of flooring is currently being investigated on three cattle farms in Germany within the framework of the joint project "Emission Reduction in Farm Animal Husbandry" (EmiMin). The project's results are expected in 2024.

Floor 1 C:

Rubber mat with a reduced number of slits for perforated floors

Brief description

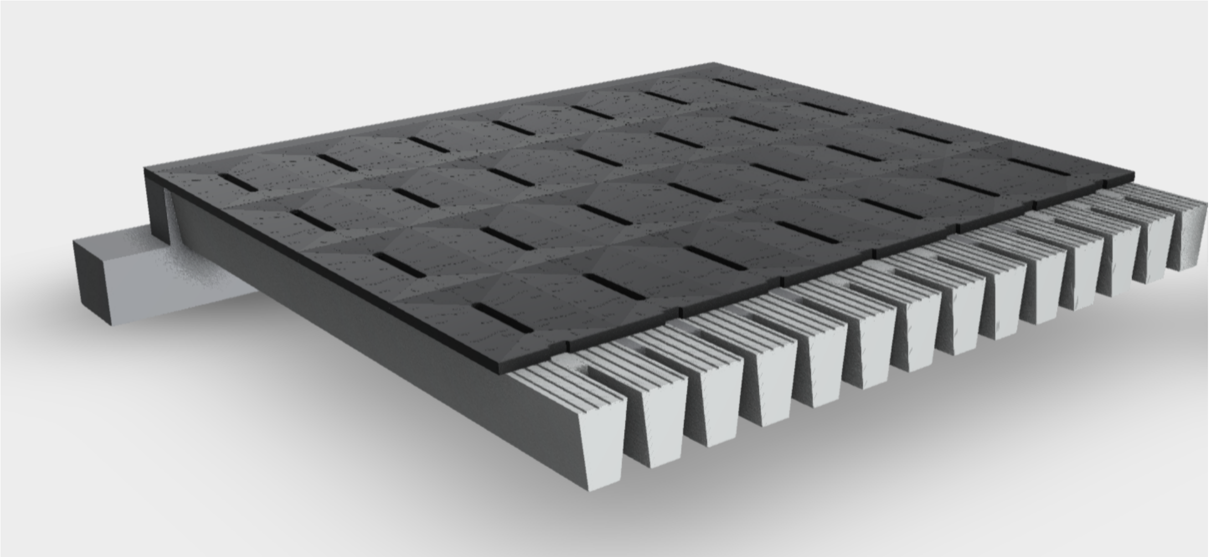
Rubber mat with a reduced number of slits for a perforated floor for reducing the emission potential of ammonia and methane as well as odour in the barn.

Technical description

Structural design

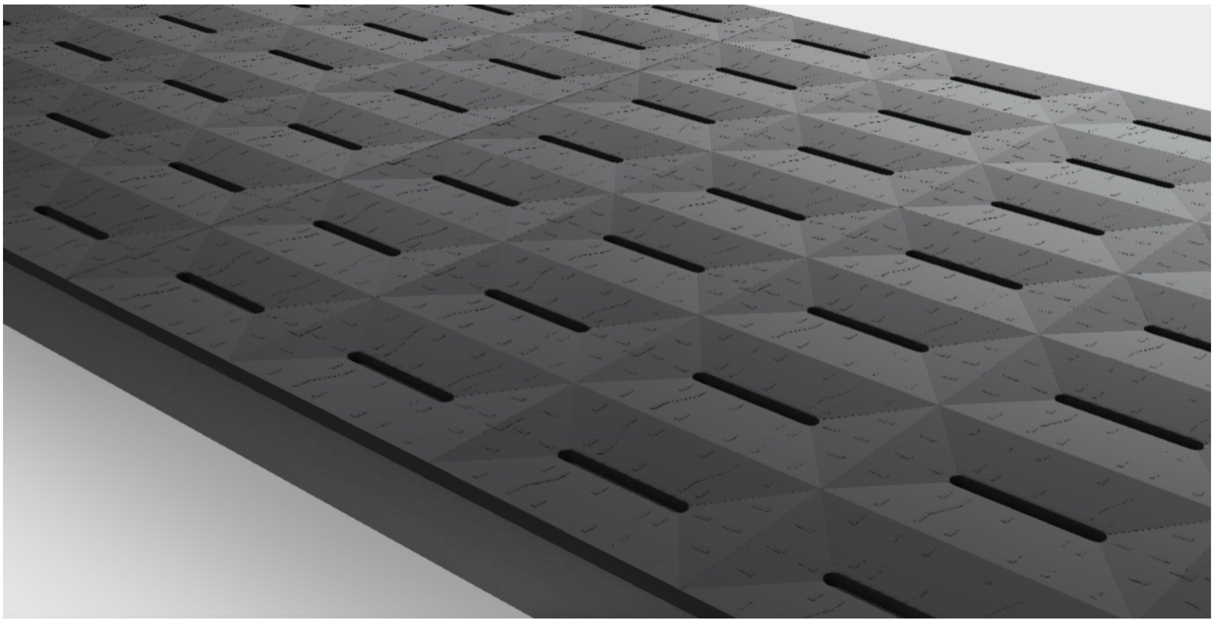
The number of slits in the rubber mat is reduced by 75% compared to a conventional perforated floor. To allow liquids to drain rapidly, the rubber mat has a longitudinal and transverse slope of approx. 3% to the slits (Figure 11 and Figure 12). Corundum is integrated into the slightly profiled surface, optimising the grip and thus increasing the animals' sure-footedness.

Figure 11: Rubber mat with a reduced number of slits for perforated floors



Source: own illustration, KTBL

Figure 12: Rubber mat with a reduced number of slits for a perforated floor, detailed view



Source: own illustration, KTBL

Operating principle

Due to the design of the floor's surface, which slopes down to the opening slits, liquids are drained off quickly. Thus, the faeces and urine are separated instantaneously, which decreases ammonia emissions from the walkway in particular. In addition, the number of slits in the floor is reduced, which decreases the gas exchange between the air space above the slurry channel and the air space in the barn as well as the emissions from the slurry channel. The faeces remaining on the surface of the floor are regularly pushed off by mobile or stationary scrapers.

Achieved environmental benefits

The reduction of the gas exchange between the slurry channel and the barn is expected to decrease ammonia, odour and methane emissions. No other positive environmental effects are currently known.

Environmental performance and operational data

Case-control measurements have shown a reduction in ammonia emissions of 40 - 50% (measurement under laboratory conditions, manufacturer's specification 2019). A perforated floor was used as a reference. The floor was cleaned with a manure scraping system.

Ammonia emissions are reduced with regular cleaning (at least every two hours), either using a stationary scraper adapted to the floor or a manure removal robot. The faeces are prevented from drying and clogging the slats through humidification of the walkway. This is likely to increase the use of process water. In addition, regular cleaning increases energy demand.

Cross-media effects

There are no cross-media effects.

Animal welfare

Corundum is integrated into the slightly profiled surface, optimising the grip and thus increasing the animals' sure-footedness (manufacturer's specification 2020). In addition to facilitating natural animal movement (LAVES 2007), dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008).

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. Manure removal should not be performed during the main feeding phase (Buck et al. 2012, KTBL 2016a). Sensors preventing collisions with animals are particularly important.

The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

The rubber mats are suitable for new buildings and reconstructions. Farmers can install them on existing perforated walkways without requiring technical assistance. A perforated barn floor with a slurry channel is a prerequisite. In housing systems with bedding and a perforated walkway, there is a risk that the slats become clogged. This flooring is therefore only suitable for housing systems with no or very little bedding. Long-stalk straw is not suitable for use with such flooring.

In principle, these low-emission floors could be used in all types of production, but so far are only available for dairy cow housing. There are restrictions regarding the width of slats for calves and younger animals (up to the end of the 6th month of life). Slat widths should be adapted to the requirements of the animals and to the specifications set out in TierSchNutztV 2021. Since emission reduction potential is only achieved in combination with regular cleaning, this flooring is of limited use for fattening cattle and young cattle, e.g. in housing systems with separate walkways and perforated floors.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by them. Especially in bull fattening, in particular larger bulls can hinder or even damage mobile cleaning technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

The rubber mat is placed and fixed on an existing conventional floor element. In existing buildings, this requires thorough cleaning of the perforated floor. The rubber mat costs € 136/m². As each animal requires 5 m² of perforated surface, investments of € 680 per animal place can be expected (During the installation phase, the barn cannot be fully used, which can decrease animal performance and, thus, lower revenues.

The annual building costs (depreciation, interest costs, repairs, insurance) amount to approx. € 100 per animal place and year (source: own surveys).

The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 per animal place for 100 animal places and € 117 for 600 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 20.90 and € 14.00 per animal place and year (KTBL 2016a).

Table 14).

During the installation phase, the barn cannot be fully used, which can decrease animal performance and, thus, lower revenues.

The annual building costs (depreciation, interest costs, repairs, insurance) amount to approx. € 100 per animal place and year (source: own surveys).

The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 per animal place for 100 animal places and € 117 for 600 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 20.90 and € 14.00 per animal place and year (KTBL 2016a).

Table 14: Economic parameters of a rubber mat with a reduced number of slits for a perforated floor

Investment and costs	**Animal places (AP)**	
	100	**600**
	€/AP	
Investment		
Buildings and structural equipment	680.00	680.00
Technology and technical system	175.00	117.00
Total investment	**855.00**	**797.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**100.00**	**100.00**
Depreciation	68.00	68.00
Interest costs	10.20	10.20
Building maintenance	20.40	20.40
Insurance	1.40	1.40
Technology and technical system	**20.90**	**14.00**
Depreciation	17.50	11.70
Interest costs	3.20	2.10
Housing	0.20	0.20
Total fixed costs	**120.90**	**114.00**
Variable costs		
Technology and technical system	**91.42**	**62.02**
Repairs	57.80	38.50

Investment and costs	Animal places (AP)	
	100	600
	€/AP	
Electrical energy	30.20	20.10
Other inputs		
Water	3.42	3.42
Total variable costs	**94.84**	**65.44**
Total costs	**215.74**	**179.44**

Source: own calculation, KTBL

The operation of the cleaning devices incurs ongoing costs for operating materials (electricity) and repairs, depending on the operating times. For 18 hours of cleaning and 6 hours of charging, the electricity demand is approximately 131 kWh per animal place per year for 100 animal places and 88 kWh for 600 animal places.

In addition, costs are incurred for water to keep the surface wet. The equipment sprays the area with about 1 l of water per m^2 per day. Approximately 1.8 m^3 of water is required per animal place per year. At a price of € 1.90/m^3, the water costs amount to € 3.42 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

In the case of a 50% reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 29.55. These costs comprise € 13.70 for annual building costs, € 2.86 for fixed engineering costs and € 12.99 for ongoing engineering costs. For 600 animal places, the total costs are € 23.44 per animal place and year; these costs comprise € 13.70 annual building costs, € 0.78 fixed engineering costs and € 8.96 variable costs.

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of approval procedures for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (AFP) as a so-called "specific investment in environmental and climate protection" (SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In addition, the animals' health is expected to improve due to increased sure-footedness and the positive influence on udder and hoof health.

Example plants

This type of barn floor is already used in a few farms in Germany but is not yet in wide usage. Information on its distribution is available from the manufacturer and can be obtained from KTBL.

Floor 1 D:

Rubber mat with convex curvature towards the slits for a perforated floor

Brief description

Rubber mat with convex curvature towards the slits for a perforated floor to reduce the potential for ammonia emissions and odour in barns.

Technical description

Structural design

The convex curvature of the rubber pad with a 5 - 7% slope to the slits enables liquids to be drained quickly into the slurry channel (**Operating principle**

The convex curved shape of the individual surface elements (Figure 15) allows liquids to drain off quickly. Thus, the faeces and urine are separated instantaneously, reducing ammonia emissions in particular. The faeces remaining on the floor surface are periodically pushed off by stationary scrapers equipped with a flexible scraper blade.

Achieved environmental benefits

The reduction in ammonia emissions is also expected to decrease odour emissions. No other positive environmental effects are currently known.

Figure 13, Figure 14). It has studs on the bottom, causing the material to deform under load, so it is easy to walk on. One rubber mat covers two beams of the perforated floor. The mat is fixed inside the slits, eliminating the need for additional fastening.

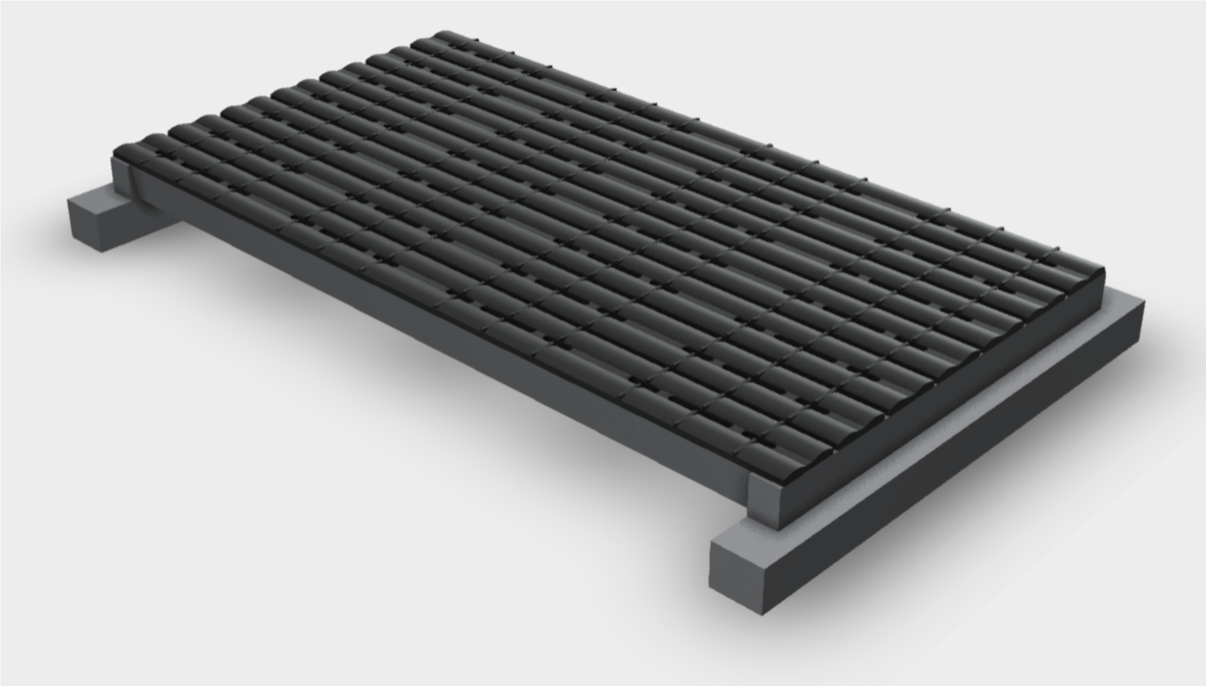
Operating principle

The convex curved shape of the individual surface elements (Figure 15) allows liquids to drain off quickly. Thus, the faeces and urine are separated instantaneously, reducing ammonia emissions in particular. The faeces remaining on the floor surface are periodically pushed off by stationary scrapers equipped with a flexible scraper blade.

Achieved environmental benefits

The reduction in ammonia emissions is also expected to decrease odour emissions. No other positive environmental effects are currently known.

Figure 13: Rubber mat with convex curvature towards the slits for a perforated floor, top view

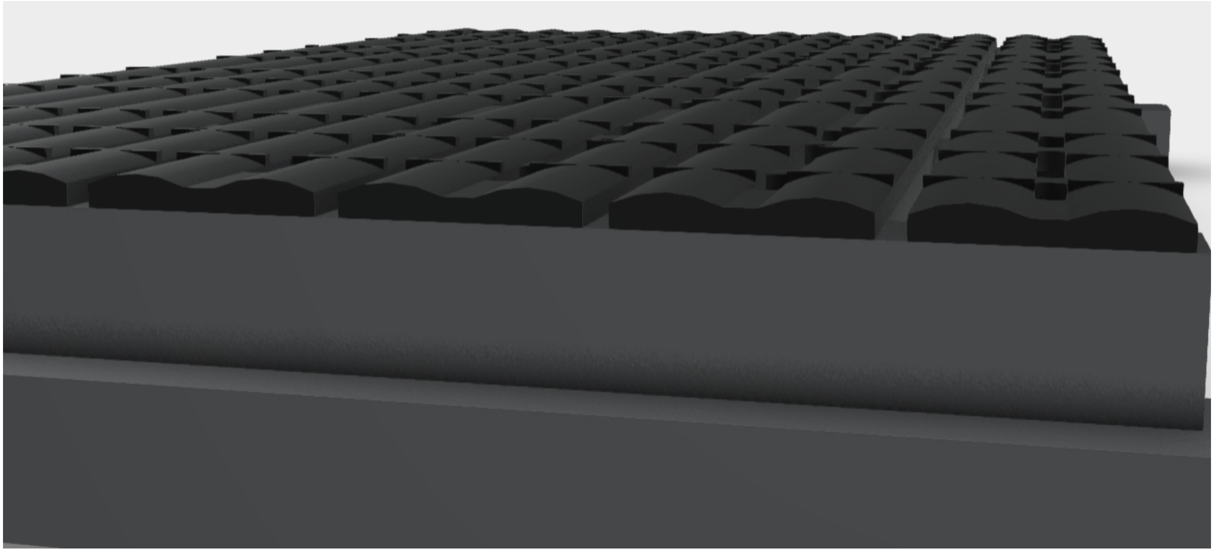


Source: own illustration, KTBL

Figure 14: Rubber mat with convex curvature towards the slits for a perforated floor, lateral view

Source: own illustration, KTBL

Figure 15: Rubber mat with convex curvature towards the slits for a perforated floor, detailed view



Source: own illustration, KTBL

Environmental performance and operational data

According to measurements in the Netherlands, ammonia emissions can be reduced by approx. 38% (emission factor: 8.0 kg NH_3 per animal place per year; cleaning every two hours; reference: perforated floor) (IenW 2021d).

The floor must be cleaned regularly (at least every two hours) with a stationary scraper adapted to the floor. The cleaning device requires a flexible scraper blade in order to adapt to the curvatures of the rubber and achieve a better cleaning result. To prevent the manure from drying and the slats from clogging, the walkway must be humidified.

This results in an increased use of process water. In addition, regular cleaning raises energy requirements.

Cross-media effects

There are no cross-media effects.

Animal welfare

In addition to facilitating natural animal movement (LAVES 2007), dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008). Profiling is necessary to ensure sure-footedness.

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. Manure removal should not be performed during the main feeding phase (Buck et al. 2012, KTBL 2016a).

The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

The rubber mats are suitable for new buildings and reconstructions. Farmers can install them on existing perforated walkways without requiring technical assistance. A perforated barn floor with a slurry channel is a prerequisite. In housing systems with bedding and a perforated walkway, there is a risk that the slats become clogged. This flooring is therefore only suitable for housing systems with no or very little bedding. Long-stalk straw is not suitable for use with such flooring.

In principle, these low-emission floors could be used in all types of production, but so far are only available for dairy cow housing. There are restrictions regarding the width of slats for calves and younger animals (up to the end of the 6th month of life). Slat widths should be adapted to the requirements of the animals and to the specifications set out in TierSchNutztV 2021. Since the emission reduction potential is only achieved in combination with regular cleaning, this flooring is of limited use for fattening cattle and young cattle, e.g. in housing systems with separate walkways and perforated floors.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by them. Especially in bull fattening, in particular larger bulls can hinder or even damage the mobile technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

The rubber mat is placed and fixed on an existing floor element instead of a conventional floor element. In existing buildings, this requires thorough cleaning of the perforated floor. The rubber mat costs € 75/m². As each animal requires 5 m² of perforated surface, an investment of € 375 per animal place can be expected (Table 15).

During the installation phase, the barn cannot be fully used, which can decrease animal performance and, thus, lower revenues.

The annual building costs (depreciation, interest costs, repairs, insurance) amount to approx. € 55 per animal place and year (source: own surveys).

The floors are cleaned using automatic cleaning devices with water nozzles to keep the surface wet. The technology costs between € 175 per animal place for 100 animal places and € 117 for 600 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 20.90 and € 14.00 per animal place and year (KTBL 2016a).

Operation of the cleaning devices incurs ongoing costs for operating materials (electricity) and repairs, depending on the operating times. For 18 hours of cleaning and 6 hours of charging, the electricity demand is approximately 131 kWh per animal place per year for 100 animal places and 88 kWh for 600 animal places.

In addition, costs are incurred for water to keep the surface wet. The equipment sprays the area with about 1 l of water per m² per day. Approximately 1.8 m³ of water is required per animal place per year. At a price of € 1.90/m³, the water costs amount to € 3.42 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

In the case of a 50 % reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs for one kg of NH_3 reduction per animal place and year are € 23.42. These costs comprise € 7.56 for annual building costs, € 2.86 for fixed engineering costs and € 12.99 for ongoing engineering costs. This does not include the costs of cleaning water. For 600 animal places, the total costs are € 17.31 per animal place and year; these costs comprise € 7.56 annual building costs, € 0.78 fixed engineering costs and € 8.96 variable costs.

Table 15: Economic parameters for rubber mat with convex curvature towards the slits for a perforated floor

Investment and costs	Animal places (AP) 100	600
	€/AP	
Investment		
Buildings and structural equipment	375.00	375.00
Technology and technical system	175.00	117.00
Total investment	**550.00**	**492.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**55.20**	**55.20**
Depreciation	37.50	37.50
Interest costs	5.60	5.60
Building maintenance	11.30	11.30
Insurance	0.80	0.80
Technology and technical plant	**20.90**	**14.00**
Depreciation	17.50	11.70
Interest costs	3.20	2.10
Housing	0.20	0.20
Total fixed costs	**76.10**	**69.20**
Variable costs		
Technology and technical plant	**91.42**	**62.02**
Repairs	57.80	38.50
Electrical energy	30.20	20.10
Other inputs		
Water	3.42	3.42
Total variable costs	**94.84**	**65.44**
Total costs	**170.94**	**134.64**

Source: own calculation, KTBL

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of approval procedures for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (AFP) as a so-called "specific investment in environmental and climate protection" (SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In compliance with the amended TierSchNutztV 2021, this technique is used in calf fattening, where the focus is on providing a soft or elastically deformable lying area for the animals.

In addition, the animals' health is expected to improve due to their increased sure-footedness and the positive influence on their udder and hoof health.

Example plants

This type of barn floor is already used in a few farms in Germany but is not yet in wide usage. According to the Federal Association of Calf Fatteners, it is used on some of its members' farms (Kontrollgemeinschaft Deutsches Kalbfleisch/Bundesverband der Kälbermäster).

1.1.3.1.2 Solid barn floors

To reduce the ammonia emissions in barns with solid floors, the urine has to flow off the walkway quickly and the walkway has to be cleaned regularly. For this purpose, the floors have either channels or slopes to drain off the urine (Zähner and Schrade 2020b) or a combination of both. The manure scrapers are fitted with attachments for clearing the urine-collection channels. Emissions can only be reduced in housing systems with no or little bedding and without long-stalk straw, because they impede urine drainage.

Floor 2 A:

Solid barn floor with a cross slope and urine-collection channel

Brief description

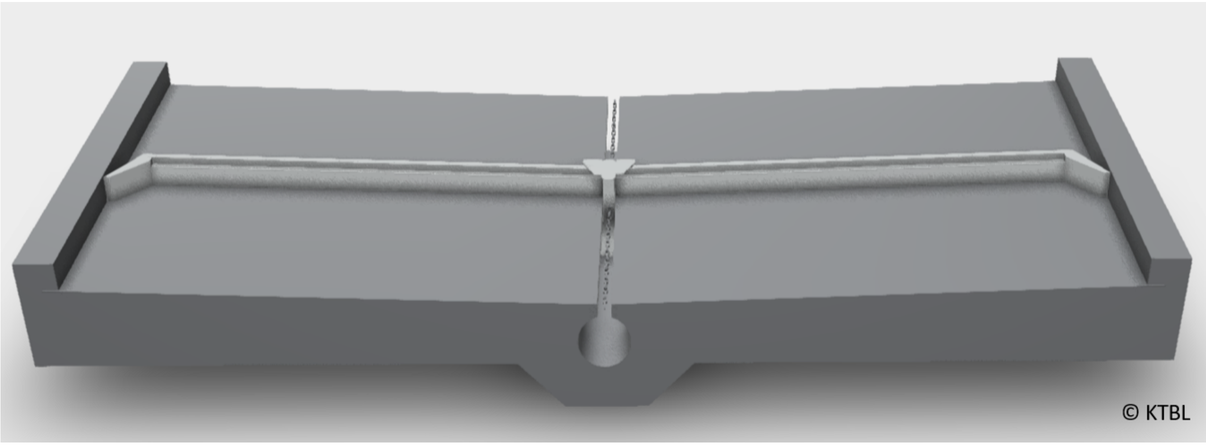
Solid barn floor with a cross slope and urine-collection channel to reduce the potential for ammonia and methane emissions or odour in the barn.

Technical description

Structural design

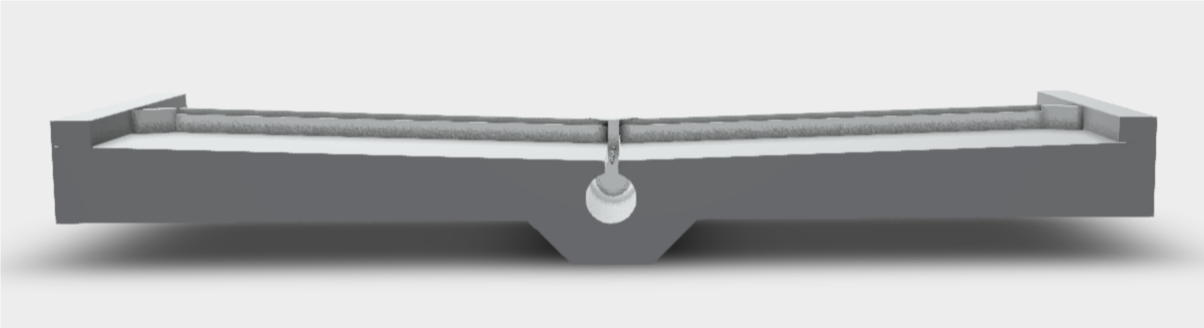
This solid barn floor has a cross slope of 3% and a urine-collection channel in the centre of the walkway (Figure 16). The surface of the walkway is either concrete or fitted with a profiled rubber mat. A slurry channel is not required. However, depending on the product, installation is possible on an existing slurry channel.

Figure 16: Solid barn floor with a cross slope and urine-collection channel, view from above



Source: own illustration, KTBL

Figure 17: Solid barn floor with a cross slope and urine-collection channel, front view



Source: own illustration, KTBL

Operating principle

The surface and slope of the floor towards the centre of the walkway allow fluids to be rapidly drained into the urine-collection channel (Figure 17). Thus, the faeces and urine are separated quickly and instantaneously, reducing ammonia emissions in particular. The faeces remaining on the floor surface are regularly pushed off by a stationary scraper that is adjusted to the cross slope. The scraper also clears the urine-collection channel. The scraper is propelled by a rope or by chain hoist technology with automatic regulation.

Achieved environmental benefits

A test in a barn in Switzerland demonstrated a 20 % reduction in ammonia compared to a reference barn which did not have a sloped floor. The measurements were performed simultaneously in two identical barn compartments (Zähner et al. 2017). According to expert estimates, a 20 % decrease (in comparison to the usual values) was also reported (VDI 3894 Blatt 1). Measurements in the Netherlands showed a reduction of 38 % (8 kg NH_3 per AP and year) (IenW 2021c).

A reduction in ammonia emissions is expected to result in a decrease of odour emissions. No other positive environmental effects are currently known.

Environmental performance and operational data

The floor must be cleaned regularly (at least every two hours) with a stationary scraper adapted to the floor. The scraper must have an attachment to simultaneously clean the urine-collection channel.

Regular cleaning raises energy requirements.

Cross-media effects

There are no cross-media effects.

Animal welfare

In addition to facilitating natural animal movement (LAVES 2007), dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008).

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. Manure removal should not be performed during the main feeding phase (Buck et al. 2012, KTBL 2016a).

The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

This barn floor is suitable for new buildings and reconstructions.

In principle, this low-emission flooring can be used in all types of production. To date, it has only been used in housing for dairy cows (cf. Figure 1). Emissions can only be reduced in housing systems with no or little bedding and without long-stalk straw.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by them. Especially in bull fattening, in particular larger bulls can hinder or even damage the mobile technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

For new buildings, the urine-collection channel costs an additional € 58 - 60 per meter. The additional cost of concreting the slope is estimated to be € 1.4 - 2.2/m^2. This results in additional costs of € 100 - 120/m^2. Assuming an area of 5 m^2 per animal place, outlays of € 600/animal place for 100 animal places and € 500/animal place for 600 animal places can be expected (Table 16).

Table 16 Economic parameters of the solid floor with a cross slope and a urine-collection channel

Investment and costs	Animal places (AP)	
	100	600
	€/AP	
Investment		
Buildings and structural equipment	600.00	500.00
Technology and technical system	95.00	63.00
Total investment	**695.00**	**563.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**88.20**	**73.50**
Depreciation	60.00	50.00
Interest costs	9.00	7.50
Building maintenance	18.00	15.00
Insurance	1.20	1.00
Technology and technical plant	**10.00**	**6.70**
Depreciation	7.60	5.10
Interest costs	1.70	1.10
Housing	0.70	0.50
Total fixed costs	**98.20**	**80.20**
Variable costs		
Technology and technical plant	**74.70**	**49.80**
Repairs	59.60	39.70
Electrical energy	15.10	10.10
Total variable costs	**74.70**	**49.80**
Total costs	**172.90**	**130.00**

Source: own calculation, KTBL

The annual building costs (depreciation, interest costs, repairs, insurance) amount to € 95 per animal place and year for 100 animal places and to € 63 per animal place and year for 600 animal places (source: own surveys).

The installation of a stationary manure removal system for cleaning the walkways costs between € 95 per animal place and year for 100 animal places and € 63 for 600 animal places. The fixed costs (depreciation, interest costs, housing) range from € 10.00 for 100 animal places to € 6.67 for 600 animal places, depending on the herd size (KTBL 2016b). The installation of a stationary manure removal system for cleaning the walkways costs between € 95 per animal place and year for 100 animal places and € 63 for 600 animal places. The fixed costs (depreciation, interest costs, housing) range from € 10.00 for 100 animal places to € 6.70 for 600 animal places, depending on the herd size (KTBL 2016b).

Operation of the scraper system incurs running costs for operating materials (electricity) and repairs, depending on the usage time. Assuming 12 cleaning cycles per day, the scraper system can be expected to have a usage time of 12 hours. If the electricity demand per scraper system is 1.5 kW/h, a dairy barn with 100 animal places and two scraper systems requires about 66 kWh per animal place and year to power the systems. In comparison, the value is about 11 kWh per animal place per year if it is only operated twice a day. For 600 cow places, four scraper systems operate at about 44 kWh per animal place per year, assuming they execute 12 cleaning cycles per day. If the walkways are only cleaned twice a day, the electricity demand drops to 7 kWh per animal place per year.

The variable costs for the stationary manure removal system amount to approx. € 74.70 per animal place and year for 100 animal places and to € 49.80 for 600 animal places. If the system is operated only twice a day, the variable costs are cut to € 12.40 per animal place and year for 100 animal places and to € 8.30 for 600 animal places. The difference in cost is € 62.30 and € 41.50 per animal place and year.

In the case of a 38 % reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 31.44. These costs comprise € 16.04 for annual building costs, € 1.82 for fixed engineering costs and € 13.58 for ongoing engineering costs. For 600 animal places, the total costs are € 23.20 per animal place and year; these costs comprise € 13.36 annual building costs, € 0.78 fixed engineering costs and € 9.05 variable costs.

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of permit applications for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (AFP) as a so-called "specific investment in environmental and climate protection" (SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In addition, the animals' health is expected to improve due to increased sure-footedness and the positive influence on udder and hoof health.

Example plants

This barn floor design is currently being investigated in barns in the field within the framework of the "European Innovation Partnership for Construction in Cattle Husbandry" project (EIP-Cattle). According to data from the Dutch Agricultural Emissions Inventory, about 0.3% of dairy cows in the Netherlands (about 5,000 dairy cows) are housed in facilities with this type of flooring (CBS 2022). In Germany, on the other hand, according to manufacturers, this type of flooring is among the most common according to manufacturers. Information on its distribution is available from the manufacturer and can be obtained from KTBL and the EIP-Cattle project.

Floor 2 B:

Solid, profiled floor with grooves

Brief description

Solid, profiled floor with grooves to reduce the potential for ammonia emissions and odour in the barn.

Technical description

Structural design

The solid barn floor has a profiled surface with grooves (**Operating principle**

The profiled and grooved surface allows liquids to drain off quickly. Thus, the faeces and urine are separated instantaneously, making it possible to reduce ammonia emissions in particular. The faeces remaining on the floor surface are regularly pushed off by a stationary scraper which also clears the grooves.

Achieved positive environmental effects

The reduction in ammonia emissions is expected to result in a decrease in odour emissions. No other positive environmental effects are currently known.

Figure 18). Liquids are drained away quickly thanks to the 3 to 4 % slope towards the grooves on both sides of the surface profile (Figure 19). The floor is equipped with either rubber mats or rubber inserts in the surface profile. The rubber mats have studs on the bottom which allow the material to deform under load, making them easy to walk on.

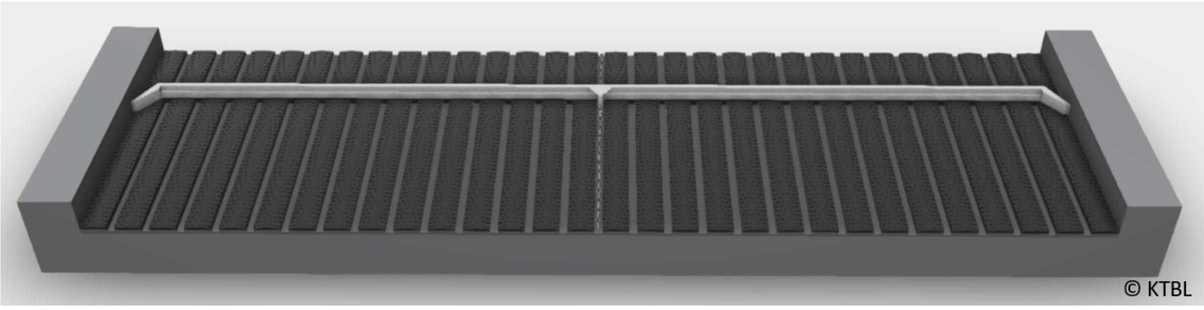
Operating principle

The profiled and grooved surface allows liquids to drain off quickly. Thus, the faeces and urine are separated instantaneously, making it possible to reduce ammonia emissions in particular. The faeces remaining on the floor surface are regularly pushed off by a stationary scraper which also clears the grooves.

Achieved positive environmental effects

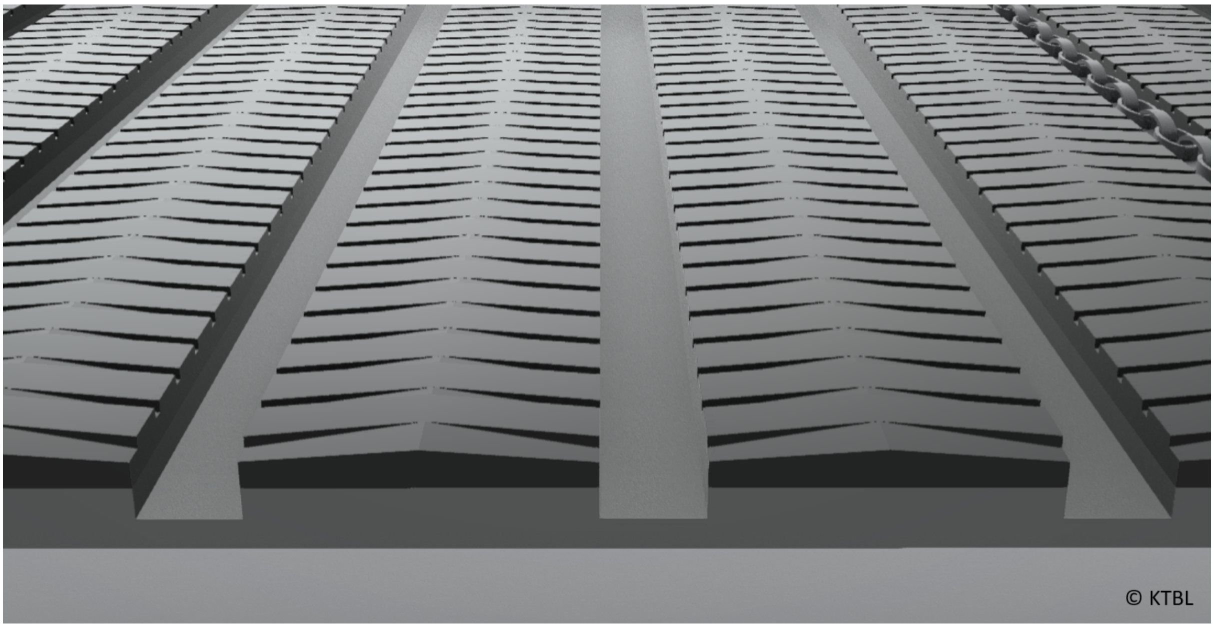
The reduction in ammonia emissions is expected to result in a decrease in odour emissions. No other positive environmental effects are currently known.

Figure 18: Solid, profiled floor with grooves, view from above



Source: own illustration, KTBL

Figure 19: Solid, profiled floor with grooves, detailed view



Source: own illustration, KTBL

Environmental performance and operational data

According to case-control measurements made in the Netherlands, the floor reduces ammonia emissions by 31 - 35% (emission factor: 8.5 - 9.0 kg NH_3 per animal place per year). A perforated floor was used as the reference (Rav code: A 1.100) (Winkel et al. 2020).

The floor must be cleaned regularly (at least every two hours) with a stationary scraper adapted to the floor. The scraper must have a blade that is adapted to the shape of the grooves. To prevent the faeces from drying, the walkway must be humidified.

Regular cleaning raises energy requirements. Humidification of the walkway also increases process water requirements.

Cross-media effects

There are no cross-media effects.

Animal welfare

Due to the profiled, rubberised surface, the animals show increased sure-footedness (manufacturer's statement 2020). In addition to facilitating natural animal movement (LAVES 2007), dry walkways have a positive effect on udder and hoof health (Somers et al. 2005, Magnusson et al. 2008).

Specific management measures must be taken to ensure that the cleaning equipment is implemented in an animal-friendly manner. Manure removal should not be performed during the main feeding phase (Buck et al. 2012, KTBL 2016a).

The reduction of ammonia emissions in the barn improves the air quality (EFSA 2009), which is conducive to good animal health.

Technical considerations relevant to applicability

The barn floor is suitable for new buildings and reconstructions. However, reconstructions require higher technical outlays as the existing floor has to be prepared beforehand.

In principle, this low-emission floor can be used in all types of production. To date, it has only been used in housing for dairy cows (Figure 1). Emissions can only be reduced in housing systems with no or little bedding and without long-stalk straw.

There are limitations regarding the use of the cleaning techniques required to reduce emissions. Dairy cows and suckler cows do not have any major problems with the cleaning devices. Young animals, however, may be injured by them. Especially in bull fattening, in particular larger bulls can hinder or even damage mobile cleaning technology. Stationary dung removal systems, on the other hand, function without any problems.

Economics

The rubber mat is placed and fixed on the existing solid floor. In existing buildings, this requires thorough cleaning of the floor. The rubber mat costs € 75 - 110/m^2. Assuming an area of 5 m^2 per animal place, outlays of € 550/animal place for 100 animal places and € 375/animal place for 600 animal places can be expected (Table 17).

Table 17: Economic parameters of the solid, profiled floor with grooves

Investment and costs	Animal places (AP) 100	Animal places (AP) 600
	€/AP	
Investment		
Buildings and structural equipment	550.00	375.00
Technology and technical plant	95.00	63.00
Total investment	**645.00**	**438.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**80.90**	**55.20**
Depreciation	55.00	37.50
Interest costs	8.30	5.60
Building maintenance	16.50	11.30
Insurance	1.10	0.80
Technology and technical system	**10.00**	**6.70**
Depreciation	7.60	5.10

Interest costs	1.70	1.10
Housing	0.70	0.50
Total fixed costs	**90.90**	**61.90**
Variable costs		
Technology and technical plant	**74.70**	**49.80**
Repairs	59.60	39.70
Electrical energy	15.10	10.10
Total variable costs	**74.70**	**49.80**
Total costs	**165.60**	**111.70**

Source: own calculation, KTBL

The annual building costs (depreciation, interest costs, repairs, insurance) amount to € 80.90 per animal place and year for 100 animal places and to € 55.20 per animal place and year for 600 animal places (source: own surveys).

The installation of a stationary manure removal system for cleaning the walkways costs between € 95 per animal place and year for 100 animal places and € 63 for 600 animal places. The fixed costs (depreciation, interest costs, housing) range from € 10.00 for 100 animal places to € 6.67 for 600 animal places, depending on the herd size (KTBL 2016b). The installation of a stationary manure removal system for cleaning the walkways costs between € 95 per animal place and year for 100 animal places and € 63 for 600 animal places. The fixed costs (depreciation, interest costs, housing) range from € 10.00 for 100 animal places to € 6.70 for 600 animal places, depending on the herd size (KTBL 2016b).

Operation of the scraper system incurs running costs for operating materials (electricity) and repairs, depending on the usage time. Assuming 12 cleaning cycles per day, the scraper system can be expected to have a usage time of 12 hours. Assuming an electricity demand of 1.5 kW/h per scraper system, a dairy barn with 100 animal places and two scraper systems requires about 66 kWh per animal place and year to power the systems. In comparison, the value is about 11 kWh per animal place per year if it is only operated twice a day. For 600 cow places, four scraper systems operate at about 44 kWh per animal place per year, assuming they execute 12 cleaning cycles per day. If the walkways are only cleaned twice a day, the electricity demand drops to 7 kWh per animal place per year.

The variable costs for the stationary manure removal system amount to approx. € 74.70 per animal place and year for 100 animal places and to € 49.80 for 600 animal places. If the system is operated only twice a day, the variable costs are cut to €12.40 per animal place and year for 100 animal places and to €8.30 for 600 animal places. The difference in cost is € 62,30 and € 41,50 per animal place and year.

In the case of a 50 % reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 22.68. These costs comprise € 11.08 for annual building costs, € 1.37 for fixed engineering costs and € 10.23 for ongoing engineering costs. For 600 animal places, the total costs are € 15.16 per animal place and year; these costs comprise € 7.56 annual building costs, € 0.78 fixed engineering costs and € 6.82 variable costs.

Driving force for implementation

By reducing ammonia emissions, farms can comply with immission control requirements regarding the emissions of ammonia or nitrogen which can have harmful environmental impacts on sensitive plants and biotopes. Compliance with these requirements is important in the context of permit applications for new barn constructions or extensions, as it makes it possible for constructions to be built closer to the plants or biotopes requiring protection.

Since the beginning of 2022, barn floors of this type have been subsidized by the German Federal Programme for the Promotion of Agricultural Investment (AFP) as a so-called "specific investment in environmental and climate protection" (SIUK measure). Accordingly, it is expected that the technique will be used more frequently as a result of this subsidy. There is no information available on the number of applications that have been submitted.

In addition, the animals' health is expected to improve due to increased sure-footedness and the positive influence on udder and hoof health.

Example plants

This floor type is being investigated on three cattle farms in Germany within the framework of the joint project "Emission Reduction in Farm Animal Husbandry" (EmiMin; Emissionsminderung Nutztierhaltung). The project's results are expected in 2023. This technique is also being investigated in barns in the field within the framework of the "European Innovation Partnership for Construction in Cattle Husbandry" project (EIP-Cattle).

1.1.3.2 Cleaning devices for barn floors

In agricultural practice, stationary manure removal systems, robotic manure scrapers or collectors automatically clean walkways. In addition to improving the animal's hoof health through clean walkways as well as saving labour time, these devices are a prerequisite for ensuring that the emission-reducing effect of the floor works in practice. Investigations by Burchill et al. (2019) have shown that frequent cleaning (scraping of the surface) of a solid surface can reduce the potential for ammonia emissions by 78% (after 1 hour) and by 57% (after 3 hours) in comparison to housing with no cleaning of the surface. On the other hand, other investigations performed under real-life conditions in cubicle houses have found no significant difference between the effect of the frequencies of cleaning cycles (frequencies of 20, 10, 4 scraping cycles per day) on ammonia emissions when a cleaning robot is used on solid barn floors (Schiefler et al. 2013).

Table 18 provides a summary of the different walkways on which robotic manure scrapers and collectors as well as stationary manure removal systems can be used. The cleaning devices specified in the table are not suitable for barns with flat- or deep-bedding methods, which is why they are not considered here.

Table 18: Overview of the possible use of robotic manure scrapers and collectors and stationary manure removal systems for different floor types with solid- or liquid-manure processes

	Robotic manure collector	Robotic manure scraper	Stationary manure removal system
Perforated walkway (liquid manure)		X	
Solid walkway (liquid manure)	X		X
Solid walkway (solid manure [1])			X

1 small amount of bedding

X= applicable

Source: own illustration, KTBL

1.1.3.2.1 Robotic manure collector for solid barn floors

Brief description

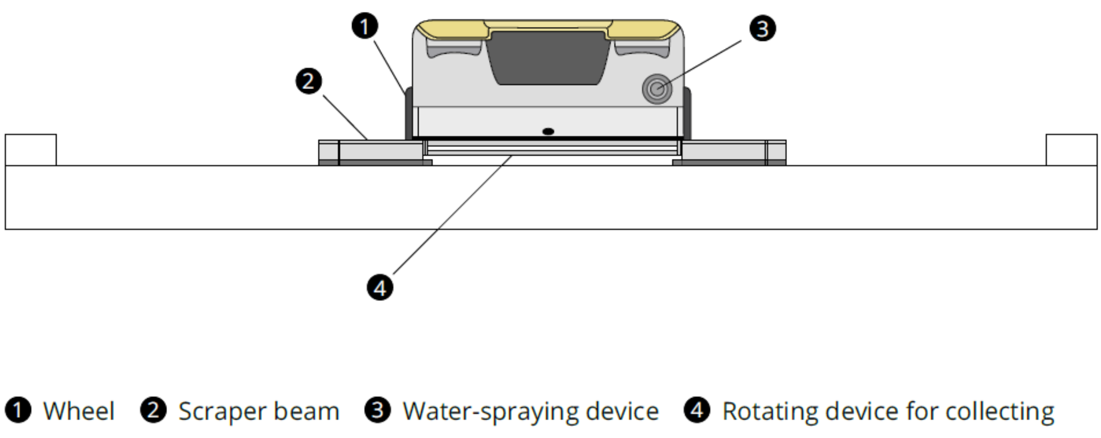
Cleaning robot for solid barn floors used with solid- and liquid-manure processes to reduce emissions.

Technical description

A robotic manure collector is an autonomous cleaning device which has been specially developed for solid barn floors. By generating a vacuum, the robot sucks in the manure (faeces, urine, feed residues) lying on the walkways and temporarily stores it. When its carrying capacity is reached, the robot moves to the discharge station and empties the contents into a dedicated discharge chute.

A robotic manure collector typically moves around the barn at a speed of 6.5 to 15 m/min. The routes it takes must be programmed in before initial use. Depending on the model, the barn must comply with minimum dimensions (e.g. width of walkway, cubicle height, height of walkway partitions) so that the robot can move around unhindered. The widths and heights of robots as well as the scraper widths vary depending on the manufacturer. Depending on the product, it is possible to humidify the walkway with a water spray to enhance the cleaning effect. A charging station must be planned in the barn.

Figure 20: Sketch of a robotic manure scraper on a solid barn floor



Source: own illustration, KTBL

Regular cleaning (i.e. humidification, scraping off and collection of manure) is necessary to ensure that the barn floor surface is dry and clean. Low-emission barn floors can only reduce emissions in conjunction with regular cleaning operations.

Achieved environmental benefits

To reduce emissions, this technique is used in combination with low-emission solid walkways. The reduction potential for ammonia emissions can be found in Chapter 1.1.3.1 Low-emission floors in cattle farming.

Environmental performance and operational data

The cleaning effect is enhanced by optionally deploying a water sprayer. To reduce water consumption, it may be sufficient to use water for every other floor-cleaning cycle by the robot.

To avoid disturbing the animals during food intake, the barn floor should not be cleaned in the area where the animals eat during peak feeding times. Alternatively, additional elevated feeding stalls with partitions between the feeding places can be installed.

Cross-media effects

The use of this automated technology increases energy requirements. Additional cleaning with a water-spraying device raises the consumption of process water.

Animal welfare

Clean and dry walkways have a positive effect on the cleanliness of the animals and promote good udder and hoof health (Somers et al. 2005, Magnusson et al. 2008) as well as natural movement (Schrade et al. 2013).

Additional cleaning with water reduces smear layers that may remain on the floor after removing faeces and urine. Reduction of these smear layers supports the animals' sure-footedness (Telezhenko et al. 2017).

Sensors mounted on the equipment are particularly important for preventing collisions with animals.

Technical considerations relevant to applicability

Robotic manure collectors have been developed especially for solid barn floors. To ensure that the robot can move around freely in the barn, it is essential that the barn complies with given minimum dimensions (e.g. width of walkway, cubicle height, height of walkway partitions). These may vary depending on the manufacturer.

Cleaning robots are mainly used in dairy cow husbandry. They are not used in fattening bull housing where there is a risk that the animals damage the device or are injured by it.

Economic impact

According to various manufacturers, the investment required for a robotic manure collector is approx. € 30,000 - 35,000. One robot can clean an area of about 500 m^2. Thus, assuming a surface area of 5 m^2 per animal place, one device is sufficient for 80 - 100 cows. Hence, 6 - 8 robots are needed for 600 animal places. The robots are in operation 24 hours a day. The cleaning, discharging processes and charging times change permanently. One robot is expected to consume about 3 kWh of power per day. The devices can apply about 3.5 litres of water per minute. Thus, approx. 1.8 m^3 of water is required per animal place per year.

Driving force for implementation

One of the main driving forces is the labour and time savings that can be achieved by automating cleaning. The technique also helps improve the animals' hoof health by ensuring that the walkways are clean and dry.

Regular cleaning is essential for low-emission floors to realise their emission reduction potential.

Example plants

This technique is already used on German cattle farms and abroad. There are no data available on how widely it is used.

1.1.3.2.2 Robotic manure scrapers for perforated barn floors

Brief description

Cleaning robot for perforated floors used with solid manure processes to reduce emissions.

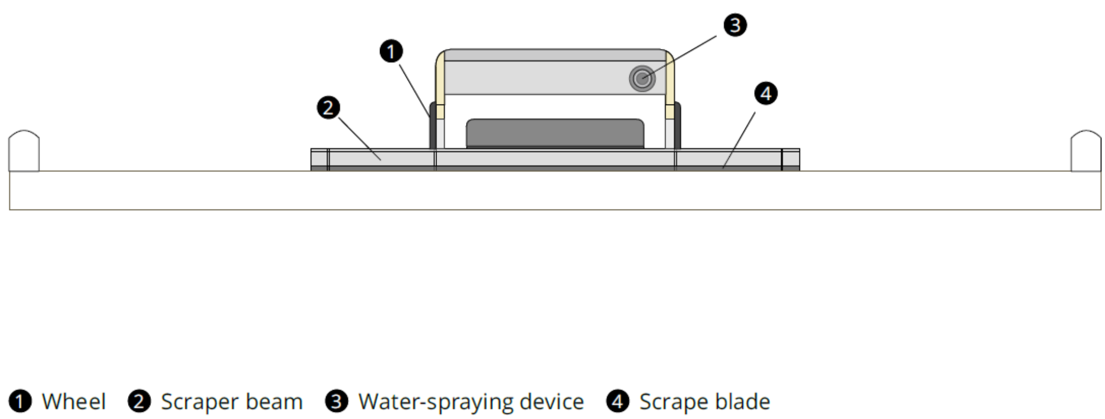
Technical description

A robotic manure scraper is an autonomous cleaning device which has been specially developed for perforated barn floors. The perforated barn floor is cleaned with a blade which pushes the manure through the slats into the storage area below.

A robotic manure scraper moves around the barn at a speed of 5 to maximum 18 m/min (depending on the manufacturer). Most models allow the routes to be programmed individually. According to the manufacturers, one unit can clean an area covering about 150 to 250 cow places (4 m^2 walkway per animal place) every day. Sensors (transponders in the floor, ultrasound, gyroscope or magnetic sensors) enable the robotic scraper to navigate around the barn. Some robots also have a water-spraying device. Water tanks with a capacity of approx. 2 x 50 litres are integrated into the device. The water-spraying device humidifies the barn floor in order to improve the cleaning result. It also prevents the formation of a slippery smear layer.

All devices run electrically and must be charged. A charging station must be planned in the barn.

Figure 21: Sketch of a robotic manure scraper for perforated barn floors



Source: own illustration, KTBL

Regular cleaning (i.e. humidification and scraping off the manure) is necessary to ensure that the barn floor surface is dry and clean. Low-emission barn floors can only reduce emissions in conjunction with regular cleaning operations.

Achieved environmental benefits

To reduce emissions, this technique is used in combination with low-emission perforated walkways. The reduction potential for ammonia emissions can be found in Chapter 1.1.3.1 Low-emission floors in cattle farming.

Environmental performance and operational data

The cleaning effect is enhanced by optionally deploying a water sprayer. To reduce water consumption, it may be sufficient to use water for every other floor-cleaning cycle by the robot.

To avoid disturbing the animals during food intake, the barn floor should not be cleaned in the area where the animals eat during peak feeding times. Alternatively, additional elevated feeding stalls with partitions between the feeding stations can be installed.

Long-stalk straw is only partially suited for walkways that are cleaned by the robots. Chopped straw is a better alternative (Leinweber et al. 2019).

Cross-media effects

The use of this automated technology increases energy requirements. Additional cleaning with a water-spraying device raises the consumption of process water.

Animal welfare

Clean and dry walkways have a positive effect on the cleanliness of the animals and promote good udder and hoof health (Somers et al. 2005, Magnusson et al. 2008) and natural movement (Schrade et al. 2013).

Additional cleaning with water reduces smear layers that may remain on the floor after removing faeces and urine. Reduction of these smear layers supports the animals' sure-footedness (Telezhenko et al. 2017).

Sensors preventing collisions with animals are particularly important.

Technical considerations relevant to applicability

Robotic manure scrapers are particularly suitable for perforated barn floors (liquid manure process). To ensure that the robot can move around freely in the barn, it is essential that the barn complies with certain minimum dimensions (e.g. width of walkway, cubicle height, height of walkway partitions). These may vary depending on the manufacturer.

Cleaning robots are mainly used in dairy cow husbandry. They are not used in fattening bull housing where there is a risk that the animals damage the device or are injured by it.

Economic

According to various manufacturers, the investment required for a robotic manure scraper is approx. € 11,000 - 27,000. One robot can clean an area for about 160 - 250 cows. Hence, 3 - 5 robots are needed for 600 animal places. Power consumption of 1.2 - 2.2 kWh per robot per day can be expected. The robots are in operation 24 hours a day. The cleaning processes and charging times change permanently. The robots equipped with water-spraying equipment can apply about 0.7 - 1.0 l litres of water per minute. Thus, approx. 1.8 m^3 of water is required per animal place per year.

Driving force for implementation

One of the main driving forces is the labour and time savings that can be achieved by automating cleaning. The technique also helps improve the animals' hoof health by ensuring that the walkways are clean and dry.

Regular cleaning is essential for low-emission floors to realise their emission reduction potential.

Example plants

This technique has already been used in German cattle farms and abroad for decades. There are no exact data available on how widely it is used.

1.1.3.2.3 Stationary manure removal system for solid barn floors

Brief description

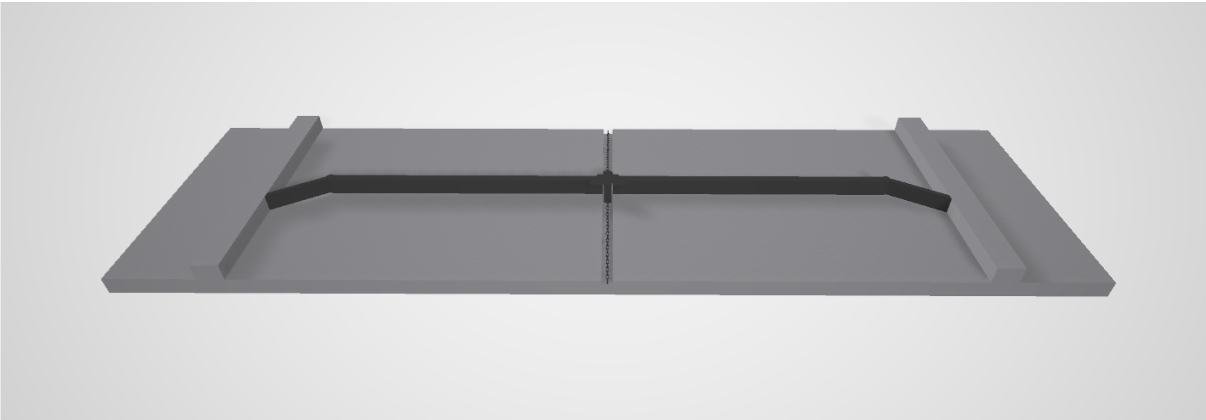
Stationary manure removal system for solid barn floors used with solid and liquid manure processes to reduce emissions.

Technical description

Stationary manure removal systems (Figure 22) are permanently installed in the barn. They clean the walkway several times a day by pulling a manure scraper blade across the floor using a rope or a chain. This involves collecting the manure along the length of the walkway and pushing it into a discharge chute. As a rule, the discharge chute is located at the front end of the barn in the clearing direction. Stationary scrapers do not clean the corridors between walkways and therefore do not clean all areas of the barn. The manure must be cleared out from these areas manually or using autonomous cleaning devices.

Flap scrapers, folding scrapers and combination scrapers have proven effective as scraper systems in practice. When the flap scraper returns to its initial position after cleaning, the clearing flap is raised to prevent repeated cleaning in the other direction. Folding scrapers have scraper wings which are folded into the centre on the return journey. When folded, the units do not serve as obstacles for the animals. The animals can thus avoid the scraper by moving to the side and do not have to step over it. A combination of a flap and folding scraper is called a combination scraper. While the middle part of a combination scraper has the same design as the flap scraper, the shorter side components are designed like the folding scraper (Ofner-Schröck et al. 2017). Due to its movable side components, the combination scraper adapts well to the floor and to the sides (Läpke et al. 2010).

Figure 22: Stationary scraper system with a chain



Source: own illustration, KTBL

Regular cleaning (scraping off the manure) is necessary to ensure that the barn floor surface is dry and clean. Low-emission barn floors can only reduce emissions in conjunction with regular cleaning operations.

Achieved environmental benefits

To reduce emissions, this technique is used in combination with low-emission solid walkways. The reduction potential for ammonia emissions is described in Chapter 1.1.3.1 Low-emission floors in cattle farming.

Environmental performance and operational data

To achieve optimal cleaning results, the barn floor must be cleaned regularly (at least every two hours).

Cross-media effects

There are no cross-media effects.

Animal welfare

Clean and dry walkways have a positive effect on the cleanliness of animals and promote good udder and hoof health (Somers et al. 2005, Magnusson et al. 2008) and natural movement (Schrade et al. 2013).

Technical considerations relevant to applicability

Stationary manure removal systems are suitable for solid barn floor systems with solid or liquid manure processes. To allow implementation of this technique, the barn must have a manure removal alley. Passages outside this manure removal alley can therefore not be cleaned with the system. The barn must have a discharge chute.

Economics

To purchase a stationary manure removal system, an investment of € 9,000 – 9,500 is required (Table 19). One unit can clear a manure removal alley up to 70 m long. For dairy cows, 100 animal places require 1 - 2 manure removal alleys; 600 animal places require 3 - 5 alleys. Table 19 lists the fixed and variable costs as well as the consumption of operating materials. The electricity demand depends on the frequency and duration of the cleaning cycles.

Table 19: Fixed and variable costs as well as consumption of operating materials for a folding scraper

Machine type Machine size	Acquisition price (€)	Utilisation potential Time (a)	Utilisation potential Performance (h)	Fixed costs Total (€/a)	Fixed costs Deprec. (€/a)	Variable costs Total (€/h)	Variable costs Repairs (€/h)	Operating materials Electricity (kWh/h)
Manure scraper, stationary Design, working width, propulsion power								
Folding scraper, 3 m, 0.75 kW	9,000	10	7,000	937	720	1.46	1.29	0.75
Flap scraper, 4 m, 1.75 kW	9,500	10	7,000	1,001	760	1.71	1.36	1.50

Source: KTBL 2022a

Driving force for implementation

One of the main driving forces is the labour and time savings that can be achieved by automating cleaning. The technique also helps improve the animals' hoof health by ensuring that the walkways are clean and dry.

Regular cleaning is essential for low-emission floors to realise their emission reduction potential.

Example plants

This technique has already been used in German cattle farms and abroad for decades. Exact information on its distribution is not available.

1.1.3.3 Elevated feeding stalls with partitions separating feeding stations

Brief description

Elevated feeding stalls with partitions separating feeding stations to improve animal welfare and reduce ammonia and odour emissions.

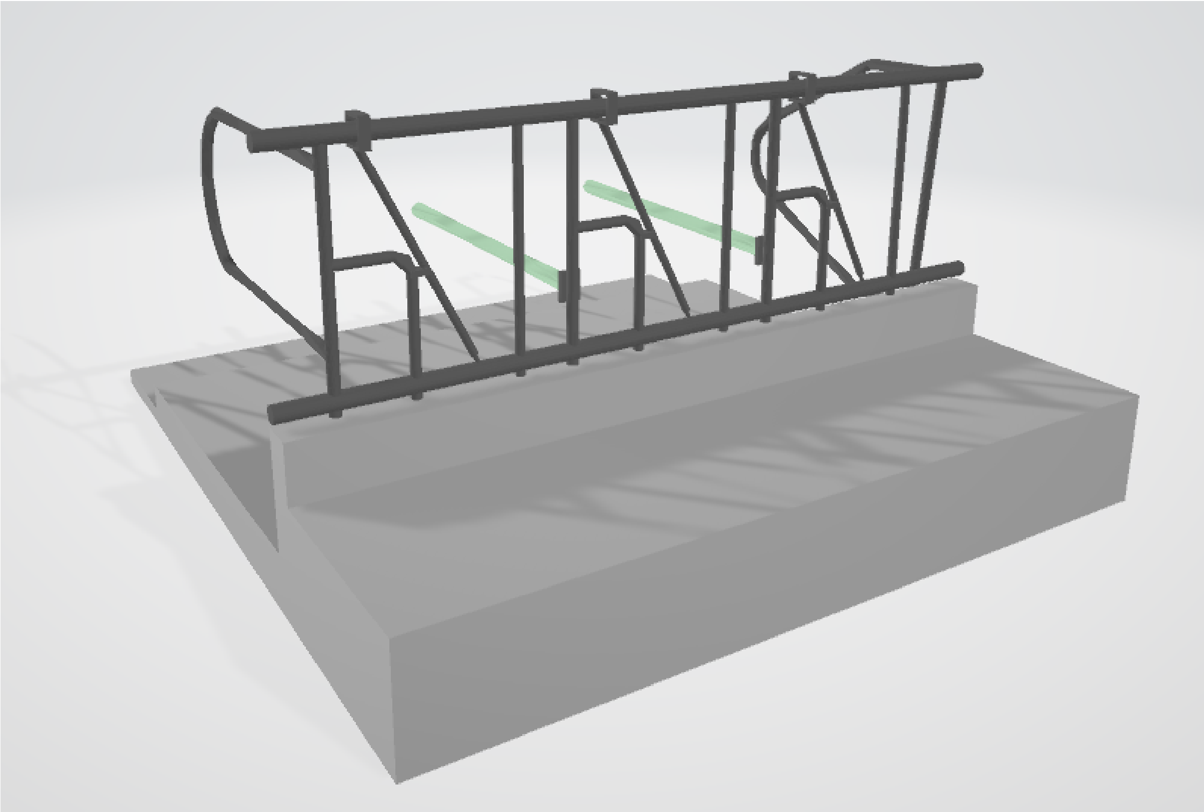
Technical description

Elevated feeding stalls are raised platforms (10 to 20 cm high) in the feeding alley at the feeding fence. The raised standing space is directly adjacent to the feeding table. The walkway is thus divided into a feeding and walking area. Partitions divide the feeding area into individual feeding stations. They are installed either at every feeding station (in case of flexible partitions) or at every second feeding station (in case of fixed partitions) (Figure 23 and Figure 24). It does not make sense to increase the space between the partitions as the animals are meant to walk backwards out of the feeding station so as not to contaminate the area with faeces.

To reduce the dirty area of the walkway, its width should be decreased when installing elevated feeding stalls. To allow undisturbed cow movement, a gangway width of 260 cm is recommended (Zähner and Schrade 2020a). As a result, the total width of the walkway including the feeding stations is approx. 4.20 m.

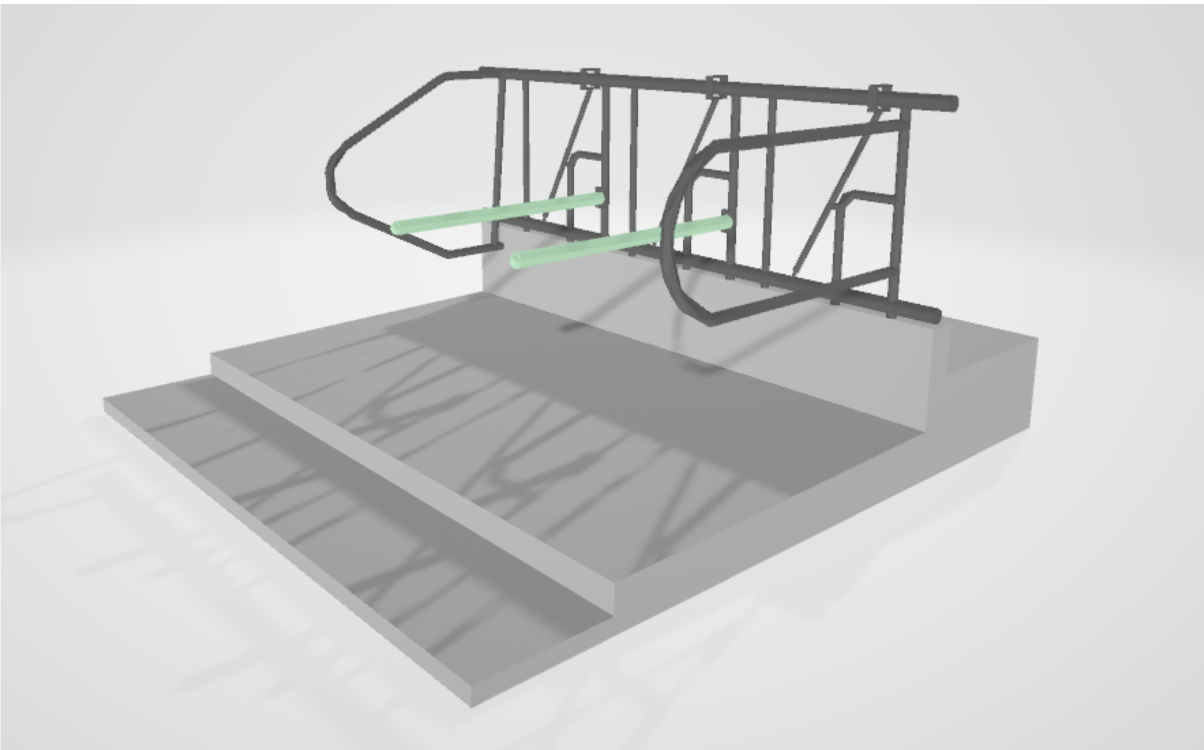
The size of the standing space in the feeding stall depends on the breed or size of the animals. The length of the standing area is 155 - 160 cm for dairy cows of the mottled Simmental, brown highland and German Holstein cattle breeds. To facilitate drainage of liquids and allow the standing area to dry quickly, the floor should have a slope of 3 % (EIP 2019). By changing the angle of inclination of the feeding fence, it is possible to individually adjust its distance to the cows (see Figure 25)(EIP 2019).

Figure 23: Elevated feeding stall with flexible partitions between each feeding station, lateral view from the front



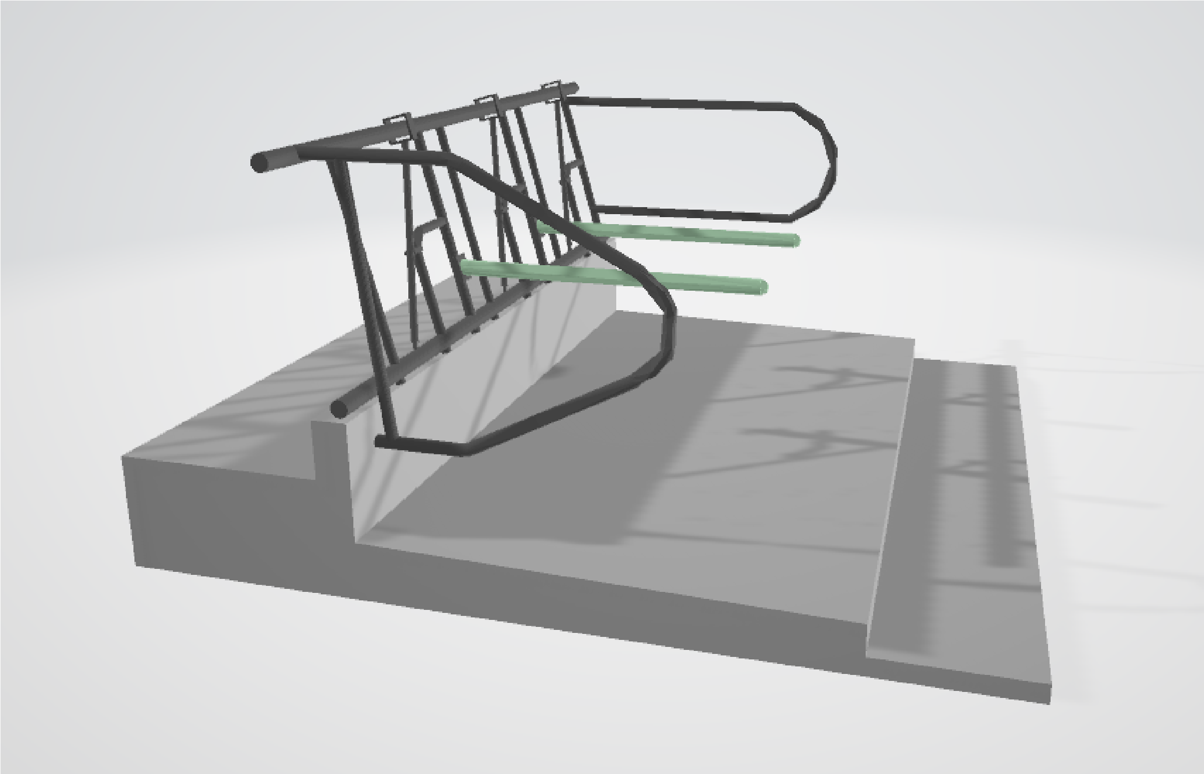
Source: own illustration, KTBL

Figure 24: Elevated feeding stall with flexible partitions between each feeding station, lateral view from the back



Source: own illustration, KTBL

Figure 25: Elevated feeding stall with slanted feeding fence, lateral view



Source: own illustration, KTBL

The following dimensions apply to the structural design:

Platform length: 155 - 160 cm (for small breeds, 5 - 10% shorter)

Platform height: 10 - 20 cm with cross slope

Feeding table height: 20 - 40 cm above standing area

Feeding station width: min. 75 cm per animal

The installation of elevated feeding stalls with partitions separating feeding stations reduces the emission-relevant surface area. This is because the elevated standing area is not contaminated by the animals during feeding, and the dimensions of the emission-relevant walkway behind it can be smaller. To prevent soiling of the standing area with excrement, the animals are forced to leave the platform backwards (Zähner and Schrade 2020a). This is achieved by installing partitions between the feeding stations.

In addition, the cleaning frequency of the walkway can be increased, as the scraper system does not disturb the animals while they are feeding. This can greatly reduce soiling of the surface of the walkway (Zähner and Schrade 2020a).

Achieved environmental benefits

When combined with a high cleaning frequency in the walking area, elevated feeding stalls with partitions separating feeding stations can help reduce ammonia emissions in barns. It can be assumed that a reduction in ammonia emissions leads to a drop in odour emissions. No other environmental effects are currently known.

Environmental performance and operational data

Measurements performed in Switzerland have shown that, depending on the season, ammonia emissions (NH_3) can be decreased by the implementation of elevated feeding stalls with partitions separating feeding stations accompanied by twelve cleaning cycles per day. The emission calculations show a reduction of 8 % in summer, 19 % in autumn and 16 % in winter compared to the reference compartment (case-control measurement; without elevated feeding stall)(Zähner et al. 2019).

Elevated feeding stalls allow a high cleaning frequency in the walkway. This can greatly reduce soiling of the walkway surface. The surface of the walkway can also be cleaned during peak feeding times without disturbing the animals and feed intake. Manure is removed from the walkway at least every 2 hours during the day. To prevent smear layers, it helps to humidify the walkway directly before the manure removal process (Zähner and Schrade 2020a).

Cross-media effects

There are no cross-media effects.

Animal welfare

With elevated feeding stalls, animals can eat without being disturbed or interrupted by cleaning equipment (Zähner and Schrade 2020a). This makes it possible to increase the feeding time (DeVries and Keyserlingk 2006).

The partitions between the feeding stations prevent subordinate animals from being pushed to the side (Benz et al. 2014). With an adequate animal-to-feeding station ratio of at least 1:1, the animals can feed at the same time (herd synchronicity) (Winckler 2009).

Alongside frequent cleaning of the walkway, dry and clean standing areas positively affect hoof health (Zähner and Schrade 2020a).

Technical considerations relevant to applicability

Elevated feeding stalls with partitions separating feeding stations can be planned directly in new buildings. Alternatively, buildings can be retrofitted, providing the width of the feeding alley is taken into account (KTBL 2017a).

In principle, they can be used in any type of production in cattle farming, in some cases with limitations (see Figure 26). In bull fattening, there is a risk that the animals damage the partitions. It is necessary to provide feeding stalls with different dimensions in terms of length and width for growing animals, depending on their body size. Elevated feeding stalls have therefore only been used for dairy cows so far. It is conceivable that they are used for other types of production, providing the aspects specified in Figure 26 are taken into consideration.

Figure 26: Use and application possibilities of elevated feeding stalls with partitions separating feeding stations, according to the individual types of production

Type of production		Elevated feeding stall with partitions between feeding stations
Dairy cows		Applicable
Calf rearing		Applicable to a limited extent (taking into account dimensions of feeding station)
Young cattle		Applicable to a limited extent (taking into account dimensions of feeding station)
Cattle for fattening	Heifers/oxen	Applicable to a limited extent (taking into account dimensions of feeding station)
	Bulls	Applicable to a limited extent

		(taking into account dimensions of feeding station, stability of partitions)
Calves for fattening		**Applicable to a limited extent** (taking into account dimensions of feeding station)
Suckler cows with offspring		**Applicable to a limited extent** (calves)

Applicable
Applicable to a limited extent

Source: own illustration, KTBL

Economics

It is assumed that an area of approx. 1.3 m² per animal place is required to install elevated feeding stalls in cubicle houses. Retrofitting with a stationary manure removal system might be necessary (Table 20).

The investment requirement for feeding stalls ranges between € 100 and € 185 per animal place, depending on the herd size. Hence, the cost is estimated to be € 157 per animal place for 100 animal places and € 127 per animal place for 600 animal places. The resulting annual building costs per animal place and year (depreciation, interest costs, repairs, insurance) range from € 18.70 for 600 animal places to € 23.10 for 100 animal places (source: own surveys).

The installation of a stationary manure removal system for cleaning the walkways behind the feeding stall costs between € 63 per animal place for 600 animal places and € 95 for 100 animal places. The fixed costs (depreciation, interest costs, housing) are between about € 6.70 and € 10.00 per animal place and year for these herd sizes (KTBL 2020).

Operation of the scraper system incurs running costs for operating materials (electricity) and repairs, depending on the usage time. Assuming 12 cleaning cycles per day, the scraper system can be expected to have a usage time of 12 hours. With a power requirement of 1.5 kW/h for the cleaning equipment, about 65,7 kWh is required per animal place per year for 100 animal places. In comparison, the value is about 14.6 kWh per animal place per year if it is only operated twice a day. With 600 animal places, the electricity requirement drops to 43.8 kWh per animal place and year when operated for 12 hours.

The variable costs for the stationary manure removal system amount to approx. € 74.70 per animal place and year for 100 animal places and to approx. € 49.80 for 600 animal places. If the system is operated only twice a day, the variable costs drop to € 12.40 or € 10.00 per animal place per year. The difference in costs amounts to € 61.30 and € 39.80 per animal place and year.

There are no additional operating costs for work processes.

Table 20: Economic parameters of elevated feeding stalls with partitions separating feeding stations

Investment and costs	Animal places (AP)	
	100	600
	€/AP	
Investment		
Buildings and structural equipment	157.00	127.00
Technology and technical plant	95.00	63.00

Total investment	**252.00**	**190.00**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**23.10**	**18.70**
Depreciation	15.70	12.70
Interest costs	2.40	1.90
Building maintenance	4.70	3.80
Insurance	0.30	0.30
Technology and technical plant	**10.00**	**6.70**
Depreciation	7.60	5.10
Interest costs	1.70	1.10
Housing	0.70	0.50
Total fixed costs	**33.10**	**25.40**
Variable costs		
Technology and technical plant	**74.70**	**49.80**
Repairs	59.60	39.70
Electrical energy	15.10	10.10
Total variable costs	**74.70**	**49.80**
Total costs	**107.80**	**75.20**

Source: own calculation, KTBL

In the case of a 50 % reduction in NH_3 emissions compared to the initial potential of 14.57 kg NH_3/animal place and year for a cubicle house without reduction measures for 100 dairy cows, the costs associated with one kg of NH_3 reduction per animal place and year are € 14.77. These costs comprise € 3.16 for annual building costs, € 1.37 for fixed engineering costs and € 10.23 for ongoing engineering costs. For 600 cow places, the costs are € 10.16 (€ 2.56 building, € 0.78 fixed engineering costs, € 6.82 operating costs).

Driving force for implementation

When used in cattle barns, this technique leads to an improvement in animal health. As there is less moisture on the walkways, the animals are more sure-footed, which positively influences their hoof health.

Moreover, it is likely that this technology will be implemented more broadly as a result of specific measures promoting emission reduction.

Example plants

In Switzerland, studies have already investigated the use of elevated feeding stalls (Schweizerische Eidgenossenschaft Agroscope). In Germany, the technique is currently being implemented in barns in the field within the framework of the "European Innovation Partnership for Construction in Cattle Husbandry" project (EIP-Cattle) to analyse its practical suitability. There are no data available on how widely the technique is used on farms in practice.

1.1.3.4 Slurry acidification in the barn

Brief description

Long-term acidification of slurry with sulphuric acid to obtain a pH below 6 and, as a result, reduce ammonia and methane emissions in the barn.

Technical description

Emission reduction or release of gaseous NH_3 from the liquid phase is based on the pH-dependent chemical equilibrium between ammonia and ammonium. The addition of acid to manure shifts the NH_4^+/NH_3 balance towards ammonium. To effectively reduce the NH_3 emissions from slurry, the pH value should be at least below 6 (Kaupenjohann et al. 2019). In practice, a pH value of 5.5 is recommended (The Danish Ministry for the Environment 2015).

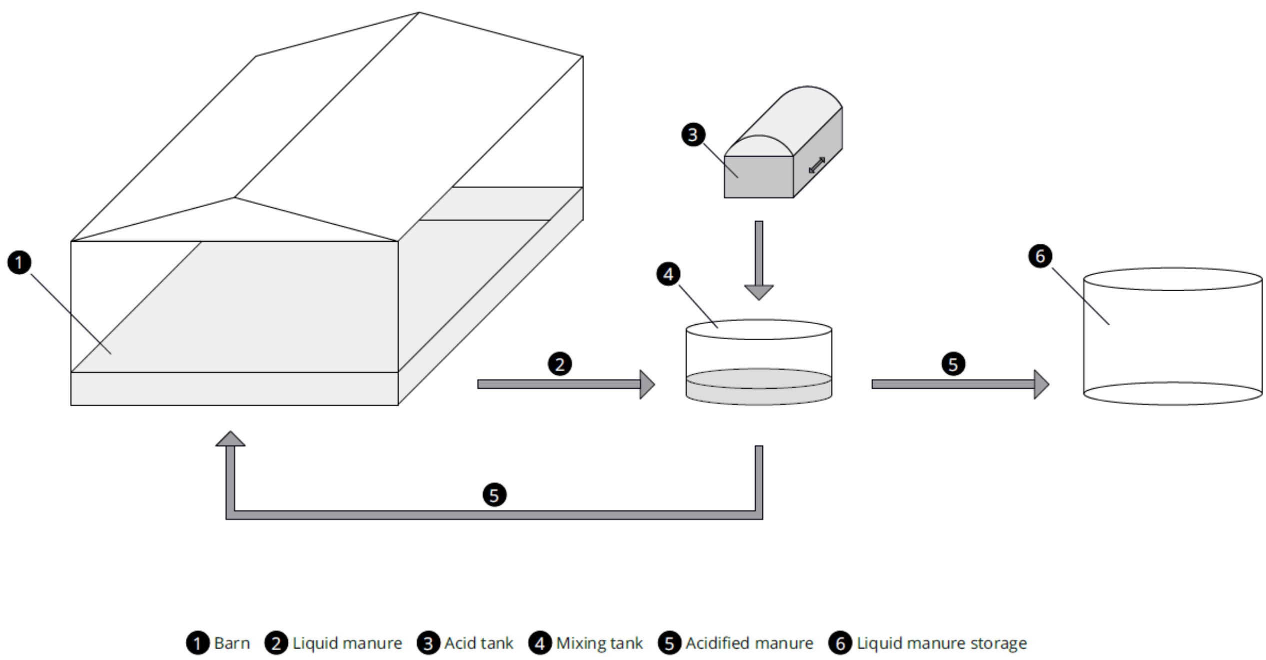
Technical sulphuric acid (concentration: 96 %) is generally used for acidification. However, other organic and inorganic acids can also be used (Kaupenjohann et al. 2019). The amount of acid used depends on the buffer capacity of the slurry and the target pH value. A smaller amount of acid is required for cattle slurry than for pig slurry or digestate (LfL 2020a, Kaupenjohann et al. 2019).

In practice, the slurry is conveyed to a mixing tank outside the barn for acidification (see Figure 27). Sulphuric acid is added daily or several times a week and controlled by simultaneously measuring the pH level until the target pH value is reached (Kupper 2017). As slurry has a high buffer capacity, which means that the pH value can rise again after the addition of acid, it is necessary to check the pH value in the mixing tank after a short time. To prevent the formation of foam (Fangueiro et al. 2015) and hydrogen sulphide (Botermans et al. 2010), the slurry is ventilated at the same time as the acid is added. In most cases, not all of the slurry is pumped back into the barn, but part of it is fed into an external storage tank. As a result, the slurry channels in the barn permanently contain slurry with a low pH value.

Achieved environmental benefits

The acidification of manure reduces emissions of ammonia (Fangueiro et al. 2015, Hou et al. 2015) and methane (Ottosen et al. 2009, Petersen et al. 2014, Petersen et al. 2012).

Figure 27: Schematic diagram of slurry acidification in the barn



Source: own representation, KTBL

Environmental performance and operational data

Acidification of cattle slurry in the barn reduces ammonia emissions by 40 % (VDI 3894 Blatt 1) to 50 % (Kupper 2017, VDI 3894 Blatt 1) compared to untreated slurry. In studies by Petersen et al. 2012, Sommer et al. 2017 and Misselbrook et al. 2016, acidification reduced methane emissions by 60 – 87 % in the storage of cattle slurry. If slurry is acidified in the barn, the magnitude of the drop in the share of methane emissions originating from slurry stored in the barn can be expected to be the same.

On the basis of studies by Zhang et al. (2004) the Danish Ministry of the Environment (Miljøministeriet Miljøstyrelsen) reports an emission reduction potential for ammonia of 50 % when liquid manure is acidified in the barn (The Danish Ministry for the Environment 2015). The addition of 5 - 7 kg of concentrated sulphuric acid per 1,000 kg of cattle slurry lowered the pH value to pH 5.5 and pH 6.0.

According to specifications by Kupper (2017) and Kaupenjohann et al. (2019), the amount of acid required to achieve a pH reduction to pH 5.5 is between 5.5 and 7.4 l H_2SO_4 per m^3. The amount of acid depends on the buffer capacity of the slurry.

Cross-media effects

Landspreading of acidified slurry can decrease the pH of the soil, which must be offset with additional liming. Sorensen (2016) estimated the lime requirement to be 153 kg/ha and 122 kg/ha (in $CaCO_3$ equivalents) for cattle and pig manure, respectively. The consumption of lime is about 20 - 25% higher than for non-acidified slurry (Kupper 2017).

The slurry acidified with sulphuric acid has a higher sulphur content. Over-fertilisation with sulphur should be avoided. Therefore, the landspreading rate must be adapted to the sulphur requirements of the plants and the status of the soil.

To avoid inputs of heavy metals into the soil, care should also be taken to use sulphuric acid with a very low heavy-metal content (UBA and KTBL 2021).

A high content of inorganic sulphur in the slurry can potentially lead to the formation of volatile sulphuric compounds (Eriksen et al. 2008) and thus result in odour emissions. According to Kupper (2017) the maximum concentration of hydrogen sulphide in barn air is 0.5 ppm. Therefore, following the addition of the acid in the external mixing tank, the slurry is ventilated (Kaupenjohann et al. 2019, Kupper 2017, Riis 2016) and monitored. By adhering to these specifications, increased formation of H_2S can be avoided (Kupper 2017).

Animal welfare

Reducing ammonia emissions in the barn improves the air quality for the animals and employees (EFSA 2009).

Considerations relevant to applicability

Handling strong acids on agricultural holdings is dangerous. To ensure the safety of farm personnel, a fully automated dosage system must be used so that employees working in the livestock facility have no manual contact with sulphuric acid. Slurry handling, including discharge operations, must also be automated.

To prevent accidents and the release of water-polluting substances, double-walled storage tanks must be implemented for concentrated sulphuric acid as well as bollards to prevent ramming damage. Acid transport, maintenance of the plant and breakdown repairs should be completely outsourced to specialist personnel or specialist companies (Kupper 2017).

To avoid danger incurred by potential H_2S formation, acid dispensing must be performed outside the barn. The usage of organic acids could prevent the H_2S problem from occurring. However, this would result in significantly higher costs (LfL 2020a).

In Germany, compliance with the provisions of the Ordinance on Installations for Handling Water-Polluting Substances (Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen; AwSV) is mandatory for the storage of slurry, dung water and silage effluent (for so-called JGS facilities) (AwSV 2017). The AwSV contains an exemption regulation for JGS facilities with regard to constructional requirements for water protection. Currently, this exemption does not apply to acidified slurry. For the latter, more stringent requirements are imposed regarding the construction of the slurry storage tank, e.g. a double-walled design. However, a draft amendment to the AwSV, which has been agreed upon by the departments, stipulates that acidified slurry can also be stored in JGS facilities in the future without incurring additional expenses.

Studies by the Bavarian State Institute for Agriculture (Bayerischen Landesanstalt für Landwirtschaft; LfL) and the Technical University of Munich have shown that the damage potential of acidified slurry is not significantly higher than that of untreated slurry when it is stored in concrete tanks and conveyed in slurry channels. However, due to its higher sulphate content, higher-quality concrete is recommended for new buildings, i.e. an increase of exposure class from XA1 to XA3 (LfL 2020a).

According to Peters (2016), the inspection of slurry storage tanks is mandatory at 10-year intervals in Denmark; for tanks near surface waters, it is mandatory at 5-year intervals (from Kupper 2017).

In order to reduce emissions using this technique, the barn must be equipped with a liquid manure system with interconnected channels ("annular channels"). To facilitate circulation of the slurry, it is recommended that the channels have a depth of at least 1.00 m (circulation system). As a result, this system is only applicable to a limited extent. At present, experience with the system is limited to dairy cows; it has not been employed for any other types of production (Figure 28).

Figure 28: Use of slurry acidification in the barn, according to the individual types of production

Type of production		Slurry acidification in the barn with liquid manure system [1)]
Dairy cows		Applicable to a limited extent
Calf rearing		No experience to date
Young cattle		No experience to date
Cattle for fattening	Heifers/oxen	No experience to date
	Bulls	No experience to date
Calves for fattening		No experience to date
Suckler cows with offspring		No experience to date

[1] Minimum channel depth of 1.00 m and annular channels (circulation system) required

Applicable to a limited extent
No experience to date

Source: own illustration, KTBL

To achieve a uniform acid concentration in the slurry, it must be homogenized regularly. Perforated barn floors are more suitable for the process than solid floors, as the excrement enters the slurry channel directly from the perforated floor.

Cattle manure acidified with sulphuric acid is used as a co-substrate in biogas plants to influence biogas formation. Investigations by Moset et al. (2016) show that the addition of small amounts of acidified slurry can slightly increase the methane yield. On the other hand, the methane yield drops by 30 % if a high proportion (e.g. 20%) of acidified cattle slurry is used. Investigations by Ottosen et al. (2009) show that introducing acidified cattle slurry (with sulphuric acid) into a biogas plant as a co-substrate negatively affects the plant's gas yield. Hence, if slurry is intended for use in a biogas plant, acidification with sulphuric acid is not recommended. In this case, the use of suitable organic acids, which can be more easily degraded in biogas plants, can be an alternative. However, the quantities required and costs are usually significantly higher than for sulphuric acid.

The high sulphur contents in acidified slurry significantly limit the applicability of this technique, also in crop production. To avoid exceeding the required amount of sulphur when fertilising soil, it is probable that only a portion of the slurry spread on the land is acidified. However, since this technique involves acidifying all of the slurry produced in the barn, the possibilities for efficient on-farm use of acidified slurry may be severely limited.

Economics

It is recommended that acid-resistant concrete of exposure class XA3 is used to construct slurry channels for the acidification of slurry in new buildings. Research on prices indicates a 12 - 15% price premium for this concrete over a comparable concrete of exposure class XA1 (Cemex 2022).

In existing buildings, the slurry channels can be retrofitted with a special protective film or, if necessary, with a protective coating for the acidification of slurry. There is currently no information on the investment required for retrofitting the channels. Prior to retrofitting, the channels must be emptied and cleaned. During construction, the affected parts of the building cannot be used, which incurs additional costs.

Only one company, JH Agro A/S, currently offers a system that automatically mixes highly concentrated sulphuric acid with slurry. In practice, investment costs of € 116,500 were reported for a farm with 130 dairy cows in northern Germany (Latacz-Lohmann and Langanke 2020). For a herd of 600 dairy cows, two or even three systems may be necessary, depending on the building's layout.

The **investment requirement for** a herd size of 100 dairy cows is € 1,165 per animal place (Table 21). This results in **annual building costs** (depreciation, interest costs, repairs, insurance) of about € 171.30 per animal space per year. For a herd of 600 dairy cows, it is assumed that two acidification systems are required for the same technique. The investment required is then about € 388 per animal place and year. The annual building costs drop to

€ 57.10 per animal place and year (source: own calculations based on manufacturer's data and Latacz-Lohmann and Langanke 2020).

An electric agitator is needed to convey the slurry between the acidification system and the barn and to homogenize the slurry in the channels. As the agitator is also used to pump slurry into the storage tank outside the barn or to fill tank lorries, it does not usually incur additional costs. If a retrofit installation is necessary, the following costs are incurred:

A submersible pump powered by an electric motor with 12.5 kW output costs about € 68 per animal place for 100 dairy cows. The **fixed costs** (depreciation, interest costs, housing) are € 5.70 per animal place and year. For a herd of 600 dairy cows, the **investment required for** two submersible motor-driven pumps, each with an output of 24 kW, is € 30 per animal place, and the fixed costs are € 2.50 per animal place per year (KTBL 2016b).

The operation of the pump incurs ongoing costs for operating materials (electricity) and repairs, depending on the usage time. Assuming a usage time of 0.5 hours per day and an electricity requirement of 12.5 kWh/h to power the pump, about 31.94 kW/h per animal place and year are required for 100 animal places. In comparison, about 43.8 kWh per animal place and year are required for a herd of 600 dairy cows and a usage time of 1.5 hours per day, assuming that the electricity demand is 2 x 24 kWh/h to power the pump.

The **variable costs** for the pumps amount to approx. € 38.30 per animal place and year for 100 animal places and to approx. € 41.40 for 600 animal places.

Approx. 3 l of concentrated sulphuric acid per m^3 of cattle slurry is used for acidification. Assuming a quantity of about 21 m^3 of slurry per animal place and year, the annual costs for sulphuric acid are approx. € 29.80 at a price of € 0.43 per litre and a demand of 69.3 l per animal place and year.

The additional labour costs for monitoring the facility are currently not known.

Table 21: Economic parameters of slurry acidification in the barn

Investment and costs	Animal places (AP)	
	100	600
	€/AP	
Investment		
Buildings and structural equipment	1165.00	388.00
Technology and technical system	68.00	30.00
Total investment	**1,233.00**	**418.33**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**171.30**	**57.10**
Depreciation	116.50	38.80
Interest costs	17.50	5.80
Building maintenance	35.00	11.70
Insurance	2.30	0.80
Technology and technical system	**5.70**	**2.50**
Depreciation	4.50	2.00
Interest costs	1.20	0.50
Housing	0.00	0.00
Total fixed costs	**177.00**	**59.60**
Variable costs		
Technology and technical system	**38.30**	**41.40**

Repairs	1.10	1.50
Electrical energy	7.40	10.10
Other inputs		
Acid	29.80	29.80
Total variable costs	**68.10**	**71.20**
Total costs	**245.10**	**130.80**

Source: own calculation, KTBL

If NH_3 emissions are reduced by 46 % compared to the initial potential of 14.57 kg NH_3 per animal place and year for a cubicle house without reduction measures for 100 dairy cows, one kg of NH_3 reduction per animal place and year costs € 36.58. These costs comprise € 25.57 for annual building costs, € 0.85 for fixed engineering costs and € 10.16 for ongoing engineering costs. For 600 animal places, the costs drop to €10.63: € 8.52 for buildings, € 0.78 for fixed engineering costs and € 10.63 for operating costs.

The increased N content of the acidified manure has an economic benefit, as usage of synthetic fertilisers is lower.

Driving force for the application

By reducing ammonia emissions, farms comply with immission control requirements regarding the emissions of ammonia or nitrogen which have a harmful environmental impact on sensitive plants and biotopes. Compliance is necessary to obtain permits for building new barns or extensions. With the permit, it is possible to construct the buildings closer to the plants or biotopes under protection.

Example plants

In Denmark, slurry has been acidified with sulphuric acid for about 15 years (Peters 2016 from Kupper 2017). According to Jonassen (2016) (from Kupper 2017) 151 barns are equipped with slurry acidification systems, of which 76 are for pigs and 75 for cattle.

In Germany, the implementation of slurry acidification has been reported in one barn so far (Latacz-Lohmann and Langanke 2020). As the farm has a biogas plant, both sulphuric and acetic acid are used for acidification.

1.1.3.5 Exhaust air treatment for reducing emissions in beddingless housing in calf fattening

Brief description

This is a two-stage exhaust air treatment system working on a biological and chemical basis. It consists of an exhaust air scrubber fitted with a pH control device and a downstream biofilter which is crucial for eliminating odour from the air in beddingless barns used for calf rearing (DLG e. V. 2014a). This system was originally developed for pig fattening units. It has been tested for suitability for reducing odours, ammonia and dust and adapted for use in calf fattening housing (DLG e. V. 2014b).

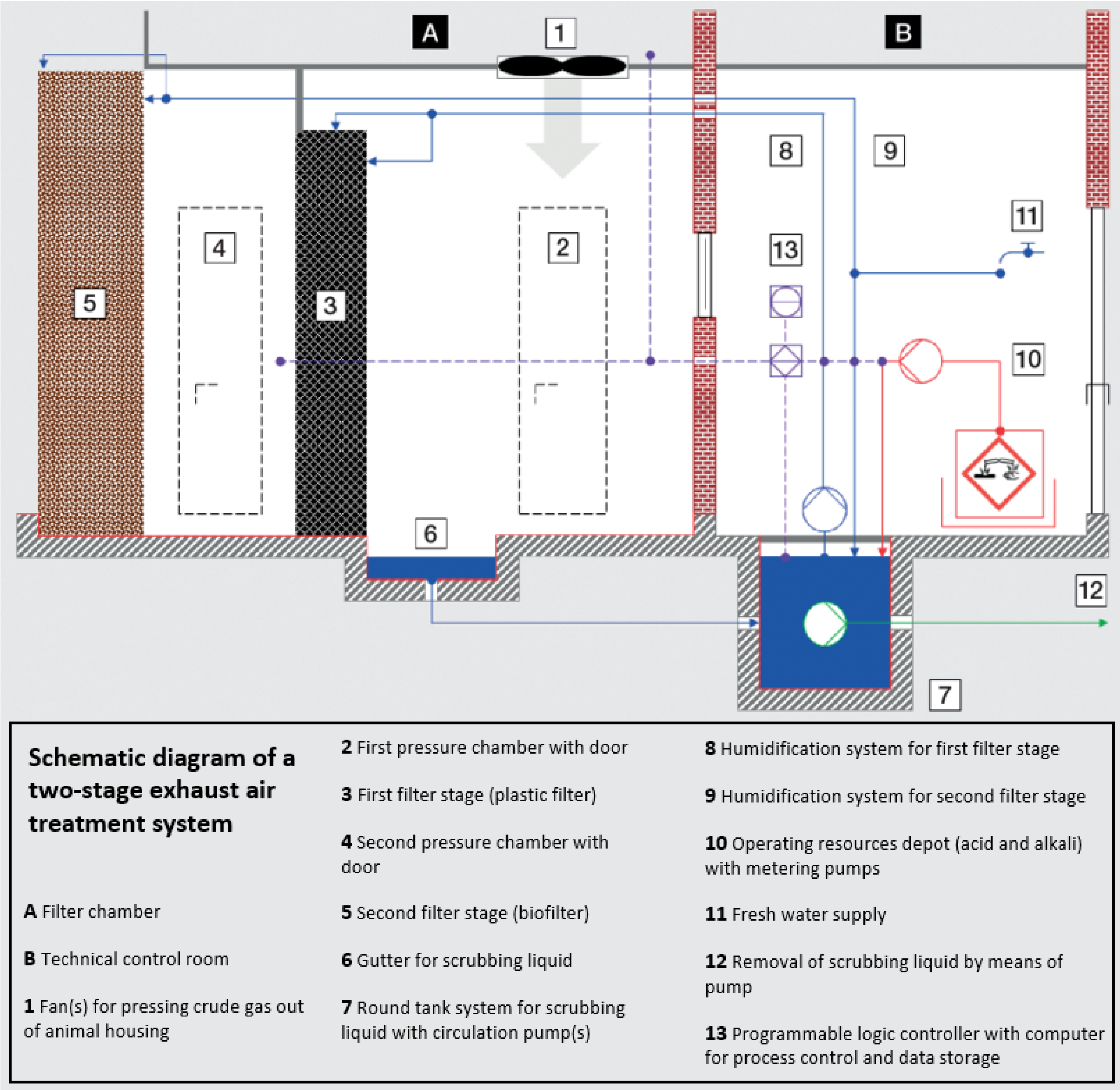
Technical description

The exhaust air treatment system consists of two treatment stages. Before the first stage, the exhaust air in the barn is forced under pressure through a pressure chamber by fans (Figure 29).

1. The first stage consists of a chemical and biological scrubber filled with packing material which is permanently sprinkled with scrubbing water from above and at right angles to the air flow (cross flow). The pH value of the scrubbing water is kept in a range of 6.5 - 6.8 through acidification by adding sulphuric acid or alkali to the water. Dust is washed off by the scrubbing water; the odorous substances and ammonia dissolve into the scrubbing water, and the ammonia is bound as ammonium by the sulphuric acid. Micro-organisms that settle on the packing material and form a biofilm break down the air pollutants. Nitrification inhibitors are increasingly being used instead of caustic solutions to prevent nitrification of the separated ammonia and a decrease in pH.
   Part of the scrubbing water must be removed at regular intervals and replaced by fresh water to compensate for losses resulting from evaporation and to prevent the accumulation of salt (especially nitrite and nitrate). The latter would inhibit the microbiological activity or physical and chemical absorption capacity. This process is performed as a function of the conductivity of the scrubbing water, which must not exceed 15 milliSiemens (mS) per cm.
2. After flowing through the packing material in the first stage, the exhaust air passes through a biofilter which is moistened intermittently. The biofilter is filled with root wood and has a sieving capacity of approx. 50 to 200 mm. Odorous substances are absorbed on its large, moist surface and broken down by the micro-organisms that settle there. Aerosols contained in the exhaust air are also separated as they pass through the root wood filling.

The maximum air rate is about 200 m^3/(AP h) in summer. The pressure loss in the exhaust air treatment system is assumed to be approx. 55 Pa.

Figure 29: **Schematic diagram of a two-stage exhaust air treatment system in beddingless housing for calf fattening**



Source: Modified according to DLG e. V. 2014a

The following *essential* design parameters are necessary to guarantee the proper operation of the system (DLG e. V. 2014a):

Scrubbing stage 1

- Packing thickness: 0.46 m
- Spec. packing surface: 80 m^2/m^3
- Maximum packing surface load: 2,530 $m^3/(m^2 \bullet h)$
- Maximum packing volume load: 5,500 $m^3/(m^3 \bullet h)$
- Minimum residence time at maximum air rate in summer: 0.65 s

- Permanent sprinkling density: 1.87 $m^3/(m^2 \bullet h)$
- Specific capacity of the scrubbing water tank: > 21 l/animal space
- Average elutriation rate: 0.67 m^3/d
- pH value of scrubbing water: 6.5 to 6.8
- Conductivity for elutriation: ≤ 15 mS/cm

Biofilter stage 2

- Thickness of biofilter: 0.6 m
- Biofilter filling with torn root wood, sieving capacity approx: 50 - 200 mm
- Minimum residence time at maximum air rate in summer: 0.98 s
- Maximum filter surface load: 2,193 $m^3/(m^2 \bullet h)$
- Maximum filter volume load: 3,655 $m^3/(m^3 \bullet h)$
- Intermittent humidification of the biofilter depending on the volume of the biofilter: 1.41 $l/(m^3 \bullet h)$

The system must be operated continuously to maintain a consistently high biological activity. Following longer downtimes, a run-in period of several weeks is to be expected. During this time, the exhaust cannot be fully treated.

The scrubbing water must be elutriated automatically in function of the conductivity, which should not exceed 15 mS/cm (DLG e. V. 2014a). Approx. 50% of the scrubbing water's volume is replaced. For this purpose, the process water is discharged into a water storage tank. The scrubbing water is elutriated from the lower layer into the slurry storage tank. The clear water above this layer is returned to the scrubber.

To comply with the requirements of the Ordinance on Installations for Handling Water-Polluting Substances (AwSV 2017), the water storage tank must be equipped with a leak detection device, which is provided by a leakage detection foil.

Both acid and alkali are required to operate the system. The manufacturer's operating instructions outline their handling. To ensure the safety of operating personnel, dispensing is fully automated. The storage tanks are located in lockable plastic containers equipped with a collecting trough to prevent damage to the environment.

In order to monitor the system and document its proper operation, the exhaust air treatment system is equipped with an electronic operating logbook in which the following data are captured and recorded:

- Pressure loss in the exhaust air treatment system
- Air flow rate
- Sprinkling density
- Power consumption of the pumps
- pH and conductivity values of the scrubbing water
- Calibration of the pH and conductivity sensors

- Total freshwater consumption of the scrubber
- Quantity of wastewater
- Outdoor and water temperature
- Crude and clean gas moisture
- Crude and clean gas temperature

The sprinkling function operates permanently and cannot be changed by the user. In the event of a pump breakdown, an alarm is triggered. Proof of acid and alkali consumption can be provided, for example, in the form of purchase receipts.

Achieved environmental benefits

The two-stage exhaust air treatment process has been tested for suitability in reducing odour emissions (DLG e. V. 2014a). Based on its design and mode of operation, it can be assumed that it can also effectively separate ammonia and dust (DLG e. V. 2014b), as is the case in pig farming

Environmental performance and operational data

The primary purpose of the exhaust air treatment system is to reduce odour emissions. Within the scope of the test procedure carried out on the system, it satisfied the criteria required for the suitability test (DLG e. V. 2015):

- Maximum concentration of odorous substances in the clean gas ≤ 300 odour units (OU) per m^3 and
- no odour of crude gas in the clean gas.

The arithmetic mean values in the clean gas after exhaust air treatment measured at three points in time were 63 and 70 OU/m^3 (under winter and summer conditions on three measuring days in each case; DLG e. V. 2014a).

Based on its design and mode of operation, it can be assumed that the system can effectively separate ammonia and dust, as is the case in pig farming. However, a suitability test for calf fattening housing has not been performed:

- Total dust and PM_{10} in dust: > 70%
- Ammonia and nitrogen removal: > 70%

Proper operation of the system requires the following inputs (summer/winter conditions; DLG e. V. 2014a):

- Fresh water consumption: 2.14 / 1.7 m^3/(AP.• a)
- Volume of elutriated waste water: 1.37 / 1.06 m^3/(AP.• a)
- Average acid consumption: 2.95 / 6.15 m^3/(AP.• a)
- Electrical energy consumption (all year)*: 76 kWh/(AP • a) pumps and 238.5 kWh/(AP • a) fans (incl. exhaust air treatment system)

* The values are for an exhaust air treatment system that has been tested for suitability for pig fattening (DLG test report 6220). They are converted for fattening calves in the test report.

Fresh water consumption is higher than the volume of wastewater, since evaporation losses have to be allowed for.

Cross-media effects

As ammonia is separated in the first scrubbing stage, a corresponding amount of nitrogen is discharged into the slurry with the elutriated wastewater. This increases the amount of nitrogen available for crop fertilisation, which should be considered in the planning of fertilisation.

Animal welfare

Exhaust air treatment has no negative impact on animal welfare if the ventilation system is designed and operated in such a way that the air flow in the barn guarantees a healthy climate in all conditions throughout the year.

Considerations relevant to applicability

The two-stage exhaust air treatment process can only be used in beddingless housing for calf fattening which is equipped with a central extractor (see Figure 30). The air from the individual compartments must be fed into the exhaust air treatment system via a sufficiently dimensioned collector duct. For this purpose, the barn must be equipped with fans that are sufficiently pressure resistant so that the maximum summer air rate according to DIN 18910 (2017) can be conveyed under all conditions.

To retrofit an existing barn with an exhaust air treatment system, the ventilation system must be modified to meet the afore mentioned requirements regarding ventilation.

Figure 30: Possibility of using exhaust air treatment systems with forced-air ventilation, according to the individual type of production

Type of production		Exhaust air treatment (forced-air ventilation)
Dairy cows		Not applicable
Calf rearing		Not applicable
Young cattle		Not applicable
Cattle for fattening	Heifers/oxen	Not applicable
	Bulls	Not applicable
Calves for fattening		Applicable
Suckler cows with offspring		Not applicable

Applicable
Not applicable

Source: own representation, KTBL

Economics

For a herd size of 500 to 600 calf places, the (net) investment required for technical installation is about € 100 per animal place (Big Dutchman 2022). A herd size of 1,000 to 1,200 calf places requires an investment of about € 65 per animal place. Transport (average transport distance of 150 km) and assembly can cost an average of € 12 per animal place.

The foundation, filter housing and tank for the scrubbing water must be constructed on site. They require an additional investment of around € 45 to € 60 per animal place.

The total investment required results in annual fixed costs (depreciation 10 years for plant technology, 20 years for building; interest costs 3% on 50% of the investment; repairs 3%; insurance 0.20%) totalling approx. € 15 to € 22/(AP • a) for the above-mentioned herd sizes (1,000 - 1,200 and 500 - 600 AP, respectively).

The ongoing costs for operating the system are estimated as follows:

- Fresh water consumption (own water supply): 2.14 / 1.7 m^3/(AP • a), i.e. on average 1.9 m^3/(AP • a) x € 0.3/m^3 = € 0.57/(AP • a)
- Average acid consumption: 2.95 / 6.15 kg/(AP • a), i.e. on average 4.55 kg/(AP • a) x € 0.78/kg = € 3.55/(AP • a)
- Electrical energy consumption (all year) for pumps: 15 kWh/(AP • a) x € 0.26/kWh = € 3.90/(AP • a).
- The additional expense for barn ventilation, that is, the expense of operating the fans to overcome the additional flow resistance of the exhaust air treatment system, can only be roughly estimated based on pig fattening housing. Hence, an additional energy consumption of about 14 Wh per 1000 m^3/h air flow rate is to be expected. According to DIN 18910 (2017), the required air flow rate depends mainly on the type of production, animal weight and season. Based on a rough calculation, an annual average of 50% of the maximum summer air rate can be expected according to DIN 18910 (2017). For fattening calves with an individual animal weight of 150 kg, the average air rate is about 80 m^3/(AP • h). Hence, the additional consumption is about 10 kWh and the additional costs about € 2.6/(AP • a). For an individual animal weight of 300 kg, the corresponding values are approximately 105 m^3/(AP • h), approx. 13 kWh and approx. € 3.4/(AP • a).
- The additional labour costs for supervision, maintenance and cleaning amount to € 600 - 800 or € 1 to 1.6/(AP • a), assuming a total working time requirement of approx. 30 - 40 h/a and salary costs of € 20/h.
- Further costs for a maintenance contract (€ 450/a) and for technical acceptance and monitoring of the system, incl. measurements, are estimated to be about € 1,000/a or € 2.5/(AP • a).
- To store the elutriated waste water (1.2 m^3/(AP • a), a larger tank volume (approx. € 3 - 4/(m^3 • a) is needed for the slurry, which incurs additional costs of approx. € 3.6/(AP • a).

The additional ongoing costs are about € 17 - 19/(AP • a).

Landspreading of the elutriated wastewater increases crop production costs. These additional costs can be partially offset by the higher fertilisation value, depending on the market situation.

The investment costs for retrofitting existing barns can only be calculated on a case-by-case basis. They depend largely on the expenses incurred by the conversion and the adaptation of the ventilation system.

Driving force for the application

The two-stage exhaust air treatment process is implemented to reduce odour emissions in housing with a high level of odours. In addition, it is deployed in barns where exhaust air treatment was mandatory for obtaining a construction permit.

Although the certification of the reduction of ammonia emissions is not currently available for calf fattening, it is likely to be expected. At present, it is only recognized in cases where a suitability test is not required by the authorities.

Example plants

In Germany, about 50 exhaust air treatment systems (400 to 1,200 animal places) are in operation (as of February 2022), particularly in North/Northwest Germany and Eastern Germany (Big Dutchman 2022).

1.1.4 In storage facilities

1.1.4.1 Slurry acidification in storage tanks

Brief description

Long-term acidification of slurry with sulphuric acid to obtain a pH below 6 during storage in order to reduce ammonia and methane emissions in storage tanks.

Technical description

Emission reduction or release of gaseous NH_3 from the liquid phase is related to the pH-dependent chemical equilibrium between ammonia and ammonium. The addition of acid to manure shifts the NH_4^+/NH_3 balance towards ammonium. To effectively reduce the NH_3 emissions from slurry, the pH value should be at least below 6 (Kaupenjohann et al. 2019). In practice, a pH value of 5.5 is recommended (The Danish Ministry for the Environment 2015).

Technical sulphuric acid (concentration: 96%) is generally used for acidification. However, other organic and inorganic acids can also be used (Kaupenjohann et al. 2019). The amount of acid used depends on the buffer capacity of the slurry and the target pH value. A smaller amount of acid is required for cattle slurry than for pig slurry or digestate (LfL 2020a, Kaupenjohann et al. 2019).

When slurry is acidified during storage, acid is added and intensively mixed into the slurry until the pH value is sufficiently lowered. The pH value is continuously checked using measuring electrodes, and the acid is dosed accordingly (Figure 31).

To prevent the formation of foam (Fangueiro et al. 2015) and hydrogen sulphide (Botermans et al. 2010), the slurry is ventilated whilst the acid is being added.

The decomposition of organic salts leads to pH buffering, which can make it necessary to repeat acidification of the slurry (Kaupenjohann et al. 2019).

Achieved positive environmental effects

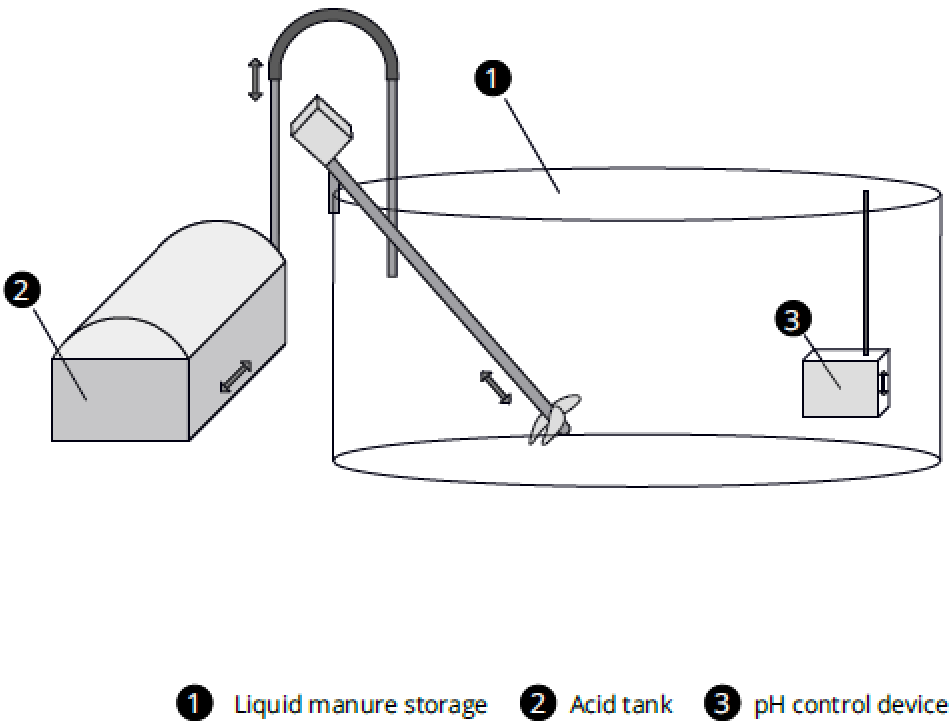
The acidification of slurry reduces emissions of ammonia (Fangueiro et al. 2015, Hou et al. 2015) and methane (Ottosen et al. 2009).

Environmental performance and operational data

Based on his studies, Kupper (2017) reports a reduction of ammonia emissions in storage tanks from 50 to > 90 % for cattle slurry that has undergone acidification. Laboratory tests showed a drop in ammonia emissions by 94 to 97 % when the pH was lowered to pH 5.5 using concentrated sulphuric acid in comparison to untreated slurry (Petersen et al. 2012). In pilot testing facilities with tanks with a capacity of 6.5 m^3, acidification with sulphuric acid was found to reduce ammonia emissions by up to 81 % (Misselbrook et al. 2016, Regueiro et al. 2016).

In addition to reducing ammonia emissions, lowering the pH inhibits microbial activity and, in turn, methanogenesis (Ottosen et al. 2009, Petersen et al. 2014, Petersen et al. 2012). Petersen et al. (2012) found a reduction in methane emissions of 67 – 87 % in a 3-month test carried out on a storage tank where the pH value of the slurry was lowered to pH 5.5 using sulphuric acid. Misselbrook et al. (2016) conducted further investigations and reported a 75 % reduction in methane emissions achieved through acidification with sulphuric acid.

Figure 31: Schematic diagram of slurry acidification in a storage tank; arrows indicate adjustable height



Source: own illustration, KTBL

Cross-media side effect

Landspreading of slurry acidified in storage can decrease the pH of soil, which must be compensated for with additional liming. Sorensen (2016) estimated the lime requirement to be 153 kg/ha and 122 kg/ha (in $CaCO_3$ equivalents) for cattle and pig manure, respectively. The consumption of lime is about 20 – 25 % higher than for non-acidified slurry (Kupper 2017).

The slurry acidified with sulphuric acid has a higher sulphur content. Over-fertilisation with sulphur should be avoided. Therefore, the landspreading rate must be adapted to the sulphur requirements of the plants and the status of the soil.

To avoid inputs of heavy metals into the soil, care should also be taken to use sulphuric acid with a very low heavy-metal content (UBA and KTBL 2021).

Animal welfare

As this technique is implemented outside of the animal housing, it has no impact on animal welfare.

Economics

The use of acid-resistant concrete of exposure class XA3 is recommended if the acidification of slurry is carried out in concrete tanks. Research on prices indicates a 12 – 15 % price premium for such concrete over a comparable concrete of exposure class XA1 (Cemex 2022).

Only one company, JH Agro A/S, currently offers a system that automatically mixes highly concentrated sulphuric acid with slurry in storage tanks. In practice, investment costs of € 116,500 were reported for a farm with 130 dairy cows in northern Germany (Latacz-Lohmann and Langanke 2020). Depending on the size of the herd and the type of tank, several systems may be necessary.

The **investment requirement for** a herd size of 100 dairy cows is € 1,165 per animal place (**Fehler! Verweisquelle konnte nicht gefunden werden.**). This results in **annual building costs** (depreciation, interest costs, repairs, insurance) of about € 171.30 per animal space per year. For a herd of 600 dairy cows, it is assumed that two acidification systems are required for the same technique. The investment required is then about € 388 per animal place and year, with the annual building costs dropping to € 57.10 per animal place and year (source: own surveys based on manufacturer's data and Latacz-Lohmann and Langanke 2020).

Table 22: Economic parameters of slurry acidification in a storage tank

Investment and costs	Animal places (AP)	
	100	600
	€/AP	
Investment		
Buildings and structural equipment	1165.00	388.00
Technology and technical system	68.00	30.00
Total investment	**1,233.00**	**418.33**
Costs	**€/(AP • a)**	
Fixed costs		
Buildings and structural equipment	**171.30**	**57.10**
Depreciation	116.50	38.80
Interest costs	17.50	5.80
Building maintenance	35.00	11.70
Insurance	2.30	0.80
Technology and technical system	**5.70**	**2.50**
Depreciation	4.50	2.00
Interest costs	1.20	0.50
Housing	0.00	0.00
Total fixed costs	**177.00**	**59.60**
Variable costs		
Technology and technical system	**38.30**	**41.40**
Repairs	1.10	1.50
Electrical energy	7.40	10.10
Other inputs		
Acid	29.80	29.80
Total variable costs	**68.10**	**71.20**
Total costs	**245.10**	**130.80**

Source: own calculation, KTBL

An electric agitator is required to convey the slurry between the acidification system and the storage tanks and to homogenize the slurry in the tanks. As the agitator is also used to fill tank lorries, this does not usually incur additional costs. If a retrofit installation is necessary, the following costs are incurred:

A submersible pump powered by an electric motor with 12.5 kW output costs about € 68 per animal place for 100 dairy cows. The **fixed costs** (depreciation, interest costs, housing) are € 5.70 per animal place and year. For a herd of 600 dairy cows, the **investment required for** two submersible motor-driven pumps, each with an output of 24 kW, is € 30 per animal place, and the fixed costs are € 2.50 per animal place per year (KTBL 2016b).

The operation of the pump incurs ongoing costs for operating materials (electricity) and repairs, depending on the usage time. Assuming a usage time of 0.5 hours per day and an electricity requirement of 12.5 kW/h to power it, about 31.94 kW/h per animal place and year are required for 100 animal places. In comparison, about 43.8 kWh per animal place and year are required for a herd of 600 dairy cows and a usage time of 1.5 hours per day, assuming that the electricity demand is 2 x 24 kW/h to power the pump.

The **variable costs** for the pumps amount to approx. € 38.30 per animal place and year for 100 animal places and to approx. € 41.40 for 600 animal places.

Assuming the same acid quantity as for acidification in the barn (about 3 l of concentrated sulphuric acid per m^3 of cattle slurry), the annual costs for sulphuric acid amount to about € 29.80 for a total volume of 21 m^3 of slurry per animal place and year. This calculation is based on the assumption that 69.3 l of sulphuric acid are required per animal place and year and that the price of sulphuric acid is € 0.43 per litre.

Considerations relevant to applicability

Handling strong acids on agricultural holdings is dangerous. To ensure the safety of farm personnel, a fully automated dispensing system must be used so that employees working in the livestock facility have no manual contact with sulphuric acid. In addition, slurry handling, including discharge operations, must be automated.

In Germany, compliance with the provisions of the Ordinance on Installations for Handling Water-Polluting Substances (AwSV) is mandatory for the storage of slurry, dung water and silage effluent (for so-called JGS facilities) (AwSV 2017). The AwSV contains an exemption regulation for JGS facilities with regard to constructional requirements for water protection. Currently, this exemption does not apply to acidified slurry. The bill drafted in November 2019 states that "technically pure substances for the acidification of slurry in order to reduce ammonia emissions" may be used in the future and can be stored in JGS facilities without additional expenditure, thus amending the AwSV 2017.

Studies by the Bavarian State Institute for Agriculture (LfL) and the Technical University of Munich have shown that the damage potential of acidified slurry is not significantly higher than that of untreated slurry when it is stored in concrete tanks and conveyed in slurry channels. However, due to its higher sulphate content, higher-quality concrete is recommended for new buildings, i.e. an increase of exposure class from XA1 to XA3 (LfL 2020a).

According to Peters (2016), the inspection of storage tanks containing acidified slurry is mandatory at 10-year intervals in Denmark; for tanks near surface waters, it is mandatory at 5-year intervals (from Kupper 2017).

The high sulphur contents in slurry acidified with sulphuric acid may limit the applicability of this technique with regard to crop production if all of the slurry on the farm is acidified. Possibly only part of the acidified slurry can be spread on the land to ensure that the soil is not over-fertilised with sulphur.

Driving force for the introduction

Farmers in Denmark are required to use low-emission techniques in order to obtain an environmental permit to expand their production capacity. The underlying motivation for this technique is that it significantly reduces ammonia and methane emissions.

Example plants

According to Kupper 2017, 75 storage facilities for slurry acidification have been set up in Denmark. Most of these facilities are acidified by contractors with mobile systems (Peters, 2016).

1.1.4.2 Covered storage of solid manure

Brief description

The storage of solid manure results in N-related losses, especially in the form of ammonia. Emissions can be reduced through covering and compaction of manure heaps to ensure that the surface area of the heap is minimised (UBA and KTBL 2021).

Technical description

To keep emissions low, storage of solid manure should be as dry and compact as possible. This can be accomplished by walling in the solid manure store on three sides and roofing or covering it. A higher heap covering a small surface area can result in a smaller quantity of leachate being formed in relation to the amount of solid manure in storage (Schultheiß et al. 2011).

Structural design

Dry storage, which can be achieved through roofing, reduces ammonia emissions and leaching of N and P (Figure 32). As an alternative to constructing a roof, a foil or water-repellent fleece can also be used as a cover (UBA and KTBL 2021).

Achieved environmental benefits

Walling in the storage site on three sides and roofing it can reduce nutrient leaching, wind-induced ammonia emissions and odour emissions.

Environmental performance and operational data

Ammonia losses from manure in storage increase with higher ammonium concentrations as well as at higher temperatures, pH, with larger emitting surfaces, greater intensities of air movement affecting it and more ventilation or frequency of conversion during storage. Studies by Chadwick (2005) show that emissions can be reduced by as much as 80 % by covering manure storage with a membrane. However, this reduction was not found for all variants investigated.

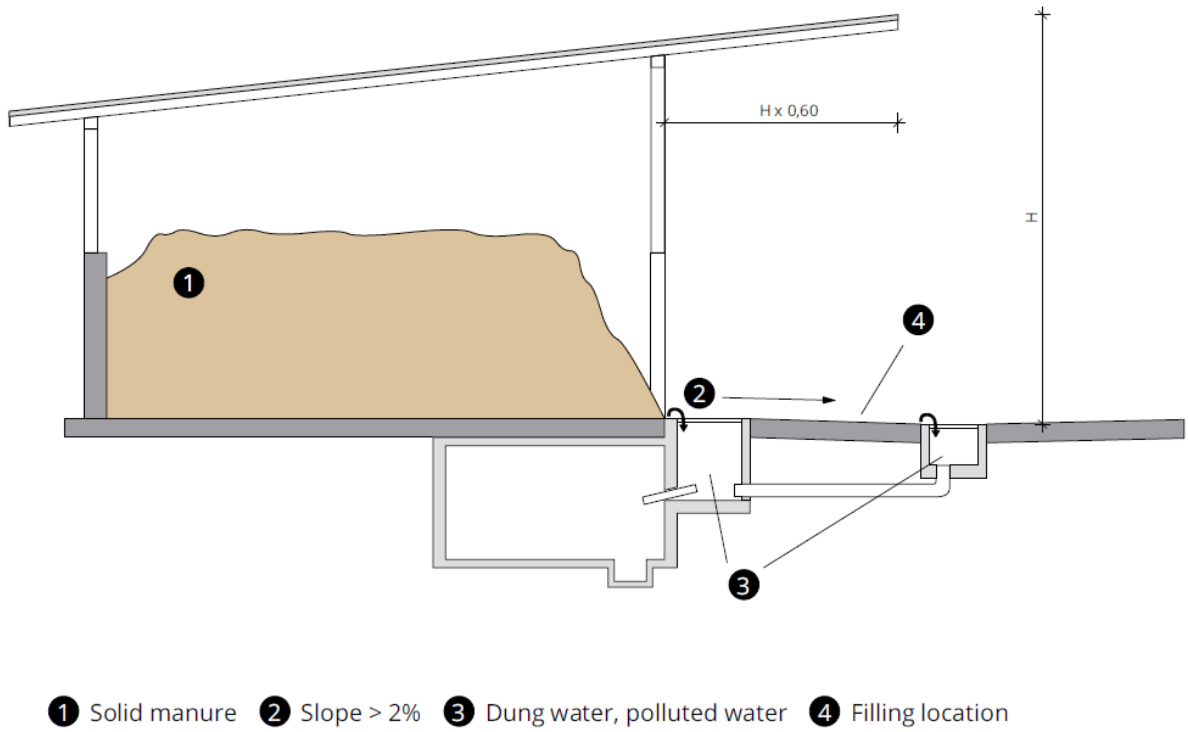
Cross-media effects

In highly compacted solid manure storage with a high moisture content, nitrous oxide is generated at the surface layers due to the anaerobic conditions. It is estimated that about 0.1 - 0.9 % of total N is emitted as N_2O (Webb et al. 2011). Chadwick (2005), however, assumes that drying of the solid manure heap results in lower N_2O and CH_4 emissions.

Animal welfare

As a downstream measure, covering solid manure storage has no impact on animal welfare.

Figure 32: Sketch of solid manure storage with permanent roofing



Source: own representation, KTBL

Figure 33: Solid manure storage with permanent roofing

Source: B. Eurich-Menden, KTBL

Technical considerations relevant to applicability

The use of a cover or roofing to mitigate emissions from solid manure storage depends on farm management. If manure is frequently added to the storage, a cover in the form of foil or fleece is unsuitable (UBA and KTBL 2021).

Economics

Table 23: Investment related to the covering of solid manure storage

Investment	Specification
Material	
Wall surfaces	€ 90 - 100/m²
Roofing	€ 150/m²
Fleece (beet or potato fleece)	€ 1 - 2/m²
Slurry pit (can be driven over)	€ 10,000/item (20 m³)

Source: modified according to Hamann-Lahr 2019, KTBL 2020

Driving force for implementation

By reducing ammonia and odour emissions, farms comply with immission control requirements regarding the emissions of ammonia or nitrogen which have harmful environmental impacts on sensitive plants and biotopes. Compliance is necessary to obtain permits to build new barns or extensions. With the permit, it is possible to construct the buildings closer to the plants or biotopes under protection.

According to TA Luft 2021, a cover or roof is mandatory for solid manure on cattle farms that are affected by the Federal Immission Protection Act (BImSchG 2021).

Example plants

Only very few farms in Germany have roofs over solid manure storage. In addition, solid manure heaps are currently rarely covered with foil or fleece when they are located at the edge of fields (LWK NI 2022).

1.1.4.3 Covered storage of liquid manure

Brief description

Covering can reduce ammonia and odour emissions from liquid manure storage by preventing surface contact with air.

Technical description

Liquid farm manure is stored in underground and elevated tanks as well as in earth-banked lagoons. To reduce odour and ammonia emissions, tanks should be covered. Odour and ammonia emissions can be decreased by at least 90 % in closed tanks in new installations (TA Luft 2021). Covers made of suitable foil, tent structures, fixed covers or equivalent measures are used for new installations. Chopped straw, granulates or filling bodies are not suitable for new installations (TA Luft 2021). When constructing a livestock facility requiring an immission control permit, the use of effective covers is mandatory for facilities storing liquid manure (KTBL 2014).

When retrofitting old plants, covers that achieve 85 % emission reduction efficiency for odour and ammonia should be used (TA Luft 2021). In addition to fixed covers, tent structures, floating foils and floating bodies are an option.

During cattle slurry storage, raw fibre components from the feed and bedding components in the slurry float upwards to create a floating layer. This layer is the simplest and most cost-effective form of cover. However, it does not reduce emissions sufficiently according to TA Luft 2021.

Structural design

To reduce the emissions of ammonia and odour from slurry storage tanks, different covers are deployed. The following are used in intensive cattle farming:

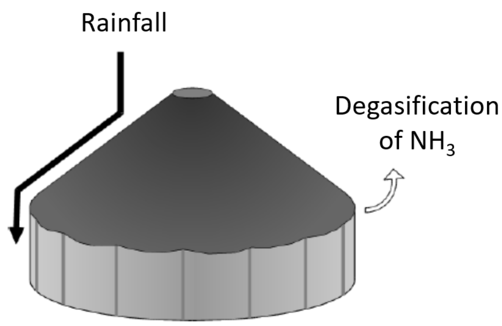
Floating foils:

An artificial cover can be provided in the form of a floating plastic foil. Made of floating elements with a sandwich-type design, these foils remain on the surface. The maintenance workload for the use of floating foils is low. However, rainwater has to be drained off or pumped away (Döhler et al. 2011a, Döhler et al. 2011b).

Fixed covers:

Fixed covers of a slurry storage tank (Figure 34) can be provided by a tent structure or a concrete cover. These coverings have a long service life and require little maintenance. They prevent rainwater from entering the tank. A central strut is required for tent roof structures, depending on the statics (Döhler et al. 2011a, Döhler et al. 2011b, KTBL 2014).

Figure 34: Round tank with a fixed cover to prevent entry of rainwater and ensure a low-emission rate



Source: Döhler et al. 2011a

Achieved environmental benefits

By covering the tank, the exchange of air on the surface of the slurry is limited, thus reducing the formation and release of ammonia (Table 24). Covering slurry tanks also reduces odour emissions.

Environmental performance and operational data

Table 24 shows the potential for reducing ammonia emissions with different covers. The highest reduction is achieved using fixed covers (concrete cover, tent).

Table 24: Emission reduction potential of different covers for slurry tanks

Cover type	Emission reduction compared to uncovered slurry tanks (%) [1] Cattle slurry	Comments
Concrete cover which can be driven on	90	Low maintenance, prevention of rainwater from entering, long service life
Tent structure with a central strut	90	Low maintenance, prevention of rainwater from entering
Floating foil	85 - 90	Low maintenance workload; only one supplier of floating foils (as of 2/2022)

[1] Reference: without natural crust. In most cases, cattle slurry forms a natural crust which reduces emissions. This reduction is not taken into account in the value specified.

Source: KTBL 2018, VDI 3894 Blatt 1

Cross-media effects

Covering reduces both ammonia and odour emissions. In addition, the use of a cover increases the amount of nitrogen in the slurry, which can be exploited in crop production when manure is applied in a manner that minimises emissions.

If the cover is gas-tight, methane can be removed and used for energy.

Animal welfare

As a downstream measure, covering liquid manure storage has no impact on animal welfare.

Technical considerations relevant to applicability

The applicability of ammonia emission reduction techniques in new buildings is unrestricted.

Tent roof structures are usually built with a central strut. If the slurry tank is designed with a central strut when it is first constructed, the tent roof structure can also be installed above it at a later stage.

Various solutions exist for gas-tight covering of slurry storage facilities, e.g. floating foils and double-diaphragm roofs, but their technical feasibility and practicability for slurry tanks have not yet been proven. This requires development, testing and preparatory work. Retrofit concepts are only possible for some of the existing tanks (KTBL 2021b). The gas-tight covering of fermentation residue tanks, which are commonly used in biogas production, cannot be readily used for tanks holding unfermented slurry.

Economics

Driving force for implementation

By reducing ammonia and odour emissions, farms comply with immission control requirements regarding the emissions of ammonia or nitrogen which have harmful environmental impacts on sensitive plants and biotopes. Compliance is necessary to obtain permits to build new barns or extensions. With a permit, it is possible to construct the buildings closer to the plants or biotopes under protection.

Table 25 presents the investment and annual costs for the different covers, based on the example of a tank with a diameter of 17 m (3,000 m³).

Driving force for implementation

By reducing ammonia and odour emissions, farms comply with immission control requirements regarding the emissions of ammonia or nitrogen which have harmful environmental impacts on sensitive plants and biotopes. Compliance is necessary to obtain permits to build new barns or extensions. With a permit, it is possible to construct the buildings closer to the plants or biotopes under protection.

Table 25: Investments and annual costs for different covers of slurry tank **(manufacturer prices without VAT)**

Cover type	Investment tank diameter: 17 m (€/m²)	Useful life (a)	Annual costs tank diameter: 17 m (€/m²)
Concrete cover which can be driven on	90	30	6.6
Tent structure with a central strut	75	15	9.5
Floating foil	25	8	4.7

Source: KTBL 2018

Example plants

Farms implement a wide variety of different types of cover for liquid manure storage in Germany.

1.1.5 During landspreading

1.1.5.1 Slurry application

1.1.5.1.1 Trailing hose distributor

Brief description

Discharge of slurry at ground level using trailing hoses to allow low-emission application to grassland and to crops growing on arable land.

Technical description

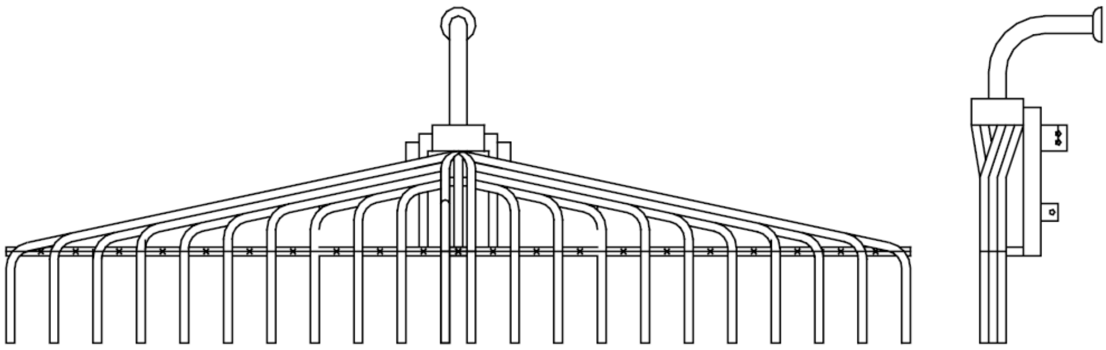
Trailing hose distributors apply the slurry in strips at ground level to the plants. As the contact of the slurry with the atmosphere is minimal, ammonia and odour emissions are reduced compared to when the slurry is widely spread.

When the slurry is spread using a trailing hose distributor, the slurry is pumped into the spreading device on the distribution vehicle by a pump or a compressor. This application device distributes the liquid manure to flexible hoses which are located in a row and attached to a frame or booms (Figure 35). As a rule, the discharge hoses are positioned at intervals of 15 to 25 cm. The liquid manure is discharged in bands on the surface of the soil.

For plants growing on arable land, it must be ensured that the trailing hoses run at ground level between the rows to minimise crop contamination. On grassland, it is not possible to deposit slurry on the soil surface using a trailing hose distributor; a trailing shoe distributor is better suited for grassland.

The weather, soil conditions and time of application have to be considered. Application should preferably be carried out on cool days or in the evening when showers or prolonged light rainfall are forecast. Slurry should not be spread on waterlogged, dried out or compact soils, as it cannot infiltrate into the soil (UBA and KTBL 2021).

Figure 35: Trailing hose distributor



Source: KTBL 2020

Achieved environmental benefits

By applying the liquid manure in bands, contact with the atmosphere is lower than when the liquid manure is broadcast. This reduces ammonia and odour emissions. On uncultivated arable land, this effect is small. The effect is greater for crops growing on arable land because the slurry is directly applied on the soil, thus avoiding contamination of the plant surfaces. In addition, the crop canopy reduces air movement and lowers the temperature above the slurry band (Santonja et al. 2017). On grassland, this effect is not present because the slurry is discharged onto the grass.

Environmental performance and operational data

Landspreading of slurry on crops growing on arable land using a trailing hose distributor is assumed to reduce ammonia emissions by between 30 - 50% compared to broadcast application (UBA and KTBL 2021, Santonja et al. 2017). The higher the crops, the higher the reduction in emissions. On grassland, the decrease in emissions compared to broadcast spreading is relatively low at 10 - 30% (Webb et al. 2010, Döhler et al. 2002).Landspreading of slurry on crops growing on arable land using a trailing hose distributor is assumed to reduce ammonia emissions by between 30 - 50% compared to widespread distribution (UBA and KTBL 2021, Santonja et al. 2017). The higher the crops, the higher the reduction in emissions. On grassland, the decrease in emissions compared to wide spreading is relatively low at 10 - 30% (Webb et al. 2010, Döhler et al. 2002).

On uncultivated arable land, the emission-reducing effect of landspreading using a trailing hose is negligible. For this reason, the Fertiliser Ordinance (DüV 2017) requires that liquid manure is incorporated within four hours of application at the latest and within one hour from 2025.

Cross-media effects

Similar to the reduction of ammonia emissions, odour emissions can be assumed to be lower than for broadcast applied slurry. More precise landspreading near water bodies reduces the risk of slurry directly entering the water.

On grassland, this technique may contaminate plant material and cause burns and agglutination (UBA and KTBL 2021).

Animal welfare

When slurry with high dry matter content is applied to grassland, the slurry may not fully penetrate the crop under dry weather conditions. In this case, under unfavourable conditions, some of the slurry may remain on the plant surfaces until mowing and reduce the quality of the fodder.

Technical considerations relevant to applicability

Particularly on grassland liquid manure is deposited on the crop surface. It is only when it rains that the manure is washed down to the roots of the plants. Viscous manure can cause agglutination and burns to the plants. Accordingly, it is recommended that only diluted slurry is used on grassland or that it is spread under ideal weather conditions.

Due to their operating width of up to 36 m, trailing hose distributors are particularly well suited for use on arable farms. The devices are available with shut-off for individual hoses and drop stop, allowing precise application. When spreading liquid manure containing a very high dry matter content, the hoses may clog. However, there are technical devices for dealing with this. Gentle slopes can be compensated by a pendulum frame. On steeper slopes, deployment is only possible with smaller operating widths.

Economics

Depending on the annual utilisation and scope of the spreading, the costs calculated for landspreading with a trailing hose distributor range between € 9.15 for an application rate of 1,000 m^3/year and € 5.01 for 80,000 m^3/year (KTBL 2020). In most cases, application rates of 80,000 m^3/year are only achieved by contractors. For farms that fall under the IE Directive, an application rate of at least 10,000 m^3/year is to be expected. This results in theoretical application costs of € 3.32/m^3. Compared to widespread distribution, an emission reduction of 10% on grassland and 30% on cultivated arable land incurs reduction costs of € 0.86/kg NH_3 on grassland and a reduction revenue (negative costs) of € 0.13/kg NH_3. Revenue is expected based on the assumption that the non-emitted NH_3 is completely effective as a fertiliser and reduces the costs for supplementary synthetic fertilisers by € 0.75/kg N (KTBL 2020).

Driving force for implementation

With the amendment of the Fertiliser Ordinance (DüV 2017) and the resulting ban on broadcast application of liquid manure on cultivated arable land and grassland, the usage of trailing shoe application systems is increasing. In comparison to other emission-reducing techniques, the trailing hose distributor requires the lowest traction power. In addition, it can cover the largest operating widths and is very suitable for application in systems where tramlines are used in arable farming.

Example plants

Usage of the trailing hose distributor is widespread on farms.

Table 26: Application costs and emission reduction costs for landspreading liquid manure with trailing hose distributors

Technique and cost type	Ammonia emission reduction (%)	Application rate (m³/a)				
		1,000	3,000	10,000	30,000 [2]	80,000 [2]
		Pump tanker (PT), towed				PT, SP
		Useful volume (m³)				
		10	10	15	10	21
Landspreading technique [1]		12; 102	12; 102	12; 138	12; 102	12; 375
Landspreading costs (€/m³)		9.15	5.11	3.32	6.06	5.01
Emission reduction costs (€/kg NH_3)						
Grassland [3]	10	10.75	3.44	0.86	0.61	0.56
Cultivated arable land [3]	30	3.17	0.74	-0.13	-0.21	-0.23

PT= pump tanker, SP= self-propelled truck

[1] Operating width in m; tractor in kW

[2] Dual process: transport with slurry transport trailer, 21 m³; 120 kW

[3] Reference procedure: broadcast application, no longer allowed on cultivated arable land since 01.01.2020.

Source: KTBL 2020

1.1.5.1.2 Trailing shoe distributor

Brief description

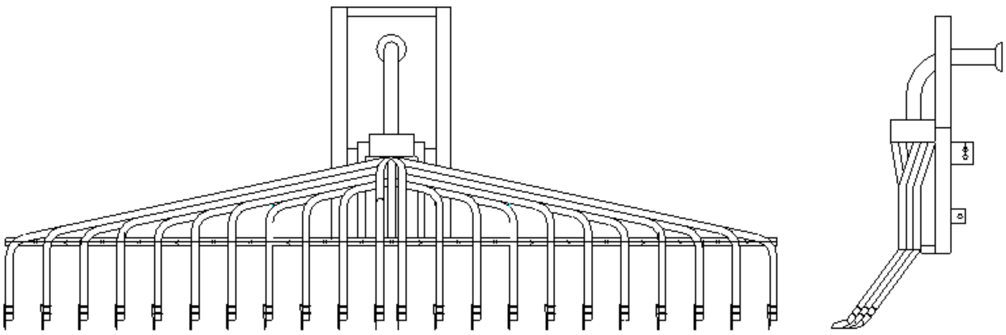
Slurry is applied on the soil by trailing hoses with skids attached to the end of the hoses which separate the crops and/or plough a small furrow into the soil. The technique allows low-emission landspreading on grassland and on crops growing on arable land.

Technical description

The trailing hose distributor is a further development of the trailing hose distributor. It enables liquid manure to be more effectively deposited on crops, especially on grassland. A shoe-like skid pushes the crops apart or separates them so that the slurry can be deposited directly on the soil. In addition, the skids cut shallow slits into the soil, which improves infiltration. As the contact of the slurry with the atmosphere is minimal, ammonia and odour emissions are reduced compared to broadcast application.

In the same way as for the trailing shoe distributor, the slurry is pumped into the spreading device on the vehicle by a pump or a compressor and distributed across the discharge hoses. The end of the hoses are fitted with shoe-like reinforcements (see Figure 36). Spring rods are used to press the hose and skids into the soil. Depending on the weight, additional pressure and width and length of these reinforcements, different amounts of plant material are pushed to the side and shallow slits with varying depths are cut into the soil (UBA and KTBL 2021). By cutting a shallow slit into the soil, the distributor can deposit a narrow strip band of fertilizer on the soil. Like with trailing hose distributors, the slurry is deposited in strips bands at intervals of 15 to 25cm.

Figure 36: Trailing shoe distributor



Source: own illustration, KTBL

In grassland, trailing shoe distributors have distinct advantages over trailing hose distributors, especially when the slurry is applied to more mature plants rather than immediately after cutting. The technique allows the plants to be effectively separated and the slurry to be deposited precisely, while minimising contamination of plant surfaces.

The weather, soil conditions and time of landspreading have to be considered. Landspreading should preferably be carried out on cool days or in the evening when showers or prolonged light rainfall are forecast. Slurry should not be spread on waterlogged, dried out or compact soils, as it cannot infiltrate into the soil (UBA and KTBL 2021).

Trailing shoe distributors do not have a significant emission-reducing effect on uncultivated arable land. Hence, according to the Fertiliser Ordinance (DüV 2017), liquid manure applied to uncultivated land must be incorporated into the soil within four hours at the latest and within one hour from 2025.

Achieved environmental benefits

By applying slurry in bands to grassland and to plants growing on arable land, it has less contact with the atmosphere than for broadcast distribution. In addition, cutting shallow slits into the soil makes it possible to apply relatively narrow bands of manure and facilitates penetration of the liquid manure into the soil (UBA and KTBL 2021). This reduces ammonia and odour emissions. On uncultivated arable land, this effect is small. The effect is greater for crops because the slurry is applied on the soil with precision, thus avoiding contamination of the plant surfaces. In addition, the crop density reduces air movement and lowers the temperature above the slurry bands (Santonja et al. 2017).

Environmental performance and operational data

Landspreading with a trailing shoe distributor on grassland and on growing crops reduces ammonia emissions by 40 - 60 % compared to broadcast spreading (Webb et al. 2010, Döhler et al. 2002, Santonja et al. 2017). The extent of emission reduction depends on the height of the crop. For short grass, emission reductions can be as low as 30%, i.e. a similar level to application with a trailing hose (Santonja et al. 2017).

On uncultivated arable land, the emission-reducing effect of landspreading with a trailing hose is negligible. For this reason, according to the Fertiliser Ordinance (DüV 2017), liquid manure must be incorporated within four hours of application at the latest and within one hour from 2025.

Cross-media effects

As the slurry is directly applied onto the surface of the soil, less plant material is contaminated in grassland. Burns and agglutination are less frequent. The traction power requirement and fuel consumption are only slightly higher than when using a trailing hose distributor.

Animal welfare

As the plant material is less contaminated than when slurry is applied with a trailing hose, there is no adverse effect on the quality of fodder.

Technical considerations relevant to applicability

Trailing shoe distributors are suitable for mitigating ammonia emissions on grassland and in arable farming. Operating widths of up to 24 m allow the use of existing tramlines. As a result, trailing shoe distributors are currently the most versatile distributors for liquid manure (UBA and KTBL 2021).

The devices are available with shut-off for individual hoses and drip stop, allowing precise application. When spreading liquid manure containing a very high dry matter content, the hoses may clog. However, there are technical devices for dealing with this. Gentle slopes can be compensated by a pendulum frame. On steeper slopes, deployment is only possible with smaller operating widths.

Economics

Depending on the annual utilisation and dimensioning of the landspreading, the costs calculated for application with a trailing hose distributor range between € 9.48 for an application rate of 1,000 m^3/year and € 5.09 for 80,000 m^3/year (KTBL 2020). In most cases, application rates of 80,000 m^3/year are only achieved by contractors. For farms that fall under the IE Directive, an application rate of at least 10,000 m^3/year is to be expected. The imputed costs for this application rate are € 3.71/m^3. Compared to broadcast application, an emission reduction of 40% is associated with reduction costs of € 0.21 /kg NH_3 on grassland and cultivated arable land. If application is performed with larger-sized spreading devices, a reduction revenue (negative cost) is also possible if the devices are sufficiently utilised. Revenues are expected based on the assumption that the non-emitted NH_3 is completely effective as a fertiliser and reduces the costs for supplementary synthetic fertilisers by € 0.75/kg N (KTBL 2020).

Driving force for implementation

With the amendment of the Fertiliser Ordinance (DüV) and the resulting ban on broadcast spreading of fertiliser on cultivated arable land and grassland, the usage of trailing shoe distribution systems is increasing. Compared to the trailing hose distributor, the trailing shoe distributor has the additional advantage of very good applicability on grassland, making it the most versatile application technique. It requires only marginally more traction power than the trailing shoe distributor.

This technique is financially supported by the Website Landwirtschaftliche Rentenbank - Investment Program Agriculture as part of the agricultural investment programme.

Example plants

Trailing shoe distributors are widely used on farms.

Table 27: Application costs and emission reduction costs for landspreading liquid manure with trailing shoe distributors

Technique and cost type	Ammonia emission reduction (%)	Application rate (m³/a)				
		1,000	3,000	10,000	30,000 [2]	80,000 [2]
		Pump tanker (PT), towed				PT, SP
		Useful volume (m³)				
		10	10	15	10	21
Landspreading technique [1]		12; 102	12; 102	12; 138	12; 102	12; 375
Landspreading costs (€/m³)		9.48	5.43	3.71	6.15	5.09
Emission reduction costs (€/kg NH_3)						
Grassland and cultivated arable land [3]	40	2.69	0.84	0.29	-0.19	-0.21

PT= pump tanker, SP= self-propelled truck

[1] Operating width in m; tractor in kW

[2] Dual process: transport with slurry transport trailer, 21 m³; 120 kW

[3] Reference procedure: broadcast application, no longer allowed on cultivated arable land since 01.01.2020.

Source: KTBL 2020

1.1.5.1.3 Slot injectors

Brief description

Device for inserting slurry into slots in the soil created by discs running ahead. It allows low-emission application of slurry on grassland and on crops growing on arable land.

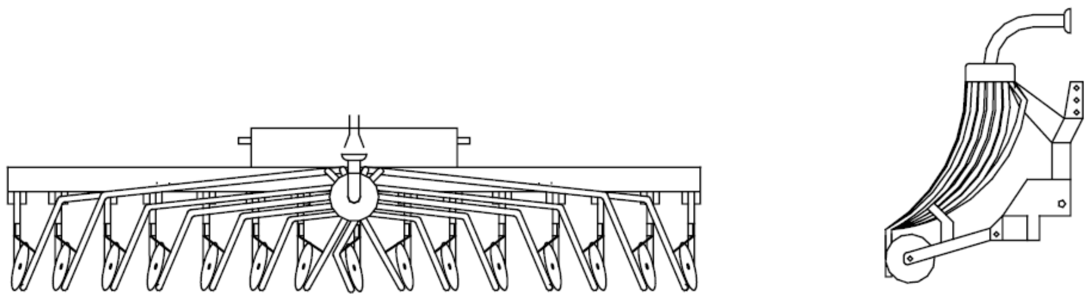
Technical description

The slot injector is fitted with discs that open up the soil in strips. The slurry is inserted into these slots. Only a very narrow strip of fertiliser is deposited. The contact of the slurry with the atmosphere is limited to the width of the slot.

In the slot injector, the liquid manure is conveyed into the dispensing device by a pump on the tanker and distributed to the discharge hoses. The discharge hoses are positioned at intervals of 20 to 30 cm. They connect to slanted or conically shaped discs; pressure is applied to these discs to open up slots in the soil. Depending on the condition of the soil and the pressure applied to the discs, the slurry is thus deposited in slots that are 3 - 6 cm deep.

The weather, soil conditions and time of application have to be considered. Care should be taken to ensure that the tyres do not damage the soil, and that the ground is easy to drive over. For landspreading of slurry on grassland, the conditions should not be too dry, especially for heavy soils, so that the slot can close again. The slot depth and application rate should be coordinated so that the slot can hold all of the slurry. Otherwise, emission reduction drops considerably. On the other hand, the slot should not be too large so as to minimise sward damage, especially when operating on grassland.

Figure 37: Slot injector



Source: KTBL 2020

Achieved environmental benefits

When applied with a slot injector, only a portion of the liquid manure has contact with the atmosphere. This reduces ammonia and odour emissions. The actual degree of emission reduction depends on the extent to which the slot produced by the device provides enough space for the applied slurry (Santonja et al. 2017). An advantage of deploying the technique on grassland is that plant contamination is low (UBA and KTBL 2021).

Environmental performance and operational data

Because the slurry is inserted at a depth of approx. 3 to 6 cm and the fertiliser strip is very narrow, it is possible to achieve emission reductions of 60 to 80% with slot injectors (Webb et al. 2010, Döhler et al. 2002) compared to broadcast application. Some studies have reported lower emission reductions (Santonja et al. 2017). The efficiency of emission reduction is often influenced by the extent to which the slot can absorb the applied slurry. In general, however, the slot injection technique reduces ammonia emissions to a greater extent on grassland and cultivated arable land than other techniques.

On grassland, another benefit is the low contamination of the crops and, as a result, low contamination of fodder.

Cross-media effects

The concentrated deposition of the slurry in the strips of slurry and the resulting denitrifying conditions can lead to increased nitrous oxide emissions compared to other application techniques (Wulf et al. 2002). However, in some other measurements this effect is not detectable (Webb et al. 2010).

Slot injectors require high traction because of the depth of application, thus increasing fuel consumption.

On very heavy soils (with high clay content) in grassland, prolonged sward damage may occur.

Animal welfare

As the plant material is not as contaminated as when slurry is applied with a trailing hose, there is no adverse effect on the quality of the fodder.

Technical considerations relevant to applicability

Due to the slot injector's high traction requirement, its operating width is currently limited to a maximum of 12 m and is usually less. This is sufficient for use on grassland. On arable land, the use of existing tramlines may not be possible with this operating width, and damage may be caused to growing crops (UBA and KTBL 2021). Application on slopes is limited. It is important to prevent slurry from being washed down slopes from the slots during heavy rainfall. The technique is not suitable for heavy, shallow or stony soils or for use in wet conditions.

Economics

Depending on the annual utilisation and dimensioning of the landspreading, the costs calculated for application with slot injector range between € 9.64 for an application rate of 1,000 m^3/year and € 5.84 for 80,000 m^3/year (KTBL 2020). In most cases, application rates of 80,000 m^3/year are only achieved by contractors. For farms that fall under the IE Directive, an application rate of at least 10,000 m^3/year is to be expected. This results in imputed output costs of € 3.94/m^3. Compared to broadcast application, an emission reduction of 60% is associated with reduction costs of € 0.20/kg NH_3 on grassland and cultivated arable land.

Table 28: Application costs and emission reduction costs for landspreading liquid manure with slot injector

Technique and cost type	Ammonia emission reduction (%)	Application rate (m^3/a)				
		1,000	3,000	10,000	30,000 [2]	80,000 [2]
		Pump tanker (PT), towed				PT, SP
		Useful volume (m^3)				
		10	10	15	10	21
Landspreading technique [1]		3; 102	3; 102	3; 138	3; 102	9; 375
Landspreading costs (€/m^3)		9.64	5.90	3.94	6.40	5.84
Emission reduction costs (€/kg NH_3)						
Grassland and cultivated arable land [3]	60	1.72	0.78	0.20	-0.10	0.33

PT= pump tanker, SP= self-propelled truck

[1] Operating width in m; tractor in kW

[2] Dual process: *t*ransport with slurry transport trailer, 21 m^3; 120 kW

[3] Reference procedure: wide spreader, no longer allowed on cultivated arable land since 01.01.2020.

Source: KTBL 2020

Driving force for implementation

With the amendment of the Fertiliser Ordinance (DüV 2017) and the resulting ban on broadcast application of fertiliser on cultivated arable land and grassland, the usage of emission-reducing techniques is increasing. The slot injector achieves the highest emission reduction for grassland and crops growing on arable land. At suitable locations (see above for limitations), slot injectors are the most versatile technique for use on grassland, both in terms of their ammonia emission reduction potential and from a crop production perspective.

This technique is financially supported by the Website Landwirtschaftliche Rentenbank - Investment Program Agriculture as part of the agricultural investment programme.

Example plants

According to assessments by experts, the use of the injector technique is widespread on farms – with regional differences – and is mainly used by contractors.

1.1.5.1.4 Arable injectors

Brief description

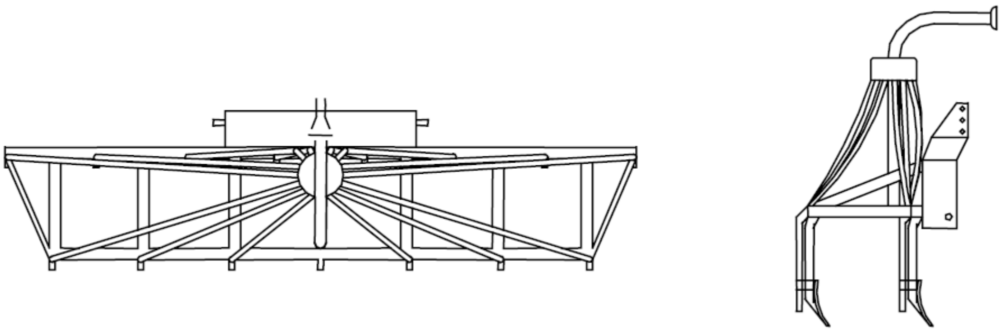
Slurry applied to uncultivated arable land is directly incorporated into the soil, ensuring its emission-reducing application.

Technical description

The injector technique involves opening the soil with tines or discs, inserting the slurry into the loosened soil at a depth of 10 to 15 cm, and levelling the soil afterwards

In the slurry injector equipment, the liquid manure is pumped into the dispensing device on the machine by a pump on the distribution vehicle and distributed to the discharge hoses. The operating width is variable as the injector is designed with several dispensing heads, but the total width is limited due to the high traction required. The end of the discharge hoses are fitted with tines or discs that loosen the soil. The manure is deposited on an uncultivated area at a depth of 10 to 15 cm in the soil. To deposit it at this depth, increased traction is required. The manure is incorporated directly into the soil. Depending on the system's design, it also has a trailing device that consolidates and levels the tilled soil (UBA and KTBL 2021).

Figure 38: Arable injector



Source: KTBL 2020

Care should be taken to ensure that the tyres do not damage the soil, and that the ground is easy to drive over. Therefore, application should only be performed when the soil has dried sufficiently in the spring. In addition, the soil type should be such that the slots close effectively and the soil can be mixed (Santonja et al. 2017). Application with the arable injector can replace a separate soil cultivation operation if the technique is suitable.

Achieved environmental benefits

When liquid manure is spread with an arable injector, it is inserted directly and mixed into the soil. As a result, the slurry is almost completely covered by soil and has no contact with the atmosphere (Santonja et al. 2017). Hence, ammonia and odour emissions are effectively reduced.

Environmental performance and operational data

The arable injector is most effective in reducing ammonia emissions on uncultivated arable land. An emission reduction of about 80% can be achieved by incorporating the slurry into the soil within 4 hours, compared to a broadcast application (Webb et al. 2010, Döhler et al. 2002).

Cross-media side effects

Although the liquid manure is inserted deeply into the soil, if the soil is mixed well, there should not be an increase in nitrous oxide emissions. In the BAT Reference Document for the Intensive Rearing of Poultry or Pigs (BREF IRPP) (Santonja et al. 2017), it is pointed out that a larger share of the denitrified N is more likely to be released as N_2 due to the long diffusion pathways.

The arable injector requires a high traction power and, as a result, high fuel consumption. However, the latter is not higher than if two separate operations were required for application and incorporation according to the Fertiliser Ordinance (DüV 2017).

Animal welfare

Use of this technique has no impact on animal welfare.

Technical considerations relevant to applicability

Arable injectors can only be used on uncultivated arable land before sowing. The process has a very high traction demand, which is why the maximum operating width is currently 8 m (UBA and KTBL 2021). If applied appropriately, it is possible to spare a separate tillage operation which is necessary for plant cultivation.

Economics

Depending on the annual utilisation and scope of landspreading, the costs calculated for application with an arable injector range between € 9.84 for an application rate of 1,000 m^3/year and € 4.19 for 80,000 m^3/year (KTBL 2020). In most cases, application rates of 80,000 m^3/year are only achieved by contractors. For farms that fall under the IE Directive, an application rate of at least 10,000 m^3/year is to be expected. The imputed costs for this application rate are € 4.91/m^3. The technique is more favourable for application rates of 3,000 m^3/year and above than the employed reference technique with broadcast application, followed by incorporation into the soil within 4 hours as required by the Fertiliser Ordinance (DüV 2017). Thus, no emission reduction costs can be reported for these application rates.

Driving force for the introduction

According to the Fertiliser Ordinance (DüV 2017), the slurry applied to the soil must be incorporated within 4 hours on uncultivated fields, and within 1 hour from 2025. It can only be incorporated separately if both the application and incorporation equipment are available. Coordinating these two operations is difficult because the operating widths for application and incorporation differ. As a result, combining application and incorporation in one operation with an arable injector is more cost effective in most cases.

This technique is financially supported by the Landwirtschaftliche Rentenbank as part of the agricultural investment programme.

Example plants

The use of arable injectors technology is widespread on farms and is used in particular by contractors.

Table 29: Application costs and emission reduction costs for landspreading liquid manure with an arable injector

Technique and cost type	Ammonia emission reduction (%)	Application rate (m³/a)				
		1,000	3,000	10,000	30,000 [2]	80,000 [2]
		Pump tanker (PT), towed				PT, SP
		Useful volume (m³)				
		10	10	15	10	21
Landspreading technique [1]		3; 138	3; 138	3; 175	3; 138	6; 375
Landspreading costs (€/m³)		9.84	6.29	4.91	6.66	4.19
(€/kg NH_3)						
Cultivated arable land [3]	80	0.51	[4]	[4]	[4]	[4]

PT= pump tanker, SP= self-propelled truck

1 Operating width in m; tractor in kW

2 Dual process: transport with slurry transport trailer, 21 m³; 120 kW

3 Reference procedure: broadcast application, incorporation within 4 h

4 No reduction costs can be reported because the application technique is already less expensive than the reference technology

Source: KTBL 2020

1.1.5.1.5 Slurry acidification during landspreading

Brief description

Landspreading of slurry with a pH lowered to a value of 6.0 using sulphuric acid in order to reduce ammonia emissions.

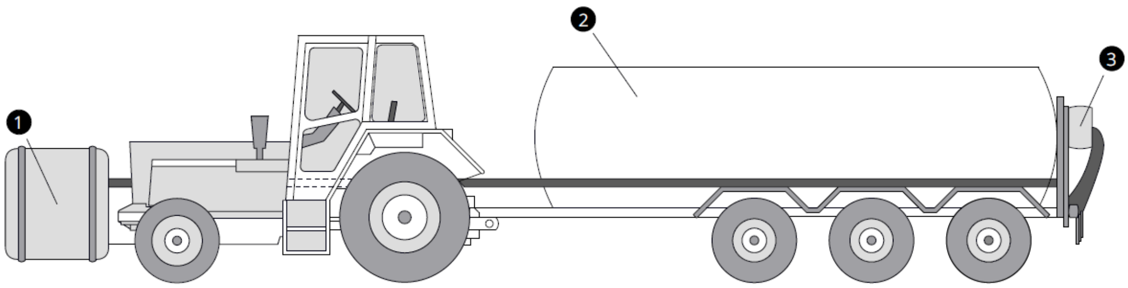
Technical description

Acidification is usually performed by adding sulphuric acid directly to the slurry to be spread on the land in front of the distribution bar of the trailing hose or the trailing shoe distribution system.

Emission reduction or release of gaseous NH_3 from the liquid phase is related to the pH-dependent chemical equilibrium between ammonia and ammonium. The addition of acid to manure shifts the NH_4^+/NH_3 balance towards ammonium. To effectively reduce the NH_3 emissions from slurry, the pH value should be below 6 at least (Kaupenjohann et al. 2019). Technical sulphuric acid (concentration: 96%) is generally used for acidification. The amount of acid used depends on the buffer capacity of the slurry and the target pH value. A smaller amount of acid is required for cattle slurry than for pig slurry or digestate (LfL 2020a, Kaupenjohann et al. 2019).

In the most common systems, the sulphuric acid used for acidification is transported in a tank located on the front hydraulic system of the tractor (Figure 39). The acid is pumped into a mixing chamber on the slurry tanker or into a dispensing device by a hydraulically powered stainless steel pump. There, the slurry and acid are effectively mixed together and then applied by a trailing hose or trailing shoe distribution system. The pH value of the slurry is continuously checked using measuring electrodes, and acid is added accordingly (Kupper 2017, Neumann 2018).

Figure 39: Schematic diagram of a vehicle used for slurry acidification during landspreading



Source: own illustration, KTBL

Achieved environmental benefits

At a pH value of 6, ammoniacal nitrogen is largely present as ammonium (NH_4^+). The amount of ammonia dissolved in the slurry is low, so that ammonia emissions are reduced considerably (Fangueiro et al. 2015, Hou et al. 2015).

Environmental performance and operational data

Acidification of cattle manure during landspreading (using a trailing hose) reduces ammonia emissions by 48% at a pH of 6.1 to 6.4 compared to landspreading of untreated slurry using a trailing hose (VERA 2012). Investigations by Seidel et al. (2017) show that a higher emission reduction potential can be achieved with a further reduction of the pH value. By lowering the pH to 6.5 and 6.0, ammonia emissions were reduced by 42% and 79%, respectively, compared to spreading of non-acidified slurry on grassland using a trailing hose.

Kaupenjohann et al. (2019) provide a comprehensive overview of the influence of acidification on the emissions of gases from slurry. The compiled results show that nitrous oxide emissions can be reduced by up to 80% through acidification. This reduction in emissions was recorded in experiments with a significant decrease in the pH value to pH 5.

Cross-media effects

Landspreading of acidified slurry can decrease the pH of the soil, which must be compensated for through additional liming. Sorensen (2016) estimated the lime requirement to be 153 kg/ha and 122 kg/ha (in $CaCO_3$ equivalents) for cattle and pig manure, respectively. The consumption of lime is about 20 - 25% higher than for non-acidified slurry (Kupper 2017).

The slurry acidified with sulphuric acid has a higher sulphur content. Over-fertilisation with sulphur should be avoided. Therefore, the landspreading rate must be adapted to the sulphur requirements of the plants and the status of the soil.

To avoid inputs of heavy metals into the soil, care should also be taken to use sulphuric acid with a very low heavy-metal content (UBA and KTBL 2021).

Animal welfare

As this technique is implemented outside of the animal housing, it has no impact on animal welfare.

Considerations relevant to applicability

Handling strong acid on agricultural holdings is dangerous. To ensure the safety of farm personnel, a closed and fully automated system must be used so that employees working in the livestock facility have no manual contact with sulphuric acid. To prevent accidents and the release of substances that present a hazard to water, the front system is protected with reinforced steel. In case of emergency, the system has a water tank for flushing. It is recommended that all users are trained by qualified personnel.

The high sulphur contents in slurry acidified with sulphuric acid limit the applicability of this technique in terms of crop production. To avoid over-fertilising the soil, it is probable that only a portion of the slurry spread on the land is acidified.

Economics

No information is currently available on the investment costs and costs for operating materials.

Driving force for the application

With the amendment of the Fertiliser Ordinance (DüV 2017) and the resulting ban on broadcast spreading of liquid manure on cultivated arable land from February 1, 2020, and grassland from February 1, 2025, emission-reducing techniques are becoming increasingly widespread. The level of emissions reduced through acidification is comparable to emission reduction achieved with the slurry injection technique. However, acidification can be deployed over wider operating widths than the slurry injection technique and has less impact on the sward when applied to grassland.

This technique is financially supported by the Landwirtschaftliche Rentenbank as part of the agricultural investment programme.

Example plants

The technique has been established in Denmark for a long time. In Germany, it is increasingly being offered by contractors (Blunk 2022, Garant-Kotte 2022).

1.1.6 Manure treatment

1.1.6.1 Separation of liquid manure

Brief description

Process of separating liquid manure into a phase with reduced content of solids (liquid phase) and a phase with increased content of solids (solid phase). As a result, the nutrients in both phases are enriched to different extents, allowing more precise and thus more efficient fertilisation.

Technical description

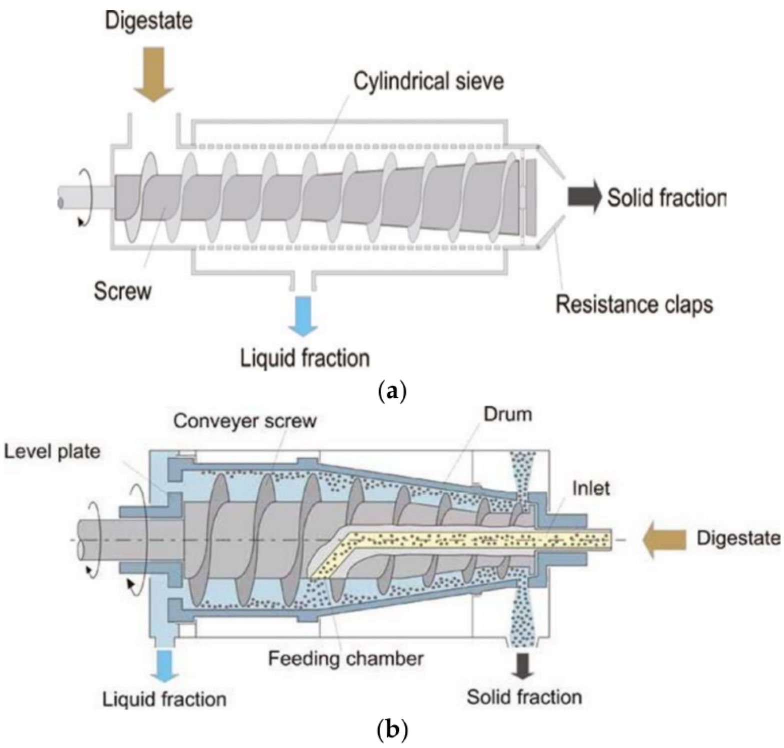
The slurry is separated into two fractions. In the liquid phase, which has a lower dry matter content, the nitrogen is mainly in mineral form, and the P content is lower. As a result, the liquid phase often has a more suitable ratio between P and N that is directly effective for fertilisation. P and organic N are enriched in the solid phase, which has higher dry matter content. However, the solid phase also still contains relevant amounts of ammonium. It is often considered more worth transporting and can be used in more remote regions if they need P and organic N.

Structural design

Separation is usually carried out using a physical process. The most commonly used processes in practice are press screw separators and decanter centrifuges.

With **press screw separators**, the liquid manure is conveyed by a pump into the inlet of the separator to be dewatered. From there, a rotating screw transports the material into a sieve basket. A discharge flap at the end of the sieve basket regulates the ejection of the solid phase. It leads to the formation of a solid plug, which facilitates squeezing of the liquid phase through the mesh of the sieve basket. This technique of separating solids is considered to be very reliable and low-maintenance. However, a basic prerequisite for successfully separating solids is that the system, especially the ejection control device, is carefully adjusted.

Figure 40: Schematic diagram of a press screw separator (a) and a decanter centrifuge (b)



Source: Lyons et al. 2021

Separators are available for different volume flows and can also be operated intermittently. Problems with separation can occur if the dry matter content (DM content) of the manure varies greatly. The settings of the discharge flaps do not readjust automatically. This affects the properties of the solid plug and, in turn, influences how successfully the solids are separated. In addition, care should be taken to ensure that the manure contains a low proportion of abrasive substances (e.g. sand), as they significantly increase wear and tear.

The application field of **decanter centrifuges** is comparable to that of press screw separators. However, the solid phase is not separated using a filter, but by applying centrifugal forces. The liquid manure is continuously fed into a rotating drum. Centrifugal forces cause the solids to separate on the wall of the drum; they are then discharged via a screw conveyor.

Decanter centrifuges achieve lower dry matter contents in the liquid phase than press screw separators. Smaller particles are also separated.

Achieved environmental benefits

The primary goal of separating slurry is to improve on-farm and regional nutrient management. It enables the nutrient supply to be better adapted to the needs of plants (Santonja et al. 2017). In addition, P can be transported in the solid phase from regions with a surplus of P specifically to regions with a P shortage. Wherever conditions permit, e.g. when there is sufficient nutrient demand, the use of untreated manure is preferable (Santonja et al. 2017).

In addition, the application of liquid phase produced through separation generates lower ammonia emissions compared to the application of unseparated cattle slurry.

Due to the low DM content of thin slurry, it infiltrates better than unseparated slurry. Sommer et al. 2006 report that this effect is greater on a soil with a medium to heavy texture (sandy loam) than on a light soil (sand). As the slurry is better infiltrated into the soil, it has less contact with the atmosphere, and ammonia emissions are lower.

Environmental performance and operational data

To regulate the separation efficiency of the press screw separator, different sieve baskets can be selected, and the setting of the discharge flaps can be varied. The separation efficiency of the decanter centrifuge, however, is mainly adjusted by varying the rotational speed of the drum and regulating the discharge screw conveyor. In addition to these settings, the type of liquid manure used and its dry matter content primarily influence the separation efficiency. Press screw separators can thus achieve DM contents in the solid phase of 30 - 40 (Santonja et al. 2017). The resulting fresh mass in the solid phase accounts for approx. 10 - 15% of the mass of the manure used. The average removal efficiency for P is 20 - 40% (Santonja et al. 2017). This removal efficiency of decanter centrifuges is considerably higher, at 60 - 70%. However, only a low DM content is obtained in the solid phase. Thus, compared to the press screw separator, the proportion of solid phase in the fresh mass used is higher. The use of additives can increase P separation above the aforementioned values.

Amon et al. 2006 report that NH_3 emissions are reduced by about 60% for cattle slurry when liquid phase is spread on the land with a trailing hose compared to unseparated slurry.

Cross-media effects

Separation requires an input of energy (see **Driving force for implementation**

In regions with a high density of livestock production, landspreading of liquid manure is severely limited due to a surplus of nutrients. In addition to the upper limit of 170 kg N of animal origin, the high nutrient supply in the soils is often a limiting factor. Separation can yield varying amounts of P and organic N in the solid phase. Thus, it is possible to provide a higher proportion of the N requirement of plants with the liquid phase when using slurry.

This technique is financially supported by the Landwirtschaftliche Rentenbank as part of the agricultural investment programme.

Table 30). This is significantly lower for the press screw separator (0.7 - 0.9 kWh/m^3 slurry) than for the decanter centrifuge (3.1 - 5.3 kWh/m^3 slurry).

NH_3 emissions may occur during separation and during storage of the liquid phase, as it does not form a floating cover due to its lower DM content. Solids resulting from separation should be kept in covered storage if possible, since > 75 % of their ammonium content is released as ammonia during open storage (Bittlmayer et al. 2015). Drying of the solids, which can be useful for stabilisation, should only be carried out in conjunction with exhaust air treatment to recover the ammonia from the dryer's exhaust air.

Storage and application of the solid phase can be associated with ammonia emissions which offset or even exceed the reduction effect from landspreading of the liquid phase (Bittlmayer et al. 2015, Dinuccio et al. 2012). It is also not clear whether there is a reduction in the emission of greenhouse gases. According to Kupper (2015), most available studies on cattle slurry indicate increased emissions of nitrous oxide and methane resulting mainly from storage of the solid phase.

Animal welfare

When spreading the liquid phase resulting from separation onto grassland, it drips off the surface of the plants better, contaminating them less than if unseparated slurry were applied with a trailing hose distributor. The quality of fodder is therefore less compromised.

Some manufacturers of press screw separators offer designs that can obtain very high contents of dry matter (greater than 35 %) in the solid phase for use as bedding. Solid phase produced in this way is comparable to mattresses made of straw and manure from the point of view of animal welfare (soft lying surface, degree and number of injuries) and hygiene (in case of own manure) (Zähner et al. 2009). If the solids are used as bedding, only fresh material should be used. The machines for changing bedding must be kept clean. In addition, regular changing bedding is necessary as the positive effects only come into play if the bedding height and cubicle care are adequate. To ensure good bacterial quality of the lying surface, one of the most important factors is that the surface of the walkways and lying areas are kept dry and clean (Zähner et al. 2009). From a legal point of view, however, the use of solids resulting from the separation of slurry as bedding in deep bed cubicles is currently not permitted (EG VO 1069/2009 2009). Current legal provisions allow their use only in research projects.

Technical considerations relevant to applicability

The separation of liquid manure is suitable for all animal species housed in liquid manure systems. The process is also used to treat digestate resulting from biogas production.

Utilisation of the solid phase resulting from separation is often more difficult on farms, and its emission potential is higher. Therefore, special attention should be paid during separation to ensure that the solid phase can be appropriately reused. For instance, it can be used in biogas plants. When drying the solid phase, care must be taken to avoid ammonia emissions from the drying process. If the solid phase is used for fertilising arable land, it should ideally be applied and incorporated without prolonged storage to avoid gaseous N losses (Lyons et al. 2021).

Separation can also be the first step in the further processing of both the solid and liquid phases. These steps are described by Döhler et al. (2021), taking into consideration the BAT conclusions.

Economics

Depending on the scale of the separation processes, for a utilisation of 12,000 operating hours/year, the calculated costs are between € 0.51 and € 3.37 per m^3 (**Driving force for implementation**

In regions with a high density of livestock production, landspreading of liquid manure is severely limited due to a surplus of nutrients. In addition to the upper limit of 170 kg N of animal origin, the high nutrient supply in the soils is often a limiting factor. Separation can yield varying amounts of P and organic N in the solid phase. Thus, it is possible to provide a higher proportion of the N requirement of plants with the liquid phase when using slurry.

This technique is financially supported by the Landwirtschaftliche Rentenbank as part of the agricultural investment programme.

Table 30). The costs of separation with a decanter centrifuge are approx. € 2 - 3/m³, that is, significantly higher than those of separation with a press screw separator. This is not only due to the higher investment, but also to the significantly higher energy requirement of this process.

Driving force for implementation

In regions with a high density of livestock production, landspreading of liquid manure is severely limited due to a surplus of nutrients. In addition to the upper limit of 170 kg N of animal origin, the high nutrient supply in the soils is often a limiting factor. Separation can yield varying amounts of P and organic N in the solid phase. Thus, it is possible to provide a higher proportion of the N requirement of plants with the liquid phase when using slurry.

This technique is financially supported by the Landwirtschaftliche Rentenbank as part of the agricultural investment programme.

Table 30: Process engineering and economic parameters of separators

	Unit	Press screw separator[1]			Decanter centrifuge [1]		
Throughput	m³/h	8	15	25	8	15	25
Electrical capacity							
Separator	kW	3	5.5	11	30	40	60
Pumps, etc.	kW	4	5.5	7.5	11	14	17
Investment	€	20,500	33,500	50,000	95,000	135,000	175,000
Fixed costs	€/a	2,870	4,690	7,000	13,300	18,900	24,500
Energy consumption	kWh/m³	0.9	0.7	0.7	5.3	3.7	3.1
Throughput [2]	m³/a	9,000	20,000	30,000	9,000	20,000	30,000
Variable costs	€/ m³	0.35	0.28	0.28	1.90	1.29	1.09
Total costs	€/ m³	0.67	0.51	0.51	3.37	2.24	1.91

1 All data for the combination of a separator and pump or discharge screw.

2 Calculations for maximum capacity of 1,200 operating hours/year with the exception of the variant with 3000 m³/a.

Source: KTBL 2018

Example plants

Separation is a process that is already frequently implemented. It is mainly used in biogas plants.

1.1.6.2 Anaerobic digestion of manure (biogas with gas-tight digestate storage)

Brief description

The storage of animal excrement from livestock farming in open slurry storage tanks results in emissions of nitrous oxide, methane and indirectly of ammonia, all of which have an adverse climatic impact. By fermenting manure in biogas plants, these emissions can be avoided to a large extent.

Technical description

Anaerobic digestion plants are technical plants where renewable gas (so-called biogas) is produced from non-woody biomass. The methane produced is used to generate renewable energy in the form of electricity, heat or fuel.

Operating principle

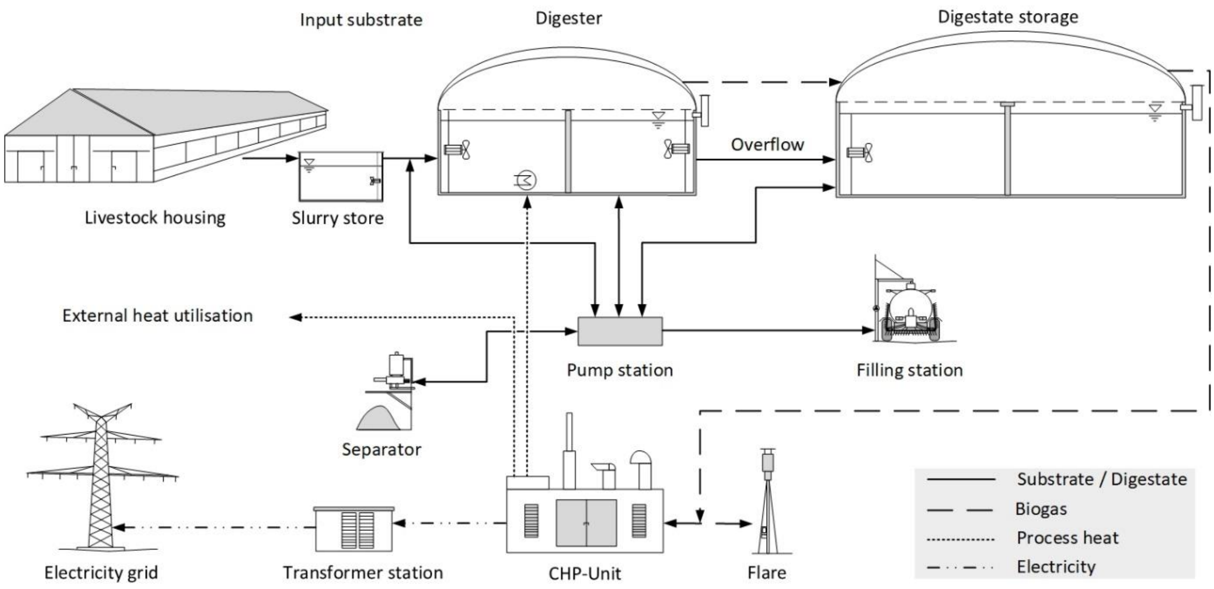
In biogas production (**Environmental performance and operational data**

The use of biogas allows the methane formation potential of slurry to be largely exploited and be used to generate energy. Providing the plant is operated properly, there are no methane emissions into the environment apart from unavoidable losses (e.g. diffusion through foils, methane slip in CHP units). Providing the digestate is stored in a gas-tight manner, there are no residual methane, nitrous oxide or ammonia emissions from digestate storage (Rösemann et al. 2021). By replacing fossil energy sources, biogas production can reduce greenhouse gas emissions, especially in the case of high slurry shares because emissions are avoided during storage. If biogas is used for power generation, it is essential that the remaining CHP waste heat after the extraction of process heat is used consistently. This plays an important role in reducing greenhouse gases (Figure 42), regardless of the input materials. In the case of manure shares of over 80%, under ideal circumstances, the benefits more than compensate for the emissions resulting from plant construction and operation; i.e. there is a net reduction in GHG emissions.

Table 31 lists the nitrous oxide, methane and ammonia emissions from the storage of cattle slurry, as an example.

), organic materials (plant and animal biomass) are degraded by bacteria in an oxygen-free environment. This process is called anaerobic digestion. It results in a combustible biogas consisting of 50 to 75 % methane, 25 to 45 % carbon dioxide and other trace gases (KTBL 2013). The biogas can be used, for example, in a combined heat and power units (CHP) to produce renewable electricity and heat according to demand.

Figure 41: Schematic diagram of an agricultural biogas plant with the main plant components



Source: own illustration, M. Paterson, KTBL

Structural design

The essential components of an agricultural biogas plant are as follows (according to KTBL 2021a):

- Substrate input: Slurry from adjacent livestock buildings enters a preliminary tank, which serves as a storage container for the digester, via a pipeline or sewer. Solid substrates are often fed into the digester using a solids feed-in system.
- Substrate preparation/sanitation: Optionally, disintegration techniques can be used for structurally diverse biomasses that are difficult to ferment, e.g. horse manure or straw. In addition, sanitation units can be used for hygienically unsafe substrates for the respective partial flow.
- Digester/post digester: The core of every biogas plant consists of an air- and light-tight tank (so-called digester), mainly made of reinforced concrete or steel with a carrying air cover (gas storage tank). The tanks are heated by the surplus heat from the combined heat and power unit and are equipped with agiators. Single- or two-stage plants that implement the flow-through method are most often deployed. In two-stage processes, a second digester (so-called post-digester) is installed downstream of the actual digester (FNR 2016).
- Central pumping station: The enclosed pumping station handles all pumping operations at many biogas plants.
- Digestate storage: After anaerobic digestions digestate remains which, according to German law, is usually stored for a period of 9 months (ban period for spreading fertiliser). In most cases, digestate storage consists of an unheated tank made of reinforced concrete with a gas-tight carrying air cover (gas storage tank) to avoid residual gas emissions. To prevent emissions, German regulations stipulate a minimum hydraulic, gas-tight retention time (digester plus digestate storage) of 150 days for biogas plants, unless only liquid manure is used.

- Separation: Optionally, digestate can be separated to enhance transportability or to reduce the required storage space for the digestate. As is the case for slurry, emission-reducing measures are essential, especially for storage and landspreading of solids, in order to minimize NH_3 emissions (see Chapter 1.1.6.1 Separation of liquid manure).
- Filling location: The plant has a sealed area where the refuelling of landspreading equipment or tankers with digestate from the digestate storage facility takes place.
- Gas utilisation: The biogas produced is dewatered by a condensation separator and used in many places in CHP units to produce electricity and heat (combined heat and power; CHP). An alternative gas utilisation device (flare) is mandatory for emergencies. The renewable electricity produced is then transferred to the public electricity grid via a transformer station. Part of the heat is used to heat the fermentation tanks; the remaining surplus heat is used on the farm and/or by third parties.

Environmental performance and operational data

The use of biogas allows the methane formation potential of slurry to be largely exploited and be used to generate energy. Providing the plant is operated properly, there are no methane emissions into the environment apart from unavoidable losses (e.g. diffusion through foils, methane slip in CHP units). Providing the digestate is stored in a gas-tight manner, there are no residual methane, nitrous oxide or ammonia emissions from digestate storage (Rösemann et al. 2021). By replacing fossil energy sources, biogas production can reduce greenhouse gas emissions, especially in the case of high slurry shares because emissions are avoided during storage. If biogas is used for power generation, it is essential that the remaining CHP waste heat after the extraction of process heat is used consistently. This plays an important role in reducing greenhouse gases (Figure 42), regardless of the input materials. In the case of manure shares of over 80%, under ideal circumstances, the benefits more than compensate for the emissions resulting from plant construction and operation; i.e. there is a net reduction in GHG emissions.

Table 31 lists the nitrous oxide, methane and ammonia emissions from the storage of cattle slurry, as an example.

Currently, about 30% of the manure produced in Germany is used to generate energy in biogas plants, thus avoiding greenhouse gas emissions in the order of about 1,6 million t CO_2e (Majer et al. 2019). Around two-thirds of the technical potential is therefore currently still unexploited. It is estimated that the current utilisation rate of manure for anaerobic digestion can be increased by an additional 35% (Majer et al. 2019).

By replacing fossil energy sources, biogas production can reduce greenhouse gas emissions, especially in the case of high slurry shares because emissions are avoided during storage. If biogas is used for power generation, it is essential that the remaining CHP waste heat after the extraction of process heat is used consistently. This plays an important role in reducing greenhouse gases (Figure 42), regardless of the input materials. In the case of manure shares of over 80%, under ideal circumstances, the benefits more than compensate for the emissions resulting from plant construction and operation; i.e. there is a net reduction in GHG emissions.

Table 31: Methane production and climate-relevant emissions in the form of NH_3, N_2O and CH_4 during the storage of cattle slurry in comparison to biogas utilisation

Design slurry tank	Open tank		Fixed covers with tent [1]	Biogas utilisation	
	without	with Natural floating cover		with gas-tight digestate storage	open digestate storage with RGP 3.7% [2] (according to TA-Luft)
Methane production in m³ CH_4/m³ liquid manure	**3.13**	**1.84**	**3.13**	**18.4** [3]	
Greenhouse gas emissions	in kg $CO_{2\text{-eq}}$/m³ slurry				
NH_3 (indirect N_2O)	2.42	0.61	0.24	0	0.77
N_2O	0.00	12.2	12.2	0	12.2
CH_4	56.3	33.1	56.3	6.6 [4]	18.9
Total GHG	**58.7**	**45.9**	**68.7**	**6.6**	**31.8**
Reduction through biogas	in %				
Gas-tight digestate storage	-88.7%	-85.6%	-90.4%		
Open digestate storage, all gases	-45.8%	-30.7%	-53.7%		
Open digestate storage, methane only	-66.5%	-43.0%	-66.5%		

RGP: Residual gas potential; GHG: Greenhouse gas emissions; TA-Luft: Technische Anleitung zur Reinhaltung der Luft (German Technical Instructions on Air Quality Control)

1 Not gas tight

2 According to TA Luft, digestate can be stored without a gas-tight cover if it has a proven residual gas potential of up to 3.7 %, i.e. if necessary, already after a retention time in the gas-tight system (digester + digestate storage) of under 150 days. The residual gas potential is determined by a fermentation test at 37 °C for 60 days without adding inoculum.

3 Used for energy, therefore no/low-emissions to the atmosphere, see Footnote 4

4 Unavoidable methane emissions during plant operation: diffusion through foils and CHP slip

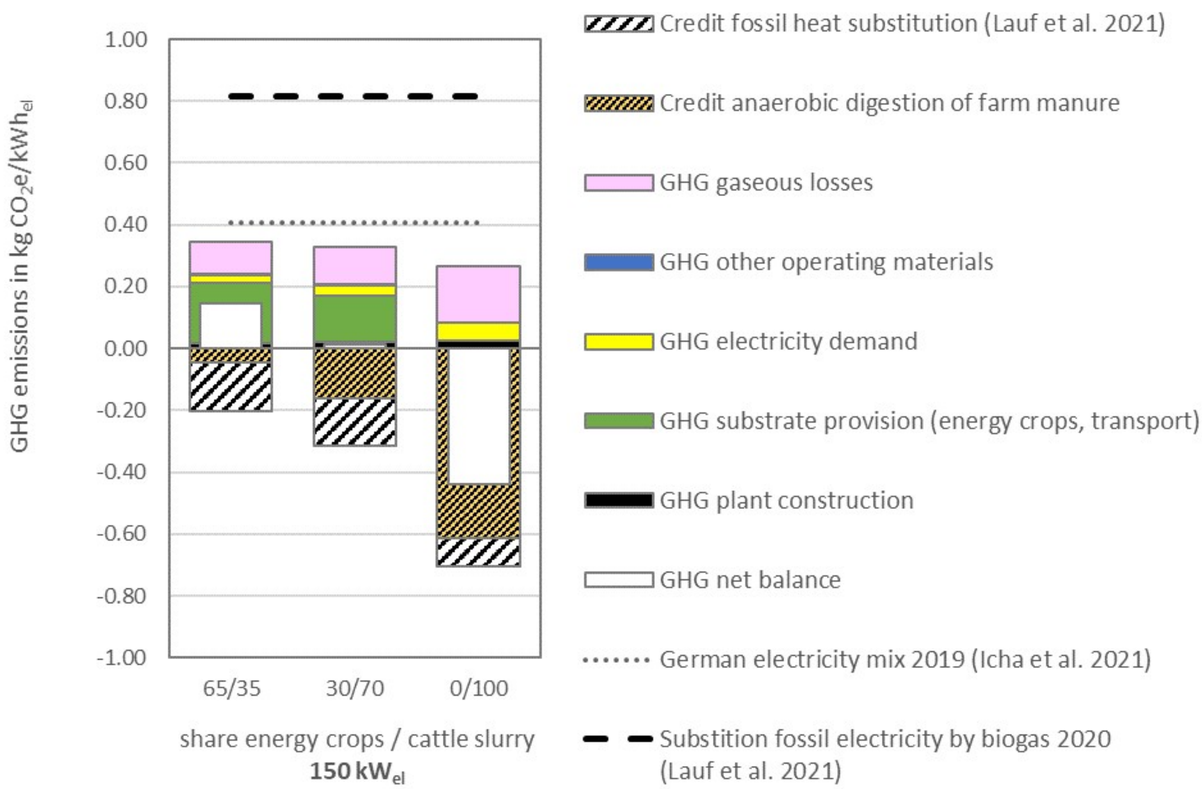
Source: own calculations based on assumptions in Rösemann et al. 2021

Cross-media effects

- As a by-product of anaerobic digestion, digestate is a versatile fertiliser (Paterson, M. et. al. 2016). It not only provides valuable plant nutrients, but also helps enhance soil structure and preserve soil fertility by supplying organic matter (KTBL 2019).
- Anaerobic digestion increases the amount of ammonium-N that is readily available to plants compared to in unfermented slurry. Therefore, it is all the more important that emission-reducing processes are employed in the storage and spreading of digestate.

- Odour-forming substances are lower in digestate than in unprocessed slurry. As a result, anaerobic digestion also results in a reduction in odour, especially during landspreading (KTBL 2019).
- The risk potential of harmful pathogens (human, zoo and phytopathogens) and weed seeds is virtually eliminated by anaerobic digestion process (KTBL 2012, Paterson, M. et. al. 2016).
- Biogas also plays a special role in comparison to other renewable energies, as it is a flexible and storable energy source that is not subject to seasonal or weather-related fluctuations.
- Energy production from biogas can reduce the use of fossil fuels and thus cut greenhouse gas emissions (Figure 42).
- Biogas plants do not cause excessive odour, dust or noise pollution during normal operation compared to other agricultural activities. Unavoidable emissions that cannot be eliminated by the gas flare (CHP slip, loss from pressure-regulating valves) are usually kept to a minimum.

Figure 42: Greenhouse gas emissions from biogas electricity for a 150 kW_{el} biogas plant (rated capacity) operated with 100 % cattle slurry; external heat use: 20 % of the heat produced; digester heating: 25 % of heat produced; reference for heat credit: natural gas heat; German electricity mix and fossil mix substituted by biogas for comparison.



Source: own illustration, KTBL; Icha et al. 2021, Lauf et al. 2021

Animal welfare

As a downstream measure, anaerobic digestion of manure has no relevant impact on animal welfare.

Technical considerations relevant to applicability

Today's agricultural biogas plants (in Germany) meet extensive requirements regarding their construction and operation as well as regarding environmental protection and safety. Depending on a biogas plant's construction, capacity, gas storage volume, substrate use, location and other characteristics, it is governed by laws and regulations from various fields of application. As a result, the safety requirements can vary considerably (KTBL 2021a). It should be possible to integrate a biogas plant, both technically and operationally, into almost every livestock farm.

Economics

In an agricultural livestock farm, slurry, feed residues and residual materials are available at low cost. However, manure, especially slurry, has only a low energy density due to its high water content and a rather low specific gas yield. As a result, it is not easily transportable and economically attractive for biogas plants located far away from the place of origin.

Table 32: Economic guideline values for exemplary new plants

Cost item	Guideline values		
Electrical installed power	75 kW_{el}	75 kW_{el}	250 kW_{el}
Rated power capacity	69 kW_{el}	69 kW_{el}	125 kW_{el}
Electricity fed into grid	608,000 kWh/a	608,000 kWh/a	1,090,000 kWh/a
Substrate share	100 % FM	70 % FM 30 % EC	70 % FM 30 % EC
Amount of farm manure	8,580 t Cattle slurry/a 600 t Cattle manure/a	2,670 t Cattle slurry/a	5,100 t Cattle slurry/a
Specific investment (based on installed capacity)	€ 14,300/kW_{el}	€ 10,050/kW_{el}	€ 5,160/kW_{el}
Operating costs/running costs (fixed/variable)	€ 150,200/a	€ 160,900/a	€ 260,600/a
Electricity production costs	24.8 ct/kWh	20.4 ct/kWh	23.8 ct/kWh
Revenues (electricity and heat)	€ 142,600/a [1] (20 % heat output)	€ 48,600/a [2] (20 % heat output)	€ 198,600/a [3] (35 % heat output)
Emission reduction costs	n.a.	n.a.	n.a.
Plant construction	Usually delivered as a turnkey installation by a plant builder (with/without in-house involvement)		
Removal after decommissioning:	Is prescribed		

FM: Farm manure EC: energy crops

1 German feed-in rate for small slurry plants with a slurry content of at least 80% by mass (EEG 2021)

2 German feed-in rate for biomass plants without participation in tender up to 100 kWel (EEG 2021)

3 German feed-in rate for biomass plants in the context of tenders (EEG 2021)

Source: KTBL 2022b, supplemented

Driving force for implementation

In addition to reducing GHG emissions from farm manure in open storage and enhancing the manure's fertilising properties through anaerobic digestion, the biggest driving force is the compensation received for the electricity produced, as provided for by the German Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz; EEG). The EEG regulates the compensation for renewable electricity and thus renders the revenue derived from electricity predictable. Biogas plants make it possible for farms to generate value from manure before it is spread or supplied to a third party.

Example plants

In most European countries, the origin of the biogas industry lies in the anaerobic digestion of manure in combination with fodder residues and by-products. As the framework conditions have been favourable for the biogas sector in Germany, it has developed more strongly than in other countries (Paterson, M. et. al. 2016).

There are currently over 9,600 predominantly agricultural biogas plants with a work-relevant electrical output of 3.8 GW (FvB 2021). The majority of biogas plants in Germany use varying proportions of manure to produce biogas. Accounting for about 40% of the total number of plants, biogas plants most commonly use (based on the quantities used) about 30 – 50 % slurry/solid manure and energy crops as substrate for biogas production (Majer et al. 2019).

1.1.7 Overview of the basic application possibilities and the techniques in the barn

The applicability of the techniques (reduction techniques) to be considered in the determination of BAT is classified in four categories – "applicable", "applicable in principle", "applicable to a limited extent" and "not applicable" – in the following figure, taking into account the individual types of production. Any restrictions are described in the relevant sections. For instance, low-emission floors can only be implemented in combination with a cleaning device, which leads to restrictions for individual types of production, e.g. for young animals or cattle fattening. In addition, the width of the slats (see TierSchNutztV 2021) must be adjusted for younger animals and perforated floors (see Chapter 1.1.3.1).

Manure can only be acidified in the barn in housing systems with liquid manure. Further requirements (e.g. liquid manure technique) are explained in Chapter 1.1.3.4.

Figure 43: Basic application possibilities and limitations of the reduction techniques to be considered in the determination of BAT in individual types of production in the barn

Type of production		Low-emission floors [1, 2]		Elevated feeding stall with partitions between feeding stations	Slurry acidification in the barn with liquid manure system [3]	Exhaust air treatment (forced air-ventilation
		Perforated	Solid			
Dairy cows		Applicable	Applicable	Applicable	Applicable to a limited extent	Not applicable
Calf rearing (until the end of 6th month of life)		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (taking into account dimensions of feeding station)	No experience to date	Not applicable
Young cattle		Applicable to a limited extent from 7th month of life	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (taking into account dimensions of feeding station)	No experience to date	Not applicable
Cattle for fattening	Heifers/oxen	Applicable to a limited extent from 7th month of life	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (taking into account dimensions of feeding station)	No experience to date	Not applicable
	Bulls	Applicable to a limited extent from 7th month of life	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (taking into account dimensions of feeding station, stability of partitions)	No experience to date	Not applicable
Calves for fattening		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (taking into account dimensions of feeding station)	No experience to date	Applicable
Suckler cows with offspring		**Applicable in principle** (depending on slot width, currently not available)	**Applicable in principle** (currently not available)	**Applicable to a limited extent** (calves)	No experience to date	Not applicable

1 Emission reduction only in combination with cleaning equipment. Use of long-stalk straw is not possible.
2 In systems with separate walkways.
3 Minimum channel depth of 1.00 m and annular channels (circulation system) required.

Legend:
- Applicable
- Applicable to a limited extent (For details on the applicability see the description of the technology in chapter 4)
- No experience to date
- Applicable in principle (currenty not available; For details on the applicability see the description of the technology in chapter 4)
- Not applicable

Source: own illustration, KTBL

2 Emerging techniques

Based on current information, the following techniques are under development. Their practical suitability is being comprehensively investigated.

2.1 Urease inhibitor (UI)

Urea is excreted by cattle as a metabolic product in the urine. The excreted urea is broken down into ammonia and carbon dioxide by the enzyme urease. Urease is present all over the barn and soil and, in particular, in faeces (Figure 44). This process of urea hydrolysis starts after about 20 minutes to 1 hour after the urea has been excreted and comes into contact with the urease and is usually completed after a few hours (Monteny and Erisman 1998).

Figure 44: Formation of ammonia

$$\underset{\text{urea}}{(NH_2)_2CO} + \underset{\text{water}}{H_2O} \xrightarrow{\text{urease enzyme}} \underset{\text{ammonia}}{2\ NH_3} + \underset{\text{carbon dioxide}}{CO_2}$$

Source: own illustration, KTBL

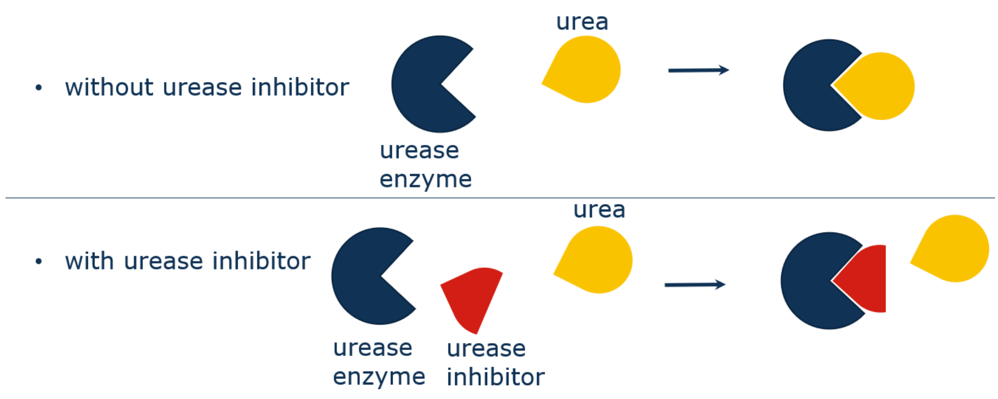
Brief description

Urease inhibitor for suppressing the process of urea hydrolysis and thus reducing ammonia emissions in the barn.

Technical description

The use of a urease inhibitor suppresses the action of the urease enzyme. The urease inhibitor combines with the enzyme urease instead of urea and thereby blocks the enzyme (Figure 45). The process of urea hydrolysis is thus inhibited, reducing or preventing the conversion of urea and thus the formation of ammonia (Reinhardt-Hanisch 2008).

Figure 45: Schematic representation of the mode of action of a urease inhibitor



Source: own illustration, KTBL

Structural design

The urease inhibitor is applied to walkways daily in the form of a liquid. This can be done manually or with (semi-)automatic spraying systems (e.g. a backpack sprayer or a device on the cleaning equipment). Fully automatic application techniques are currently being tested in practice, for example, a floor-level spraying device for cleaning robots or a rail system in the ceiling area with an integrated spraying system with vertically positioned hoses.

Achieved environmental benefits

Based on studies in cattle barns in the field and in laboratories, a reduction in ammonia emissions of 40 - 50% (estimated value) is assumed, providing the inhibitor is correctly applied (application with low level of surface contamination, uniform application, etc.) (Leinker 2007). Studies of different inhibitors under laboratory conditions (substrate temperatures of 18, 20 and 25°C) have shown an average reduction potential of 48% (Hagenkamp-Korth et al. 2015b).

Environmental conditions such as the temperature, air velocity, urea concentration and pH can affect the process (Elzing et al. 1992).

It is assumed that odour emissions are also mitigated. Information on the impact on greenhouse gas emissions is not currently available.

Environmental performance and operational data

The urease inhibitor shows the highest efficacy at low levels of surface contamination. Therefore, to ensure its effectiveness, the surface must be cleaned before application (Leinker 2007).

In cattle barns, 2.5 mg/m^2 of inhibitor solution mixed with a water volume of 200 ml/m^2 per operation are considered sufficient to coat one square meter of barn surface and thus reduce urease activity on smooth surfaces. The inhibitor solution is applied once daily. A higher application rate is required in pig barns than in cattle barns (Leinker 2007, Hagenkamp-Korth et al. 2015a).

Cross-media effects

There are no cross-media effects.

Animal welfare

According to the current state of knowledge from the PraxREDUCE project (2022), the urease inhibitor is assumed to not harm animals, humans and the environment.

Technical considerations relevant to applicability

The use of a urease inhibitor is an effective method for mitigating ammonia emissions but is currently not yet ready to be put into practice. So far, it has been tested only in dairy cow housing. The application of a UI is effective only when combined with liquid manure processes. Application is carried out daily.

Economics

This technology is currently not yet ready for the market. The data are not sufficient to evaluate its economic impact. As an alternative, information from a manufacturer of urease inhibitors has therefore been used.

No structural measures need to be taken for the use of the urease inhibitor. The technique can be used in existing buildings without any construction work.

The urease inhibitor is mixed with water using a metering and mixing station. The investment required for this station ranges between € 20,000 and € 30,000. The solution is applied to the walkways in the barn using equipment such as a stationary manure removal system or manure removal robot. For this purpose, the scraper system or robot must be equipped with nozzles. The investment required for the technique ranges between € 3,000 - 5,000 per scraper system or robot.

The equipment, consisting of the metering and mixing station and a dispenser device, costs about € 230 per animal place for 100 dairy cows. The **fixed costs** (depreciation, interest costs, housing) are € 15.00 per animal place and year. For a herd of 600 dairy cows, the **investment required** for the equipment is € 77 per animal place, and the fixed costs are € 5.00 per animal place per year (Table 33).

Table 33: Economic guideline values for use of the urease inhibitor (UI)

Investment and costs	**Animal places (AP)**	
	100	**600**
	€/AP	
Investment		
Technology and technical system	230.00	77.00
Total investment	**230.00**	**77.00**
Costs	**€/(AP • a)**	
Fixed costs		
Technology and technical system	**15.00**	**5.00**
Depreciation	11.50	3.80
Interest costs	3.50	1.20
Housing	0.00	0.00
Total fixed costs	**15.00**	**5.00**
Variable costs		
Technology and technical system	**10.50**	**3.90**
Repairs	6.40	2.10
Electrical energy	3.40	1.10
Other inputs		
Water	0.7	0.7
Urease	n.a.	n.a.
Total variable costs	**11.20**	**4.60**
Total costs	**26.20**	**9.60**

n.a. not available

Source: own calculation, KTBL

The operation of the system incurs ongoing costs for operating materials (electricity) and repairs, depending on the usage time. Assuming a usage time of 0.5 hours per day and an electricity requirement of 2 kWh/h for power transmission, about 3.65 kW/h per animal place and year are required for 100 animal places. In comparison, about 4.87 kWh per animal place and year are required for a herd of 600 dairy cows and a usage time of 2 hours per day.

The **variable costs** amount to approx. € 3.10 per animal place and year for 100 animal places and to approx. € 3.90 for 600 animal places.

In addition, costs are incurred for water to produce the solution. The equipment sprays the area with about 0.2 l of water per m^2 per day. Approximately 0.4 m^3 of water is required per animal place and year. At a price of € 1.90/m^3, the water costs amount to € 0.70 per animal place and year. At least some of this water drains down into the slurry channels, requiring additional storage volume.

No information is currently available on the cost of the urease inhibitor.

Driving force for implementation

The use of this technology could be important in the future for reducing emissions in the context of permit applications.

Example plants

A current research project (Practical application of a urease inhibitor compound for mitigating ammonia emissions in barns for sustainable, animal- and environmentally friendly cattle management; PraxREDUCE; Kiel University (CAU)) is focusing on developing an all-in-one solution that is suitable for practical use (metering, mixing, filling and application technology) to enable the automated use of a UI. The project is testing application techniques such as a cleaning robot with a floor-level spraying device and a rail system running along the ceiling with vertically positioned application hoses in combination with a stationary dosing-mixing-filling station.

2.2 Urine catchment and collection device

Brief description

Device for catching and collecting urine directly from the animal so that the urine cannot act as an emission source for ammonia in barns.

Technical description

Structural design

The animal is lured into the station with the help of a food bait (e.g. concentrate, total mixed ration (TMR)) (Figure 46). At the station, a device mechanically stimulates the nerve pathways between the udder and vulva, triggering a reflex at the central ligament of the udder. This external stimulus causes the animal to urinate. The urine is collected in a container and stored separately.

The urine is collected directly from the animal, conducted away and stored separately. The system almost completely separates faeces and urine, preventing the formation of ammonia from the urea and reducing emissions in the barn.

Achieved environmental benefits

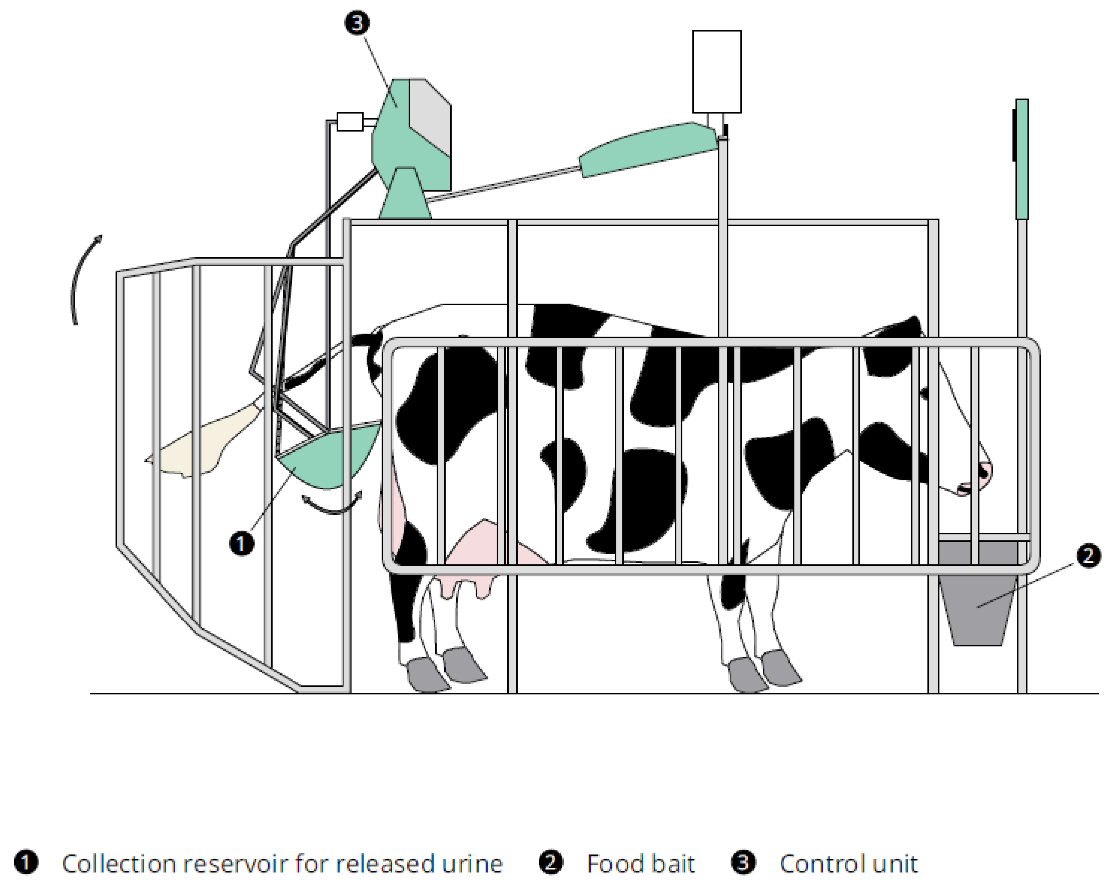
The rapid separation of faeces and urine reduces ammonia emissions in the barn. This system can reduce emissions throughout the entire process chain if the urine is stored separately outside the barn and distributed after collection.

Environmental performance and operational data

According to the manufacturer, the catchment and collection device collects approx. 10 litres of urine per animal per day. In addition, the manufacturer reports a reduction in ammonia emissions of 50% (based on modelling), assuming ammonia emissions of 13 kg per animal place and year. The reduction in ammonia emissions is associated with a drop in odour emissions.

The emission-reducing effect of the system on ammonia and greenhouse gases is currently being investigated in a test barn in the Netherlands (Hanskamp AgroTech BV 2022). The results are currently not available.

Figure 46: Sketch of a urine catchment and collection device



Source: own illustration, KTBL

Cross-media effects

After collection, the urine must be stored and applied separately. By separating the faeces and urine, both can be used for precise and needs-based fertilisation of crops, and nutrient efficiency can be increased. However, the technique incurs an additional workload for storage and landspreading.

The manure is more viscous than the original slurry in the system. According to the manufacturer, the proportion of carbon is therefore higher. This higher concentration of organic components in the manure yields more energy when it is processed in a biogas plant.

Animal welfare

There is currently no scientific knowledge about the adverse health effects of this technology. It is likely that it is harmless.

In principle, clean and dry walkways have a positive effect on the cleanliness of animals and promote good udder and hoof health (Somers et al. 2005, Magnusson et al. 2008) and natural movement as animals are more sure-footed (Telezhenko et al. 2017).

Technical considerations relevant to applicability

The device is only suitable for female cattle and is currently only used on dairy cows (see Figure 47). Its suitability in practice is currently being tested in dairy cow barns. The manufacturer is currently investigating whether it can be integrated into an automatic milking system.

Retrofitting is possible. Additional space is required for the equipment.

There are currently no housing systems that completely separate and apply faeces and urine until storage.

Figure 47: Possible applications of a urine catchment and collection device, according to the types of production

Type of production		Urine catchment and collection device
Dairy cows		Applicable
Calf rearing		-
Young cattle		-
Cattle for fattening	Heifers/oxen	-
	Bulls	-
Calves for fattening		-
Suckler cows with offspring		-

Applicable

- not applicable for this type of production

Source: own illustration, KTBL

Economics

According to the manufacturer, a device costs about € 20,000. It has a capacity for 25 cows. Thus, costs of about € 800 per animal place can be estimated. Additional costs are incurred by the separate collection and storage of urine. In practice, this has not yet been done.

So far, there is no experience with operation of the system and no evaluations of it. Therefore, it is currently not possible to draw any further conclusions on its economic impact.

Driving force for implementation

It is likely that this technology will be implemented more broadly as a result of measures promoting emission reduction.

Example plants

The technique has been on the market in the Netherlands since 2021. It is expected to be offered for export from 2022. In Germany, the technique is being investigated at the Haus Düsse

Research and Training Centre for Agriculture to evaluate its emission-reducing effects and practical applicability.

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