DLG Test Report 6178

Uniqfill Air BV

BioCombie biological trickle-bed reactor

for pig housing

DLG SIGNUM TEST
May 14 passed

Test Center
Technology and Farm Inputs

www.DLG-Test.de

Overview

The SignumTest is DLG's comprehensive utility value test based on independent and recognized assessment criteria for agricultural machinery and equipment and related products. The DLG-SignumTest provides a neutral assessment of the essential features of the product, from performance capability and animal welfare, via stability, to work safety and functional safety. These aspects are examined and evaluated on test rigs and under various operating conditions of use, and in the same way the product is put to the test in practical operation on a user farm. The precise testing conditions and methods as well as the assessment of the test results are defined in corresponding test schedules by the respective independent Test Commissions and are continuously adapted to the recognized state of the art, scientific findings and agricultural requirements. The tests are conducted using methods that allow objective assessment on the grounds of reproducible values. A successful test closes with publication of a test report and award of a test certification mark. The DLG SignumTest comprised technical measurements on test stands, examinations in use, behavioural observations, joint evaluations, and a survey of user farms.

This DLG SignumTest was conducted to test the BioCombie air scrubber by Uniqfill Air BV for its suitability to reduce dust, ammonia and odour from the emissions exhausted from slatted-floor pig houses. The test refers to a ventilation system that meets the following criteria:

– DIN 18910 approval,
– achieves a separation efficiency of ammonia and dust levels by a least 70 % while complying with the process parameters described, and
– reduces odour levels to less than 300 odour units per cubic metre of clean gas with no detectable raw-gas odour left in the clean gas.

Assessment – Brief Summary

The BioCombie biological trickle-bed reactor by Uniqfill is a single-step system used to extract dust, ammonia and odour from the raw-gas flow. It is designed for use in slatted-floor barns with an overhead ventilation system. After moisturising the exhaust air and removing coarse dust particles by continuous primary spraying, the filter is constantly sprayed with scrub water. The aerosols created in this process are separated in a downstream demister. During the winter test, the trickle-bed reactor achieved an exceptionally high average separation efficiency of 94.4 % for $PM_{2,5}$ particulate matter. During the summer and winter tests, the continuous ammonia measurements showed very high separation efficiency levels of 92 % and 92.3 %, respectively. During winter operation a high recovery rate of 85 % of the separated nitrogen was found. Table 1 shows an overview of the results.

More test results are shown on page 10.

Table 1:
Overview of results

Test criteria		Result	Rating*
Emission measurement results			
Total dust (gravimetric analysis, four measurements)			
– Summer (1 measurement)	Separation efficiency [%]	76	○
– Winter (3 measurements)	Average separation efficiency [%]	88	+
Particulate matter (gravimetric analysis, two measurements)			
– Winter	Average PM_{10} separation efficiency [%]	88.3	+
	Average $PM_{2,5}$ separation efficiency [%] **	94.4	+ +
Ammonia (continuous measurement of concentration levels at a conductivity of 16 mS/cm)			
– Summer	Average separation efficiency calculated from half-hour averages [%]	92	+ +
– Winter	Average separation efficiency calculated from half-hour averages [%]	92.3	+ +

Test criteria		Result	Rating*
Emission measurement results			
N-balance test			
– Summer (at 16 mS/cm)	Recovery rate of separated nitrogen [%]	81	+
– Winter	Recovery rate of separated nitrogen [%]	85	+
Odour			
– Summer		< 300 OU/m³ and no detectable raw gas	N/R
– Winter		< 300 OU/m³ and no detectable raw gas	N/R
N-removal			
– Summer		81***	+
– Winter		85	+
Consumption measurements (averages per day or per pen place and year)			
Fresh water consumption			
– Summer at 16 mS/cm	Fresh water consumption [m³/d] / [m³/(PP × a)]	7.75 / 2.18	N/R
– Summer at > 20 mS/cm	Fresh water consumption [m³/d] / [m³/(PP × a)]	5.62 / 1.63	N/R
– Winter at 16 mS/cm	Fresh water consumption [m³/d] / [m³/(PP × a)]	3.64 / 1.19	N/R
Desludging volume			
– Summer at 16 mS/cm	Desludging volume [m³/d] / [m³/(PP × a)]	2.78 / 0.79	N/R
– Summer at > 20 mS/cm	Desludging volume [m³/d] / [m³/(PP × a)]	2.02 / 0.58	N/R
– Winter at 16 mS/cm	Desludging volume [m³/d] / [m³/(PP × a)]	2.54 / 0.83	N/R
Acid consumption			
– Summer	Acid consumption	Not required	N/R
– Winter	Acid consumption [kg/d] / [kg/(PP × a)]	14.81 / 4.85	N/R
$NaHCO_3$ buffer substance consumption			
– Summer	Minimum buffer substance ($NaHCO_3$) consumption [kg/d] / [kg/(PP × a)]	20.50 / 5.83	N/R
	Maximum buffer substance ($NaHCO_3$) consumption [kg/d] / [kg/(PP × a)]	49.25 /14.00	N/R
– Winter	Buffer substance ($NaHCO_3$)	Not required	N/R
Power consumption			
– Exhaust air cleaning (pump operation)			
– Summer	Energy consumption [kWh/d] / [kWh/(PP × a)]	110.0 / 31.6	N/R
– Winter	Energy consumption [kWh/d] / [kWh/(PP × a)]	81.1 / 27.1	N/R
– Fans			
– Summer	Fan power [kWh/d] / [kWh/(PP × a)]	90.3 / 25.7	N/R
– Winter	Fan power [kWh/d] / [kWh/(PP × a)]	27.3 / 9.1	N/R

* Rating scores: ++ / + / ○ / – / – – (○ = average performance, N/R = no rating available)

** Experience has shown that 2.5...10 µm sized droplets may form in the scrubbing process, increasing the presence of PM_{10} particle fractions inside the cascade impactor. The $PM_{2,5}$ particle fraction is not affected. Therefore, a higher separation efficiency value is calculated for this particle fraction than for the PM_{10} fraction.

*** During the summer test period, an implausible N-removal value was recorded; in this instance, the gaseous clean-gas levels were used for evaluation.

Test criteria	Result	Rating*
Operational behaviour		
Technical safety	Apart from a few power cuts and related interruptions in buffer substance supply, the facility did not suffer any notable faults during the examination periods.	+
Biological safety	The facility's automatic pH-value control system ensures a very stable nitrification process.	+
Durability	No notable wear occurred during the examination periods.	+
Facility management		
Operator manual	The operator manual is easy to read, clearly describing all necessary maintenance work and the automatic function of the facility's monitoring and control system. The facility's principle of operation is illustrated by various pictures and graphics.	+
Operation	The facility is intended to operate fully automatically. If a maintenance contract has been signed, the manufacturer will perform a thorough facility inspection at least once a year. The owner is required to perform weekly inspections of the facility's monitoring and control system. Due to the biological activities, the facility must remain in continuous operation.	○
Maintenance	The manufacturer strongly recommends signing a maintenance contract to ensure all required maintenance tasks will be correctly performed by the manufacturer. The manufacturer offers a remote facility monitoring service as an option.	○
	The level of cleaning required depends on the facility's condition. If the pressure loss value exceeds the manufacturer's specified value by more than 20 Pa, the facility should be cleaned by authorised personnel.	○
Cleaning	If the pressure loss exceeds the specified value, the filter beds should be cleaned by authorised personnel. No other parts of the facility will require cleaning.	○
Filter bed replacement	According to the manufacturer, the filter bed does not require replacement as long as the facility remains in continuous operation.	N/R
Required labour times for		
– Daily checks	No manufacturer specification	○
– Weekly checks	Approx. 15 minutes per week	○
– Cleaning	Approx. 4 hours per quarter of the year	○
Documentation		
Technical documentation	Meets all requirements	+
Digital logbook	Meets all requirements	+
Safety		
Operational safety	Confirmed by SVLFG (German social insurance institution for agriculture, forestry and horticulture)	N/R
Fire safety	The owner is responsible for developing a fire prevention strategy before submitting their application for construction permit for the entire building.	N/R
Environmental safety		
Noise emissions	No increase in noise levels as caused by the exhaust-air cleaning system were measured.	○
Disposal	It is recommended to dispose of the scrub-water together with the slurry in line with the nutrient requirements of the plants. Facility components are disposed of by authorised recycling plants.	○
Warranty		
Manufacturer's warranty	One year	N/R

* Rating scores: ++ / + / ○ / – / – – (○ = average performance, N/R = no rating available)

The Product

Manufacturer and applicant

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Product:
BioCombie biological
trickle-bed reactor

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Description and specifications

The BioCombie trickle-bed reactor is a biologically controlled facility operated under pressure. It is designed to clean the exhaust air produced by slatted-floor pig houses.

The principle of a trickle-bed reactor relies on the contact between the substances contained in the exhaust air and the recirculated scrub water (slightly acidic, pH value 6,5...6,9) as well as the micro-organisms residing in the filter bed. The exhaust air is extracted from all connected compartments and flows to the filter bed via a collection duct. Once the exhaust air enters the top section of the pre-chamber of the scrubber, it is sprayed with a co-current flow of water that separates the coarse dust particles.

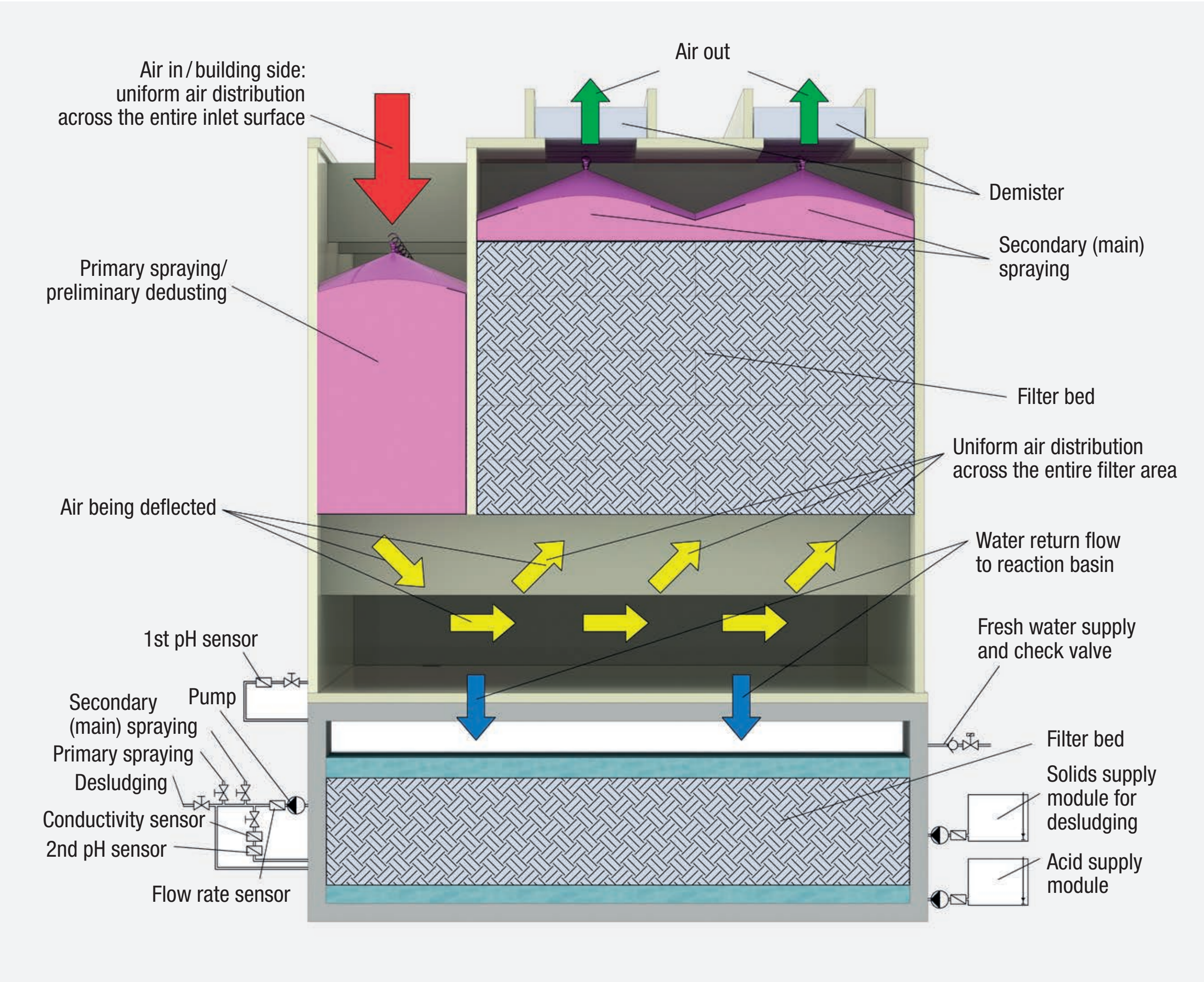

Fig. 2:
BioCombie functional description (schematic diagram)

Table 2:
Trickle-bed reactor manufactured by Uniqfill

Property	Result / value
Description	Single-step, continuous trickle-bed reactor
Suitability	Cleans exhaust air from slatted-floor pig houses with an overhead ventilation system by reducing the emission of dust, ammonia and odour
Reference facility dimensions	
Filter bed dimensions	
– Filter bed length / height / width [m/m/m]	13.2 / 1.5 / 2.4
– Filter surface [m²] / filter bed volume [m³]	31.68 / 47.52
– Specific filter bed surface [m²/m³]	240
– Minimum residence time at summer air-flow rate (contact time) [sec]	1.54
– Maximum filter surface load [m³/(m² h)]	3504
– Maximum filter volume load [m³/(m³ h)]	2336
Secondary spraying (continuous)	
– Spray-flow rate [m³/h]	30
– Spray density [m³/(m² h)]	0.95
– No. of nozzles per m² of filter bed surface [pcs/m²]	1.0
Primary spraying (continuous)	
– Spray-flow rate [m³/h]	10
– Spray density [m³/(m² h)]	0.32
Demister	
– Demister thickness [m]	0.17
Desludging	
– Scrub water trap basin capacity [m³]	approx. 18*
– Summer desludging rate at 16 mS/cm conductivity [m³/d]	2.78
– Summer desludging rate at 16 mS/cm conductivity [m³/pen place and year]	0.78
– Summer desludging rate at > 20 mS/cm conductivity [m³/d]	1.73
– Summer desludging rate at > 20 mS/cm conductivity [m³/pen place and year]	0.54
– Winter desludging rate at 16 mS/cm conductivity [m³/d]	2.54
– Winter desludging rate at 16 mS/cm conductivity [m³/pen place and year]	0.83
– Scrub water pH value	6.5...6.9
– Conductivity [mS/cm]**	16
Reference operation for conducted measurements	
Pig fattening system (all-in/all-out method per compartment): pen places [pcs]	1,288
Average livestock weight [kg of LW]	70
Installed maximum fan capacity [m³/h]	111.000 (5 fans)
Filter bed pressure loss [Pa]	Max. 50 at 111.000 m³/h exhaust air
Total pressure loss (barn + exhaust-air cleaning system) [Pa]	Max. 100 at 111.000 m³/h exhaust air
Maximum summer air-flow rate to DIN 18910 [m³/h]	102.000 at temperature zone II and 120 kg of LW

* Depending on the barn's installed fan capacity
** Conductivity was 16 mS/cm throughout the summer and winter tests. After completing the summer test period, conductivity levels were gradually increased to 25 mS/cm and kept constant for three weeks. Operating the facility at a conductivity of 25 mS/cm proved unsafe in field operation.

The exhaust air is then deflected 180 degrees and passes a filter bed that is continuously sprayed with circulating water in a counter-current bottom-up flow. The large specific surface of the filter bed offers an increased contact area for the exhaust air and the water, enabling the absorption of dust, ammonia and odour particles, and also serving as a residence for micro-organisms which chemically convert the substances to be removed. Since ammonia is highly water-soluble, it is scrubbed by the circulating water and oxidated into nitrite and nitrate by nitrifying bacteria. The circulating water carries bacteria and dust, ammonia and odour substances into the scrub water trap to ensure further biological decomposition of the exhaust-air substances.

The scrub water requires frequent desludging to avoid accumulation of salts. The desludging frequency depends on the scrub water salt content, the latter determining the scrub water electrical conductivity. The desludged scrub water is periodically replaced with fresh water.

After flowing through the filter bed, the exhaust air passes a demister and is then released to the environment as clean gas. The demister holds back the aerosols left in the gas.

As it is necessary to maintain a high level of biological activity for an effective cleaning by air, the air scrubber must be constantly operated. For the desired micro-organisms to survive, the building must be continuously filled with livestock. After an extended period of facility downtime, at least eight weeks should be allowed for biological regeneration upon a re-startup. However, production-related downtimes during no more than a few days are considered non-critical, provided spraying is continued.

Warranty

The manufacturer provides a one-year warranty, provided that the facility is operated as intended.

Facility installation and maintenance must be performed by an authorised expert.

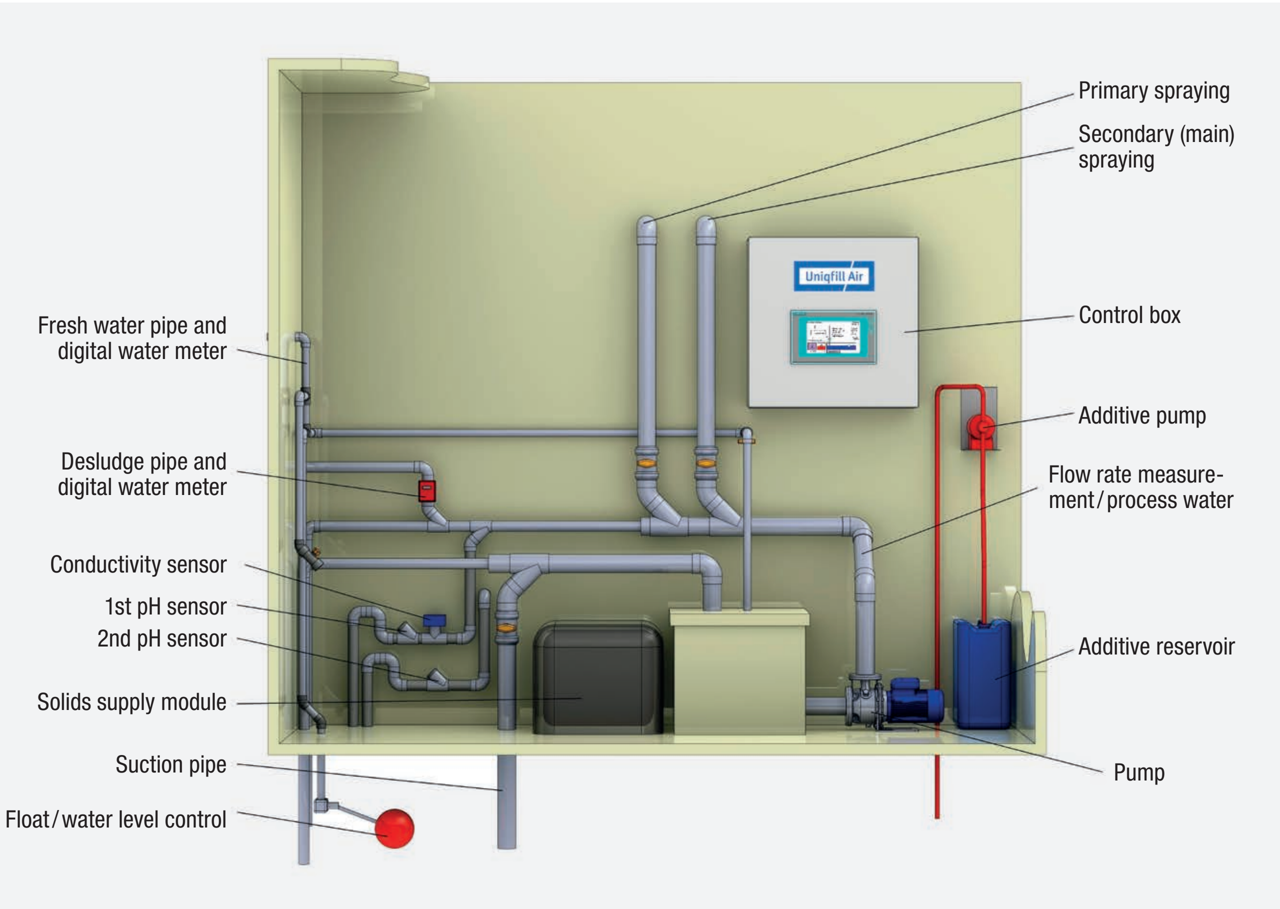

Fig. 3:
BioCombie 2014 plumbing room
The reservoir sizes shown are relative to the number of pen places (reference building: 25 L acid trap, $NaHCO_3$ powder: 100 kg).

The Method

The measurements were performed at a reference facility located in the northern German community of Visbek. The full examination period comprised a summer test and a winter test. As the facility under test was a prototype, the examiners were unable to conduct a survey among owners of identical exhaust-air cleaning systems during the examination period.

The slatted-floor reference building used for conducting the tests held roughly 1,288 fattening pigs held across four compartments. The air from the compartments was extracted by overhead fans (overhead ventilation system), collected in an exhaust air duct (centralised collection duct) and passed through the exhaust-air cleaning system. The ventilation system was designed to DIN 18910 standard. Derived from this standard, the maximum fan capacity for continuous fattening systems should be approx. 111,000 m³/h at a pressure difference of < 100 Pa (according to manufacturer's specifications).

The measurements were performed from October 2011 to January 2012 (winter test) and from July to September 2013 (summer test). The summer test originally scheduled for the summer of 2012 was cancelled before the eight-week test period expired. This was due to instable facility operation caused by a rapidly decreasing pH value (< 6). Consequently, the clean gas contained increased percentages of secondary trace gases (N_2O, NO_X). Manufacturer Uniqfill then installed an alkali solids supply module to control the pH value within the required tolerances. This application of $NaHCO_3$ provided reliable control over the system and enabled a trouble-free, stable operation of the facility.

The winter test was performed at a conductivity-dependent desludging rate at 16 mS/cm. The summer test was also performed at a conductivity of 16 mS/cm. After completing the scheduled test period, conductivity was gradually increased to 25 mS/cm. This showed that temporary operation at increased conductivity levels is possible, while long-term operation under these conditions should be avoided due to the increased nitrite contents in the scrub water.

During the measurements the ambient conditions (inside/outside temperatures and relative humidity levels) were also measured. The following additional parameters were recorded on the dust and odour measurement dates:

- Estimated livestock weights and animal numbers
- Fresh water and electric power consumption (meter readings)
- Absolute air flow rate
- Desludging volume
- Pressure loss across the facility and pressure loss across the fan system

Furthermore, the recordings as logged by the manufacturer in the digital logbook of the facility were verified for plausibility.

The evaluation the exhaust-air cleaning system was based on following parameters:

Dust

The dust sample was taken in line with the VDI directive 2066 and the DIN EN 13284-1 standard. To this end, an isokinetic plane filter head sampling system (50 mm diameter, Paul Gothe) was installed. A drying tower filled with silica gel was used for absorption. The gravimetric analysis of the dust content provided the basis for evaluation. The particulate matter analysis was performed using a cascade impactor.

Ammonia

The raw-gas and clean-gas ammonia measurements were performed using an FTIR gas analyzer throughout the examination period. To avoid condensation, the gas pipes used for the measurements were heated along their entire length. In-house measurements at animal height were performed during periodic visits to check the ammonia concentration in the air inside the building.

Odour

The odour samplings and evaluations were performed in line with the DIN EN 13725 standard using a TO-8 type olfactometer manufactured by ECOMA GmbH. On a weekly basis, odour samples were taken from the raw-gas and clean-gas pipes. The olfactometric properties of these samples were analyzed by a group of trained test subjects.

For evaluation, the level of odorous substance concentration was noted and the test subjects checked the clean gas for raw-gas odour. The odorous substance concentration must not exceed 300 OU/m³ in the clean gas.

Aerosol emissions

In an exhaust-air cleaning system, aerosols containing nitrogen are scrubbed as N-aerosols in the trap basins and carried away by the exhaust-air flow. This way the separated nitrogen is inadvertently fed back to the environment. The N-aerosols are measured by determining the difference between the filtered and unfiltered samples; the scrub water nitrogen content is used to determine the percentage of inorganic nitrogen contained in the aerosols. In the reference facility, an aerosol impactor measurement was performed for summer and winter conditions.

Nitrogen balance

During the summer and winter tests, the cleaning system's nitrogen separation capacity was checked every 14 days by testing the N-balance on the basis of the raw-gas and clean-gas ammonia contents, the aerosol emissions, the nitrogen oxides contained in the raw and clean gases as well as the nitrogen compounds dissolved in the scrub water. This meant that the nitrogen separated from the raw-gas ammonia by the cleaning system was detected in the clean gas in the form of ammonium, nitrite and nitrate and also in the form of residual ammonia and nitrogen oxide emissions. Balance tests of the nitrogen flows inside the facility are essential for the following reasons:

- to detect and locate all relevant nitrogen compounds,
- to determine whether the facility produces notable amounts of greenhouse gases such as NO, NO_2 or N_2O, as this would reduce the facility's purpose to absurdity,
- to detect and troubleshoot potential faults in biological nitrification systems, and
- to measure the nitrogen contained in the desludging water and quantify its nutritional value.

According to the DLG testing framework the nitrogen recovery rate in the nitrogen balance should be > 70 % for the summer and winter test periods.

N-removal

Unlike the separation capacity and recovery rate values, N-removal only relates to the extractable substances contained in the scrub water. N-removal represents the mass of nitrogen removed from the facility in kilograms. Insufficient N-removal might indicate that desludging measurements were either incomplete, or there are leaks in the facility, or other processes have caused nitrogen compounds to fall out inside the exhaust-air cleaning system.

Consumption levels, environmental conditions and facility loads

Fresh water and power consumption levels were read off the relevant meters. The acid consumption during the examination period and the solids supply of the relevant buffer substances used to maintain the desired pH value in the scrub solution were both measured using a weighing system (precision balance or load cell). During the measurements, the inside and outside temperatures and the relative inside and outside humidity levels were measured to document the ambient conditions.

On the dust and odour measurement dates, animal numbers and estimated livestock weights were recorded as additional parameters. Also, differential pressure measurements were performed to record the absolute air-flow rate, the desludging volume and the pressure losses across the facility and fan system. Furthermore, the recordings as logged by the manufacturer in the digital logbook of the facility were verified for plausibility.

Operational safety and durability

For the Operational Safety and Durability test, any faults occurring to the facility and its physical components during the examination period were recorded and evaluated. Additional evaluations included the level of corrosion and durability under continuous operation.

Operator manual, facility management and related labour, maintenance

The operator manual is evaluated from the operator's point of view. Particular attention is paid to a functional description of the facility, the level of detail used to describe the facility, including pictures, and the unambiguous description of all periodic maintenance work.

The Facility Management and Related Labour test evaluates whether a manufacturer-led introductory briefing is required to enable commissioning of the facility; in addition, it determines the labour time required for periodic inspections and servicing work on a daily, weekly, monthly etc. basis or whenever a fault occurs.

The maintenance requirements are evaluated on the basis of service intervals and their associated task lists.

Documentation

The digital logbook should document the following parameters:

- Pressure loss across the facility
- Air throughput in m^3/h
- Pump operation time (recirculation and desludging pumps)
- Spraying intervals and spray-flow rate
- Total facility fresh water consumption
- Desludging rate and further use of desludging water
- Raw-gas and clean-gas temperatures

Additional documentation should include spray pattern checks, maintenance and repair times, compliance with pH-value and scrub-water conductivity setpoints, and pH-probe calibrations. Proof should be provided for acid and, in biological facilities, alkali consumption levels.

This data will be used to verify correct exhaust-air cleaning system operation.

Environmental safety

Environmental Safety testing included the use of any inputs required for facility operation (e. g. acids and alkalis), further utilisation of any waste produced during operation (e. g. desludged water) and the removal and disposal of facility components. Testing was used to determine what type of personnel will be responsible for these aspects.

Safety aspects

Facility safety was evaluated by determining to what degree the facility complied with the current fire protection and work safety regulations.

Dust

During the winter test, a total of three total-dust measurements were performed. Due to technical and physical circumstances the summer test delivered no more than one total-dust measurement. Particulate matter measurements (PM_{10} and $PM_{2,5}$) were performed during the winter test only. The facility design suggested that the facility might permanently achieve separation capacities of more than 70 %; this assumption was confirmed by the test results.

Table 3 shows that 76 % of total dust was separated during the summer test. In the winter test, the facility achieved an average total-dust separation capacity of 88 %. This means the Uniqfill BioCombie scrubber is able to achieve a permanent separation capacity of more than 70 % for slatted-floor pig houses. The separation efficiency levels associated with PM_{10} particulate matter averaged 88.3 % in winter.

For $PM_{2,5}$ the facility constantly achieved more than 90 % separation efficiency in winter.

Experience has shown that 2.5...10 µm sized droplets may form in the scrubbing process, increasing the presence of PM_{10} particle fractions for dust measurement using the cascade impactor. The $PM_{2,5}$ particle fraction is not affected. Therefore, a higher separation efficiency value is calculated for this particle fraction than for the PM_{10} fraction.

Ammonia

The measured raw-gas values in the summer varied between 8 and 20 ppm in compliance with the German livestock husbandry legislation. In the winter, raw-gas values averaged between 10 and 40 ppm. It should be noted that the required maximum value of 20 ppm at animal height was met at all times. The BioCombie scrubber effectively reduced the raw-gas content in the clean gas to < 4 ppm (see table 6).

Fig. 4 shows a graphical representation of the ammonia concentration levels. The negative peak value shown was caused by a power cut and the subsequent breakdown of the pH-value control system.

This means that the facility, provided that it is operated as intended, ensures effective separation of ammonia in slatted-floor pig houses under the operating conditions described (see table 1).

Table 3:
Results of dust reduction measurements on Uniqfill trickle-bed reactor

	Winter					Summer
Date	**03/11/2011**	**17/11/2011**	**08/12/2011**	**15/12/2011**	**21/12/2011**	**15/07/2013**
Comments	– –	– –	– –	– –	– –	– –
Environmental and boundary conditions						
Rel. outside humidity [%]	73	90	83	82	72	56
Ambient temperature [°C]	15.4	2.3	6.9	7.5	4	21.4
Raw/clean gas humidity [relative %]	79/100	66/100	65/100	60/100	68/100	68/100
Raw/clean gas temperature [°C]	20/16.5	16.7/12.8	20.9/16.5	21/16.5	20/17.5	24.3/20.0
Number of animals in the building	1300	850	943	1417	1407	1300
Average livestock weight [kg]	95	107	36	38	38	45
Total air-flow rate [m³/h]	– –*	20,000	15,000	22,000	25,000	110,000
Filter bed pressure loss [Pa]	– –*	4**	4**	4**	5**	24
Total dust (normalised)						
Raw-gas dust concentration [mg/m³]	2.01	1.45	– –	– –	2.79	1.64
Clean-gas dust concentration [mg/m³]	0.13	0.22	– –	– –	0.38	0.39
Separation efficiency [%]	93	85	– –	– –	86	76
Particulate matter (normalised)						
Raw gas $PM_{10}/PM_{2,5}$ [mg/m³]	– –	– –	0.49/0,21	0.71/0.42	– –	– –
Clean gas $PM_{10}/PM_{2,5}$ [mg/m³]	– –	– –	0.07/0,02	0.07/0.01	– –	– –
$PM_{10}/PM_{2,5}$ separation efficiency [%]	– –	– –	86.3/92,2	90.3/96.5	– –	– –

* No measured values available
** Measured values taken from the digital logbook

Odour

The results of the odour samples taken during the DLG test are shown in table 7. During the summer test, a total of nine samples were taken, eight of which met the required criteria (300 OU/m³ and no detectable raw gas). In all samples, all or the majority of test subjects did not detect any raw-gas odour in the clean gas.

Ten samples were taken during the winter test, eight of which met all criteria. Low odour reduction levels were caused by insufficient biological activity (27 October 2011) and by powder blockages inside the sodium hydrogen carbonate supply pipe (30 July 2013). On 21 December 2011, despite increased clean-gas odour concentration levels, no raw-gas odour was detected in the clean gas.

Aerosol emissions

All aerosols escaping from the BioCombie's water basin were measured.

The NH_3 aerosols (detected by determining the difference between the filtered and unfiltered samples) and the scrub water nitrogen contents (determined using the percentage of inorganic nitrogen contained in the aerosols) are plotted in Table 5. The Uniqfill facility as a whole displays very low aerosol values.

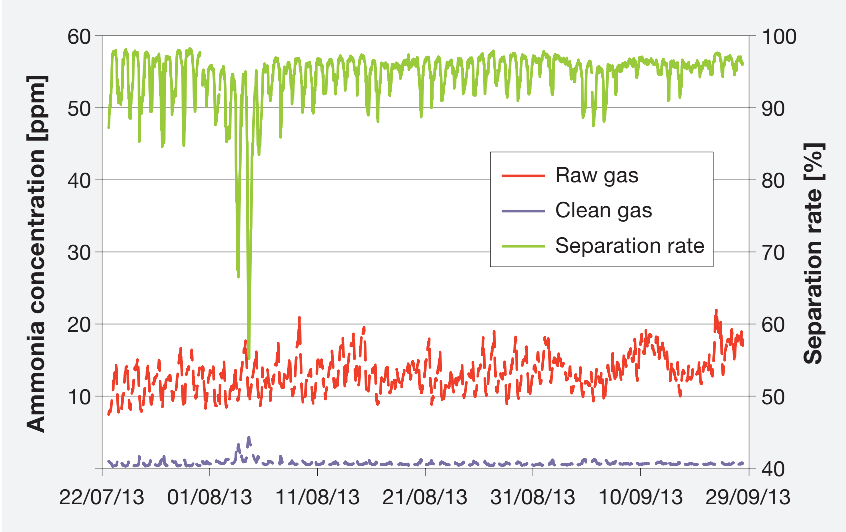

Fig. 4:
Example ammonia separation efficiency and development of ammonia concentration levels in the raw and clean gases during the summer test

Table 4:
Typical composition and fluctuation range of desludging water produced by the Uniqfill exhaust-air cleaning system

	Summer	Winter
pH value	6.7-7.2	6.7-7.3
Conductivity [mS/cm]	16.7-18.4	15.2-20.6
Ammoniacal nitrogen (NH_4-N) [mg/l]	390-600	1940-2600
Nitrite nitrogen (NO_2-N) [mg/l]	1860-2565	840-1365
Nitrate nitrogen (NO_3-N) [mg/l]	< 100	< 100

Table 5:
Aerosol analysis average values

	Summer	Winter
NH_3 aerosols [mg NH_3/m³]	0.007	0.094
Inorganic N aerosol [mg N/m³]	0.037	0.110

Table 6:
Results of ammonia reduction measurements on Uniqfill trickle-bed reactor and process data during summer and winter tests (selected daily averages)

	Winter		Summer		
	27/10/2011	11/11/2011	23/07/2013	30/07/2013	16/08/2013
Ventilation rate [m³/h]	65,986	29,431	86,951	72,740	84,911
Flow velocity* [m/s]	0.58	0.26	0.76	0.64	0.74
Residence time* [sec]	2.59	5.81	1.97	2.35	2.01
Filter bed surface load* [m³/(m² x h)]	2083	929	2745	2296	2680
Filter bed volumetric load* [m³/(m³ x h)]	1389	619	1830	1531	1787
Spray density* [m³/(m² x h)]	1.22	1.25	1.27	1.27	1.28
Raw-gas ammonia concentration [ppm]	18.0	30.0	10.3	12.9	11.6
Clean-gas ammonia concentration [ppm]	3.4	1.5	0.5	0.5	0.7
Ammonia separation efficiency [%]	80.6	94.9	94.5	95.7	94.1

* Calculated values

Table 7:
Results of odour measurements on Uniqfill trickle-bed reactor

Winter test										
Date	**27/10/11**	**03/11/11**	**10/11/11**	**17/11/11**	**24/11/11**	**01/12/11**	**08/12/11**	**15/12/11**	**21/12/11**	**12/01/12**
Comments	**– –**	**– –**	**– –**	**– –**	**– –**	**– –**	**– –**	**– –**	**– –**	**– –**
Environmental and boundary conditions										
Rel. outside humidity [%]	85	73	96	90	93	78	83	82	72	69
Ambient temperature [°C]	10.3	15.4	6.9	2.3	9.2	7.4	6.9	7.5	4	8.1
Raw/clean gas humidity [relative %]	78/100	75/100	83/100	68/100	69/100	65/100	68/100	68/100	68/100	69/100
Raw/clean gas temperature [°C]	19.7/14.8	21.1/16.4	17.3/14.1	16.7/12.8	17.6/15.3	18.2/14.4	20.2/19.4	21.4/16.8	20.1/17.5	21.7/19.0
Number of animals in the barn	1,284	1,300	995	850	880	545	943	1,417	1,407	1,315
Average livestock weight [kg]	89	95	100	107	106	112	36	38	38	52
Total air-flow rate [m³/h]	60,000	– –*	42,000	20,000	30,000	40,000	15,000	22,000	25,000	28,000
Filter bed pressure loss [Pa]	– –*	– –*	7**	4**	7**	9**	4**	4**	5**	– –*
Odour* **										
Raw-gas OU/m³	411	572	477	410	431	406	439	474	1004	967
Clean-gas OU/m³	72	81	147	114	136	163	159	82	376****	199
Raw-gas odour in clean gas detectable?	Yes****	No*****	No	No	No	No*****	No	No	No	No

Summer test									
Date	**08/07/13**	**15/07/13**	**22/07/13**	**30/07/13**	**08/08/13**	**14/08/13**	**19/08/13**	**12/09/13**	**19/09/13**
Comments	**16 mS/cm**	**16 mS/cm**	**16 mS/cm**	**16 mS/cm**	**16 mS/cm**	**16 mS/cm**	**16 mS/cm**	**25 mS/cm**	**25 mS/cm**
Environmental and boundary conditions									
Rel. outside humidity [%]	60	56	34	57	83	70	83	75	79
Ambient temperature [°C]	23.9	21.4	30	23.2	18.1	19.9	17.3	19.9	14.8
Raw/clean gas humidity [relative %]	59/100	68/100	43/100	67/100	81/100	55/100	82/99	67/99	69/99
Raw/clean gas temperature [°C]	26.7/21.3	24.4/20.2	31.5/22.0	24.6/21.4	23.7/25.0	24.8/18.9	24.2/19.7	23.2/21.7	22.0/18.3
Number of animals in the building	1300	1300	1300	1300	1300	1300	1300	1300	1180
Average livestock weight [kg]	40	45	55	60	65	70	80	115	110
Total air-flow rate [m³/h]	115,000	110,000	120,000	105,000	100,000	90,000	85,000	90,000	75,000
Filter bed pressure loss [Pa]	35	24	49	48	28	15	19	28	42
Total pressure loss [Pa]	73	50	100	76	53	40	44	60	72
Odour* **									
Raw-gas OU/m³	123	936	341	613	187	254	364	175	293
Clean-gas OU/m³	97	215	133	410****	50	74	97	83	100
Raw-gas odour in clean gas detectable?	No*****	No*****	No	No	No	No	No	No*****	No

* No measured values available
** Measured values taken from the digital logbook
*** Geometric average values
**** Manufacturer's information (see page 11)
***** During the olfactometric analysis, the majority of test subjects did not detect any raw-gas odour in the clean gas

Nitrogen balance

The recovery rate derived from the nitrogen contents was 81 % during the summer test (at 16 mS/cm) and 85 % during the winter test. The examination included a total of three N-balance tests. The results show that nitrogen accumulates in the scrub water in the form of ammonium, nitrite and nitrate. This enables it to be extracted from the exhaust-air cleaning system and utilised for further purposes. Table 4 shows the composition of the desludging water.

N-removal

The measured N-removal values are shown in table 8. In the summer they amount to 81 % and in the winter, to 85 %.

Consumption levels, environmental conditions and facility loads

Water consumption

Initially, the summer test was performed at a conductivity-dependent desludging rate at 16 mS/cm and, during the additional follow-up test period, at a conductivity of 25 mS/cm. As the increase of electrical conductivity resulted in a decrease of scrub water usage, this change also affects the consumption values and, consequently, the fixed cost incurred by the owner. The scrub water consumed for desludging needs to be replaced by fresh water. Water consumption is largely dependent on the desludging rate and evaporation losses. This means that weather conditions have a substantial impact on consumption values.

In the summer test, the meter readings resulted in an average daily fresh water consumption of approx. 7.75 m³ at a conductivity-dependent desludging rate at 16 mS/cm and 5.62 m³ at 25 mS/cm, respectively.

When calculated per pen place (PP) and year (a), this amounts to 2.18 and 1.63 m³/(PP × a). During the winter test, the facility consumed an average daily fresh water volume of 3.64 m³, which corresponds to a consumption of 1.19 m³/(PP × a).

Table 8:
N-removal at 16 mS/cm

Examination period	N-removal [%]
12 Jan 2012 to 26 Jan 2012 (winter)	85
08 Sep 2013 to 19 Sep 2013 (summer)	81*

* During the summer test period, an implausible N-removal value was recorded; in this instance, the gaseous clean-gas levels were used for evaluation

During the summer test, the facility desludged an average daily scrub water volume of approx. 2.78 m³ at 16 mS/cm, which corresponds to an annual 0.79 m³/(PP × a). At a conductivity of 25 mS/cm during the summer test, the facility achieved a daily desludging volume of approx. 2.02 m³, which corresponds to 0.58 m³/(PP × a). In the winter test, the facility achieved a daily desludging volume of 2.54 m³ or 0.83 m³/(PP × a). See table 1 for a graphic representation of the measurements.

Electrical energy consumption

The major electrical loads within the core exhaust-air cleaning system are the continuously-operated recirculation pump and the intermittently-operated desludging pump. The fans are the major loads inside the building; due to the additional pressure loss caused by the cleaning system they require larger dimensions than standard barn ventilation systems with no emissions control. The following values were recorded throughout the examination period using an electricity meter:

Pumps (recirculation and desludging)
– Summer 111.0 kWh per day or 31.6 kWh per pen place and year
– Winter 81.1 kWh per day or 27.1 kWh per pen place and year

Fans
– Summer 90.3 kWh per day or 25.7 kWh per pen place and year
– Winter 27.3 kWh per day or 9.1 kWh per pen place and year

The difference in pump power consumption between the winter and summer tests is due to a more powerful recirculation pump that was installed by Uniqfill for the summer test, whereas the winter test was performed with a smaller pump installed.

It should also be noted that for testing purposes the facility was fitted with measuring fans that determined the air-flow rates. These measuring fans led to a higer consumption of electricity by causing additional pressure loss throughout the examination period.

Other consumption levels

To ensure safe operation, the facility has an automatic acid supply module controlling the scrub water and filter bed pH values. Generally, the pH value in the area downstream of (underneath) the filter bed should not exceed or drop below 6.5...6.9. The following acid consumption averages were recorded during examination:

Acid consumption
14.81 kg H_2SO_4 per day or
4.85 kg H_2SO_4 per pen place and year

These values refer to 100 % pure sulphuric acid. For testing, the reference facility was supplied with 96 %-purity sulphuric acid.

The scrubbing process in a biological scrubber requires counteractive measures to prevent the pH value from dropping below the setpoint. This may be achieved by adding a suitable alkali substance which has a buffer effect on the scrub water to actively control the pH value. At very low pH values below 6, buffering is no longer effective and the water trap must be replaced. During the summer test, sodium hydrogen carbonate was used as a buffer substance for the reference building. It was supplied by a solids supply module. Consumption levels were measured using a suitable scale.

Depending on the ventilation system installed for the building, recorded consumption levels were between 20.5 kg/d (min) and 49.25 kg/d (max). This corresponds to 5.83 kg/(PP × a) up to 14 kg/(PP × a).

A stable operation cannot be guaranteed unless a suitable pH value (6.5... 6.9) is provided and so most facilities require the addition of acids or alkalis. It may, however, be assumed that the facility is able to operate for approx. 6 out of 12 months without any additives being added. This means only half of the annual amounts of acid and alkali stated above will actually be required.

Safe facility operation at the specified efficiency levels is ensured only if the pH value control system is adjusted properly. The pH value must be maintained at a level between 6.5 and 6.9. Due to the risk of increased trace-gas release it is not recommended to operate the facility permanently at 25 mS/cm.

Operational safety and durability

No notable faults occurred to the facility's assemblies throughout the examination period. Similarly, no notable faults or signs of wear were detected on the exhaust-air cleaning system.

Observations throughout the examination period suggest that the corrosion protection measures taken for each assembly are sufficient. Almost the entire facility is made of polypropylene material.

Operator manual, facility management and related labour, maintenance

The operator manual is sufficiently accurate and provides an overview of the facility's principle of operation. The operator manual and other technical documentation describe all daily, weekly and monthly work required to maintain the facility. For added clarity, the operator manual contains several pictures showing the facility assemblies.

It is necessary to seek instruction from the manufacturer and fully read the operator manual before operating the facility.

As the exhaust-air cleaning system is fully automated, facility management is rather straightforward (after successful commissioning and an adequate run-in phase). The only work required is a daily check of the operating parameters and a weekly inspection of the entire exhaust-air cleaning system and its spray nozzles. If the monitoring and control system reports a fault, the operator manual should be consulted for instructions on how to troubleshoot the relevant assemblies. To simplify facility management and to reduce the labour required it is advised to sign a

Table 9:
BioCombie air scrubber digital logbook and how it meets the requirements

	Fully met	Partially met	Not met	Comments
Pressure loss across the exhaust-air cleaning system	X			Electronic pressure differential sensors installed upstream of the filter bed to measure the pressure loss across the air scrubber
Air flow rate	X			Recording and digital storage of the air flow rate in m³/h as calculated from pressure loss and facility performance curve
Pump operation period	X			Recording and digital storage of the recirculation pump operation periods
Spray intervals and spray-flow rate	X			Primary and secondary spraying is continuous and cannot be altered by the operator. Circulation rate measured using a flow-rate sensor
Total scrubber fresh-water consumption	X			Measured using a water meter and pulse sensor
Desludging rate and further use of desludging water	X			Measured using a digital water meter and pulse sensor; further use of desludging water documented in the analogue logbook
Raw and clean gas temperatures	X			PT100 resistance thermometers measure the temperatures inside the exhaust duct and directly downstream of the demister
Spray pattern check	X			Proof provided by analogue logbook
Maintenance and repair times	X			Proof provided by analogue logbook
Meets pH-value requirements and scrub water conductivity levels	X			Digital storage of pH values upstream and downstream of the filter bed (including conductivity value)
pH-sensor calibration	X			Proof provided by analogue logbook
Proof of acid and alkali consumption levels		X		Proof provided by copies of the relevant purchase invoices added to the analogue or digital logbook

maintenance contract with the manufacturer.

If a maintenance contract is signed, the first maintenance check will be performed no sooner than one week after commissioning and no later than one week before the animals are moved out of the barn for the first time. For continuous barn use, the first maintenance check will be performed three months after commissioning. Subsequently, periodic maintenance checks will be performed at least once a year (depending on regional legislation). This includes the inspection and, if needed, re-calibration of all measurement devices. At each semi-annual maintenance check, scrub water samples are taken to measure pH value, conductivity, oxygen content as well as ammonium, nitrate and nitrite levels. The inspection includes calibration of any existing measurement devices and also a measurement of the ammonia concentration levels present in the raw and clean gases. If necessary, the facility will be cleaned. All maintenance work will be recorded in a log book.

If the pressure loss value exceeds the manufacturer's specified value by more than 20 Pa, the filter beds and the demister must be cleaned by authorised personnel. If the monitoring and control system reports a fault, the relevant checks must be carried out in line with the operator manual. It is possible to have fault messages sent to the manufacturer by means of a remote-maintenance system.

If the spray pattern is erratic, the nozzles must be cleaned or replaced as necessary. Weekly checks are essential to keep the spray system in order. This activity must be recorded in the analogue and digital logbooks.

The pH sensors must be calibrated every month and replaced every 18 months; the conductivity sensor must be calibrated twice a year.

The recirculation pumps and the desludging pump must be inspected on a weekly basis (including a visual and an acoustic check). Uniqfill's analogue logbook also instructs the owner to read off the pipe pressures. Acid and alkali supplies must be checked on a weekly basis.

Documentation

The digital logbook provides consistent, half-hourly records of the parameters required for safe facility operation. The relevant data will be recorded by the manufacturer and stored over a period of five years. This data can be accessed by the farmer or by official authorities via a USB port and copied into any common spreadsheet application. Table 9 shows a detailed representation of the data recorded.

If the barn ventilation system and the exhaust-air cleaning system have been installed by different suppliers, the manufacturer of the cleaning system will record the ventilation system data as a performance curve and use it to adjust the cleaning system. In the control system, the maximum fan capacity is set to 100 %. No other adjustments will be made. According to the testing framework, the air-flow rate must be specified as an absolute m^3/h value. Therefore, before commissioning, a performance curve for the entire ventilation system (barn + exhaust-air cleaning system) must be recorded in the digital logbook. This curve should comprise at least five different sampling points between air-flow rates of 0 and 100 %.

Environmental safety

As the nitrogen contained in the desludged water is a valuable nutrient, the desludged water produced by the facility may be further utilised as slurry. Scrub water with a pH value > 6 may be stored together with the slurry.

According to the manufacturer, the removal and disposal of other facility assemblies should be performed by authorised recycling plants.

The operation of the facility requires the supply of acids and alkalis. Instructions on handling these additives are provided by the manufacturer. The owner is responsible for correct handling of the additives.

Safety aspects

Fire protection should be provided by means of an adequate fire prevention strategy. The owner is responsible for drafting this strategy in collaboration with the manufacturer. A copy of this draft should be added to the application for construction permit.

The Uniqfill BioCombie air scrubber described here was safety-checked by the German social insurance institution for agriculture, forestry and horticulture (SVLFG, Sozialversicherung für Landwirtschaft, Forsten und Gartenbau). According to the SVLFG's assessment, facility operation is deemed safe.

Summary

The BioCombie air scrubber manufactured by Uniqfill Air BV is suitable for the removal of dust, ammonia and odour emissions from the exhaust-air flow as produced by slatted-floor pig houses using a DIN 18910-approved ventilation system – provided that the system complies with the described process parameters related to ammonia separation efficiency (≥ 70 %), dust separation efficiency (≥ 70 %) and odour reduction (< 300 OU/m^3 with no detectable raw-gas odour left in the clean gas). The BioCombie facility is suitable for processing exhaust air from animal houses that is exhausted by overhead ventilation systems.

Further Information

Please go to **www.dlg-test.de/stallbau** to download more reports on exhaust-air cleaning systems.

The DLG technical committee for animal husbandry systems has published a bulletin on pig house ventilation titled “DLG-AU Lüftung”. This bulletin is available for free PDF download at: **www.dlg.org/technik_tierproduktion.html**

Find more DLG bulletins published by the DLG Competence Centre at: **www.dlg.org/schweineproduktion.html** and **www.dlg.org/tiergerechtheit.html**

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Laboratory- and emissions measurements
LUFA Nord-West, Jägerstraße 23-27
26121 Oldenburg, Germany

DLG Testing Framework
SignumTest “Exhaust air cleaning systems for livestock farming installations” (revised 10/2010)

Field
Renewable energies

Project manager
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