Big Dutchman International GmbH

HelixX exhaust air cleaning system

DLG Test Report 5957

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DLG e.V.
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Technik und Betriebsmittel

Brief description

- chemical exhaust air cleaning system consisting of up to five continuously sprinkled spray tower gas scrubbers and a wash water treatment system consisting of three chambers, two of which are used for the sedimentation of solids and one as a water reservoir
- continually operated, frequency-regulated circulation pump with an admission pressure of 4.5 bar and a volume flow of 2.0 m³/h for each connected spray tower gas scrubber
- the pH of the permanently circulating wash water is < 3
- downstream demister for aerosol separation with automatic, timed-interval discontinuous high-pressure cleaning using fresh water and an operating pressure of 100 bar at a volume flow rate of 35 l/min
- conductivity-controlled desludging (≤ 100 mS/cm) via two water jet pumps operated in parallel with an intake rate of 1250 l/h at 5.0 bar for the sediments and a delivery rate of 330 l/h at 5.0 bar for the process water
- a butterfly valve is used to prevent wash water from escaping into the house at low air volume flows; at high air volume flows the wash water separation takes place via a helical coil

Assessment – summarised

Summary 1:
HelixX exhaust air cleaning system

Test criterion	Result	Rating
Results of emission measurements		
Total dust (gravimetric, six measurement times)		
– Average separation from six measurements [%]	88.6	+
Ammonia (measured continuously)		
– Total separation efficiency from		
half-hour mean values [%]	86.0	+
– Recovery rate of separated nitrogen		
(nitrogen balance) [%]	> 70	not rated
Consumption measurements		
Fresh water consumption in winter [l / fattening place and year]	291	not rated
Fresh water consumption in summer [l / fattening place and year]	1,200	not rated
Desludging volumes in summer/winter		
[l/fattening place and year]	139/165	not rated
Acid consumption during the test in summer/winter		
[kg/fattening place and year]	6.77/3.69	not rated
Electricity consumption		
– Exhaust air cleaning [kWh/fattening place and year]	75.6	not rated
– Fans (summer only) [kWh/fattening place and year]	96.6	not rated
Operating performance		
Technical reliability	Following extensive improvement measures during	+
	the testing period, the system is operating smoothly.	
Durability	no noteworthy wear during the test periods	+
Operation		
Operating instructions	clear operating instructions with good explanation of the	+
	servicing tasks to be done and the automatic control system	
Operation	The system is fully automated when operated as intended.	○
	Daily function checks are to be carried out.	
	However, defoaming agent has to be used as necessary.	
Servicing	A service contract can be taken out with the manufacturer,	○
	providing for six-monthly servicing.	
	In addition to the daily function check and any work	
	required as a result, regular cleaning of the entire system	
	has to be carried out using a high-pressure cleaner.	
Work time required for daily checks	approx. 5 minutes per day	+
Cleaning of demister	The cleaning of the demister is fully automatic, by means	○
	of a timed-interval high-pressure cleaning system.	
Cleaning of the entire system	After each process water change, cleaning of the water treat-	○
	ment station has to be carried out. It also has to be cleaned	
	using a high-pressure cleaner.	

Test criterion	Result	Rating
Documentation		
Technical documentation	Requirements met	+
Electronic operating logbook	Requirements met	+
Safety		
Industrial safety	confirmed by DPLF (German Testing and Certification Authority	not rated
	for Agricultural and Forestry Equipment)	
Fire safety	Fire protection concept is to be drawn up by the operator	not rated
	as part of the building permit procedure for the whole house.	
Environmental safety		
Noise emissions	no detectable increase in sound intensity level due to exhaust	not rated
	air cleaning system	
Waste disposal	Storage of sludge water in a separate	not rated
	sludge container (with at least 6 months' storage capacity).	
	Spreading on agricultural land is permitted, but	
	mixing of the sludge water with liquid manure must take	
	place immediately prior to spreading. Mixing must not be	
	done in the occupied house.	
Guarantee		
Manufacturer's guarantee	2 years	not rated

Bewertungsbereich: ++/+/○/–/– – (○ = Standard; o. B. = ohne Bewertung)

Description and dimensions

Summary 2:
HelixX exhaust air cleaning system

Feature	Result / Value
Description	
single-stage, wet-chemical exhaust air cleaning system (spray tower gas scrubber principle) with wash water treatment and central supply pump for the connection of up to 5 spray tower gas scrubbers to a wash water treatment system	
Suitability	
Cleaning of exhaust air from litterless pig housing systems by reducing dust and ammonia	
Dimensioning parameters of reference system	
Dimensions of spray tower gas scrubber per module	
– Internal diameter [mm]	820
– Length of treatment line [mm]	2000
– Length of water collection coil [mm]	780
– max. volume flow	8,500 m³/h
– max. flow rate [m/s]	4.47
– min. residence time in treatment line [s]	0.45
Demister	
– Thickness [mm]	100
– Type	T01M1
– Cleaning	periodical high-pressure cleaning with 35 l/min at 100 bar using
	2 type 4002 cleaning nozzles and 2 type 4007 cleaning nozzles
	stationary high-pressure cleaning system type 8.5/35-120
Sprinkling (continuous)	
– Number of nozzle assemblies	8
– Nozzles per nozzle assembly	**4**
– Nozzle type	Excentric hollow cone nozzles type 302.408
– Droplet size [µm]	300 - 400
– Pump pressure [bar]	min. 4.5
– volume of water required for sprinkling [l/h]	2,000
– min. wash water [l] per m³ of exhaust air	0.24
Dimensioning of wash water reservoir (3 chamber system)	
– Capacity of wash water reservoir	Chamber 1: 260 l
for two spray tower gas scrubbers (helices)	Chamber 2: 45 l
	Chamber 3: 325 l (plus 550 l buffer volume)
– Physical cleaning stages (solids separation)	Chamber 1: sedimentation stage
	Chamber 2: fine screen [300 µm]
– Desludging rate [l / fattening place and year]	165
– pH of wash water	< 3
– nitrogen concentration [g/l]	≤ 20
– conductivity [mS/cm]	≤ 100
Reference farm for measurements carried out (pig fattening house, all in/all out)	
Fattening places [number]	180
max. weight of animal [kg live weight]	120
Installed air flow rate [m³/h]	17,000 (2 HelixX at 8,500 m³/h with 140 Pa pressure loss)
Total pressure loss (house + exhaust air cleaning) [Pa]	max. 140 at 8,500 m³/h of exhaust air per HelixX
Maximum air change rate in summer according to DIN 18910 [m³/h]	21,420

Test results

Suitability

The HelixX exhaust air cleaning system is suitable for reducing emissions in the exhaust air flow from litterless pig housing systems where the house ventilation is designed to DIN 18910 and, where the process engineering parameters described are adhered to, for the separation of ammonia (≥ 70 % separation efficiency) and dust (≥ 70 % separation efficiency).

Description/Function

The HelixX exhaust air cleaning system from Big Dutchman is a chemical system operated under excess pressure for cleaning the exhaust air from litterless pig houses. The system consists of up to five continuously sprinkled spray tower gas scrubbers and a wash water treatment system. Each spray tower gas scrubber unit (HelixX) is designed for a maximum volume flow rate of 8,500 m³/h per spray tower.

The spray tower gas scrubbers are sprinkled continuously via a circulation pump with a minimum admission pressure of 4.5 bar and a minimum wash water volume of 2.0 m³/h per spray tower. The pH of the wash water has to be below 3 and is adjusted automatically by means of a pH control system using sulphuric acid. The circulation pump conveys the wash water to the nozzle assembly of the treatment unit of the spray tower gas scrubber, where there are a total of 32 excentric hollow cone nozzles over 8 levels per spray tower. The nozzles on each level are arranged alternately with and against the exhaust air flow. This arrangement results in further fine atomisation of the wash water because the nozzles' atomising cones meet. The nozzles produce an extremely fine spray pattern, increasing the contact areas between substances contained in the exhaust air and the wash water. The pH < 3 increases the ammonia absorption capacity of the wash water. The use of sulphuric acid converts the ammonia absorbed by the wash water into ammonium sulphate.

The wash water is then collected via a helical coil and a water collection channel and carried to the wash water treatment system. At low volume flows, an automatically operated butterfly valve installed beneath the nozzle assembly serves to prevent wash water from escaping into the house.

To ensure that no atomised wash water contaminated with ammonium, ammonium sulphate and dust is carried outside with the exhaust air, a type T01M1 demister (thickness 100 mm, diameter 1200 mm) is installed at the exhaust air outlet from the spray tower gas scrubber. To stop the demister becoming blocked up during operation, it is cleaned from below once a day for 120 seconds using a type 8.5/35-120 high-pressure cleaning system. If the preset desired values are exceeded (pressure difference over the demister), the cleaning interval is automatically reduced. If the pressure difference caused by choking up of the demister exceeds 100 Pa for more than 6 hours, the control system activates an automatic 180-second emergency flush using the high-pressure cleaning system.

After wash water separation in the spray tower, the wash water flows unpressurised to the treatment system. The total volume for two spray tower gas scrubbers is approximately 1,200 litres. This volume is divided between three chambers. The first chamber serves to collect the returning wash water. The specifically designed tall water column allows heavy particulate components to be deposited here. The wash water reaches the third chamber via an overflow with a fine screen (mesh size 300 µm). The screen serves to separate out low-density particles (flies, etc.). The third chamber contains the supply pump, water level detector and fresh water supply. The separated particles are channelled to the second chamber (volume 45 l) via the screen. The filling level of the third chamber during operation is 325 l; for buffering of the wash water volume during stoppage periods, the third chamber can take up to an additional 550 l. According to the manufacturer, the wash water treatment system can be designed for up to five spray towers with a total exhaust air flow of 42,500 m³/h. In the reference system the exhaust air cleaning system was tested with two connected spray tower gas scrubbers (2 HelixX units).

The operation of the exhaust air cleaning system depends on the necessary filling level and pump pressure values being met. The pressure line is therefore equipped with a pressure sensor (desired pressure: min. 4.5 bar). The pump pressure is controlled by means of a frequency converter.

The exhaust air cleaning and ventilation can only be operated in parallel. After the ventilation has been switched off, the wash water contained in the nozzle assembly is automatically returned to the wash water treatment system to protect against freezing. To guarantee the water flow, each nozzle assembly is fitted with a flow meter. If the overall flow rate falls below 2.0 m³/h due to blocked nozzles etc., an alarm message is displayed in the controller.

To avoid the build-up of salts such as ammonium sulphate etc., wash water desludging is necessary. The wash water is desludged from the third chamber at a maximum conductivity of 100 mS/cm via a time-switched magnetic valve and a water jet pump. Once 100 mS/cm is reached, the magnetic valve opens and the pump pressure of the circulation pump drives the water jet pump (driving medium). The desludging is activated for 30 seconds in each case, and 7.25 l are desludged each time (suction medium). The water jet pump is configured on the suction side in such a way that sediments can also be desludged. The ratio between desludged process water and suction medium is 2:3.

The fresh water is added after the end of desludging, via the water level control in the third chamber. When the maximum filling level is reached in the stage 2 wash water reservoir, the wash water flows via an overflow to stage 1.

Defoaming agent has to be used if there is a lot of foaming. It is added either manually or via a separate metering device.

Test conditions/reference house

The reference house in which the measurements were conducted consists of a section housing up to 180 fattening pigs without litter. The house is run on an all in/all out basis. The exhaust air is extracted at the top of the house and pressurised by the HelixX exhaust air cleaning system. The fans are located below the system's treatment unit, which makes it an excess pressure system.

The house ventilation was designed to DIN 18910. Accordingly, the maximum flow rate for fattening by the all in/all out method must be approximately 21,420 m³/h (according to DIN 18910 Appendix Table A.2, 119 m³/h x fattening place). The installed fans give a total ventilation rate of 17,000 m³/h at 140 Pa. This figure was confirmed by establishing a characteristic ventilation curve for the whole system of house plus exhaust air cleaning system. The house was not found to be under-ventilated due to insufficient system capacity. As regards ammonia and carbon dioxide concentrations in the house, levels were not found to exceed those prescribed by the German Animal Welfare and Animal Farming Regulation (Nutztierhaltungsverordnung). The house temperature does not exceed the standards pursuant to DIN 18910.

Testing started with the first summer measurements in July/August 2008. The winter measurements took place in March/April 2009 and February 2010. Further summer measurements were needed in August/September 2009. In total, 16 weeks of summer measurements and 12 weeks of winter measurements were carried out.

The summer measurements in 2008 started with a different demister system. However, it soon emerged that this system could not prevent a release of aerosols. As a result, a new demister (type T01M1) was installed in July 2008. The latter was equipped with a cleaning system but it was not sufficient to prevent an increased pressure loss. As a result of this, a high-pressure cleaning system was installed in the winter of 2009.

In addition, it was noted during the first measurement that the desludging was not functioning correctly. Sediments were gradually building up in the wash water treatment system. This problem was eliminated, which was confirmed by means of a dust assessment.

Dust

At the start of the measurements it was agreed that three total dust measurements and one PM 10 and one PM 2.5 dust measurement per measurement period would be sufficient. Samples were taken isokinetically in accordance with VDI Guideline 2066 and each sample was assessed one day after being taken, because the samples were first dried to constant weight in the drying chamber.

However, the values obtained for dust separation were very poor at the start of the 2008 summer measurements, which is why a new demister was installed and the sprinkling adjusted. After that, the necessary dust separation was guaranteed but large quantities of dust built up in the new demister. As a result of this, a new cleaning system for the demister was installed during the 2009 winter measurements.

In the remaining dust measurements in winter 2009, and in summer 2009, the separation efficiencies and cleaning performance of the high-pressure cleaning system were satisfactory. Samples were taken isokinetically in accordance with VDI Guideline 2066 and each sample was assessed one day after being taken, because the samples were first dried to constant weight in the drying chamber.

As shown in Table 1 (page 7), the separation efficiencies for total dust were > 70 % on all six measurement dates. The average separation from six measurements was 89 %, indicating that effective dust separation in litterless pig housing systems is possible using the HelixX exhaust air cleaning system. For the six PM 10 measurements, the separation efficiency was between 72.4 % and 88.6 %; for the six PM 2.5 measurements, separation efficiencies of between 68.4 % and 83.1 % were established.

Due to the poor desludging of deposits at the start of the measurements, two dust assessments were carried out. All of the desludged water was collected, and tested for solids less any ammonium sulphate.

The dust assessment in the winter of 2010 indicated that the desludging was now removing sufficient quantities of solids from the system.

Ammonia

Ammonia measurements in the untreated and clean gas were carried out continuously throughout the test period. All measurement gas pipes were heated to avoid condensation. The ammonia concentrations in the untreated and clean gas were measured using an FTIR analyzer.

Table 2 and Figure 2 (page 8) show selected daily mean values or half-hour mean values for the ammonia concentration which are typical of the measurement period. During the summer and winter measurements the untreated gas values varied between 5 and 18 mg/m³. The exhaust air cleaning system reduced the concentration permanently to < 1.9 mg/m³. For example, the

Table 1:
Boundary conditions and measurement results for the HelixX exhaust air cleaning system for dust (total dust)

Date	06.08.2008	08.08.2008	14.08.2008	31.03.2009	15.04.2009	01.09.2009
Environmental and boundary conditions						
Rel. humidity environment [%]	65	75	62	53	51	62
Ambient temperature [°C]	23.7	18.1	21.2	12.0	20.7	24.9
Untreated gas/clean gas moisture [%]	77/100	73/100	70/100	71/100	50/100	62/100
Untreated gas/clean gas temperature [°C]	24.3/22.7	21.7/18.0	21.0/18.2	21.7/19.0	24.7/19.3	25.7/22.0
Number of animals in house	176	176	176	189	189	183
Average fattening weight [kg]	95	95	100	95	100	105
Air volume flow Total [m³/h]	15,600	12,000	17,000	4,200	9,000	17,000
Results for dust						
Concentration untreated gas [mg/m³]	3.49	1.95	1.65	2.75	1.43	0.78
Concentration clean gas [mg/m³]	0.42	0.03	0.32	0.58	0.11	0.05
Separation efficiency [%]	88.0%	98.5%	80.6%	78.9%	92.3%	93.6%

* Mean value from three measurements

Table 2:
Measurement results for emission reduction in the HelixX exhaust air cleaning system for ammonia and process engineering data during the summer and winter measurements (selected daily mean values)

Date	02.08.2009	22.08.2009	12.09.2009	09.02.2010
Air volume flow per HelixX [m³/h]	7,400	7,450	7,600	1,300
Flow rate* [m/s]	3.89	3.92	4.00	0.68
Residence time* [sec]	0.51	0.51	0.50	2.92
Min. wash water per m³ of exhaust air [l/m³]	0.27	0.27	0.26	1.54
Ammonia in untreated gas** [mg/m³]	5.34	11.24	12.64	13.82
Ammonia in clean gas [mg/m³]	0.69	1.27	1.45	1.87
Ammonia separation efficiency [%]	87.0	88.5	88.4	86.2

* Values calculated from measurement results
** Includes only values measured after modification of the demister

ammonia separation rate during the period from 31.8.2009 to 18.9.2009 was over 80 % (see Figure 2, page 8). On average, the separation efficiency for all summer and winter measurements is 86 %. Effective ammonia separation in litterless pig keeping methods is guaranteed, within wide fluctuation margins, if the system is operated properly under the described operating conditions.

To test the ammonia concentration in the air inside the house, measurements were carried out in the house at animal level during regular inspections. These checks did not find any excessive ammonia concentrations according to the German pig-keeping regulation (Schweinehaltungsverordnung).

Nitrogen balance

The nitrogen separation of the exhaust air cleaning system was verified by means of a nitrogen balance taking account of the ammonia loads (untreated and clean gas), the aerosol discharge (clean gas), the nitrogen oxides in the untreated and clean gas and the nitrogen compounds dissolved in the wash water. This was done every two weeks during the summer and winter measurements (Figure 3, page 9). This means that the nitrogen separated by the exhaust air cleaning system was demonstrated. A balancing of nitrogen flows within the system is important because

– all relevant nitrogen compounds and their residues are demonstrated.
– it shows whether environmentally relevant gases such as NO, N2O and NO2 are produced in the system. This would reduce the operation of the system to cut emissions to an absurdity.
– in organic nitrification systems, any faults can be identified and remedied.
– the nitrogen content of the sludge water is known and its fertiliser value is quantified.

According to DLG test standards, the nitrogen recovery rate within the nitrogen balance during the summer and winter measurements must be > 70 % in each case. The recovery rate from the loads shown in Figure 4 was 112% ± 19.0 % in the 2009 summer measurements and 101% ± 17.0 % in the winter

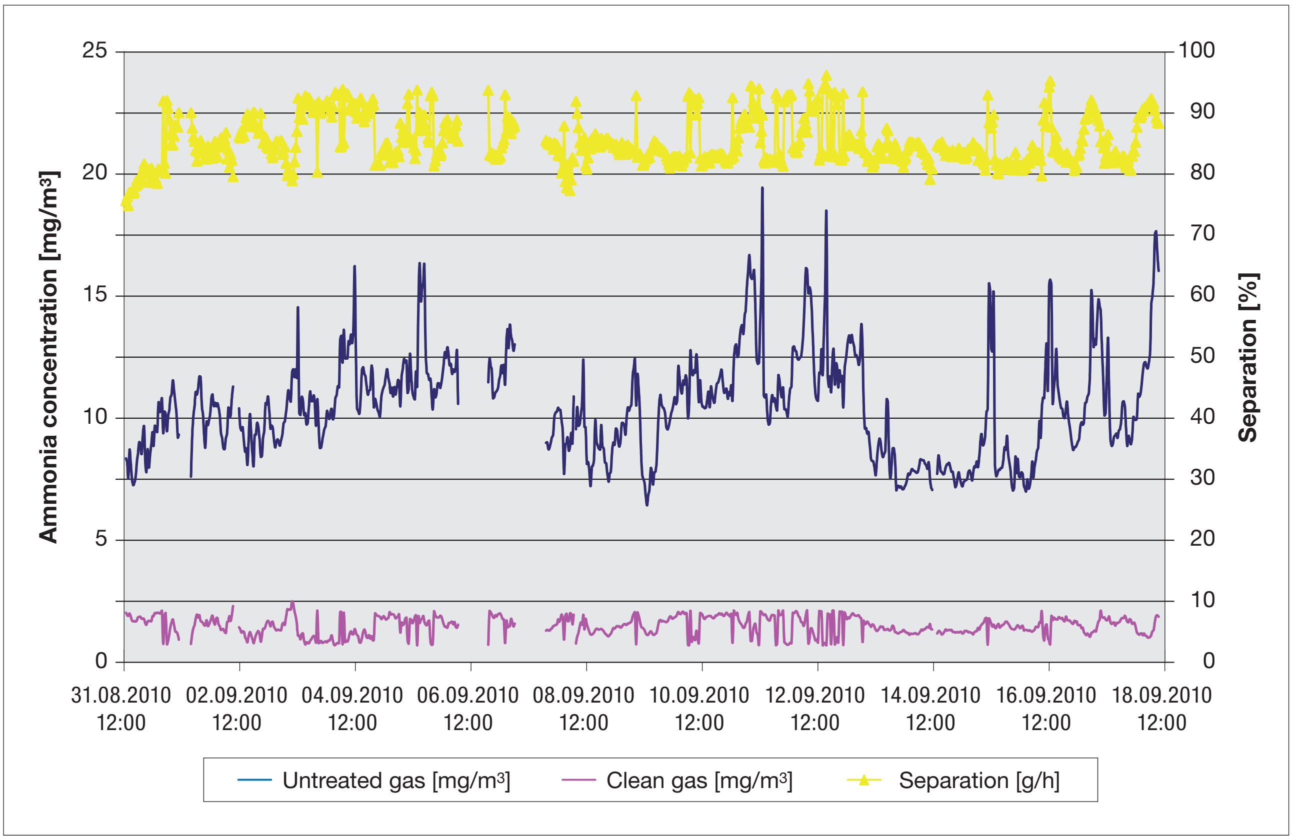

Figure 2:
Changes in ammonia concentrations in untreated and clean gas and separation efficiency between 31.8.2009 and 18.9.2009

measurements. This total measuring uncertainty comprises the gas-side uncertainty of 8.6 % and the water-side uncertainty of 8.2 %.

Consumption figures

Water consumption

Desludged water and evaporated water must be replaced by fresh water. As a result, the water consumption depends essentially on the desludging rate and evaporation losses and is consequently also weather-dependent.

The fresh water consumption was established during the measurement period by means of a water flow meter. The evaluation of the individual meter readings indicated an average consumption of 1,200 l per fattening place and year for the summer measurements, and 291 l per fattening place and year for the winter measurements.

For the desludging volume, an average of 139 l per fattening place and year was found during the summer measurements and 165 l per fattening place and year for the winter measurements.

Electricity consumption

By far the biggest consumers of electricity in the exhaust air cleaning system are the irrigation pumps (quasi-continuously operated circulation pumps) and the fans, which need to have a larger capacity than those in straight house ventilation due to the pressure loss in the exhaust air cleaning system. On average, the following values were recorded over the course of the measurement period (summer and winter):

Exhaust air cleaning (total):
75.5 kWh/fattening place and year

Fans (total):
96.6 kWh/fattening place and year

Other consumption figures

To guarantee the pH < 3, the system is equipped with automatic acid dosage for pH control. During the measurements, at the established average ammonia separation efficiency of 86.0 %, the acid consumption rate was found to be 12.77 kg per fattening place and year in the summer and 3.69 kg per fattening place and year in the winter.

Reliability and durability

Several technical improvements to the system configuration were made during the test period. At its current stage of development, reliability is ensured provided the servicing intervals are adhered to.

No noteworthy damage or wear affected the exhaust air cleaning system as a whole during the trial. The corrosion protection of the individual system parts appears to be sufficiently durable, as far as could be observed during the trial period.

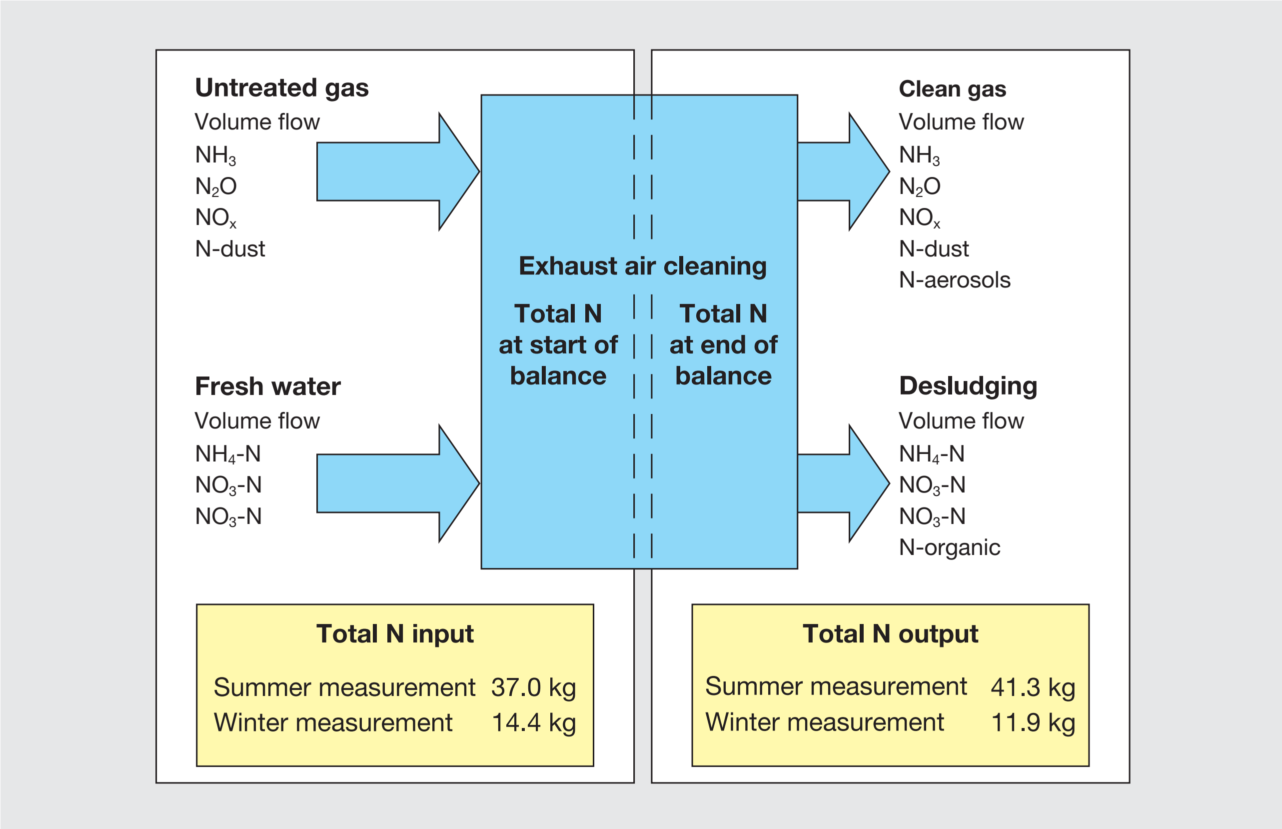

Figure 3:
Input and output nitrogen flows in the nitrogen balance

Documentation

The data recorded in the electronic operating logbook are shown in Summary 3 (see page 10).

The storage time should be at least 5 years.

Operation and work time requirements

To operate the system, it is necessary to receive instruction from the manufacturer and to familiarise oneself with the operating instructions.

After the system has been put into service its operation can be regarded as straightforward because the exhaust air cleaning system is fully automatic when in normal operation and all it requires is daily checking of the operating data in the controller.

For each error message displayed by the control system, the operating instructions give directions for checking the relevant parts of the system.

Any intervention by the operator in the system configuration is noted in the electronic operating protocol, as far as possible, which helps the operator to trace any changes made. To simplify the system's operation and reduce the work time needed, it is recommended that a service contract be taken out with the manufacturer.

The filling level of the sulphuric acid reservoir is recorded by a sensor and can be read off in the controller.

Servicing requirements

If a service contract is taken out, the manufacturer carries out two services per year at six-monthly intervals. All measurement devices, fans and pumps are checked and the measurement devices are recalibrated. Faulty parts are replaced (charges apply). The service also includes a demister inspection and a visual inspection of the whole system. If required, the manufacturer can carry out cleaning of the system (charges apply).

During the daily inspections, the control system must be checked and any faults must be remedied immediately. Important checks include the pH and conductivity of the process water, the filling level of the sulphuric acid reservoir and defoaming agent, and the pressure increase by the demister. For error messages displayed by the control system, separate checks should be carried out according to the operating manual.

Operating instructions

The operating instructions are adequate and broadly describe the operation of the system. In conjunction with the system documentation, they tell the operator which

Summary 3:
Meeting of requirements concerning the electronic operating logbook of the exhaust air cleaning system

	met in full	met in part	not met	Comments
Pressure loss over the exhaust air cleaning system	X			Electronic differential pressure sensors before and after the exhaust air cleaning and over the demister with alarm triggering and storage of the alarm in the control system
Air flow	X			Air volume flow is recorded and stored in m^3/h
Pump operating time/sprinkling	X			The hourly flow through the nozzle assemblies in each spray tower is recorded [l/h].
Pump pressure	X			The pump pressure is recorded hourly.
Filling level of wash water treatment system	X			The filling level of the wash water treatment system is recorded hourly.
pH	X			Hourly pH recording
Filling level of acid supply system	X			The filling level of the acid supply system is recorded hourly.
Calibration of pH probe	X			The pH probe is calibrated by the service engineer every four months under the framework agreement
Total fresh water consumption of the scrubber	X			The fresh water consumption is recorded in the electronic operating logbook by means of a water meter with pulse generator.
Desludged water quantity and residue	X			The desludging is recorded in the electronic operating logbook by means of a water meter with pulse generator.
Spray pattern checking	X			Reduced water flow through the nozzle assemblies allows changes in nozzle condition to be detected.
Servicing and repair times		X		Daily and weekly servicing tasks or inspections have to be noted in the operating logbook.

tasks to carry out on the system on a daily or annual basis.

The electronic operating logbook including the electronic operating protocol allows the complete recording of all data necessary for the safe operation of the system. Recording is automatic and the data are stored for 5 years.

Environmental safety

The desludged water must be stored in the interim in a separate sludge container with a minimum of 6 months' capacity.

The sludge container must be suitable for the sludge water (pH < 3).

The sludge water may be mixed with liquid manure outside the house immediately prior to spreading on agricultural land.

According to the manufacturer, the disassembly of the system and disposal of system parts can be undertaken by recognised recyclers.

The operation of the system requires the use of acid. The handling of the acid is explained in operating instructions provided by the manufacturer and is the responsibility of the operator.

Safety aspects

Fire safety is to be demonstrated by a fire protection concept, to be drawn up by the operator in conjunction with the manufacturer and attached to the building application.

The HelixX system from Big Dutchman described here has been approved by the German Testing and Certification Authority for Agricultural and Forestry Equipment (DPLF). There are no objections to the use of the system from an industrial safety perspective.

Guarantee

The manufacturer gives a two-year manufacturer's warranty on the exhaust air cleaning system.

The guarantee is conditional upon the proper operation of the system, including the correct keeping of the operating logbook and the completion of the servicing tasks by the operator.

Survey results

A survey of owners of similar exhaust air cleaning systems could not be carried out during the test period because the system tested was a prototype.

Testing

Testing was carried out in accordance with DLG test standards "Exhaust air cleaning systems for livestock keeping systems" (as at 06/2009).

The measurements were carried out on a reference system in Schüttorf. The total testing period was 16 months.

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