GrainProteinTech Climate Control & Air Treatment Germany GmbH

Exhaust air treatment system Munters Reventa Lavamatic

for broilers

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FULL TEST

GRAINPROTEINTECH MUNTERS REVENTA LAVAMATIC FOR BROILERS

DLG Test Report 7561

Overview

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The DLG APPROVED FULL TEST quality mark is awarded to agricultural equipment that has passed a comprehensive DLG usability test. A DLG usability test is carried out to independent and recognised test criteria and provides an objective and unbiased assessment of the product and all features considered essential by users. The test comprises individual lab tests as well as field tests in various conditions; in addition to that the product has to prove itself in on-farm applications. The test conditions and procedures are defined by an independent test commission and described in a test framework which defines the parameters for evaluation. Yet the test conditions and procedures as defined are revised on an ongoing basis so they reflect what is acknowledged as the current state of the art as well as the latest scientific findings and also agricultural insights and requirements. After a product has passed the test, a test report is produced and published and the quality mark is awarded to the product and will retain its validity for five years from the date of award.

To obtain the test mark, the “Lavamatic” exhaust air treatment system from GrainProteinTech Climate Control & Air Treatment Germany GmbH was tested for its suitability for emission reduction of dust and ammonia from the exhaust air flow of a broiler farm using the heavy fattening method. The test is based on the design of the ventilation system in accordance with the TierSchNutztV, which stipulates a maximum air volume flow of 4.5 m^3 per kilogramme per hour for floor broiling.

According to the current DLG test framework, at least 70 % of total dust and particulate matter (PM_{10}) and at least 70 % of ammonia must be reduced in a broiler farm to demonstrate emission reduction. At least 70 % N reduction (N removal) must be demonstrated within a N balance and the aerosol discharge must not exceed 0.5 mg N/m^3 in the clean gas.

The test was carried out on a broiler farm with a Lavamatic unit, whereby only a partial flow of the exhaust air was cleaned. The test was carried out on a Lavamatic XL for an exhaust air volume flow of 110,000 m^3/h. In addition to the tested system with 110,000 m^3/h, systems with 55,000 m^3/h and 27,500 m^3/h are also available.

The stated minimum requirements were satisfied and in some cases exceeded. This enabled Lavamatic to be certified for broiler chicken farming in accordance with DLG test framework.

Assessment in brief

The “Lavamatic” exhaust air treatment system from GrainProteinTech Climate Control & Air Treatment Germany GmbH is a single-stage, chemically operating exhaust air washer for the separation of dust and ammonia from littered broiler housing using the heavy fattening method.

The Lavamatic is operated according to the pressurised principle. The minimum distances are cited in Table 2. If the minimum distances are not met, a uniform flow with the specified reduction performances is no longer guaranteed. The investigations were carried out on a barn system using the pressurised principle.

The raw gas was extracted from the barn area as a partial flow via fans and pressed through a cleaning stage. All fans are controlled in groups and regulate themselves according to the outside temperature. The cleaning stage consists of a continuously operated washing drum that rotates in a water storage tank with pH ≤ 3. The exhaust air flow is channelled through the drum. Due to the continuous rotation of the drum, it is always kept moist and is able to retain ammonia and dust particles.

In order to guarantee the reduction performance described in the DLG test report, a maximum conductivity of the washing water of 170 mS/cm must be maintained in addition to a pH value of ≤ 3. The filter volume load must not exceed 8,700 $m^3/(m^3*h)$, the drum speed must be at least 3 revolutions per minute (rpm), while the water in the storage tank must not sink below 30 cm and the minimum immersion depth of the drum must be 20 cm.

In the test, the exhaust air treatment system achieved a minimum reduction rate for total dust of 88.9 % in winter and 81.1 % in summer. At least 74.0 % of particulate matter PM_{10} was retained in winter and at least 72.3 % in summer. Chemical reactions (the formation of ammonium sulphate) remove at least 83.0 % of ammonia in winter and at least 77.4 % in summer. In summer, 75.6 % and in winter 92.2 % of the nitrogen was removed from the system via the washing water (N removal). The aerosol discharge measurement remained unremarkable and satisfied the requirements of the DLG test framework. The results are summarised in Table 1.

Since the emissions according to VDI 3894-1 for ammonia and dust in light fattening up to 33 days are safely below the specified emission factors for broiler chicken farming (floor broiling up to 42 days) and the expected emission mass flow is lower, the tested exhaust air treatment system can also be used in a broiler system with light fattening.

Table 1:
Results of the Lavamatic exhaust air treatment system at a glance

Test criterion	Result	Evaluation*
Results of the emission measurements		
Total dust (gravimetric)		
Winter (8 measurements), minimum reduction rate [%][1],[2]	88.9	■■■■□
Summer (4 measurements), minimum reduction rate [%][1],[2]	81.1	■■■■□
Particulate matter PM_{10} (gravimetric)[3]		
Winter (4 measurements), minimum reduction rate [%][1],[2]	74.0	■■■□□
Summer (4 measurements), minimum reduction rate [%][1],[2]	72.3	■■■□□
Particulate matter $PM_{2,5}$ (gravimetric)[3]		
Winter (4 measurements), minimum reduction rate [%][1],[2]	84.0	N/A
Summer (4 measurements), minimum reduction rate [%][1],[2]	81.4	N/A

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Test criterion	Result	Evaluation*
Results of the emission measurements		
Ammonia (2 runs each in winter and summer, continuously measured)		
Winter, minimum reduction rate [%][1]	83.0	■■■■□
Summer, minimum reduction rate [%][1]	73.8	■■■□□
N removal		
Winter [%]	92.2	■■■■■
Summer [%]	79.6	■■■□□
Consumption measurements (mean values per day or per animal place AP and year)[4], [5], [6]		
Fresh water consumption		
Winter [m^3/d] / [m^3/(AP · a)] / [m^3/(AP · a)]	1.4 / 0.02 / 0.01	N/A
Summer [m^3/d] / [m^3/(AP · a)] / [m^3/(AP · a)]	2.9 / 0.04 / 0.02	N/A
Annual mean [m^3/d] / [m^3/(AP · a)] / [m^3/(AP · a)]	2.2 / 0.03 / 0.02	N/A
Elutriation volume[7]		
Annual mean [m^3/d] / [m^3/(AP · a)] / [m^3/(AP · a)]	0.039 / 0.001 / 0.001	N/A
Acid consumption (ased on 96 % sulphuric acid))		
Winter [kg/d] / [kg/(AP · a)] / [kg/(AP · a)]	9.2 / 0.10 / 0.07	N/A
Summer [kg/d] / [kg/(AP · a)] / [kg/(AP · a)]	7.5 / 0.09 / 0.06	N/A
Annual mean [kg/d] / [kg/(AP · a)] / [kg/(AP · a)]	8.4 / 0.10 / 0.06	N/A
Electrical energy consumption		
Exhaust air treatment		
Winter [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	16.1 / 0.18 / 0.12	N/A
Summer [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	19.7 / 0.23 / 0.15	N/A
Annual mean [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	17.9 / 0.21 / 0.14	N/A
Fans		
Winter [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	47.0 / 0.53 / 0.46	N/A
Summer [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	163.6 / 1.95 / 1.68	N/A
Annual mean [kWh/d] / [kWh/(AP · a)] / [kWh/(AP · a)]	105.3 / 1.24 / 1.07	N/A

* DLG Evaluation range:
■■■ or better = meets, exceeds or significantly exceeds the established DLG standards,
■■ = meets the legal requirements for marketability, ■ = failed, N/A = not assessed

1 The minimum reduction rate with regard to dust is defined as the lowest value determined during the measurement period. The minimum reduction rate for ammonia is the average reduction rate minus the standard deviation.
2 The chimneys that were active at the time of measurement were always sampled.
3 Experience has shown that the washing process can lead to the formation of droplets in a size range of 2.5 to 10 µm, which cause an increased finding for the PM_{10} particle fraction in the cascade impactor. The $PM_{2.5}$ particle fraction is less affected by this effect. Therefore, a higher reduction rate is calculated for this particle fraction than for the PM_{10} fraction.
4 Due to partial flow treatment at the reference system, the consumption data determined can only be compared with other plants to a limited extent. During the investigation period, 100 % of the exhaust air from the animals housed was cleaned in winter and 94 % in summer. This meant that almost the entire exhaust air flow from the animals was conveyed via the exhaust air treatment system. The media consumption was therefore calculated in such a way that it relates to the average number of 32,500 animals housed. The specifications only refer to partial exhaust air flow treatment. Higher consumption is expected with full filtration (100 % exhaust air treatment).
5 The animal location-related consumption data were given for a washer operation of 365 days per year on the one hand and – with the exception of fan power consumption – for a washer operation of 240 days (service times taken into account and washer start from the 10th fattening day) on the other. This enables a better comparison with other systems.
6 Some of the measurements were carried out before the procedural changes. Therefore, some measured values are not or only partially meaningful. Only measured values that can be considered representative are shown.
7 No sludge was removed during the measurement period. In order to be able to estimate a real wastewater consumption, an annual consumption was calculated.

Manufacturer and applicant

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Product:
Munters Reventa Lavamatic exhaust air treatment system for broiler chicken farming

Description and technical details

The “Lavamatic” exhaust air treatment system is a single-stage system with a chemical stage for purifying exhaust air from broilers using the heavy fattening process. This system is operated using the pressurised process. The feed used is standard feed.

The exhaust air is extracted from the animal area by a total of four fans and conveyed directly into the cleaning stage.

A drum washer works here, constantly rotating at three revolutions per minute. On the raw gas side, the drum is immersed into the water storage tank (washing water, process water) and wets the filling material installed in the drum with washing water. To ensure a pH value of ≤ 3 in the washing water, 96 % sulphuric acid is added. The exhaust air flows through the rotating drum and then enters the vertical exhaust air duct after a 90° bend and flows upwards into the open air. There is a measuring fan in each fresh air chimney to record the air flows.

In the drum washer, coarse and fine dust particles in the process water are washed out and later removed from the system by means of elutriation and basic cleaning. Gaseous ammonia reacts with sulphuric acid washing water to form ammonium sulphate. The rising salt content leads to increasing conductivity in the washing water. At a maximum conductivity of 170 mS/cm, part of the water storage tank is automatically elutriated and removed from the system.

The rotation of the washing drum partially cleans the filling material. A wiper mounted at the top of the

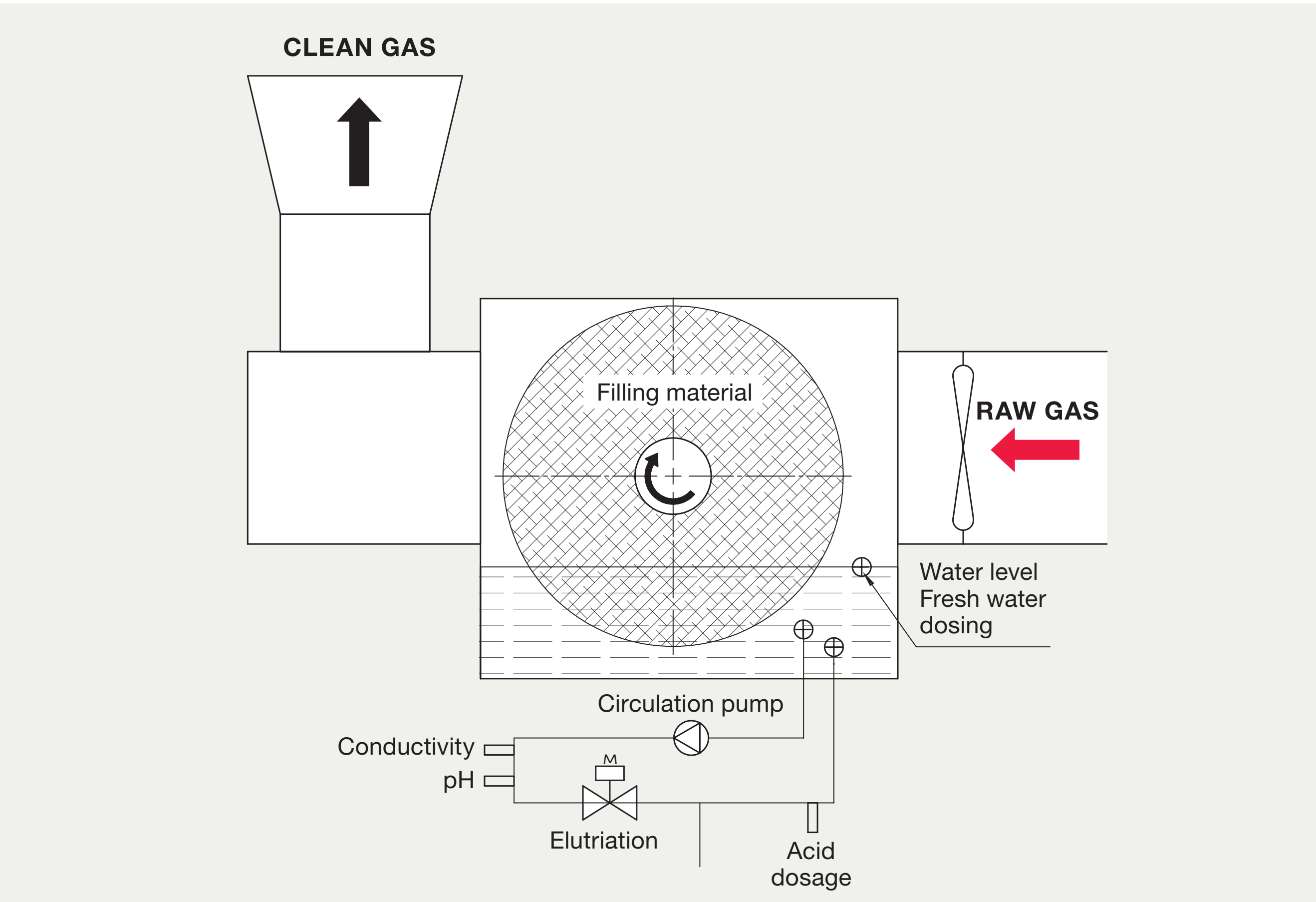

Figure 2:
Functional description of Lavamatic (schematic diagram)

washing drum ensures that the coarser particles are removed from the drum's exterior. Simultaneously, the wiper is used for sealing the drum. This cleaning system does not require a circulation pump to achieve the described reduction performance, as the drum moistens itself through the rotary movement.

The large specific surface area of the filling material serves to increase the contact surface between the barn exhaust air and washing water for effective reduction of ammonia and dust. The design of the exhaust air duct (90° bend upwards) can retain nitrogenous aerosols and thus reduce water losses.

The optimum pH value is ≤ 3 as intended. Compliance with this must be monitored automatically and saved as a half-hourly average value in the electronic operating logbook (EBTB). If the maximum permitted pH value is exceeded, acid is added to the process water via an acid dosing system, causing the pH value to drop again.

Water droplets (aerosols) are to be retained in the system due to the specified structure of the Lavamatic between the fresh air and exhaust air module. A droplet separator is not provided.

Of four fans, fans 1 and 2 (group A) were first run up to 100 %, then fans 3 and 4 (group B) were run up to the maximum speed. Both groups were controlled via the rotational speed. The design of the exhaust air treatment system must not exceed a maximum filter volume load of 8,700 $m^3/(m^3*h)$.

To avoid excessive salt accumulation, which would lead to salt precipitation and thereby also to malfunctions, the water must be elutriated at regular intervals. Elutriation is automated depending on the salt content of the washing water, i.e. depending on the electrical conductivity. Following elutriation, the washing water is replaced with fresh water. The conductivity of the washing water is limited to 170 mS/cm.

In order to prevent an unacceptable rise of the pH value in the washing water during operation, acid is added via an acid dosing system if the maximum permitted pH value is exceeded, resulting in an immediate drop of the pH value. A sufficient quantity of acid must therefore be available for correct operation.

In addition to the filter volume load and pH or conductivity value, the process parameters of the drum operation must also be maintained for stable system operation. The rotational speed must not be less than 3 revolutions per minute and the water level in the storage tank must be kept at a minimum of 30 cm, whereby the immersion depth of the drum must be 20 cm.

As increased water evaporation also occurs during system operation, the fresh water input and elutriation volume must be recorded and stored in the electronic logbook (EBTB). The water level is checked by an electronic level sensor, which also ensures that the drum does not run dry and that fresh water is topped up to the normal level.

The drum must be thoroughly cleaned after each fattening cycle. In individual cases, cleaning may also be necessary earlier. In this case, the operator is informed that the back pressure across the drum has reached the limit value of 250 Pa and that a blow-down is required. An alarm message is generated in the control unit and in the EBTB and the operator is requested to carry out a manual blow-down.

Figure 2 is a schematic illustration of the process. Important process engineering parameters can be found in Table 2.

Warranty

The manufacturer provides a 2-year warranty, which assumes correct operation of the system and does not apply to wearing parts. This is subject to installation being overseen by the manufacturer, as well as maintenance in accordance with the maintenance schedule in the operating instructions.

Table 2:
Process engineering parameters of the exhaust air treatment system

	Characteristic	Result / value
Description	single-stage, chemically operating cleaning system	
Suitability	Purification of exhaust air from broiler chicken farming when	
	using standard feed by reducing dust and ammonia	
Dimensioning parameters of reference system according to manufacturer's specifications (continuous operation)		
	Distance animal area / Fan (pressurised operation) [m]	1.0
	Fan distance / Drum centre (pressurised operation) [m]	1.9
	Maximum air volume flow (partial flow treatment) [m³/h]	110,000
	Clean gas outlet area at the reference system [m²]	5.1
Chem. cleaning stage	Number of drum modules [units]	4
	Length / outer diameter / inner diameter [m/m/m]	1.815 / 1.7 / 0.8
	Free inflow area [m²] / active filter volume [m³]	15.33 / 11.8
	Min. dwell time at summer air rates [s]	approx. 0.06
	Maximum inflow velocity [m/s]	2.00
	Immersion depth of the drum / water level [mm]	200 / 300
	Maximum filter volume load [m³/(m³ · h)]	8,700
	Filling material type [-]	NC 20-27
	Spec. surface area of the filling material [m²/m³]	125
	Degree of gap [%]	> 97
	Drum speed [rpm]	3
	Direction of rotation [-]	Raw gas side immersion
		into water
	Distance drum / start of duct [m]	1.20
Elutriation	Water tank capacity [m³]	4.12 to 4.42
	Elutriation rate at the reference operation,	0.001
	annual mean [m³/(AP · a)] [1]	
	pH value in the washing water [-]	≤ 3
	Maximum conductivity in the water storage tank [mS/cm]	≤ 170
Reference farm for the measurements carried out (broiler farm with pre-catch)		
Broiler housing system [system]]		Floor broiling, heavy fattening (42 d)
Approved livestock spaces, total barn [number]		32,900
Usable area total barn [m²]		1,600
Maximum stocking density in the barn [kg/m²]		35
ø-live weight pre-catch/final fattening [kg/animal]		2.2 / 3.0
Installed air requirement per animal [m³/(h · kg)]		4.5
Summer air rate according to TierSchNutztV, total barn [m³/h]		252,000
Maximum installed exhaust air volume flow, total barn at 20 Pa [m³/h]		282,776
Treated exhaust air volume flow (partial flow, Lavamatic) [m³/h]		110,000
Max. pressure loss barn plus ARA at 110,000 m³/h [Pa] [2]		260 to 330
Max. pressure loss ARA at 110,000 m³/h [Pa] [2]		220 to 280
Number of fans, filtered (Lavamatic) [number]		4
Number of fans, unfiltered [number]		4

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Characteristic		Evaluation*
Operating behaviour		
Technical operational safety	Apart from a few failures (power failure, acid dosing failure), no significant malfunctions were detected during the test periods. The fans are controlled in groups (2 each).	✓
Durability	No significant wear was detected during the investigation period.	N/A
Handling		
Operating instructions	The operating instructions are detailed and clearly structured. Maintenance work to be carried out and the automatic control system are clearly described. Many safety instructions are given and possible dangers are pointed out.	✓
Operation	The system runs fully automatically during normal operation. The system operator must check the system control on a daily basis. The system must be operated continuously.	✓
Maintenance	A maintenance contract between the installer/dealer and the system operator is strongly recommended. Maintenance should be carried out at least once a year. In addition to daily checks of the system control, monthly and half-yearly visual inspections and cleaning must be carried out. These checks must be documented. The maintenance work is clearly described in the operating instructions.	N/A
Cleaning the entire system	The system must be cleaned at least after every fattening cycle. If a pressure loss of 250 Pa is exceeded, the system operator is prompted to clean the system prematurely. Every alarm message is documented.	N/A
Filling material exchange	According to the manufacturer, it is not necessary to change the filling material with correct operation and regular performance of the necessary maintenance work.	N/A
Workload (manufacturer's specifications)		
Daily checks	approx. 15 min., plus occasional changing of the sieve basket (25 min.)	N/A
Weekly checks	Approx. 30 minutes	N/A
Cleaning the entire system	Approx. 2 hours for 2 people	N/A
Documentation		
Technical documentation	Requirements satisfied	✓
Electronic logbook	Requirements satisfied	✓
Safety		
Machine and system safety	Confirmed by a recognised expert for occupational safety, internal risk assessment	N/A
Fire safety	A fire protection concept must be drawn up by the operator as part of the building permit procedure for the entire barn.	N/A
Environmental safety	The washing water must be stored temporarily in a designated storage tank in accordance with the AwSV. It is advisable to utilise the washing water according to the requirements of the system. Proof of correct utilisation is provided by the system operator. The disposal of other system components is carried out by recognised recycling companies.	N/A
Warranty		
Manufacturer’s warranty	2-year warranty on all system parts that are not subject to normal wear and tear. Assembly overseen by manufacturer and maintenance according to maintenance schedule.	N/A

* Evaluation range:
Requirements fulfilled (✓) / Requirements not fulfilled (✗); N/A = not assessed

1 The elutriation was calculated from the measured nitrogen input.
2 ARA is here the German abbreviation for exhaust air treatment system. The filter pressure loss can fluctuate significantly depending on the dust input. The pressure loss of the ARA corresponds to the pressure loss of the washer plus the pressure loss of the exhaust air section (chimney).

The method

The measurements were performed at a reference facility in North Rhine-Westphalia.

Due to the fact that dust reduction in this cleaning system depends primarily on the air volume flow, individual dust measurements were carried out under simulated winter conditions before or during the summer measurement for reasons of time, whereby the air volume flow was adjusted to the specifications for the period of the dust measurement.

All measurement periods were carried out in accordance with the DLG test framework. Due to a structural optimisation measure carried out by the manufacturer in the meantime, all previous measurements cannot or can only partially be used for the evaluation.

An explicit test of the optional odour level offered by the manufacturer was not performed at the manufacturer's request.

A broiler farm with a permitted number of 38,000 animals served as a reference facility, although only around 33,000 animals were housed during the investigation period for animal welfare reasons. The barn's ventilation system is designed for a total volume flow of 252,000 m³/h, for which four exhaust fans were installed in the barn ceiling on the gable side. Of this total air rate, 110,000 m³/h were conveyed via the exhaust air treatment system, while the total ventilation was reduced accordingly (partial flow treatment).

A survey of owners of exhaust air treatment systems of the same type could not be carried out during the investigation period, because the tested system in its present form was not yet in practical use.

The exhaust air treatment system is approved for pressurised operation.

The measurements took place from August 2023 to August 2024; individual dust measurements were carried out in 2025.

The following parameters were used to assess the exhaust air treatment system:

Dust

Sampling was carried out in accordance with VDI Guideline 2066, Sheet 1 and DIN EN 13284-1. An isokinetic sampling system according to Paul Gothe with a flat filter head device (Ø 50 mm) was installed for this purpose.

A round glass fibre filter with a diameter of 45 mm was selected as the reduction medium.

Determination of the particulate matter (PM_{10} and $PM_{2.5}$) was carried out in accordance with VDI Guideline 2066, Sheet 10 and DIN EN ISO 23210. A Johnas II cascade impactor according to Paul Gothe with three flat filters (Ø 50 mm) was used. A round filter made of glass fibre, now with a filter diameter of 50 mm, was once again used as the reduction medium. The evaluation was carried out through gravimetric determination of the dust load.

According to the DLG test framework, the reduction rate must not fall below 70 %. This applies to total dust and particulate matter (PM_{10} fraction). The results of the $PM_{2.5}$ measurement are presented for information purposes. The minimum degree of reduction is recognised as the lowest degree of reduction resulting from all measurements taken on the measurement days.

As the dust input at all four supply air stacks (raw gas) of the Lavamatic was not uniform and led to significantly fluctuating reduction rates of total dust and particulate matter, a measuring method was used after consultation with the Technical Committee, which is heavily aligned with the aforementioned procedure, whereby all four fresh air chimneys were sampled almost simultaneously and could be evaluated together with the corresponding measurements in the clean gas.

Ammonia

The ammonia measurements in the raw and clean gas range were carried out continuously over the entire test period using FTIR spectroscopy in accordance with KTBL publication 401 and DIN EN 15483, whereby the measurements were carried out using a measuring cell. To avoid condensation in the gas-carrying PTFE lines, the sample gas lines were heated along their entire length on the clean gas side.

Interferometer purging was used throughout the measurement period.

The results shown refer to measured values. If less than 0.8 ppm is measured in the clean gas of an exhaust air treatment system, this value is raised to

0.8 ppm. This is due to the measurement uncertainty of the measuring device used. Below this value, a reliable measurement cannot be quantified. Without continuous interferometer purging, the lower measuring range limit is 1.0 ppm.

The ammonia concentration at livestock level was continuously recorded on the measurement days to verify compliance with the German Animal Welfare and Livestock Farming Ordinance (TierSchNutztV) (max. 20 ppm ammonia in the animal area).

According to the assessment criteria of the DLG test framework, the minimum reduction rate for ammonia must be permanently above 70 %. The minimum reduction rate to be recognised is determined from the mean reduction rate of all results minus their standard deviation.

Aerosol discharge

Nitrogen-containing aerosols are expelled from the filling material of exhaust air treatment systems as ammonium aerosols due to the humidification of the filling material packs, and are carried along by the exhaust air flow. This means that the nitrogen originally separated is unintentionally released back into the environment.

The dust filters of the total dust measurements were analysed for ammonium sulphate $(NH_4)_2SO_4$ for aerosol determination during the investigation period in summer. The conversion to ammonium nitrogen (NH_4-N) is carried out using the molar masses of the compounds. The molar mass of ammonium sulphate is 132.1332 g/mol and the molar mass of the nitrogen it contains (2 x N) is 28.0134 g/mol. This equates to a proportion of 21.2 %. The ammonium sulphate content was therefore multiplied by a factor of 0.212 to determine the ammonium nitrogen content.

To determine the N discharge with the aerosols, a measurement was taken during the winter measurement using a flat filter in the clean gas downstream of the second droplet separator. Two sampling devices were installed, one of which was equipped with a particle filter for aerosol separation. Sampling was carried out in accordance with VDI 3496-1 (measurement of gaseous emissions).

According to the DLG test framework, the aerosol discharge must not exceed 0.50 mg nitrogen per standard cubic metre.

Nitrogen balance, N removal

The ammonia reduction of the exhaust air treatment system was verified by means of N balancing, taking into account the ammonia loads (in the raw and clean gas) and the inorganic nitrogen compounds dissolved in the washing water.

When balancing chemically operated washers, the process water is only analysed to determine the NH_4-N concentration, because no biological oxidation usually takes place.

To determine the actual N removal, the inorganic N mass removed is compared with the N load entering on the raw gas side.

Balancing the nitrogen flows within the system is important because:

- all relevant nitrogen compounds and their remnants can be detected
- the nitrogen content of the elutriation water is known and its manure value is quantified

According to the DLG test framework, the N removal within the nitrogen balance must be at least 70 % during both the winter and summer measurements.

The recovery rate of nitrogen (N balance) must be at least 80 %, but no more than 120 %, according to the test framework.

Consumption values, ambient conditions and system load

The consumption of fresh water, elutriation and electrical energy was determined by recording the corresponding meter readings (electricity meter for exhaust air treatment and separately for ventilation).

The acid consumption was determined using a weighing system (load cell or scale).

During the measurements, the ambient conditions (outside/inside temperature, outside/inside relative humidity) were recorded. On the days of the

dust and odour concentration measurements, the following parameters were also documented:

- Livestock weights (estimated) and livestock numbers
- Fresh water and electrical energy consumption (meter readings)
- Air volume flow (manufacturer's measuring fans and separate fan characteristic curve)

- Pressure loss via the system and pressure loss via the fan
- pH value and conductivity in the process water

Furthermore, the measured values recorded by the manufacturer in the electronic logbook were checked for plausibility.

Operational safety and durability

Operational safety and durability were assessed. Any faults that occurred in the overall system and in technical components were documented during the investigation period.

Operating instructions, handling and work requirements, maintenance effort

A detailed functional description of the system with a graphic representation and clear description of the regular maintenance work were checked and assessed from the user's point of view.
In the test scope for handling and working time requirements, an evaluation determines whether instruction is required from the manufacturer for commissioning and what effort is required for regularly recurring checks and work at intervals of days, weeks, months, etc. or in the event of malfunctions.

The service intervals and their duty lists are assessed for the maintenance effort.

Documentation

The following parameters must be recorded and saved in the electronic logbook as half-hourly averages or half-hourly values:

- Pressure loss across the system [Pa]
- Air flow rate [m^3/h]
- Pump running time and operating time of drum operation (circulation, elutriation) [h]
- Total fresh water consumption of the system [m^3], cumulative
- Elutriation volume [m^3], cumulative
- Raw and clean gas temperature [°C]
- pH value [-] and electrical conductivity [mS/cm], both as half-hourly averages
- Power consumption of the exhaust air treatment system [kWh], cumulative

Furthermore, maintenance and repair times as well as calibrations of the pH value probe must be recorded. Proof of the consumption of chemical operating materials (acid, anti-foaming agent) as additives must be provided.

This data serves as proof of correct operation of the exhaust air treatment system and was checked on the reference system.

For broiler farms, the running time of all emergency ventilators used must also be documented.

Environmental safety

The environmental safety test included an assessment of any operating materials required for system operation, such as acids and alkalis. Furthermore, the material utilisation of operational waste, such as the elutriated process water, as well as the dismantling and disposal of system components are investigated and assessed. The areas of responsibility for these aspects were also examined.

Safety aspects

To assess the system safety, compliance of the system with the currently valid regulations in the areas of fire and system safety was checked.

The test results in detail

The test was carried out on a reference system with an installed cleaning capacity of 110,000 m³/h per exhaust air treatment system (4 supply air fans). Systems that are operated with fewer fans but are otherwise identical in design and function can also be considered certified.

All necessary measurements were carried out during the test, but the manufacturer decided in the meantime to optimise the process technology and thus also improve the separation values. The measured emission values and consumption figures from the first three measurement periods (1x summer, 2x winter) can therefore only be used to a limited extent or not at all. In addition, measurements were carried out after the process engineering change in order to demonstrate reliable separation. This also applies to subsequent dust measurements (total/fine particulate matter PM_{10}) under winter conditions, which did not lead to satisfactory results due to a lack of technical optimisation work in the previous measurement periods. A dust particle must hit a drop of water with sufficient momentum, be bound by it and then separated mechanically. Accordingly in this case, the volume flow and the speed of the drum are decisive for dust separation. Other influences (e. g.

Table 3:
Measurement results for emission reduction (total and particulate matter) at the exhaust air treatment system

	Measurement under					
	Summer conditions		Winter conditions			
Date	**19/09/2024**	**23/09/2024**	**07/08/2024**	**31/03/2025**	**07/04/2025**	**08/04/2025**
Mast course	**36th day**	**40th day**	**41th day**	**32nd day**	**39th day**	**40th day**
Ambient and boundary conditions [1]						
Rel. outdoor air humidity [%rh]	63	70	70	68	40	48
Ambient temperature [°C]	18.2	22.1	22.1	9.9	11.4	11.5
Raw gas/pure gas humidity [%rh]	83/97	74/96	79/98	72/99	57/98	76/99
Raw gas/pure gas temperature [°C]	21.3/20.0	24.3/20.0	25.2/22.4	24.3/18.3	22.4/15.8	20.6/17.8
Quantity of livestock in the barn [units]	21,897	21,883	20,761	31,548	21,007	20,996
Average livestock weight [kg]	2.23	2.62	2.9	2.00	2.70	2.80
Air volume flow [m³/h]	95,000	95,000	36,900	39,500	39,500	39,500
Pressure loss ARA [Pa]	278	243	38	– –[2]	– –[2]	– –[2]
Total dust (standardised) [2]						
Raw gas [mg/m³]	2.08	2.62	– –	4.3	6.33	5.61
Clean gas [mg/m³]	0.39	0.33	– –	0.47	0.47	0.38
Mean reduction rate [%]	81.1	87.3	– –	88.9	92.6	93.3
Minimum reduction rate [%]	81.1		88.9			
Particulate matter $PM_{10}/PM_{2.5}$ (standardised) [3]						
Raw gas [mg/m³]	1.42/0.85	1.39/0.86	1.58/0.62	1.76/0.54	2.41/1.00	2.44/0.80
Clean gas [mg/m³]	0.37/0.15	0.39/0.16	0.32/0.10	0.46/0.09	0.30/0.03	0.31/0.01
Mean reduction rate $PM_{10}/PM_{2.5}$ [%]	74.2/82.1	72.3/81.4	79.4/84.0	74.0/84.2	87.6/96.9	87.2/98.2
Minimum reduction rate $PM_{10}/PM_{2.5}$ [%]	72.3/81.4		74.0/84.0			

1 The data was collected at the time of dust measurement. ARA is the German abbreviation for exhaust air cleaning system.
2 The measured values were implausible or could not be collected for technical reasons.
3 Some of the figures shown have been rounded to one decimal place. However, the reduction values were calculated using the non-rounded values.

humidity/temperature) play a subordinate role in dust reduction. For this reason, dust measurements at low volume flows (winter measurement) could also be carried out in a warmer season. For this purpose, the air flow was briefly reduced to the winter air flow rate (approx. 30 %) during the dust measurements. With this tactic, all the necessary dust measurements could be carried out within a few days after the official measurement periods. The ammonia separation was checked in parallel to each dust measurement and all necessary boundary parameters and animal-specific data were always collected, so that this measurement planning could be authorised here.

Dust

The exhaust air treatment system used was able to fulfil the requirements of the DLG test framework. Table 3 shows the measurement data from the winter and summer measurements.

A total of eight total particulate matter and four fine particulate matter measurements (PM_{10} and $PM_{2.5}$) were carried out in winter. Four total dust measurements and particulate matter measurements were performed in summer. All values were above 70 %, but only the values after the procedural change are presented and evaluated in this report.

A minimum reduction rate of 88.9 % (winter) and 81.1 % (summer) was measured for total dust. In addition, particulate matter PM_{10} of at least 74.0 % in winter and 72.3 % in summer was separated.

Experience has shown that the washing process can lead to the formation of droplets in the size range 2.5 to 10 µm, which cause an increased result for the PM_{10} particle fraction when measuring dust with the cascade impactor. The $PM_{2.5}$ particle fraction is less affected by this effect. Therefore, a higher reduction rate is usually calculated for this particle fraction than for the PM_{10} fraction.

Ammonia

Ammonia reduction that satisfies the requirements as a minimum can only be ensured if the process water is automatically elutriated at a maximum conductivity of 170 mS/cm and the pH value in the water is adjusted to ≤ 3.0.

The continuous monitoring of the ammonia concentration at livestock level revealed almost no abnormalities. The few times it exceeded over 20 ppm are attributable to manure removal and manure removal processes as well as the pre-catch and are therefore part of a regular operation.

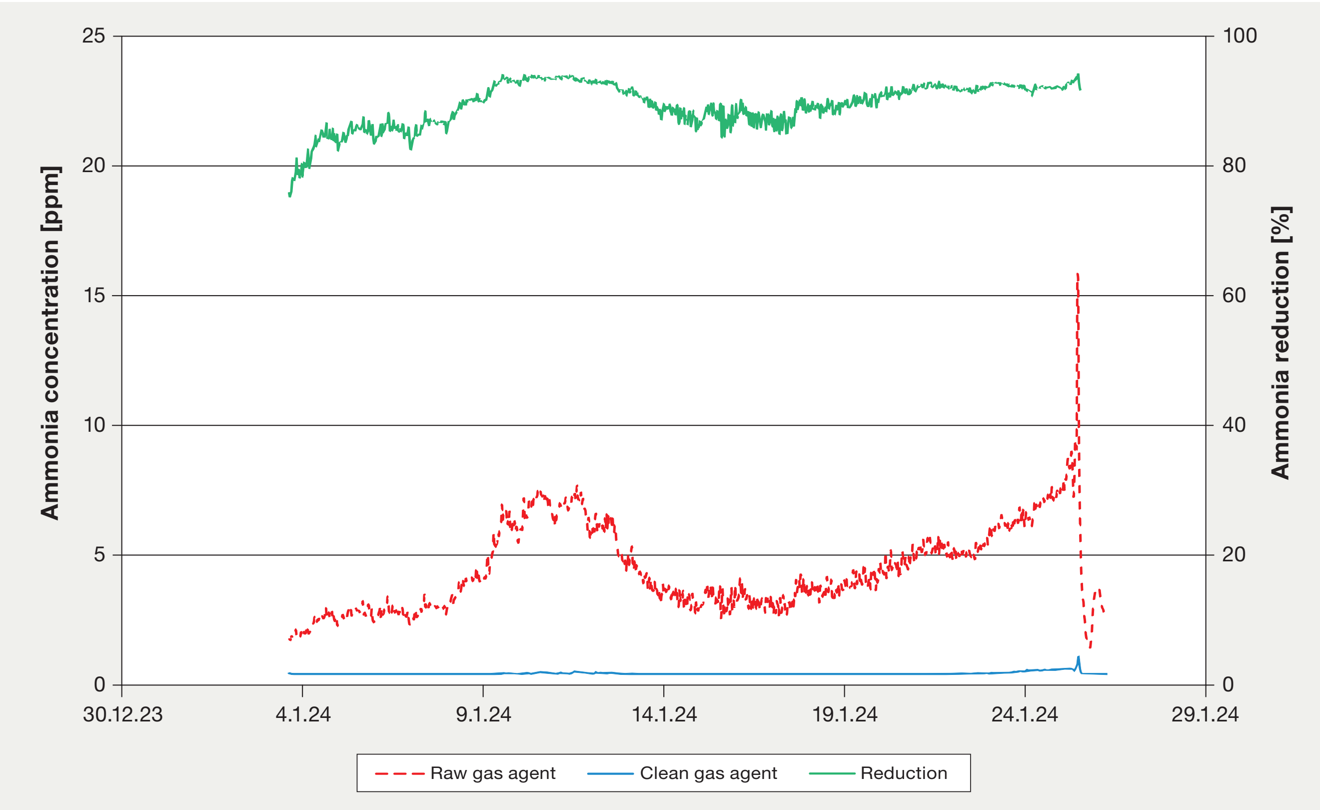

Figure 3:
Degree of separation and course of the ammonia concentration in the raw and clean gas (winter measurement)

Table 4:
Results of the aerosol discharge at the Lavamatic exhaust air treatment system

	Summer measurement 2	
Date	19/09/2024	19/09/2024
Total air volume flow [m³/h]	95,000	95,000
Ammonium sulphate [mg/filter]	0.08	< 0.07 [1]
NH_3-N aerosol discharge [mg/m³]	0.03	< 0.02 [1]

1 The analyses were below the detection limit.

Table 5:
Measurement results (N-balancing and wash water composition) of the exhaust air treatment system

Measurement period		Winter measurement 1 03/01 to 24/01/2024	Winter measurement 2 20/02 to 13/03/2024	Summer measurement 2 05/09 to 23/09/2024
Total number of animals	[Unit(s)]	32,400	32,400	32,900
Gas side				
NH_3-N raw gas input	[kg]	87.92	96.77	50.12
Other gaseous N-compounds	[kg]	0	0	0
NH_3-N clean gas discharge	[kg]	6.62	8.65	8.91
Other gaseous N-compounds	[kg]	0	0	0
Difference	[kg]	81.3	88.1	41.2
Reduction capacity NH_3-N	[%]	92.5	91.1	82.2
Water side				
pH value [1]	[-]	2.3 to 3.2	2.6 to 3.1	2.9 to 3.2 [2]
Conductivity [1]	[mS/cm]	14 to 94	10 to 88	0 to 39
Ammonium-N	[g/l]	4.9 to 21.2	1.2 to 19.0	0.2 to 8.3
Nitrate-N	[mg/l]	29.4 to 45.0	0.1 to 21.8	– – [3]
Nitrite-N	[mg/l]	< 0.03	< 0.03	– – [3]
Filterable substances	[g/l]	7.2 to 11.4	1.6 to 12.2	– – [3]
N aerosol discharge	[kg]	– –	– –	– –
N-circulating water discharge	[kg]	80.96	89.42	39.9
N elutriation discharge	[kg]	0	0	0
N discharge in water, total	[kg]	80.96	89.42	39.9
Recovery rate N	[%]	99.6	101.3	97.4
N removal [4]	[%]	92.1	92.4	79.6

1 The data was taken from the electronic logbook.
2 On some days, there was a significant increase in the pH value due to an empty acid container or air in the circulation line. As these processes do not reflect normal operation, the affected values are not shown here.
3 Measurement data was not collected.
4 The N removal was calculated without taking aerosol discharge into account.

In order to exclude the influence of increased ammonia concentrations of more than 20 ppm in the raw gas on the calculation of the separation efficiency, all pairs of measured values in which more than 20 ppm was measured in the raw gas were eliminated. In the end, 1957 pairs of measured values in winter and 605 pairs of measured values from the summer measurement were available for evaluation. As process engineering optimisation work was carried out on the plant after the first summer measurement, which could have an influence on separation, this data cannot be used for evaluation.

In the winter measurement, a minimum separation efficiency of 83.0 % was measured. At least 73.8 % was always achieved in summer.

Figure 3 graphically shows the ammonia concentrations based on the winter measurement. All measured values were corrected, i. e. values below 0.8 ppm were raised to 0.8 ppm (interferometer purging).

At least 70 % reduction was always achieved on all measurement days. Effective separation of ammonia in broiler farms and proper operation is therefore ensured under the operating conditions described.

Aerosol discharge

The results of the aerosol measurements are summarised in Table 4. Six measurements were carried out in winter and four in summer, of which only two measurements from the last series of measurements could be visualised and evaluated. Measurements were taken behind the drum washer.

Both before and after the process optimisation, the limit value from the DLG test framework of 0.5 mg N/m³ was clearly undercut. This ensures good aerosol retention.

Nitrogen balance / N removal

The results of the nitrogen balance and N removal are shown in Table 5.

In the winter measurement, the nitrogen recovery rate was 99.6 % and 101.3 % in winter and 97.4 % in summer. In terms of measurement accuracy, the balance lies within a very good range.

In winter, 92.1 % and 92.4 % and in summer 79.6 % of nitrogen was removed, reflecting stable and reliable operation overall. Due to the optimisation measures described for the system, the N balance of the first summer measurement cannot be used for evaluation.

Consumption values, ambient conditions and system load

The daily average values were recorded and stated in the test report to visualise all consumption figures. As only a partial flow was treated at the reference plant, a representative representation is only possible to a limited extent. As almost the entire exhaust air flow at the reference facility was conveyed via the exhaust air treatment system during the investigation period, the consumption values determined can be related to the animals housed (32,500 animals on average). However, these consumption figures only apply to barns that are operated with exactly the same partial flow filtration. Since a larger exhaust air treatment system must be provided for a complete exhaust air treatment of 32,500 animals, higher media consumption is expected with full filtration.

The consumption values stated in the test report (Table 1) for each measurement period (winter / summer) are standardised to annual consumption values (operation 365 days per year). This enables a direct comparison with comparable systems in other DLG test reports. In order to be able to provide a more practical value, the value was also based on around 240 days per year. The service times (7.5 cycles per year are assumed) and a start of washing from the 10th fattening day are taken into account. In deviation from this, only the service time was taken into account when specifying the energy consumption of the fan, as the ventilation is already running from fattening day 1. Only the average annual consumption is discussed below.

The first summer measurement cannot be used to assess the consumption figures (drum speed only 2 rpm). However, the measurement data from the immediately following winter measurement (drum speed 3 rpm) can be used with restrictions, as the adaptation of the exhaust air chimneys (4 stacks in the clean gas instead of 2 as before, use of more powerful fans) had not yet been completed, but this is only expected to have a limited influence on the consumption figures.

Water consumption

The water consumption depends on the elutriation rate and evaporation. The greater the elutriation rate and the more evaporation takes place, the more fresh water must be added to keep the process water volume in the system constant. The elutriation rate depends on the nitrogen input via the exhaust air flow and the limit value for the maximum conductivity in the process water. This was 170 mS/cm during the measurement period. As this limit value was never reached in the measurement, no sludge could be removed. A theoretical value was therefore calculated from the nitrogen input. This is 0.001 m^3 per animal place AP.

The total consumption of fresh water was 2.2 m^3/d, which corresponds to 0.03 $m^3/(AP \cdot a)$ for 365 days of washer operation per year or 0.02 $m^3/(AP \cdot a)$ for 240 days per year. The fresh water was added directly to the water storage tank.

Consumption of electrical energy

Energy-intensive circulation pumps are not required in this process, because in this case the exhaust air is cleaned and the filling material is moistened by immersing it in the washing liquid. The circulation pump (Figure 2) and the drum rotation cause comparatively low energy consumption. This means that the power consumption of the exhaust air treatment system is significantly lower than for systems with vertical or horizontal filter walls. Exhaust air treatment consumed 17.9 kWh per day. Converted to a year, this would be 0.21 $kWh/(AP \cdot a)$ or 0.14 $kWh/(AP \cdot a)$.

In the barn area, the fans are the largest consumers. In reference operation, four pressure-stable exhaust air fans were used on the exhaust air treatment system. The fans were controlled with 0-10 V in order to adapt the rotation speed to the exhaust air volume flow to be conveyed.

The maximum pressure losses determined on the Lavamatic were 220 to 280 Pa for the washing drum, including the exhaust air duct. The exhaust air treatment system plus barn system generated a total pressure loss of 260 to 330 Pa. The fluctuations were caused by the varying degree of soiling of the washing drum.

For optimum ventilation design, the fans must be designed for at least 300 Pa if the required air volume is to be conveyed.

As an annual mean, a total of 105.3 kWh/d was consumed by the fans. It should be noted that significantly more energy was consumed in summer. Based on the number of animals and year, this would be a consumption of electrical energy of 1.24 and 1.07 kWh respectively.

The consumption of electrical energy for exhaust air purification is significantly lower than for comparable systems due to the lack of circulation pumps. The higher power consumption of the ventilation is mainly due to the higher back pressure of the washing drum.

The specified values refer to partial flow filtration. As the test was carried out on a reference system with partial flow treatment, no reliable values can be given for complete exhaust air treatment. The fans of the exhaust air treatment system always ran in an unfavourable range of the characteristic curve during the investigation period.

Other consumption values

Safe system function with the efficiency rates shown is only possible with correctly operated pH value regulation at 3.0 and elutriation at a maximum rate of 170 mS/cm. An automatic acid dosing system and a conductivity measurement system must therefore be installed and operated on the system. To lower the pH value, sulphuric acid with a concentration of 96 % was used in the reference plant.

An annual average acid consumption of 8.4 kg/d was measured. In relation to animal place and year, 0.10 kg or 0.06 kg of acid was consumed.

The manufacturer offers the addition of an anti-foaming agent in the form of a dosing device as standard. No consumption of anti-foaming agents was detected during the DLG test.

No other additives were added during the test.

Operational safety and durability

Hardly any significant faults were identified in the system engineering and equipment during the investigation period. There were also no significant damage or signs of wear to the entire exhaust air treatment system during the test.

The corrosion protection of the individual system components appears to be sufficiently durable, as far as it could be observed during the test period. The system is a complete system made almost entirely of plastic.

The shelf life could only be observed over the duration of the test (measurement period). A survey of operators of similar systems was not carried out, as the tested system was still unique in this form.

Operating instructions, handling and work requirements, maintenance effort

The operating instructions are sufficiently well described and explain the operation of the system simply and clearly. In conjunction with the documentation, the operator is informed of the work to be carried out on the system at daily, weekly and annual intervals. To make operation easier to understand, photos of the control display can be found in the operating manual.

In order to operate the system, it is necessary to receive instruction from the manufacturer and to familiarise yourself with the operating instructions.

After commissioning and a sufficient run-in phase, using the system can be regarded as simple, because the exhaust air treatment system runs fully automatically in normal operation. Only a daily check of the operating data and a weekly check of the entire exhaust air treatment system including drum operation, as well as occasional cleaning of the sieve basket are required.

In the event of error messages from the control unit, instructions for checking the relevant system components are described in the operating instructions. To simplify use and reduce the amount of labour required, we recommend concluding a maintenance contract with the dealer. The manufacturer trains all listed dealers.

The exhaust air treatment system (basic cleaning) must be cleaned after each fattening cycle. If possible, basic cleaning should not be carried out during the fattening cycle. However, when the conductivity in the washing water reaches 170 mS/cm, a blow-down is carried out (automatically). When a pressure loss of 250 Pa is reached, the operator is requested to carry out a blow-down (manually). An alarm message is generated each time, which is also saved in the electronic logbook.

Documentation

The electronic logbook enables regular recording of the data needed for safe system operation in accordance with the requirements, which must be saved as half-hourly average values (pH value and conductivity) or half-hourly values. Recording is automatic and

Table 6:
Fulfilment of the requirements for the electronic logbook of the Lavamatic system

	completely fulfilled	not fulfilled	Remarks
Pressure loss via the exhaust air treatment system	X		Is recorded and stored by means of an electronic differential pressure cell
Air flow rate of exhaust air treatment system	X		Is measured via measuring fans in the fresh air chimney
Air flow emergency ventilator	X		A measurement signal is tapped and stored via the switching contacts of the emergency fans
Drum operation	X		Is recorded and stored via the motor sensor of the drum (0 to 100 %)
Fresh water consumption	X		The total fresh water consumption is recorded using a water meter
Quantity of elutriated water	X		Is recorded and stored via a flow meter
Raw and clean gas temperature	X		The raw and clean gas temperatures are measured and recorded by means of a thermal sensor
Maintenance and repair times	X		Can be recorded and saved by the operator in the manual operating logbook
pH value and conductivity	X		Are recorded and stored
Calibration of the pH value sensors	X		Can be recorded and saved by the operator in the manual operating logbook
Detection of additive consumption (acid, anti-foaming agent)	X		The acid consumption is recorded and stored via the strokes of the acid pump; the consumption of anti-foaming agent can be verified via delivery notes
Electrical power consumption	X		The electricity consumption of the washer is recorded and stored using a suitable electricity meter

the data must be stored for 5 years. This data can be read out by the operator, the manufacturer and also by authorities via an USB connection and converted into a standard table format. A detailed presentation of the recorded data can be found in Table 6.

If the barn ventilation and exhaust air treatment system are installed by different manufacturers, the manufacturer of the exhaust air treatment system records the ventilation data as a characteristic line and also integrates it into the control system of the exhaust air treatment for regulation purposes. The maximum fan power is set to 100 % in the control unit. However, there is no adjustment in a further performance range. Given that the air flow rate should be specified in absolute m³/h in accordance with the test framework and the requirements of TA Luft (chapter 5.4.7.1), a characteristic line of the entire ventilation system (barn plus exhaust air treatment) must be recorded before commissioning and entered into the electronic logbook. The characteristic line should consist of at least five different interpolation points between an air rate of 0 and 100 %.

According to the current TA Luft, the density in the wash water of chemically operated systems must also be continuously measured and stored in parallel with the storage of conductivity, as conductivity measurement becomes too inaccurate above around 250 mS/cm. In a resolution passed by the TC, it was determined that density determination is not necessary for the present procedure, as concentration is only carried out up to a maximum conductance of 170 mS/cm.

Environmental safety

Primary ammonia reduction takes place purely chemically with the formation of ammonium sulphate. Ammonium sulphate is a substance hazardous to water and is assigned to water hazard class WGK 1 (slightly hazardous to water).

The storage space is based on the current fertiliser ordinance, which stipulates the storage period for liquid manure. The feed pipe into the elutriation tank and the storage tank itself must be suitable for the elutriation water. The administrative regulation for substances hazardous to water (ammonium sulphate) must be complied with in each country. Immediately before spreading on agricultural land, the elutriated water can be mixed with liquid manure outside the barn. Plant-specific agricultural utilisation in line with system requirements, taking into account the nitrogen and sulphur content, is technically expedient.

Acid is required for safe system operation. Handling must be explained by the manufacturer in operating instructions and carried out in accordance with the EC safety data sheets for 96 % sulphuric acid and is the responsibility of the system operator. All associated safety equipment (eye wash, full body shower, protective clothing) must be provided. An acid reservoir in the form of an IBC container is recommended.

According to the manufacturer, the dismantling and disposal of other system components can be performed by registered recycling companies.

Safety aspects

Fire safety must be verified by means of a corresponding fire protection concept, which must be drawn up by the operator in conjunction with the manufacturer and attached to the building application.

The machinery and system safety of the described exhaust air washer was assessed by Klaus Ahlendorf GmbH during the initial inspection in 2024. There are no objections to the use of the system from an occupational safety perspective.

Conclusion

The “Lavamatic” exhaust air treatment system from GrainProteinTech Climate Control & Air Treatment Germany GmbH is suitable for emission reduction of dust and ammonia (including nitrogen removal) from the exhaust air flow of littered broiler processes.

The single-stage process consists of a wet-chemical exhaust air washer. The system is operated according to the pressurised principle. To ensure that the system functions safely, the filter volume load of the washing stage must not exceed a maximum of 8,700 $m^3/(m^3 \cdot h)$. The pH value in the water storage tank must be set to ≤ 3.0 and the conductivity must not exceed 170 mS/cm.

The minimum requirements of the DLG test framework for dust and ammonia reduction are satisfied and, in some cases, exceeded if the process engineering parameters described are adhered to.

The recognised minimum reduction rate for total dust is 88.9 % in winter and 81.1 % in summer. Particulate matter PM_{10} is reduced by 74.0 % in winter and 72.3 % in summer. The minimum reduction rate for ammonia is 83.0 % in winter and 73.8 % in summer. A total of 92.2 % of nitrogen is removed in winter and 75.6 % in summer.

Further information

Testing agency

DLG TestService GmbH,
Gross-Umstadt location, Germany

The tests are conducted on behalf of DLG e.V.

Laboratory and emission measurements

LUFA North-West
Jägerstraße 23-27, 26121 Oldenburg, Germany

DLG test framework

DLG APPROVED Full Test "Exhaust air treatment systems for livestock facilities" (status 04/2022)

Department

Operating inputs

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