

CHEMICAL CHARACTERIZATION AND SOURCE LEVEL REDUCTION OF ODOR ACTIVE COMPOUNDS (NH₃ AND H₂S) IN A NON-HAZARDOUS WASTE DRYING FACILITY

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This study evaluates odor, ammonia (NH₃), and hydrogen sulfide (H₂S) emissions from a mechanical treatment and drying installation for non-hazardous waste, in relation to the implementation of a deodorization system. Measurements and AERMOD dispersion modeling were used to assess both source-level emissions and ground-level impact. Results show pollutant-dependent performance: maximum ground-level H₂S concentrations decreased by approximately 9% (from 469 to 429 µg/m³) following implementation of the deodorization system, while odor concentrations decreased by approximately 21% (from 175 to 139 ouE/m³). In contrast, NH₃ concentrations increased by approximately 78% (from 55 to 98 µg/m³) when the deodorization system was operating, possibly due to the composition of the applied reagent. The findings highlight the influence of process parameters and dispersion conditions, as well as limitations of current regulatory approaches in addressing odor emissions.

Keywords: odor emissions; ammonia (NH₃); hydrogen sulfide (H₂S); mechanical treatment of waste; deodorization system; atmospheric dispersion modeling.

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1. Introduction

Across Central and Eastern Europe, the implementation of sustainability and health-oriented regional development agendas is increasingly discussed in relation to the European Green Deal and the governance capacity required to deliver environmentally protective infrastructure (with Romania explicitly included among the Central and Eastern European country groupings considered in this debate [1]. In parallel, the European Union has developed an extensive body of environmental legislation addressing waste prevention and management, with stated long-term policy objectives oriented toward higher recycling rates, reduced landfilling, and

improved protection of environmental media (including air) from waste-related impacts [2]. These two strands region-level sustainability governance and EU waste-policy evolution toward reduced environmental burdens jointly motivate the modernization of waste treatment infrastructure, including installations that mechanically process mixed waste streams and apply thermal operations (e.g., drying) to reduce volume and improve downstream handling [1, 3].

Within this policy trajectory, air emissions and, in particular, odor nuisance are widely recognized as a practical constraint on the social acceptance, siting, and permitting of waste treatment infrastructure, especially where facilities are located near population centers or sensitive receptors [4, 5]. Evidence from organics management systems indicates that odor complaints can become sufficiently consequential to force operational changes (e.g., relocation of composting activities), demonstrating that odor is not merely a subjective concern but also a determinant of facility viability and regulatory friction [4, 6]. Consequently, studies that explicitly connect source-level odorant emissions to downwind ground-level impacts are necessary to support defensible environmental assessments and risk communication in EU-aligned waste-management transitions, including those relevant to Romania's modernization pathway within the broader Green Deal framework [1, 4].

Modern waste treatment plants integrating biological and/or physical processing stages are repeatedly identified as sources of malodorous emissions and community concerns [7]. In municipal solid waste (MSW) treatment, odors and volatile organic compounds (VOCs) are associated with unloading, sorting, and biological processing, yielding complex mixtures that often include hydrogen sulfide (H_2S) and ammonia (NH_3) among other species (e.g., mercaptans, low molecular weight fatty acids) [7, 8]. Such emissions are highly sensitive to waste type, processing technology, and operational conditions, and can hinder sustainable deployment of biological treatment capacity [7, 9].

Although mechanical treatment and drying (MT&D) of non-hazardous solid waste differs from composting or anaerobic digestion (AD), the same fundamental drivers of odor formation, microbial and chemical decomposition of organic matter, and nitrogen/sulfur transformation pathways are relevant wherever mixed or putrescible fractions are handled, heated, and aerated in industrial enclosures with forced ventilation [8, 9]. In addition, drying operations themselves have been directly linked to NH_3 volatilization in waste-derived matrices (e.g., digestate drying), indicating that thermal water removal can coincide with measurable nitrogen losses to air and thus contribute to odorant release [10]. Practical engineering guidance on thermal drying systems for wet biowastes similarly recognizes that dryer exhaust streams often require dedicated air pollution control to manage odors and VOCs, reinforcing that drying stages can be emission-relevant even when primarily designed for volume reduction [7, 11]. Taken together, these

findings motivate targeted characterization of directed (stacked) emissions from MT&D installations and a quantitative assessment of how these releases translate into off-site odorant concentrations [4, 7].

Among the diverse compounds contributing to odor nuisance at waste treatment facilities, NH₃ and H₂S are recurrently highlighted as critical due to their prevalence and their capacity to cause nuisance and/or adverse effects at comparatively low concentrations [8, 12]. Empirical research on integrated dry AD and composting systems has shown that composting stages can dominate NH₃ and H₂S emissions (>90% of those species in the process-wide inventory), with community odor complaints occurring at facilities handling organic MSW fractions, illustrating the practical relevance of these compounds [6]. Experimental evidence on digestate drying confirms NH₃ volatilization dynamics, with substantially higher cumulative NH₃ emissions observed for untreated vs. dewatered material under otherwise comparable dryer conditions [10]. H₂S is widely described as a common odorous gas arising from decomposition in waste-related environments (including WWTPs and landfills) and as a pollutant frequently targeted by odor-control technologies [13, 14].

H₂S relevance is sharpened by its low odor threshold (approximately 0.003–0.02 ppm) and toxicity profile, with risk depending on exposure concentration and duration [15]. Even where exhaust concentrations comply with workplace or boundary standards, the odor-perception threshold can be substantially lower, complicating “odor-free” compliance and highlighting why H₂S control is often judged by nuisance performance rather than toxicity thresholds alone [15, 16]. Health risk evidence from landfill-adjacent populations indicates that H₂S exposure can yield a risk quotient (RQ) above 1 within hundreds of meters of a waste facility, while NH₃ may yield a lower RQ, suggesting H₂S can be the more acute local health risk driver even when both gases contribute to odor concentration [17].

NH₃ is also relevant beyond odor, as a significant atmospheric pollutant and precursor of particulate ammonium, contributing to secondary particle formation and human exposure burdens [18, 19]. NH₃ is also characterized as toxic and corrosive, causing respiratory irritation and contributing to fine particulate matter (PM_{2.5}) formation, motivating increasingly stringent standards and heightened attention to its emission restriction [19, 20]. These coupled odor and air-quality roles strengthen the rationale to treat NH₃ not only as a nuisance compound but also as a regulation-relevant pollutant in broader air-quality and health-impact management [18, 19].

A substantial body of literature describes a portfolio of odor abatement options, including adsorption, chemical scrubbing, combustion, and biological technologies such as biofiltration [8, 12]. Biofilters are widely used in MSW treatment plants due to low costs and operational simplicity; full-scale data for a three-stage integrated biofilter show high, stable removal efficiencies for H₂S and

NH₃ together with VOC control [8]. Industrial case research in a rendering-plant context shows biofiltration removing a high fraction of H₂S (>83%), although removal performance can be limited by conditions such as nutrient limitation or acidic pH [12, 21]. These observations collectively indicate that treatment efficiency is measurable and potentially high, but also contingent on facility-specific process integration and operating regimes [8, 21].

Despite the breadth of available control technologies, odor control remains a central challenge for sustainable waste treatment, implying that site-specific performance assessment is necessary rather than assuming transferability of generic removal rates across installations [9, 22], since odorant mixtures vary widely by waste composition and operating conditions, and odor nuisance and community acceptance can hinge on relatively small changes in key odorants such as NH₃ and H₂S [6, 9]. Accordingly, an empirical “before/after” evaluation of a deodorization system in an MT&D installation focused on NH₃ and H₂S as priority odorants directly responds to the literature’s identified need for performance evidence under real operating conditions.

Even when emission reductions are demonstrable at the source, their environmental relevance depends on how the residual plume disperses and what concentrations occur at ground level. This “source-to-receptor” translation matters because siting and expansion decisions can be constrained by anticipated health damages and nuisance impacts, requiring quantitative estimates of off-site impacts rather than stack-concentration measurements alone [4, 5]. Recent policy-and-technology analysis of anaerobic digestion deployment notes that improved odor dispersion modeling can inform regulated emission levels, while also stressing the lack of standardized protocols for odor modeling and the use of models such as AERMOD to simulate hourly surface concentrations. This supports coupling measured emission scenarios with dispersion modeling to assess receptor exposure under “with control” vs. “without control” configurations [4, 5].

NH₃ and H₂S are well documented as important odorants in waste-processing emissions. Their nuisance and health relevance is further underscored by the low odor threshold and toxicity concerns associated with H₂S and by the broader air-quality relevance of NH₃. Given the recognized need to connect source controls with receptor impacts using dispersion modeling tools such as AERMOD, this study evaluates emissions from a non-hazardous solid waste mechanical treatment and drying installation under two operational scenarios.[22]

2. Materials and Methods

2.1 Description of the mechanical treatment and drying installation

The investigated facility performs mechanical treatment and thermal drying of non-hazardous solid waste, with an operational capacity of approximately 30

t·h⁻¹ (≈510 t·day⁻¹; ≈137.700 t·year⁻¹). The process includes mechanical pre-treatment followed by belt-type thermal drying using recovered hot gases from an existing incineration installation.

Waste material is fed from a buffer bunker into the belt dryer through controlled screw conveyors, with the feed rate adjusted according to material moisture content. Inside the dryer, the material is evenly distributed onto a perforated moving belt, whose speed is regulated by a variable frequency drive to ensure controlled drying conditions.

The drying process uses recovered flue gases extracted after filtration from the incineration system. The initial gas flow rate is approximately 50,000 m³·h⁻¹ at about 180°C. Prior to entering the dryer, the hot gases are mixed with ambient air to reduce the temperature to a maximum of 90°C, resulting in an overall drying air flow of approximately 100.000 m³·h⁻¹.

After heat exchange and moisture removal, the cooled process gases are extracted by three exhaust fans and discharged through three exhaust stacks. For the purpose of emission characterization and atmospheric dispersion modeling, these three stacks represent the directed emission sources of the installation. In the investigated configuration, each stack has a height of $H = 4$ m and a diameter of $D = 2$ m.

Gas samples for NH₃ and H₂S determination were collected from these stacks during the measurement campaign. A general view of the drying installation is presented in Fig. 1. The odor reduction system implemented at stack level is described in the following subsection.

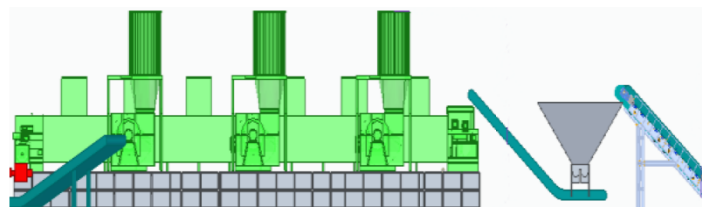


Figure 1. General view of the mechanical treatment and drying installation for non-hazardous solid waste.

2.2 Description of the odor reduction system

An odor reduction system was implemented at stack level in order to mitigate ammonia (NH₃) and hydrogen sulfide (H₂S) emissions generated during the mechanical treatment and drying of municipal solid waste. The installation is located in Romania and includes three exhaust stacks, each characterized by a gas flow rate of approximately 50.000 m³·h⁻¹.

The deodorization process is based on direct injection of a neutralizing reagent into the exhaust gas stream prior to atmospheric release. The system operates through vaporization of a concentrated reagent (AP5 NF P VS) without

water dilution, at a controlled low dosing rate ranging between 80 and 200 mL·h⁻¹ per stack. The treatment is performed inside each exhaust stack, upstream of the discharge point, in order to achieve source-level mitigation of odor-active compounds.

The installation comprises three independent VS200 P injection units, one dedicated to each exhaust stack. The reagent is introduced via an internal-mix atomizing nozzle connected through a DN80 flange. Each nozzle operates at a dosing rate between 40 and 200 mL·h⁻¹ at 3 bar, requiring a minimum compressed air flow of 7 m³·h⁻¹ to ensure proper atomization.

The objective of the system is to neutralize odor-active compounds directly within the exhaust flow, before dispersion into the atmosphere. The quantitative performance of this system was assessed through comparative emission measurements and dispersion modeling, as presented in the following sections.

2.3 Measurement campaign and analytical methods

The emission characterization campaign was conducted on 13 June 2025 and included the determination of physical parameters of the emission sources, odor concentration, and the concentrations of ammonia (NH₃) and hydrogen sulfide (H₂S) in the exhaust gases discharged through the three stacks.

2.3.1 Physical parameters and odor concentration

For each directed emission source, the measured physical parameters included stack height and diameter, gas temperature, and effluent velocity. These parameters were determined during the sampling campaign using an Optima 7 gas analyzer (Fig. 2B).

Odor concentration was determined by the Air Pollution Control Laboratory of INCD ECOIND using dynamic olfactometry, in accordance with SR EN 13725:2022 – Air quality – Determination of odor concentration by dynamic olfactometry. This method is recognized at the European level and recommended in BAT conclusions for the determination of odor concentration and odor emission rates from both point and area sources.

Gas samples were collected from the stacks using certified Nalophan sampling bags and a vacuum sampling system (Olfasense 10 L) (Fig. 2C). The samples were subsequently analyzed using a dynamic olfactometer (Fig. 2D), which operates as a high-precision diluter. The detection system consisted of a trained panel of four selected assessors.

The olfactometer dilutes the sample with odor-free synthetic air according to a predefined sequence and presents it to the panel for evaluation. The assessors were selected, trained, and periodically validated using certified reference material (n-butanol), according to the acceptability criteria defined by SR EN 13725:2022.



Figure 2. Multi RAE gas analyzer (A), Optima 7 gas analyzer (B), vacuum sampling system with nalophan sampling bags (C), Olfasense T08 dynamic olfactometer for 4 assessors (D).

Odor concentration is expressed in European odor units per cubic meter ($\text{ouE} \cdot \text{m}^{-3}$) and corresponds to the dilution factor at which 50% of the panel can detect the odor. The expanded measurement uncertainty associated with odor determination was 18.35%.

2.3.2 Determination of NH₃ and H₂S concentrations

Ammonia (NH₃) and hydrogen sulfide (H₂S) concentrations were measured directly at stack level during the sampling campaign in order to characterize gaseous emissions generated by the mechanical treatment and drying installation. NH₃ measurements were performed using a portable gas analyzer manufactured by RAE Systems, model Multi-RAE Lite (Fig. 2A), equipped with an electrochemical sensor for ammonia detection. The instrument allows real-time monitoring of NH₃ concentrations in the exhaust gas stream, providing rapid measurements under field and operational conditions.

Hydrogen sulfide (H₂S) concentrations were determined using an Optima 7 gas analyzer (Fig. 2B), operating as an automated measuring system based on infrared absorption detection. The analyzer enables continuous monitoring of gaseous compounds from stationary emission sources and provides stable measurements under varying process conditions.

Sampling locations and measurement conditions were established in accordance with SR EN 15259:2008, which provides guidance for the selection of measurement sections and sampling points for stationary source emissions. In the case of H₂S monitoring, the measurement procedure also complies with SR ISO 10396:2008 regarding automated gas concentration determination from stationary sources.

Prior to the monitoring campaign, both analyzers were calibrated according to the manufacturer's specifications using certified reference gas mixtures. In addition, zero/span checks were conducted before and after measurements to ensure measurement stability, accuracy, and data reliability throughout the sampling campaign. The expanded measurement uncertainty associated with NH₃ and H₂S determinations was 8.9% and 9.02%, respectively.

2.4 Dispersion modeling

Atmospheric dispersion modeling was performed in order to evaluate the environmental impact of odor, ammonia (NH_3), and hydrogen sulfide (H_2S) emissions generated by the mechanical treatment and drying installation.

The dispersion calculations were carried out using the AERMOD atmospheric dispersion model, widely applied for the assessment of pollutant dispersion from industrial emission sources. The model simulations were based on emission data obtained during the measurement campaign, as well as on meteorological and topographical input data representative of the study area.

Meteorological data corresponding to the year 2024 were used in the simulations. These data were obtained from the meteorological station located in Pitești, which represents the closest monitoring station to the investigated installation. Topographical information used in the model was based on SRTM30 terrain data, integrated within the AERMOD modeling system.

The following emission source parameters were introduced into the dispersion model: stack height, stack diameter, emission area, exhaust gas temperature, gas pressure, exhaust gas velocity, volumetric flow rate, and pollutant mass emission rates.

The mass emission rates of the investigated pollutants (odor, NH_3 and H_2S) were calculated using the relationships presented in equations (4) and (5).

Two operational scenarios were analyzed in order to evaluate the effectiveness of the odor reduction system:

Scenario 1 – operation of the installation without the deodorization system;

Scenario 2 – operation with the deodorization system in operation.

The modeling results were used to estimate the spatial distribution of pollutants and the maximum ground-level concentrations generated by the installation under the analyzed operational conditions. The comparison between the two scenarios allowed the assessment of the pollutant reduction efficiency achieved through the implementation of the odor control system.

2.5 Calculation of pollutant mass emission rate

The mass emission rates of the investigated pollutants, namely ammonia (NH_3), hydrogen sulfide (H_2S), and odor concentration, were calculated based on the measured pollutant concentrations and the volumetric flow rate of the exhaust gases. These parameters were subsequently used as input data for the atmospheric dispersion modeling performed with the AERMOD model.

The calculation procedure involved several steps, including the determination of the volumetric flow rate of the exhaust gases, normalization to reference temperature and pressure conditions, and the calculation of the pollutant mass emission rates.

2.6 Determination of volumetric flow rate

The volumetric flow rate of the exhaust gases at actual stack conditions was determined based on the measured gas velocity and the cross-sectional area of the stack, according to equation (1):

$$Q_{act} = v \times A \quad (1)$$

where:

Q_{act} – volumetric flow rate at actual stack conditions (m³·s⁻¹ or m³·h⁻¹)

v – measured gas velocity in the stack (m·s⁻¹)

A – cross-sectional area of the stack (m²)

The cross-sectional area of the emission stack was calculated using equation (2):

$$A = \frac{\pi D^2}{4} \quad (2)$$

where:

A – stack cross-sectional area (m²)

D – stack diameter (m)

2.7 Normalization of volumetric flow rate

Since pollutant concentrations are typically expressed at reference temperature and pressure conditions, the volumetric flow rate was normalized using equation (3):

$$Q_N = Q_{act} \times \frac{P}{P_N} \times \frac{T_N}{T} \quad (3)$$

where:

Q_N – normalized volumetric flow rate (Nm³·h⁻¹)

Q_{act} – volumetric flow rate at actual conditions (m³·h⁻¹)

P – measured gas pressure in the stack (kPa)

P_N – reference pressure (101.3 kPa)

T – gas temperature in the stack (K)

T_N – reference temperature (K)

For gaseous pollutants such as NH₃ and H₂S, the reference temperature used for normalization was 273.15 K, according to conventional normalization conditions for industrial emissions.

For odor emissions, the volumetric flow rate was normalized according to the requirements of SR EN 13725:2022, using a reference temperature of 293 K (20°C) and a reference pressure of 101.3 kPa.

2.8 Calculation of pollutant mass emission rates

The mass emission rates of ammonia and hydrogen sulfide were calculated using the normalized volumetric flow rate and the measured pollutant concentrations, according to equation (4):

$$\dot{m} = C \times Q_N \quad (4)$$

where:

$\dot{m}$ – mass emission rate of the pollutant ($\text{mg}\cdot\text{s}^{-1}$ or $\text{g}\cdot\text{s}^{-1}$)

C – pollutant concentration in the exhaust gas ($\text{mg}\cdot\text{m}^{-3}$)

Q_N – normalized volumetric flow rate ($\text{Nm}^3\cdot\text{s}^{-1}$)

When necessary, the resulting values were converted to $\text{g}\cdot\text{s}^{-1}$ for use in the dispersion model.

For odor emissions, the odor emission rate (OER) was calculated using equation (5):

$$OER = C_{odor} \times Q_N \quad (5)$$

where:

OER – odor emission rate ($\text{ouE}\cdot\text{s}^{-1}$)

C_{odor} – odor concentration ($\text{ouE}\cdot\text{m}^{-3}$)

Q_N – normalized volumetric flow rate ($\text{Nm}^3\cdot\text{s}^{-1}$)

The calculated emission rates of NH_3 , H_2S , and odor were used as input parameters in the atmospheric dispersion simulations performed using the AERMOD model.

3. Results

3.1 Measured pollutant concentrations at stack level

The emission measurements performed during the sampling campaign provided the concentration levels of odor, ammonia (NH_3), and hydrogen sulfide (H_2S) in the exhaust gases released from the three stacks of the drying installation, as presented in Table 1. These values represent the basis for the calculation of emission rates and subsequent atmospheric dispersion modeling.

Table 1. Measured concentrations of odor, NH_3 and H_2S at stack level.

Source	Scenario 1 – operation of the installation without the deodorization system			Scenario 2 – operation with the deodorization system in operation		
	Odor (ouE/m^3)	NH_3 (mg/m^3)	H_2S (mg/m^3)	Odor (ouE/m^3)	NH_3 (mg/m^3)	H_2S (mg/m^3)
Stack 1	6763	1.52	13.83	9217	3.04	11.55
Stack 2	7195	1.52	13.07	2531	2.28	9.57
Stack 3	3665	1.52	12.16	4666	2.28	11.70

The measured concentrations indicate distinct behaviors for the analyzed pollutants between the two operational scenarios. Ammonia (NH₃) concentrations increased across all stacks during the operation of the deodorization system, which may suggest that the applied reagent contains ammonium-based compounds contributing to the observed values. In contrast, hydrogen sulfide (H₂S) concentrations decreased for all stacks, indicating a higher removal efficiency for sulfur-based compounds. Odor concentrations did not show a consistent reduction, with significant variability observed between stacks. This behavior suggests that odor levels are influenced not only by chemical treatment but also by the physical parameters of the exhaust gases (e.g., temperature, humidity, flow rate) at the time of sampling. Overall, the results highlight the pollutant-specific and condition-dependent performance of the deodorization system.

3.2 Stack gas flow parameters

The physical parameters of the exhaust gases emitted through the three stacks of the drying installation were measured during the sampling campaign. These parameters include gas temperature, exhaust gas velocity, pressure, and the resulting volumetric flow rate. The measured values were used to characterize the emission conditions at stack level and to calculate the pollutant emission rates required as input data for the atmospheric dispersion modeling. The measured physical parameters of the exhaust gas flow are presented in Table 2.

Table 2. Measured physical parameters of exhaust gas flow at the emission stacks.

Source	Scenario 1 – operation of the installation without the deodorization system					Scenario 2 – operation with the deodorization system in operation				
	Temp. (°C)	Velocity (m/s)	RH (%)	Pres. (kPa)	Volumetric Flow (Nm ³ /s)	Temp. (°C)	Velocity (m/s)	RH (%)	Pres. (kPa)	Volumetric Flow (Nm ³ /s)
Stack 1	37.3	3.2	97.2	99.7	8.96	40.4	3.7	99.2	99.6	10.35
Stack 2	39.5	3.1	98.5	99.5	8.67	30.2	3.3	85.1	99.7	9.21
Stack 3	30.9	2.9	86.4	99.6	8.20	33.4	3.0	87.6	99.7	8.26

Table 2 shows the measured physical parameters of the exhaust gases, which indicate variations in temperature, velocity, relative humidity (RH), and volumetric flow between the two operational scenarios. The high RH values primarily result from the municipal waste drying process, during which moisture in the waste evaporates and transfers into the exhaust gas stream. In Scenario 2, Stack 1 shows an increase in both temperature (40.4°C vs. 37.3°C) and RH (99.2% vs. 97.2%), along with a higher volumetric flow rate. These conditions may contribute to enhanced volatilization and transport of odor-active compounds, which could explain the higher odor concentrations observed in Table 1.

In contrast, Stack 2 presents a significant decrease in temperature (30.2°C vs. 39.5°C) and RH (85.1% vs. 98.5%), which correlates with a substantial

reduction in odor concentration. This suggests that lower temperature and moisture content limit the release and dispersion of odor-generating compounds. For Stack 3, only minor variations in temperature and RH are observed, corresponding to moderate changes in odor concentration.

Overall, the results highlight the important role of temperature and moisture, originating from the drying of municipal waste, in influencing odor emissions. Higher temperature and RH conditions promote increased odor release, while lower values contribute to reduced concentrations, indicating that physical parameters of the exhaust gas significantly affect the efficiency of odor mitigation.

3.3 Calculated pollutant emission rates

Based on the measured pollutant concentrations and the normalized volumetric flow rates of the exhaust gases, the emission rates of odor, ammonia (NH_3), and hydrogen sulfide (H_2S) were calculated using the relationships presented in equations (4) and (5). These emission rates represent the mass flow of pollutants released from each stack and were used as input parameters in the atmospheric dispersion simulations performed with the AERMOD model. The calculated emission rates for the three stacks are presented in Table 3.

Table 3. Calculated emission rates of odor, NH_3 and H_2S used as input for AERMOD dispersion modeling.

Source	Scenario 1 – operation of the installation without the deodorization system			Scenario 2 – operation with the deodorization system in operation.		
	Odor (ouE/s)	NH_3 (mg/s)	H_2S (mg/s)	Odor (ouE/s)	NH_3 (mg/s)	H_2S (mg/s)
Stack 1	63946	17.1	155.5	100632	39.9	151.5
Stack 2	65730	16.6	143.1	24607	25.8	108.5
Stack 3	31694	15.2	121.2	40684	23.7	121.8

The calculated emission rates, shown in Table 3, obtained based on the measured concentrations and normalized volumetric flow rates, provide a more representative assessment of the actual pollutant load released into the atmosphere. The results show distinct variations between the two operational scenarios, reflecting the combined influence of concentration levels and exhaust gas flow parameters.

For ammonia (NH_3), a significant increase in emission rates is observed for all stacks under Scenario 2, which is consistent with the higher measured concentrations and increased volumetric flow rates. In contrast, hydrogen sulfide (H_2S) emission rates show an overall decrease, particularly for Stack 2, indicating the effectiveness of the deodorization system for sulfur-based compounds.

Odor emission rates exhibit non-uniform behavior. A substantial reduction is observed for Stack 2, while increases are recorded for Stacks 1 and 3. This

indicates that, although odor concentrations may vary, the overall emission rate is strongly influenced by the exhaust gas flow conditions.

These results highlight the importance of using emission rates rather than concentrations alone when evaluating environmental impact, as they account for both pollutant levels and gas flow dynamics.

3.4 Atmospheric dispersion modeling results

Atmospheric dispersion modeling was performed using the AERMOD model in order to evaluate the spatial distribution of odor, ammonia (NH₃), and hydrogen sulfide (H₂S) concentrations generated by the mechanical treatment and drying installation. The simulations were carried out for two operational scenarios: operation without the deodorization system and operation with the deodorization system in operation.

The model inputs included the calculated emission rates for each stack, along with the physical parameters of the exhaust gases and site-specific meteorological data. The results are presented as ground-level concentration maps, highlighting the dispersion patterns and maximum impact areas for each pollutant.

The dispersion maps allow for a direct comparison between the two scenarios, providing insight into the effectiveness of the deodorization system in reducing the atmospheric impact of odor and gaseous pollutants. The analysis focuses on the spatial distribution, concentration gradients, and identification of areas potentially affected by emissions from the installation.

3.4.1 Odor dispersion

The spatial distribution of odor concentrations at ground level, obtained using the AERMOD model, is presented in Fig. 3 for the two operational scenarios. The maps illustrate the dispersion patterns generated by emissions from the three stacks of the drying installation, highlighting the areas of maximum impact in the vicinity of the site. The results reflect the combined influence of emission rates, stack parameters, and meteorological conditions on odor propagation. A comparative analysis between the two scenarios allows the evaluation of the deodorization system efficiency in reducing odor impact at ground level and identifying potential differences in the extent and intensity of affected areas.

The dispersion maps indicate a similar spatial distribution pattern of odor concentrations for both operational scenarios, with the highest values occurring in the immediate vicinity of the emission source and along the dominant wind direction. However, a slight reduction in maximum ground-level concentrations can be observed when the deodorization system is in operation, decreasing from approximately 175 ouE/m³ to 139 ouE/m³.

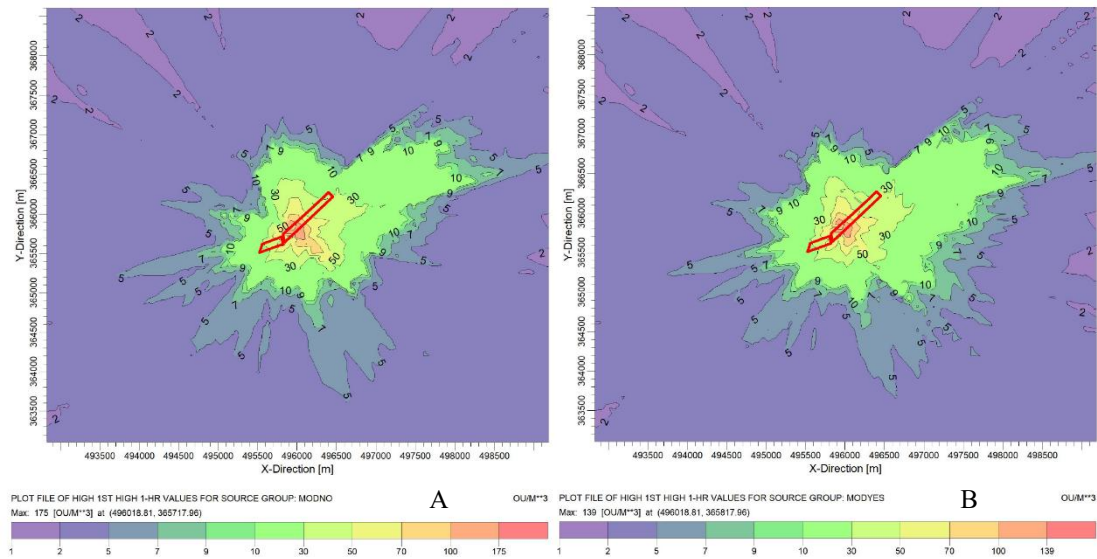


Figure 3. Spatial distribution of odor concentrations for Scenario 1 (A) and Scenario 2 (B).

Despite this reduction, the overall dispersion pattern and the extent of the impacted area remain largely unchanged, suggesting a limited effectiveness of the deodorization system in reducing odor impact at ground level. These results indicate that, although some reduction is achieved at the source, its influence on atmospheric dispersion is relatively low under the given operating and meteorological conditions.

3.4.2 NH_3 dispersion

The spatial distribution of ammonia (NH_3) concentrations at ground level, obtained using the AERMOD dispersion model, is presented in Fig. 4 for the two operational scenarios. The maps illustrate the dispersion behavior of NH_3 emissions generated by the drying installation, taking into account the calculated emission rates, stack characteristics, and meteorological conditions. The results highlight the influence of emission sources and atmospheric transport processes on the distribution of ammonia in the surrounding area. A comparison between the two scenarios allows the assessment of the deodorization system impact on NH_3 dispersion, with particular focus on changes in maximum concentrations and the extent of the affected area.

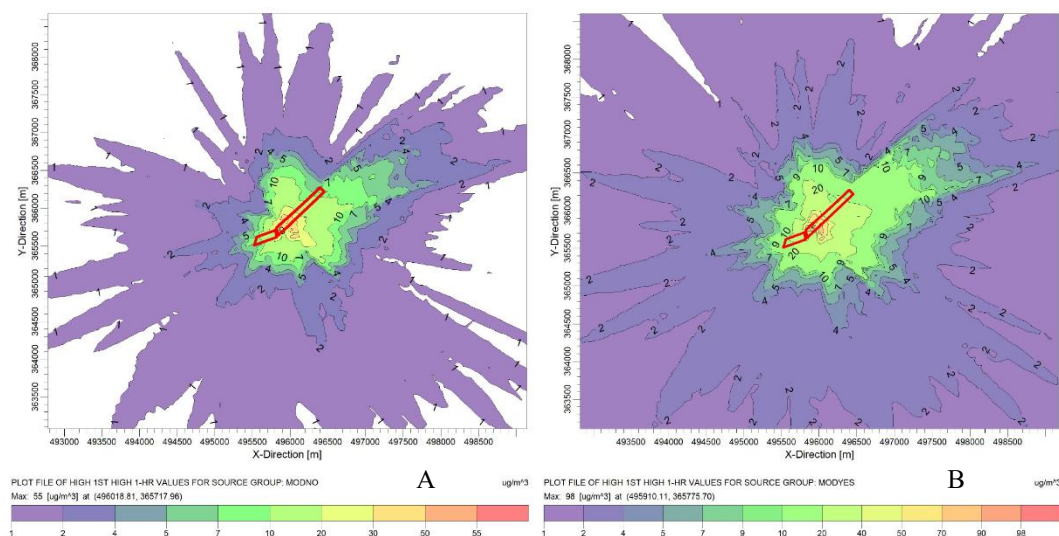


Figure 4. Spatial distribution of (NH₃) concentrations for Scenario 1 (A) and Scenario 2 (B).

The dispersion maps of ammonia (NH₃) show similar spatial patterns for both operational scenarios, with maximum concentrations occurring near the emission source and decreasing with distance. However, higher ground-level concentrations are observed when the deodorization system is in operation, with maximum values increasing from approximately 55 $\mu\text{g}/\text{m}^3$ to 98 $\mu\text{g}/\text{m}^3$.

This increase is also reflected in the spatial extent of the impacted area, which becomes noticeably larger under Scenario 2. Unlike odor concentrations, which showed a slight decrease when the deodorization system was operating, NH₃ concentrations increased, indicating a different behavior of ammonia during the deodorization process. It should be noted that, although emission rate calculations also indicated an increase in NH₃ at source level when the deodorization system was operating, the exact cause of this behavior is not fully understood. One possible explanation is that the deodorizing reagent may contain ammonium-based compounds, contributing to the measured NH₃ concentrations. These findings highlight the importance of both process conditions and atmospheric dispersion in determining the actual environmental impact.

3.4.3 H₂S dispersion

The spatial distribution of hydrogen sulfide (H₂S) concentrations at ground level, obtained using the AERMOD model, is presented for the two operational scenarios. The maps illustrate the dispersion patterns generated by emissions from the three stacks of the drying installation, highlighting the areas of maximum impact in the vicinity of the site. The results reflect the combined influence of emission rates, stack parameters, and meteorological conditions on H₂S propagation. A

comparative analysis between the two scenarios allows the evaluation of the deodorization system efficiency in reducing impact at ground level and identifying potential differences in the extent and intensity of affected areas.

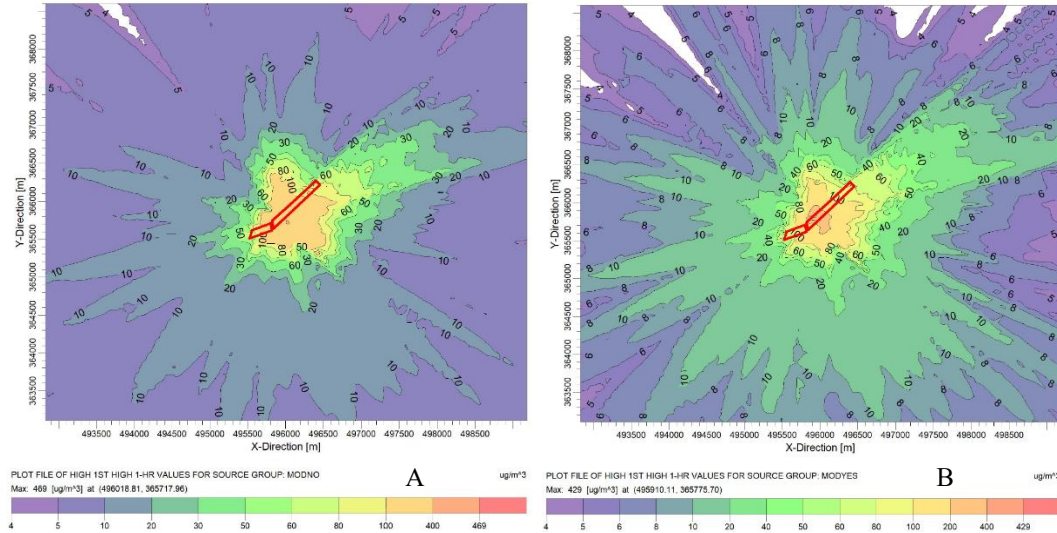


Figure 5. Spatial distribution of H₂S concentrations for Scenario 1 (A) and Scenario 2 (B).

The dispersion maps of hydrogen sulfide (H₂S) show similar spatial distribution patterns for both operational scenarios, with maximum concentrations occurring near the emission source and decreasing with distance. A slight reduction in maximum ground-level concentrations is observed when the deodorization system is in operation, decreasing from approximately 469 μg/m³ to 429 μg/m³.

However, the overall dispersion pattern and the extent of the impacted area remain largely unchanged between the two scenarios. This indicates that the deodorization system has a limited influence on H₂S concentrations at ground level.

These results suggest that, although some reduction may occur at source level, its impact on atmospheric dispersion is relatively low, with meteorological conditions and emission characteristics playing a dominant role in the observed concentration patterns.

4. Discussion

Positioning this evaluation (odor, NH₃, H₂S) within the Romanian permitting context is consistent with practice under Law 278/2013 and the use of standardized methods such as SR EN 13725 for odor [23]. At EU level, BAT-based permitting increasingly incorporates BAT-associated emission levels (BAT-AELs), yet odor-related BAT-AELs remain limited and sector-specific; an odor concentration range of 200–1000 ouE·m⁻³ is noted in the Waste Treatment BREF for certain biological waste-treatment activities [24]. This is coherent with

international findings that odor criteria vary widely by jurisdiction, from minimal explicit provisions to detailed regimes integrating source testing and dispersion modeling [24]. Consistent with BAT conclusions for waste treatment, differentiating organized (ducted/stack) emissions from diffuse sources is important when interpreting performance and impacts, because regulatory and technical characterization approaches differ by source type [25].

The pollutant-dependent deodorization performance found here (NH₃ increasing at the stack while H₂S decreased, with non-uniform odor response) is consistent with literature showing that abatement effectiveness can differ markedly by pollutant and technology, and that “odor” cannot be inferred reliably from a small set of chemical indicators alone [26, 27]. Dynamic-olfactometry evaluations of odor-gas purification show wide ranges of deodorization efficiencies, and measuring individual compounds may not capture the overall perceived odor impact of treated streams [26, 27]. Field studies comparing air-cleaning technologies (e.g., wet scrubbers vs. dry filters) likewise report differing odor removal performance, depending on both pollutant class and operating conditions [27, 28].

The non-uniform odor response observed in this study aligns with evidence that odor is a complex mixture effect: sensory results can diverge from instrumental/chemical surrogates because real-world odor nuisance typically involves mixtures of many compounds and interaction effects [29]. Methodological research also cautions against treating single marker compounds as universal proxies for noxious odor near waste facilities, since correlations can be compound-specific (e.g., significant for H₂S and methyl mercaptan but not necessarily for other trace sulfur compounds), supporting olfactometry as a core measurement rather than relying only on chemical indicators [30]. Taken together, these points support interpreting the study’s divergence between NH₃/H₂S trends and odor trends as an expected outcome in complex odor mixtures, rather than an anomaly attributable to measurement alone [27, 29].

Regarding the hypothesis that increased NH₃ during deodorization might be linked to reagent composition, the wider literature does not provide a single general mechanism applicable to all deodorization reagents. It does, however, support the methodological inference that unexpected behavior warrants additional chemical characterization to identify key odorants and to select/optimize reduction strategies in a site-specific manner [29, 31]. This is consistent with broader waste/odor management conclusions that mitigation must be tailored to source-specific conditions rather than assumed from generic indicators [26, 31]. The chemical composition of the deodorizing reagent was not available; therefore, the proposed explanation regarding increased NH₃ concentrations remains speculative.

Calculating emission rates by integrating concentration with exhaust gas flow directly matches established odor-emission quantification practice, where the

odor emission rate (OER) is the product of odor concentration and volumetric flow rate, used as the primary source term for dispersion modeling [32, 33]. This is not merely procedural: research on odor impact assessment stresses that concentration measurements alone are often insufficient to attribute responsibility or quantify off-site nuisance, whereas OER enables consistent comparison across operating states and supports model-based receptor assessment [32, 34]. Consistent OER formulations are repeatedly used across studies evaluating odor-control efficiency, underscoring the centrality of flow characterization alongside concentration [32, 33].

The finding that temperature and relative humidity associated with waste drying significantly influence the release/transport of odor-active compounds is consistent with evidence that environmental conditions affect both emissions and measurement representativeness [35, 36]. In livestock buildings, odorant and NH_3 emission variability depends on temperature and humidity, supporting the principle that thermodynamic and microclimatic conditions can modulate volatilization and emission strength [35]. From a measurement-quality perspective, odor sampling and storage are also sensitive to humidity and temperature, with diffusion losses through sampling bags affecting situations involving NH_3 and H_2S [32]. High moisture can further necessitate pre-dilution to prevent condensation and related artifacts in olfactometric workflows, reinforcing the need to treat humidity as a practical factor in reliable odor quantification [28, 36].

The finding that source-level reductions do not necessarily produce proportional reductions in ground-level concentrations, particularly for odor, is consistent with how regulatory odor assessment criteria are constructed and how dispersion modeling is used in practice [24, 32, 34]. International regulatory reviews show that odor impact criteria commonly incorporate exceedance probabilities/percentiles rather than relying solely on mean concentrations, reflecting that nuisance is often driven by intermittent peaks under unfavorable meteorology [24]. Methodological work using AERMOD likewise models both “highest values” and percentile-based scenarios (e.g., 98th percentile) to distinguish worst-case from typical high-end impacts, demonstrating that meteorology and statistical treatment of variability materially affect predicted receptor concentrations even when emissions are reduced [32].

More generally, Gaussian dispersion modeling studies emphasize that the relationship between emission rate changes and predicted impacts depends on stability, wind fields, and modeling assumptions, so assessing impact requires explicit modeling rather than extrapolation from stack concentrations [33, 34]. This aligns with odor-assessment scholarship arguing that OER alone does not determine nuisance at receptors; receptor impact emerges only when OER is combined with dispersion and (in many frameworks) FIDOL-type considerations of frequency/intensity/duration/offensiveness/location [37].

The conclusion that effective mitigation requires an integrated approach combining control technologies, standardized measurement, and dispersion modeling is strongly supported by the odor-management literature and by regulatory practice in multiple jurisdictions [24, 34]. Reviews of odor measurement approaches stress that no single method is sufficient; dynamic olfactometry is the European reference for quantifying odor concentration at sources, but complementary tools and modeling are needed to connect emissions to community exposure and complaints [24, 32]. Several regions/jurisdictions operationalize odor management through the combined use of olfactometric measurements and dispersion modeling to assess impacts against acceptability criteria [24, 31].

Within this integrated approach, reliance on SR EN 13725 is consistent with Romanian and broader European practice for odor quantification [23, 24, 31]. However, dynamic olfactometry is also subject to substantial measurement uncertainty in practice, which reinforces the need for cautious interpretation of “before/after” comparisons and for quality assurance and replication [36, 38]. Furthermore, because odor nuisance is ultimately receptor-experienced and complaint-driven, studies integrating standardized measurements with complementary exposure/complaint systems have demonstrated added value for identifying sources and contextualizing results, supporting the broader argument that mitigation effectiveness should be judged by impacts, not only by emission-point compliance [34, 39].

5. Conclusion

This study characterized odor, NH₃, and H₂S emissions from a mechanical treatment and drying installation for non-hazardous waste, before and after implementation of a deodorization system, combining source-level measurements with AERMOD dispersion modeling. The results show that the effect of the deodorization system is pollutant-dependent rather than uniform: ground-level H₂S and odor concentrations decreased modestly, whereas NH₃ concentrations increased, an outcome that could not be attributed to a single mechanism and that, in the absence of the deodorizing reagent’s chemical composition, remains only partly explained. This asymmetry confirms that abatement performance cannot be assumed from generic removal rates and must instead be verified for each pollutant and each installation. The dispersion modeling further shows that changes at the source do not translate proportionally into changes at the receptor, underlining that ground-level impact, not stack concentration alone, should guide the assessment of mitigation measures. Taken together, these findings support an integrated approach to managing odor-active emissions from waste-drying facilities, one that combines standardized source characterization, technology-specific verification of control performance, and dispersion-based assessment of off-site impact, rather than relying on any single line of evidence. Future work should prioritize obtaining full

chemical data on deodorizing reagents and extending measurement campaigns to confirm whether the NH_3 increase observed here is reagent-related or reflects broader process variability.

Author Contributions

Conceptualization, C.C. and C.M.; methodology, C.C. and V.D.; software, C.C.; validation, C.M., A.M.D., and G.G.V.; formal analysis, V.D. and C.C.; investigation, V.D. and M.L.M.; data curation, G.G.V.; writing – original draft preparation, C.C., V.D. and M.L.M.; writing – review and editing, C.C. and M.L.M.; visualization, G.G.V., A.M.D., and C.M.; supervision, G.G.V., A.M.D., and C.M. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

Data are contained within the article.

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Conflicts of Interest

The authors declare no conflicts of interest.

Artificial Intelligence Disclosure

Artificial intelligence-based tools were used to improve language clarity, grammar, and readability during manuscript preparation. The tool used was Claude Sonnet 4.6 (Anthropic). No AI tools were used for study design, data analysis, interpretation of results, or generation of scientific content. The authors remain fully responsible for the manuscript.

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