Limitation of Ammonia Exposure Among Workers in Fertilizers Industry using Modern Modified Technology Towards Sustainability

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ABSTRACT

Background: Fertilizer production is a global industry, and workers in the processing areas may be exposed to various airborne contaminants, including mineral dust, water-soluble and insoluble compounds, as well as gases such as nitric acid, nitrogen dioxide, nitrogen monoxide, ammonia, and hydrogen fluoride, which can be released into the work environment across different departments.

Subjects and methods: This study took place at a modern nitrogen fertilizer company in Alexandria, Egypt. The company mainly produces high-quality granular urea (46%) and anhydrous ammonia using advanced technology. The research used a descriptive, quantitative, case study approach. Two structured and pre-tested questionnaires were used to collect data from workers. Questionnaire A gathered information about the workers' job roles and workplace hygiene conditions. Questionnaire B focused on symptoms reported by employees and their awareness of ammonia exposure. Ammonia levels were measured in ten different areas of the factory using a direct-reading infrared spectrophotometer.

Results: The study involved 168 male workers, comprising 74.4% technicians and 25.6% engineers. Most technicians were engaged in operation (61.6%) and maintenance (25.6%), while engineers primarily worked in operation (76.7%). A majority of workers (70.8%) were on day shifts, with an average workweek of 47.68 ± 1.85 hours. Personal protective equipment (PPE) usage was reported by 99.4% of workers, and 100% were non-smokers, reflecting a strong safety culture and high awareness of occupational hazards. A statistically significant association was observed between years of employment and the prevalence of symptoms affecting the ocular/nasal symptoms (p = 0.001, 0.019, and 0.009, respectively).

Ammonia concentrations measured at various factory locations were consistently below the TLV-TWA of 25 ppm, indicating effective environmental and occupational exposure control within the facility.

Conclusion: The current study highlighted the role of applying modern modified industry in limiting exposure to potential occupational hazards, improving the health of the workers, and achieving sustainability.

Keywords: Fertilizer production, modern modified technology, exposure to ammonia, sustainability, Egypt.

INTRODUCTION

Fertilizers play a crucial role in sustaining global food production. Chemical fertilizers were instrumental in driving the green revolution, significantly boosting crop yields and reducing costs through advanced technologies and farming practices (Menadi *et al.*, 2024). However, the widespread use of synthetic fertilizers has led to environmental concerns. Many investigators indicated that these fertilizers contribute to global greenhouse gas emissions, both from their production processes and their decomposition by soil microbes after application (NIOSH, 2016; Avşar, 2024 and Menadi *et al.*, 2024).

Ammonia is typically specified as a colorless gas with ≥99.5% purity (anhydrous), ≤0.2% water content, ≤5 ppm oil, and for aqueous forms, 25–30% NH_3 by weight with a strong alkaline pH >11 and minimal heavy metal impurities (<1 ppm). Ammonia is chemically occurring within the atmosphere by nature, also as an important synthetic chemical. The greatest amount of ammonia in the environment arises from the natural breakdown of manure and dead plants and animals (Isaifan and Al-Thani, 2024). Manufactured ammonia includes petrochemical fertilizers, which are synthetic products produced by using large quantities of petroleum or natural gas and other fossil fuels; other sources are from power plants, mobile sources and other manufacturing emissions (Sabry, 2015). More than 78% of the synthetic manufactured ammonia is applied as fertilizers (Soltanzadeh *et al.*, 2023).

Fertilizers production is a worldwide industry; the process is based on the dissolving of phosphate rock in mineral acid followed by neutralization, concentration, and granulation or Pilling. Workers in the production area may be exposed to mineral dust, water-soluble and

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insoluble compounds, nitric acid, nitrogen dioxide, nitrogen monoxide, ammonia, and hydrogen fluoride, which might be emitted into the work environment (Khan *et al.,* 2016).

Exposure to ammonia, within the range of 25-50 ppm, has been shown to irritate the upper airways in humans (Isaifan and Al-Thani, 2024). It interacts directly upon contact with accessible moisture within the eyes, skin, mouth, tract, and mainly mucous surfaces to compose caustic ammonia water. Intensive exposure to ammonia can be a reason for burning and irritation of the nose, throat and respiratory tract (Mohammadbeigi *et al.,* 2020). The substance could cause airway destruction, leading to respiratory suffering or failure. In addition, ammonia can be a source of olfactory failure or adaptation (Reis *et al.*, 2024).

A very important question to be answered: do modern technologies in Egyptian fertilizer plants reduce ammonia exposure below occupational exposure limits? To answer that question, one must know that Egypt plays a pivotal role in the global fertilizer industry, particularly in the production and export of nitrogen-based fertilizers such as urea (Khan *et al.,* 2016). With abundant natural gas reserves, a key feedstock in ammonia and urea production. Egypt has emerged as a major exporter, especially to markets in Africa, Europe, and Asia. According to industry reports, Egypt ranks among the top ten global urea exporters, with an annual production capacity exceeding 6 million metric tonnes and over 50% of this output allocated for export (Elwardany and Mohammed, 2020). The country's strategic location, coupled with government investments in modernizing fertilizer plants and expanding petrochemical infrastructure, has positioned Egypt as a regional hub for fertilizer manufacturing. This makes the occupational and environmental performance of its fertilizer industry highly relevant not only for national industrial sustainability but also for meeting international environmental standards and safeguarding worker health. Therefore, studying ammonia exposure and mitigation practices within an Egyptian fertilizer plant offers valuable insights into broader challenges faced by high-output, export-driven industries across developing and transitional economies. Reducing the environmental footprint and occupational hazards of the fertilizer industry amid these challenges will require strong collaboration among policymakers, multilateral financial institutions like the International Finance Corporation (IFC), synthetic fertilizer manufacturers, and the farming communities that rely on these products (Madanhire *et al.,* 2015).

Another study by Rashid *et al.* (2024) demonstrated that the potential risks of ammonia releases to surrounding communities can be effectively reduced through measures such as isolating release sources, using water sprays for dilution, applying steam or air for further dispersion, and activating emergency sirens to inform the public (Rashid *et al.,* 2024). The transition to net-zero fertilizer production highlights the significant obstacles high-emission industries face in adopting more sustainable and circular practices (IFC, 2023). One recognized advancement in ammonia manufacturing involves replacing the melting and Prilling units in urea production with an eco-friendly granulation process, which Helps to minimize ammonia exposure (Khan *et al.,* 2016). This study aims to emphasize the need for effective mitigation strategies to reduce both occupational and environmental risks associated with ammonia exposure in the fertilizer industry.

MATERIAL AND METHODS

Study settings and design:

The study was conducted in one of the modern nitrogenous fertilizer companies in Alexandria, Egypt. The company specializes in producing high-quality nitrogenous fertilizers, mainly granular urea as a final product and anhydrous ammonia as an intermediate product using advanced technology. This takes place in two main plants, which are ammonia and urea plants. The study involved descriptive research adopting a quantitative and case study approach.

Sample size and sampling techniques

The workers of the nitrogenous fertilizer company's locations, such as operation, production, maintenance and inspection in Alexandria (Egypt), who were exposed to ammonia (N = 300 workers) and accepted to participate in the case study, were included (n = 168 workers; 56%).

Sampling adequacy limit

Sampling adequacy limit is assessed using Cochran's formula for sample size determination, which is applicable when estimating proportions in large populations:

$$n_0 = \frac{Z^2 \cdot p \cdot (1-p)}{e^2}$$

Where: n_0= required sample size, Z= Z-value (e.g., 1.96 for 95% confidence), p = estimated proportion of the population with the attribute (commonly 0.5 is used for maximum variability), e = desired margin of error (e.g., 0.05 for ±5% precision) (Shojaee Barjoee and Rodionov Alekseevich, 2024).

The participants (n=168), according to the working locations, were distributed as 92 workers of the operation sector (54.8%), 31 workers of the production sector (18.5%), and 45 workers of the maintenance and inspection sector (26.8%).

Exclusion criterion:

The control room workers were excluded from the study, as they are assumed to have no direct exposure to ammonia.

The work environment of the nitrogenous fertilizer company's all productive locations (N = 10 locations; administration building, storehouse, urea/bulk store, water treatment utilities, compressor, ammonia plant, urea synthesis, urea granulation, area between the ammonia and urea plants, and finally the south area of the factory) were analyzed, and ammonia concentrations were determined in the selected locations monthly during a course of six months, from January to June 2020, considering the seasonal variations and the wind direction (n = 60 air samples).

Data collection

1- Pre-designed and pre- tested structured two questionnaires for workers' data were used. The first questionnaire (A) was used for the professional characters and occupational hygiene profile (Osborne *et al.,* 2023). The second questionnaire (B) was an optimal symptom score for employee's complaints and their awareness about the occupational exposure to ammonia (Langenbruch *et al.,* 2022). To ensure cultural relevance and clarity for participants, all questionnaires used in the study were translated into Arabic following a forward-backward translation method. A bilingual expert first translated the items from English to Arabic, followed by a back-translation to English by an independent translator. Discrepancies were reviewed and resolved by a panel of subject-matter experts to maintain semantic and conceptual equivalence. The translated version was then pilot tested with a representative sample of 30 participants to evaluate the clarity, cultural appropriateness, and psychometric reliability of the items. Reliability analysis showed high internal consistency across all scales, with Cronbach's alpha values ranging from 0.82 to 0.91, indicating strong reliability of the instrument in the Arabic context.

2- The measurements of ammonia gas were taken from ten different working areas in the factory. The measured concentrations were recorded in a sheet for each week for six months, starting from January till June 2020, considering the seasonal variation between the months from winter till summer and the wind direction.

A direct reading method, Infrared spectrophotometry was used (LeBouf *et al.,* 2013). As MIRAN SapphIRe Portable Ambient Analyzers, Model 205B-XL 1A3N STAA, serial no. 205B-80218-457, Thermo scientific, US (Villanueva *et al.,* 2022), which provides real-time gas concentration readings. It exhibits excellent reliability and repeatability in various environmental conditions. It has a detection limit as low as 0.1 ppm and a response time of less than 10 seconds, making it suitable for real-time exposure assessment. Internal diagnostics and self-check routines ensure consistent performance, making it highly sensitive and suitable for monitoring low levels of ammonia in occupational settings. Its fast response time allows for accurate and immediate assessment of air quality in different working areas.

The MIRAN SapphIRe analyzer, which has been validated for field use in industrial hygiene by multiple studies such as the work by Batterman *et al.* (2012) meets the performance criteria set by NIOSH (National Institute for Occupational Safety and Health) and OSHA (Occupational Safety and Health Administration), making it a reliable tool for real-time monitoring of ammonia and other airborne contaminants in occupational environments. It uses non-dispersive infrared (NDIR) technology to provide selective and accurate detection of gases, with minimal cross-interference. The MIRAN SapphIRe analyzer was pre-calibrated for a list of chemicals which are stored in the instrument library according to the manufacturer's recommendations (Thermo Electron Corporation, 2004). A calibration check can be performed using the sampling loop kit. The sampling loop kit redistributes a known volume of air and allows the injection of a volatile liquid or gas into the IR sampling cell. Instrument zeroing is performed by using a charcoal filter attachment to remove chemicals from the air.

Ethical Consideration

- The protocol was approved by the "Committee of Ethics of the High Institute of Public Health" with approval No.00013692.
- This study was conducted in accordance with the ethical standards outlined in the 1964 Declaration of Helsinki and its later amendments or comparable ethical guidelines (WMA, 2013). All procedures involving human participants were reviewed and approved by the Ethics Committee of the High Institute of Public Health, and written informed consent was obtained from all participants prior to their involvement in the study.
- Oral consent was obtained from all individuals. All workers involved in this study provided written informed consent before participation. They were fully informed about the study's purpose, procedures, potential risks, and benefits, and they voluntarily agreed to participate.

- Confidentiality of data was ensured.
- Transcript sheets were analyzed anonymously.
- Each respondent was given a code number for identification.
- There was no conflict of interest

Statistical analysis:

Data were analyzed using IBM SPSS version 20.0. Qualitative data were presented as numbers and percentages, while quantitative data were summarized using range, mean ± SD, and median (IQR). Normality was assessed using the Kolmogorov-Smirnov test. A *p*-value < 0.05 was considered statistically significant.

RESULTS AND DISCUSSION

1. Modern sustainable technology-driven occupational exposure reduction to ammonia in fertilizer plants

The ammonia synthesis factory is based on reliable and proven process steps controlled through automated operation of plants and machines. In the ammonia plant, the major features are the high-power primary reformer with a cold outlet manifold, the secondary reformer with a peripheral vortex burner, and the three-bed radial heat exchanger of magnetite with one or two synthesized transformers. In addition, the conventional process steps sequence for ammonia synthesis is one of the Best Available Techniques (BAT) reforming processes. The process undergoes major modifications to realize ammonia emission reduction, which are the steam reforming section, including its waste heat recovery system, the carbon dioxide removal unit, and the ammonia synthesis unit.

In urea plants, the use of possible and available emission reduction techniques such as scrubbing the emission gases with the condensation process before inlet ventilation into the atmosphere, especially the acidic scrubber, using sulfuric or nitric acid to produce ammonium sulphate or ammonium nitrate salts. In addition, wet washing of the Prill tower and granulating plant to recover urea and ammonia.

In addition to the dual-pressure ammonia manufacturing loop with a distinctive secondary optimized design, dedicated waste heat boiler, and radial flow converters, the pollution prevention techniques include the recycling of ammonia back to the process and the use of post-combustion control technologies, such as selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR), which are used to control nitrogen oxide emissions from fossil fuel combustion sources.

Table 1. Modern sustainable Technologies for Reducing Occupational Exposure to Ammonia in Fertilizer Plants

Serial No.	Technology	Description	Effectiveness
1	Scrubbers	Remove ammonia from exhaust gases through chemical absorption.	Achieves up to 95% removal efficiency.
2	Ammonia Sensors	Real-time monitoring and detection of ammonia leaks.	Allows early detection and prevents exposure.
3	Closed-loop Systems	ecycles ammonia within the production process to minimize emissions.	Significantly reduces ammonia release.
4	Personal Protective Equipment (PPE)	Advanced PPE, including respirators and ammonia-resistant suits.	Reduces inhalation and skin exposure risks.
5	Automated Control Systems	Automated systems that manage ammonia levels and detect leaks.	Enhances safety through prompt responses.
6	Bio filtration	Utilizes bio filters to biologically treat ammonia emissions.	An efficient and eco-friendly solution.
7	Ventilation Systems	Improved designs to effectively disperse ammonia.	Lowers airborne ammonia concentrations.
8	Sealing and Insulation	Advanced materials for sealing and insulating ammonia handling areas.	Prevents leaks and minimizes exposure.
9	Catalytic Oxidation	Converts ammonia into nitrogen and water using catalysts.	Reduces ammonia concentration in emissions.
10	Ammonia Absorption Units	Specialized units designed to absorb and neutralize ammonia.	Highly effective in localized ammonia reduction.

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Capture systems such as hoods which collect ammonia emissions, and good maintenance practices implemented as well as adherence to safety practice guidelines to reduce and eliminate the occupational exposure hazards of ammonia emissions. A summary of modern sustainable technologies for reducing occupational exposure to ammonia fertilizer plants is shown in Table (1).

2. Professional characteristics of the workers in fertilizers plant

Table (2) shows the distribution of the workers of fertilizers plants according to their professional characteristics, including gender, current position and job roles, work regime and the number of work hours per week. It is obvious from the Data presented in the Table (2) that all workers are males (100%). Current position, which includes specifications as technicians (n=125, 74.4 %) and engineers (n=43, 25.6%). The technicians' job duties are operation (n=77, 61.6%), production (n=2, 1.6%), maintenance (n=32, 25.6%) and inspection (n=14, 11.2%). Otherwise, the engineers' job duties are operation (n=33, 76.7%), production (n=1, 2.3%), and maintenance (n=9, 20.9%). The work regime is day shift (n=119, 70.8%) and night shift (n=49, 29.2%). The total number of working hours/week ranges from 24 to 48 hours with a mean of 47.68±1.85 and a median (IQR) of 48 hours.

3. Occupational Hygiene Profile of the workers in fertilizers plant

Table (3) represents the occupational hygiene profile of the workers of fertilizers plants including work duration (years of employment), period of exposure to ammonia, the availability and usage of personal protective equipment (PPE), and smoking habits among workers. The work duration ranges from 5.0 to 17.0 years with a mean of 10.23±2.79 and a median (IQR) range from 7.50 to 12.0 and equal to 11.0 years. Considering the exposure to ammonia, the majority of the employees have already been exposed, with a percentage of 97.6 % (n=164).

As regards the healthy habits, the majority of the workers (n=147, 99.4%) have reported regular use of PPE. The most frequent types of PPE used include gloves (95.8%, n=161), goggles (88.7%, n=149), safety boots (95.8%, n=161), suits (73.2%, n=123) and aprons (74.4%, n=125). In addition, all the workers are never smoked (100%, n=168).

Table 2. Distribution of workers according to professional characteristics (n=168)

professional characteristics		No.	%
Gender			
	Male	168	100.0
	Female	00	0.0
Current position			
	Job/Position		
	Technician	125	74.4
	Engineer	43	25.6
	Total	168	100
Current Job duties			
	Operation technician	77	61.6
	Production technician	2	1.6
	Maintenance technician	32	25.6
	Inspection technician	14	11.2
	Total	125	100.0
	Operation engineer	33	76.7
	Production engineer	1	2.3
	Maintenance engineer	9	20.9
	Total	43	100
Work Regime			
	Day shift	119	70.8
	Night shift	49	29.2
	Total	168	100
Hours of Work per Week			
	Min. – Max.	24.0 – 48.0	
	Mean ± SD.	47.86 ± 1.85	
	Median (IQR)	48.0	

Table 3. Distribution of workers according to occupational hygiene profile (n=168)

Occupational hygiene profile	No.	%
Current job duties		
Operation technician	77	45.8
Production technician	2	1.2
Maintenance technician	32	19.0
Inspection technician	14	8.3
Operation engineer	33	19.6
Production engineer	1	0.6
Maintenance engineer	9	5.4
Total	168	100
Work duration (years)		
<10	59	35.1
10-15	100	59.5
>15	9	5.4
Min. – Max.	5.0 – 17.0	
Mean ± SD.	10.23 ± 2.79	
Median (IQR)	11.0 (7.50–12.0)	
Exposure to ammonia		
No	4	2.4
Yes	164	97.6
Period of exposure to ammonia (hrs. /day)		
Min. – Max.	12.0 – 12.0	
Mean ± SD.	12.0 ± 0.0	
Median (IQR)	12.0	
Using personal protective equipment		
No	1	0.6
Yes	167	99.4
Total	168	100
Types of personal protective equipment used		
Gloves	161	95.8
Goggle	149	88.7
Boot	161	95.8
Air respirator	65	38.7
Mask	99	58.9
Hat	77	45.8
Suit	123	73.2
Apron	125	74.4
Smoking history		
Never smokers	168	100.0
Ex-smokers	0	0.0
Present smokers	0	0.0
Total	168	100

4. Occupational health complaints

Table (4) reveals the role of the worker's work duration (years of employment) in relation to the occupational health complaints and the overall total score of the symptoms. The worker's duration is categorized as; <10, (10 - 15), or >15 years. The majority of eyes, nose, and sinuses symptoms were within the workers having 10-15 years of employment, where the median values (IQR) were 22.22, 33.33, and 22.22 years, respectively. There was a statistically significant difference between the years of employment and eyes, nose and sinuses symptoms *(P = 0.001, 0.019 and 0.009,* respectively). In addition, there was also a statistically significant difference between the overall total score of workers' symptoms and the worker's work duration, as the most suffering workers are those with a work duration of 10–15 years with a median (IQR) of 16.67 years *(P=0.004)*. Otherwise, according to the breathing symptoms among the workers, there was no statistically significant difference between the workers' work duration (years) and the breathing symptoms *(P = 0.997*, *0.621*, respectively).

5. Ammonia concentrations

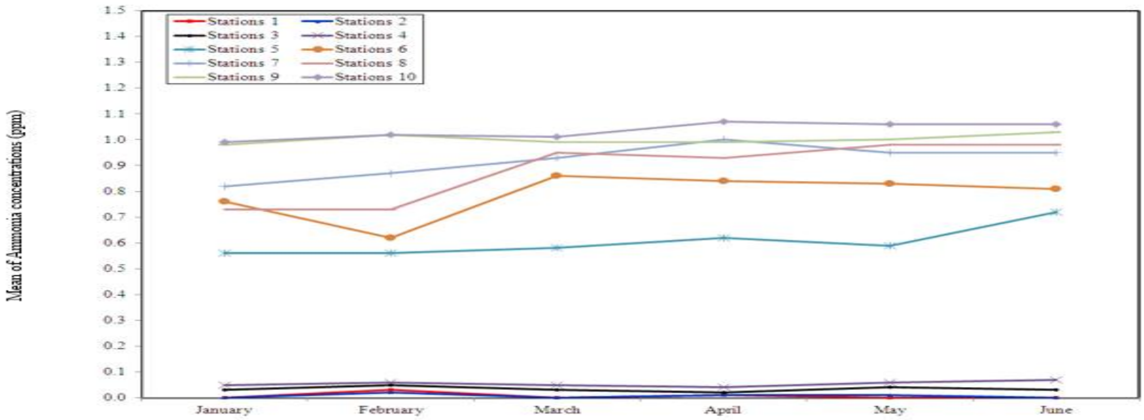
Figure (1) presents the concentration of NH_3 detected monthly at ten workplace stations during the course of six months starting from January till June 2020. The highest concentrations are found in the station between NH_3 and urea plant [ranged from (0.98±0.02) to (1.03±0.03) ppm] and the area at the south of the factory [ranged from 0.99± 0.02 to 1.07±0.030 ppm] through the period of measurements. Otherwise; NH_3 has not been detected in the administrative building (especially in January, March, May, and June) and in the store house (especially in January, March, and June). Regarding the mean concentration of NH_3 in the different working stations, it was found to be lower than the TLV-TWA of 25 ppm.

According to Figure (2), there is a slight decrease in the mean concentration of NH_3 during versus winter (January and February); versus spring months (March and April) and the summer months (May and June) especially in NH_3 plant (0.76 ± 0.11 and 0.62 ± 0.10 ppm) in winter; versus (0.86 ± 0.09 and 0.84 ± 0.08 ppm) in Spring and (0.83 ± 0.05 and 0.81 ± 0.03 ppm) in Summer, Urea synthesis (0.82 ± 0.11 and 0.87± 0.07 ppm) in winter; versus (0.93 ± 0.05 and 1.00 ± 0.01 ppm) in Spring and (0.95 ± 0.07 and 0.95 ± 0.06 ppm) in Summer , and in Urea granulation (0.73 ± 0.10 and 0.73 ± 0.05 ppm) in winter; versus (0.95 ± 0.07 and 0.93 ± 0.05 ppm) in Spring and (0.98 ± 0.02 and 0.98 ± 0.01 ppm) in Summer. There is a statistically significant difference between the concentrations of NH_3 within the different locations in the different months (p<0.001).

Table 4. Relation between job duration (years) and the occupational health complaints (n=168)

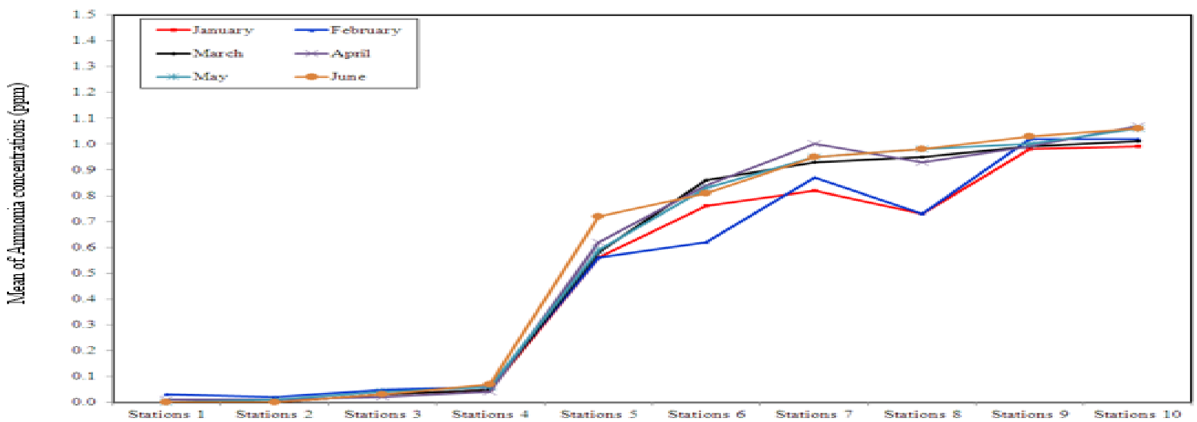
% Score of symptoms	job duration (years)			H	P
	<10 (n = 59)	**(10 -15) (n = 100)**	**>15 (n = 9)**		
Eyes					
Min. – Max.	0.0 – 44.44	0.0 – 55.56	0.0 – 33.33		
Mean ± SD.	9.04 ± 13.13	18.89 ±15.99	11.11 ±14.70	14.571*	0.001*
Median	0.0	22.22	0.0		
Nose					
Min. – Max.	0.0 – 66.67	0.0 – 75.0	0.0 – 58.33		
Mean ± SD.	18.64 ± 14.63	25.42 ± 15.86	24.07 ± 21.02	7.921*	0.019*
Median	16.67	33.33	16.67		
Sinuses					
Min. – Max.	0.0 – 44.44	0.0 – 44.44	0.0 – 44.44		
Mean ± SD.	14.88 ± 14.39	23.33 ± 16.82	18.52 ± 18.43	9.339*	0.009*
Median	11.11	22.22	11.11		
Breathing at awakening or during the day					
Min. – Max.	0.0 – 33.33	0.0 – 33.33	0.0 – 41.67		
Mean ± SD.	4.52 ± 7.63	5.25 ± 9.22	6.48 ± 13.68	0.007	0.997
Median	0.0	0.0	0.0		
Breathing at night					
Min. – Max.	0.0 – 25.0	0.0 – 33.33	0.0 – 33.33		
Mean ± SD.	1.69 ± 5.31	2.08 ± 5.60	4.63 ± 11.11	0.953	0.621
Median	0.0	0.0	0.0		
Overall total score					
Min. – Max.	0.0 – 38.89	0.0 – 42.59	0.0 – 42.59		
Mean ± SD.	9.53 ± 8.15	14.35 ± 9.23	12.76 ± 13.50	11.171*	0.004*
Median	7.41	16.67	5.56		

H: H for Kruskal Wallis test p: p value for association between different categories *: Statistically significant at p ≤ 0.05



1	Administration building	2	Store house
3	bulk store/urea storage	4	Utilities (water treatment)
5	Compressor	6	Ammonia plant
7	Urea synthesis	8	Urea granulation
9	Station between ammonia plant and urea plant	10	Air direction south of the factory

Fig. 1. Ammonia concentrations (ppm) during six months in different stations in modern modified nitrogenous fertilizer factory



1	Administration building	2	Store house
3	bulk store/urea storage	4	Utilities (water treatment)
5	Compressor	6	Ammonia plant
7	Urea synthesis	8	Urea granulation
9	Station between ammonia plant and urea plant	10	Air direction south of the factory

Fig. 2. Ammonia concentrations (ppm) in different stations in modern modified nitrogenous fertilizer factory

The current study revealed that the majority of the workers were male technicians with 10–15 years of experience, most of whom used PPE (99.4%) such as gloves (95.8%), goggles (88.7%), and respirators (38.7%), indicating improved safety awareness; these findings align with Kamel *et al.* (2017); Aly & Mohammed (2018) and Neghab *et al.* (2018), but differ from studies by Awodele *et al.* (2014) and Pratiwi *et al.* (2019), which reported lower PPE usage and higher respiratory complaints in other fertilizer and chemical factories. Despite ammonia exposure levels remaining below the TLV-TWA of 25 ppm (Hovland, 2014), workers still reported symptoms such as asthma (39.3%), chronic cough (44.6%), and shortness of breath (49.4%), with significant associations found between job role, PPE use, symptom prevalence, and years of service consistent with studies by Ballal *et al.* (1998); Rahman *et al.* (2007); Al-Yassen (2012) and Mohamed & Omar (2018), confirming that long-term exposure and work duration are key factors in the development of occupational respiratory issues (Gezerman and Çorbacıoğlu, 2016).

A significant association was identified between years of employment and the presence of symptoms affecting the eyes, nose, and sinuses, with p-values of 0.001, 0.019, and 0.009, respectively. These findings align with those reported by Mohamed and Omar (2018) in a similar study conducted at the Elberga Petroleum Factory in Libya, where a significant correlation was found between job duration and the incidence of ocular/nasal symptoms irritation ($p = 0.03$ and 0.037, respectively). However, no significant relationship was found between work duration and respiratory symptoms. The most frequently reported mild health complaints were nasal and sinus irritation, while more severe respiratory issues were less common.

The study's findings are in line with similar research conducted in other fertilizer factories in Egypt, Libya, and Iran, where workers in operational roles with longer service durations were also more prone to mild irritation symptoms (Soltanzadeh *et al.,* 2023). Literature on acute ammonia exposure paints a contrasting picture. Short-term spikes can lead to immediate irritant effects on the eyes, skin, and respiratory tract at concentrations as low as 35 ppm, with exposures above 300 ppm posing life-threatening risks (Agency for Toxic Substances and Disease Registry, (ATSDR, 2020 and Perl, 2016). Acute exposure scenarios are especially concerning in confined spaces or during maintenance tasks when proper PPE is not used.

Concerning the job qualifications in this occupation; the current study has shown that all the workers were males (100%), similar results were achieved in a study of occupational injuries in a fertilizer company in Egypt with a percent of 98.4% (Nm *et al.*, 2017). The results were consistent with the study conducted in fertilizer factory in Asyut city (Egypt) stated that about 73.5% of workers were technicians (Elwardany and Mohammed, 2020), and the significantly higher participation of workers job duties was in the operational process for both technicians (n=77,61.6%) and engineers (n=33,76.7%). This complies with the study conducted in Iran where the studied population consisted of 67 (54%) male operational workers (high exposed group) and 57 (46%) male repair & maintenance workers (low exposed group) who were selected as exposed group (Neghab *et al.*, 2018).

As regards the work duration (years of employment) and its impact on health complaints; the present study has declared that the majority of the employees (n=100, 59.5%) practice their work within 10-15 years. This is disagreed with the study reporting that 77% of workers had years of experience of at least 15 years (Jeffree *et al.,* 2016).

In our study, time-weighted average (TWA) values of ammonia emissions were consistently below the recommended threshold limit value (TLV-TWA) of 25 ppm, indicating compliance with occupational exposure guidelines. The highest ammonia concentrations were recorded in the area between the ammonia and urea plants and in the southern region of the factory throughout the monitoring period. These elevated levels may be influenced by the dominant northwest-to-north wind direction commonly observed in Alexandria. A seasonal variation in ammonia concentrations were also observed. A slight decrease in mean ammonia levels was observed during the winter months (January and February, with average temperatures of 12–16°C) compared to the warmer spring (March and April, 20–25°C) and summer months (May and June, 28–34°C), particularly in the ammonia plant, urea synthesis unit, and urea granulation areas. This trend may be attributed to the increased volatility of ammonia at higher ambient temperatures, which enhances its dispersion and detectability in warmer seasons, and ammonia volatilization is highly temperature-dependent (Harper *et al.,* 2017 and Liang *et al.,* 2021). Lower ambient and surface temperatures in winter reduce the kinetic energy of molecules, thereby limiting the rate at which ammonia transitions from aqueous or adsorbed phases into the air (Ossohou *et al.,* 2023).

Significance and Contribution

This study provides evidence that integrating advanced process engineering with best available techniques (BAT) significantly reduces occupational exposure to hazardous substances such as ammonia. By demonstrating the effectiveness of emission reduction strategies, including energy-efficient ammonia production systems, granulation, retrofitting with scrubbers and bio-filters, and integration of smart IAQ monitoring and control, this research contributes valuable insights into sustainable practices in the fertilizer industry. The high compliance with PPE usage and reduced ammonia levels underscore the success of safety and environmental management systems currently in place.

Additionally, the association between work duration and specific symptoms reinforces the importance of periodic health surveillance, even under low-exposure conditions, for early detection and prevention of occupational illnesses.

Summary of Findings

The study assessed the occupational exposure to ammonia gas in a modern nitrogenous fertilizer plant and its potential health impacts on workers. Results revealed that all monitored ammonia concentrations across ten key plant locations were significantly below the ACGIH/NIOSH TLV-TWA of 25 ppm, with values ranging between 0.81 and 1.06 ppm. A slight seasonal variation was observed, with lower concentrations during winter (12–16°C) compared to spring (20–25°C) and summer (28–34°C). Technological advancements such as dual-pressure ammonia synthesis, pressure swing adsorption (PSA), acidic scrubbing, wet scrubbers, and improved granulation systems contributed to emission reductions and increased energy efficiency.

Most workers were male technicians with 10–15 years of experience, and PPE usage was high (99.4%), reflecting a strong safety culture. However, health complaints persisted, including asthma (39.3%), chronic cough (44.6%), and shortness of breath (49.4%), suggesting that even low-level chronic exposure may contribute to respiratory symptoms. Significant associations were found between job duties, PPE use, and symptom prevalence. Modern plant design and cleaner production technologies, implemented by ThyssenKrupp Uhde GmbH, have proven effective in reducing ammonia emissions, supporting occupational health and workplace environmental quality.

Limitations

Although the study presents finding certain limitations must be acknowledged:

- Cross-sectional design limits the ability to establish causal relationships between exposure and health effects.
- Self-reported symptoms may be subject to recall bias.
- Environmental measurements were limited to ammonia concentrations and did not include other potential co-pollutants or long-term biological monitoring.

The sample size was 168 workers out of 300 eligible participants, which met the corrected sample adequacy but still leaves room for broader inclusion.

CONCLUSION

The current study highlighted the role of applying modern modified industry in limiting exposure to potential occupational hazards, improving the health of the workers, and achieving sustainability. The study concludes that workers in the modern nitrogenous fertilizer plant, primarily male technicians with 10–15 years of experience, demonstrated high levels of awareness and compliance with occupational safety practices reflected in the widespread use of personal protective equipment (PPE), particularly gloves and boots. Although some health complaints were reported, the highest prevalence of ocular/nasal symptoms and the prevalence of respiratory issues were low. A statistically significant relationship was found between work duration and irritation symptoms, but not with respiratory complaints.

The study measured ammonia gas concentrations in 10 different locations within the nitrogenous fertilizer plant, including the Ammonia Plant, Urea Synthesis, Urea Granulation, Administration Building, Storehouse, Water Treatment Utilities, Compressor Area, the Area between the Ammonia and Urea Plants, and the South Factory Area. The recorded concentrations ranged from 0.81 to 1.06 ppm, all of which were well below the occupational exposure limit (TLV-TWA) of 25 ppm. The lowest concentrations were found in less industrially active areas such as the Administration Building (0.81 ± 0.03 ppm) and Storehouse, indicating minimal emission sources or good ventilation. In contrast, slightly higher concentrations were recorded in production-intensive areas such as the Urea Granulation (0.98 ± 0.01 ppm) and the Area between the Ammonia and Urea Plants (1.03 ± 0.03 ppm), likely due to proximity to active processing zones and emission points. This distribution pattern suggests a direct relationship between ammonia levels and the proximity to ammonia-handling or producing equipment, with higher concentrations closer to operational zones. However, the relatively low levels across all sites reflect the effectiveness of modern emission control technologies and facility design in maintaining safe workplace air quality.

The findings reveal a clear association between work duration and specific health symptoms, emphasizing the value of continuous monitoring and preventive strategies. It is heartening to note that from implementing the modern developed technologies as best available techniques and adoption of cleaner production technologies in ammonia manufacturing, promotes reduction and minimizing exposure to ammonia emission positively improves health of the workers in the modern modified nitrogenous fertilize industries.

RECOMMENDATIONS

In light of the results of the study, the following recommendations were suggested:

- Implementing longitudinal cohort designs to monitor the chronic effects of low-level NH_3 exposure over time.
- Expanding monitoring to include biomarkers of exposure and co-exposure to other chemicals commonly found in fertilizer production.
- Evaluating the effectiveness of training programs, maintenance protocols, and engineering controls through performance-based audits.

- Investigating gender-related vulnerabilities and inclusion strategies, as all current workers were male.

Further research on the economic impact and return on investment (ROI) of these technological upgrades could strengthen the business case for cleaner production in similar industrial settings.

Declarations

Consent to participate: Not applicable

Consent for publication: Not applicable.

Clinical trial: Not applicable.

Authors' contributions

Both authors (Safinaz M. Elhadad and Fadia A. Elmarakby) were involved in choosing the topic, writing the research proposal, and collecting data. The corresponding author analyzed data and wrote the results, discussion and the manuscript, Taher A. Mansour contributed to conceptualization, supervision, visualization, writing-review & editing. Ibrahim A. Elshibiny provided formal analysis, recommendations and suggestions by reviewing the manuscript. All authors reviewed and approved the final version.

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Competing interests

The authors declare that they do not have any financial or non-financial Competing interests.

Availability of data and materials

The datasets used and/or analyzed during the current study are accessible

From the corresponding author upon reasonable request.

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الملخص العربي

الحد من التعرض للأمونيا بين العاملين في صناعة الأسمدة باستخدام التكنولوجيا الحديثة المعدلة لتحقيق الاستدامة

صافيناز الحداد، طاهر منصور، إبراهيم الشبيني، فادية المراكبي

الخلفية: يتضمن إنتاج الأسمدة التعرض للملوثات المحمولة جوًا، بما في ذلك الغبار المعدني وغازات مختلفة مثل حمض النيتريك، وثاني أكسيد النيتروجين، وأول أكسيد النيتروجين، والأمونيا، وفلوريد الهيدروجين. تُشكل هذه المواد مخاطر مهنية محتملة، لا سيما في مناطق المعالجة.

الموضوعات والطرق: أُجريت هذه الدراسة في مصنع حديث لإنتاج الأسمدة النيتروجينية في الإسكندرية، مصر، والذي يُنتج اليوريا الحبيبية عالية الجودة (٤٦%) والأمونيا اللامائية باستخدام تقنيات متطورة. استُخدم نهج دراسة الحالة الوصفية الكمية، وجُمعت البيانات من ١٦٨ عاملًا من خلال استبيانين مُهيكلين ومُختبرين مسبقًا. غطى الاستبيان (أ) الأدوار الوظيفية وظروف النظافة في مكان العمل، بينما قيّم الاستبيان (ب) الأعراض الصحية المُبلغ عنها والوعي بالتعرض للأمونيا. رُصدت مستويات الأمونيا البيئية في عشرة مواقع للمصنع باستخدام مطياف الأشعة تحت الحمراء ذي القراءة المباشرة.

النتائج: من بين المشاركين، كان ٧٤,٤% فنيين و٢٥,٦% مهندسين. عمل معظم الفنيين في أقسام التشغيل (٦١,٦%) والصيانة (٢٥,٦%)، بينما كان معظم المهندسين في أقسام التشغيل (٧٦,٧%). عُيّن معظمهم (٧٠,٨%) في نوبات عمل نهارية، بمتوسط عبء عمل أسبوعي قدره ٤٧,٦٨ ± ١,٨٥ ساعة. أفاد جميع العمال تقريبًا (٩٩,٤%) باستخدام معدات الوقاية الشخصية، وكان جميعهم من غير المدخنين، مما يشير إلى ثقافة سلامة قوية في مكان العمل. وُجد ارتباط ذو دلالة إحصائية بين سنوات العمل والأعراض الواضحة على العين/الأنف ($p = 0.001$، 0.019، 0.009). ظلت تركيزات الأمونيا في جميع مناطق المصنع أقل من الحد الأقصى المسموح به (TLV-TWA) البالغ ٢٥ جزءًا في المليون، مما يدل على فعالية التحكم في التعرض.

الاستنتاج: تؤكد نتائج هذه الدراسة على أن تطبيق الممارسات الصناعية الحديثة، مثل استخدام تقنيات الإنتاج الأنظف، أنظمة المعالجة المتقدمة، ومعدات التحكم في الانبعاثات (كالمصافي الرطبة وأجهزة تقطير المكثفات)، قد ساهم بشكل فعّال في تقليل مستويات التعرض المهني لغاز الأمونيا داخل بيئة العمل.

هذا الانخفاض الملحوظ في تركيزات الغازات الضارة يعكس التزام المصنع بمعايير الصحة والسلامة المهنية، ويؤدي إلى تقليل المخاطر الصحية المزمنة التي قد تصيب العاملين، خاصة الأمراض التنفسية. كما تسهم هذه الإجراءات في تعزيز كفاءة الطاقة وتقليل الانبعاثات الكربونية، مما يدعم توجهات الاستدامة البيئية والاقتصادية على المدى الطويل في صناعة الأسمدة.

الكلمات المفتاحية: إنتاج الأسمدة، التكنولوجيا الحديثة المُعدّلة، التعرض للأمونيا، الاستدامة، مصر.