CHEMICAL ENGINEERING TRANSACTIONS

VOL. 115, 2025

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Carlo Pirola, Antonio Espuña, Sabrina Copelli

ISBN 979-12-81206-16-8; **ISSN** 2283-9216

DOI: 10.3303/CET25115007

Occupational and Environmental Risks of N-Hexane in Industries: a Review on Risk and Regulatory Perspectives

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N-hexane, which is a volatile hydrocarbon, is widely utilized as a solvent in various industrial operations. However, its neurotoxic potential is a major concern, especially in the occupational workplace. Acute health and chronic consequences, including irritation of the eyes and respiratory tract, peripheral neuropathy, and cognitive impairments, can affect workers in the related sectors. Those in susceptible populations, such as those who work in exposed environments, are more likely to experience neuro-related health problems. Since it is a volatile organic chemical, n-hexane is a potential fire hazard, pollutant of soil and air, and possibly harmful to aquatic habitats. Considering these potential dangers of N-hexane to human and environmental health, regulatory efforts have mostly focused on reducing emissions and improving exposure management. Through a comprehensive review, this study assesses countermeasures by enumerating the environmental and health hazards and solutions associated with N-hexane in industrial exposure.

1. Introduction

N-hexane (C_6H_{14}) has properties that make it useful as a solvent in adhesive and cleaning agent compositions, which is commonly used in plastic manufacturing and its supply chain. When applying the solvent or handling goods containing it, workers risk inhaling n-hexane particle fumes or coming into direct skin contact with the solvent. Some plastics are dissolved or separated in recycling processes using n-hexane, which might expose workers to the chemical directly. Acute and chronic health impacts are possible outcomes of exposure to n-hexane. Headaches, nausea, and vertigo are some of the symptoms that may occur after acute exposure at workplaces. The symptoms of peripheral neuropathy, including tingling, weak muscles, and poor motor coordination, have been associated with long-term exposure, especially in the workplace. Neurological symptoms are more common in industrial processes where n-hexane is used in adhesives, such as shoe manufacture, according to studies (Sendur et al., 2009).

On top of that, n-hexane as a chemical is harmful to the environmental ecosystem. It is a VOC (Volatile organic compound) that releases harmful gases into the air and has the potential to cause the creation of smog-inducing ground-level ozone. Soil and water bodies can be contaminated by n-hexane due to improper disposal or unintentional discharges, which can have a negative impact on ecosystems. Its flammability makes it a potential fire hazard in commercial and industrial environments. The risks of n-hexane have prompted regulatory bodies to set standards for limiting exposure. For the sake of worker protection, the United State's Occupational Safety and Health Administration (OSHA) has established allowable exposure levels. Similarly, to reduce the negative effects on air quality, environmental organizations keep an eye on n-hexane emissions and control them as needed through local and global regulations. Industries that utilize n-hexane must adhere to fundamental safety measures, which include the implementation of sufficient ventilation, personal protection equipment, and frequent monitoring. Following the layout in Figure 1, this study investigates the many facets of the environmental and health concerns connected with n-hexane. The goal of the work is to identify and comprehend the dangers of n-hexane by comprehending recent relevant studies and regulations and then discussing mitigation pathways to lessen those dangers.

Paper Received: 02 July 2024; Revised: 12 October 2024; Accepted: 19 January 2025
Please cite this article as: Kumar B., Deak C., 2025, Occupational and Environmental Risks of N-hexane in Industries: a Review on Risk and Regulatory Perspectives, Chemical Engineering Transactions, 115, 37-42 DOI:10.3303/CET25115007

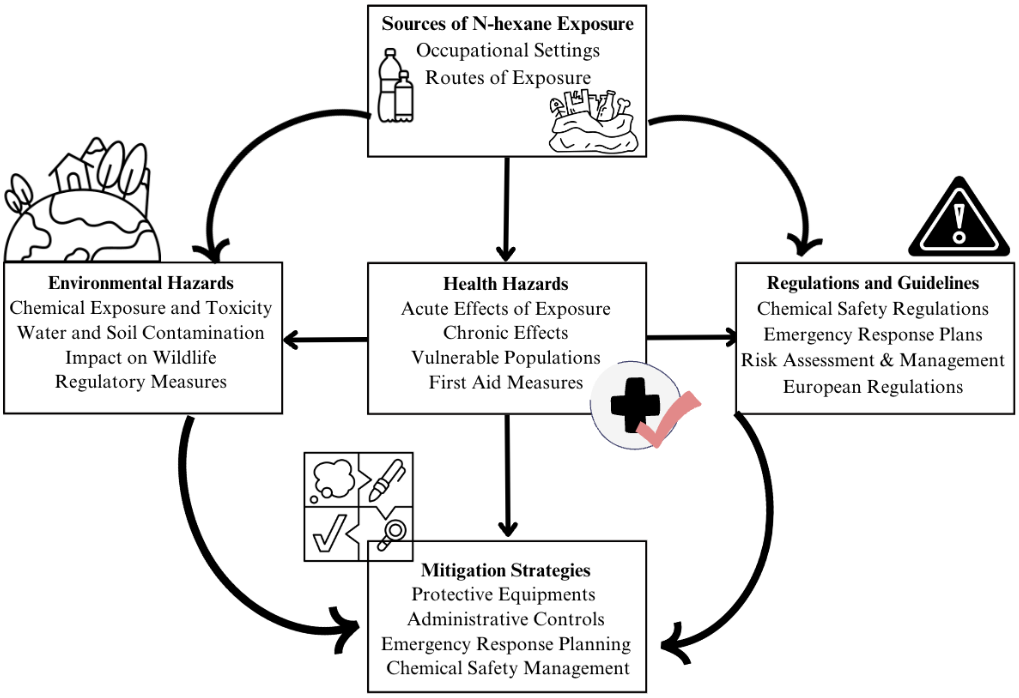

Figure1. The various facets of the hazards related to N-hexane are considered in the present study.

2. Environmental Hazards

In the manufacturing of polymers, shoes, etc. particularly during extraction and recovery operations in manufacturing setups, the release of n-hexane into the environment can cause secondary pollutants such as ozone and photo chemicals to develop. It is known that inhalation and exposure to it can cause neurological damage, this transition not only adds to air pollution but also directly offers direct health hazards to workers and the surrounding population. In many environments, the mobility and durability of n-hexane enhance its environmental influence and create nerve causes of motor and sensory neurological dysfunction, which shows as hypodynamic and numbness of distal extremities (X. Zhang et al., 2021). Significant sources of this pollutant, chemical facilities, and industries using n-hexane help to explain why it accumulates in the atmosphere. Long-term n-hexane exposure has been linked to peripheral neuropathies, which emphasizes its possibility to create chronic health problems among plastic manufacturing industry employees (LoPachin & Gavin, 2015). Moreover, n-hexane's presence in the surroundings might impede the biodegradation of other contaminants as it generates steric obstacles that restrict their availability to processes of microbial degradation (Gatti et al., 2017).
Apart from its direct medical consequences, n-hexane's presence in the production sector begs questions about how it interacts with other environmental pollutants. When n-hexane is present in mixes with other hydrocarbons, for example, it might change the adsorption properties of these compounds on surfaces like zeolites, therefore perhaps influencing their environmental behavior and toxicity. Furthermore, the use of n-hexane as a solvent in the extraction of different materials, including food items, begs problems concerning its residual presence in final products and the consequent consequences for human health and ecological safety (Cravotto et al., 2022).
In addition to the typical industrial atmospheres, the Spacecraft Maximum Allowable Concentrations (SMACs) for C2-C9 alkanes that were established by NASA in 2008 under the direction and approval of the National Research Council notably excluded SMACs for n-hexane. n-Hexane, in contrast to other C2-C9 alkanes, has the potential to induce polyneuropathy in humans or rodents following its metabolism. As a result, it necessitates the implementation of stricter SMACs than the other members of this group do.
Table 1. Presents a brief list of primary environmental hazards related to N-hexane.

Table 1: Identified environmental hazards of using N-hexane in industries

Type of health hazard	Consequences
Air Pollution	N-hexane being a VOC, plays a significant role in the formation of ground-level ozone and smog upon its release into the atmosphere, thereby affecting air quality and posing risks to human health.
Contaminated soil	Releases or seepages of n-hexane have the potential to compromise soil integrity, resulting in a decline in soil quality and posing risks to soil-dwelling organisms, farming and vegetation.
Aquatic/water toxicity	Release of of n-hexane into aquatic environments via industrial runoff leads to its persistence in groundwater, subsequently contaminating sources of drinking water and presenting significant health risks to human populations. Furthermore, exposure has the potential to result in bioaccumulation within fish and various aquatic organisms, thereby disturbing local water ecosystems.
Climate change	As a VOC, n-hexane emissions can indirectly influence global warming through their involvement in reactions that generate greenhouse gases such as ozone.
Flammability hazard	It exhibits a significant propensity for combustion, and its vapors have the potential to create explosive combinations with atmospheric air, thereby presenting considerable risks of fire and explosion that could result in environmental degradation and contamination stemming from fire suppression activities.

3. Health hazards

When workers are exposed to n-Hexane continuously for long hours, it can result in chronic or subchronic poisoning, primarily affecting the peripheral nervous system through its metabolite, 2,5-hexanedione (HD). In the past, between the years 1983 and 1985, printing companies in the Taipei region had an epidemic of n-hexane polyneuropathy as a result of occupational exposure (Chang, 1987). One of the well-known causes of peripheral neuropathy is chronic exposure to n-hexane. Workers at shoe and bag companies that do not have enough air often get this form of neuropathy. An experiment conducted in Portugal in 2001 on employees of the shoe industry found a significant association between n-hexane exposure and 2,5 HD in urine, as shown by a substantial correlation coefficient (Mayan et al., 2001). The results of the multiple regression analysis showed that both the concentration of 2,5 HD and the co-exposure to other solvents could be strongly predicted by exposure to n-hexane.

Table 2: Identified primary health hazards of occupational workers exposed to N-hexane

Type of health hazard	Consequences	References
Neurological Effects	Chronic exposure can lead to peripheral neuropathy, characterized by numbness, tingling, muscle weakness, and impaired motor coordination, particularly in the extremities.	(Sendur et al., 2009b)
Respiratory Irritation	Inhalation of n-hexane vapours may cause irritation of the respiratory tract, leading to coughing, shortness of breath, and chest discomfort.	(Kumar & Pandey, 2024)
Central Nervous System Depression	Acute exposure to high concentrations can result in dizziness, headache, nausea, and, in severe cases, unconsciousness.	(L. J. Zhang et al., 2023)
Dermal Effects	Prolonged skin contact may cause irritation, dryness, and dermatitis due to the defatting action of n-hexane.	(Arast et al., 2024)
Ocular Irritation	Exposure to n-hexane vapours or liquid can cause eye irritation, redness, and tearing.	(Khan et al., 2021)
Reproductive Effects	Some studies suggest that high levels of exposure may affect reproductive health, though evidence in humans is limited.	(Ruiz-García et al., 2020)

Greater urine 2,5 HD concentrations resulted from co-exposure. Particularly in areas like Shenzhen and Guangdong Province, China, outbreaks of chronic n-hexane poisoning have also been recorded in small and micro firms within the electronics and printing sectors throughout 2009–18 (Hu et al., 2024).

Also, n-hexane is used as a degreasing agent in industries other than plastic manufacturing (Baldasseroni et al., 2003). Recent years have seen reports of occupational intoxication in several countries such as the USA, Japan, Italy, etc., where the workers suffered hugely. Table 2 identifies the most severe health problems noticed among the workers. It has been demonstrated that exposure to n-hexane in industrial settings can lead to subfertility and menstrual disorders. Furthermore, considering the correlations observed between individual exposure to n-hexane and levels of FSH (follicle-stimulating hormone), as well as the correlation between 2,5-HD and FSH levels in women who have been exposed to oligomenorrhea, a recent study has demonstrated that n-hexane is possibly one of the volatile organic compounds (VOCs) that can act as an endocrine disruptor. These findings suggest the dire consequences of n-hexane exposure irrespective of men or women workers.

4. Regulations and Guidelines

The European Chemical Agency (ECHA) recognizes N-hexane as a substance that must be registered under the REACH Regulation, with its production and/or importation within the European Economic Area occurring at quantities ranging from 1,000 to less than 10,000 tonnes annually. In the United States, the permissible exposure limits in the workplace are established by OSHA (Occupational Safety and Health Administration) The legally established airborne permissible exposure limit (PEL) is set at 500 ppm, calculated as an average over an 8-hour work shift. The National Institute for Occupational Safety and Health (NIOSH) advises that the suggested airborne exposure limit (REL) is 50 ppm, calculated as an average over a 10-hour work shift. The American Conference of Governmental Industrial Hygienists (ACGIH): The threshold limit value (TLV) is established at 50 ppm, calculated as an average over an 8-hour work shift. These exposure limits pertain exclusively to airborne concentrations. In instances where skin contact is present, there exists a possibility of overexposure despite air concentrations being below the limits. Table 3 compiles the latest and most relevant regulations in curbing the health and environmental hazards of n-hexane. It is observed that regulations often lack specific mandates for environmental monitoring and remediation for areas surrounding industrial facilities. Soil and groundwater contamination from accidental spills, for example, receive less attention in regulatory frameworks, leaving gaps in accountability for long-term environmental impacts. Moreover, there is insufficient regulatory focus on lifecycle management, such as how industries dispose of or treat n-hexane waste to prevent it from entering ecosystems. Expanding regulations to include not only workplace safety but also environmental sustainability would encourage industries to develop more comprehensive risk management practices.

Table 3: Recent regulations adopted by institutions to limit the use and safe handling of N-hexane

Type of regulation/policy	Consequences	References
REACH Regulation (EC) 1907/2006	Registration, Evaluation, Authorisation, and Restriction of Chemicals; n-hexane is registered under this regulation, requiring manufacturers and importers to provide safety information.	(ECHA, 2023)
Commission Delegated Regulation (EU) 2024/2564	Amends Regulation (EC) No 1272/2008 regarding the harmonized classification and labelling of certain substances, including n-hexane.	(EU commission, 2024)
Workplace Hazardous Materials Information System (WHMIS)	Classifies n-hexane as a hazardous substance, mandating proper labelling and safety data sheets for workplace use.	(CNESST, 2024)
Permissible Exposure Limit (PEL)	Sets an 8-hour time-weighted average (TWA) exposure limit of 500 ppm for n-hexane in the workplace.	(NJ Health Department, 2012)
Safe Work Australia Exposure Standards	Establishes an 8-hour TWA exposure limit of 20 ppm for n-hexane to protect worker health.	(Safe work Australia, 2024)
Industrial Safety and Health Act, Occupational Safety and Health Administration (OSHA)	Regulates the handling of hazardous substances, including n-hexane, requiring employers to implement safety measures and monitor exposure levels.	(OSHA, 2022)

5. Conclusion (Mitigation strategy)

In the plastics or shoe manufacturing sector, reduced N-hexane use is unavoidable. While existing studies have explored various mitigation strategies for N-hexane exposure, there remains a gap in the comprehensive integration of alternative solvents, engineering controls, and long-term environmental remediation methods. This work aims to bridge that gap by not only emphasizing the need for safer solvent replacements but also highlighting the importance of workplace interventions such as ventilation, automation, and phytoremediation.

By addressing both immediate and long-term risks, this study provides a structured approach that aligns with sustainability goals while ensuring worker safety and regulatory compliance. A major precursor of ozone, N-hexane is a saturated aliphatic hydrocarbon. N-hexane is being broken down via research; a new double dielectric barrier discharge (DDBD) reactor design is under development and pilot-scale testing (Li et al., 2024). Change n-hexane with safer solvents first to reduce environmental impact and health risks. Supercritical carbon dioxide, water-based solvents, bio-based solvents such as Rhodiasolv have low VOC emissions and strong solubility (Marino et al., 2018). Another sensible extraction method is supercritical carbon dioxide as it has a low environmental impact and may find usage in various industrial sectors. Adopting green, Renewable-based biological solvents lowers petrochemical dependency and advances sustainability. Such solutions foster environmental responsibility and worker safety, therefore establishing a safer, more sustainable workplace. Industrial environments have to have effective methods of ventilation. Good ventilation systems catch and eliminate n-hexane vapours at the source, therefore lowering inhaling risk. Excellent for catching vapors as they are emitted is local exhaust ventilation. Increasing workplace ventilation helps to avoid the accumulation of residual vapours, therefore improving workers' health. Automating processes helps to lower manual handling, a main cause of n-hexane contacts and inhalation hazards. Closed solvent transfer and storage systems Stop vapor leaks to safeguard employees. Automation minimizes solvent handling processes, therefore lowering exposure frequency and duration. Apart from safeguarding employees, engineering controls can help to improve operational effectiveness and simplify processes. One extra layer of protection the plastic sector has to follow is occupational PPE. Retaining workplace in industrial workplace safety calls for risk analyses and monitoring. Early health issues and quick fixes made possible by worker health assessments for n-hexane exposure enable Monitoring air quality and exposure levels to quickly react to changes in n-hexane concentration, therefore minimizing worker injury. It is observed that in areas affected by long-term pollution, it is suggested that phytoremediation, helps in reducing the levels of n-hexane in the soil and groundwater. Phytoremediation is a low-cost, time-consuming process that improves soil health and biodiversity over time. The OSHA rules mandate that countries like the USA allowable exposure limits (PELs) to protect workers from chemical contact. These rules define safe handling and workplace n-hexane monitoring and management. Following these guidelines helps companies meet safety criteria and stay out of legal hotbeds. A comprehensive strategy is required to curb the negative connotations of n-hexane. Further industry may reduce the risks to human and environmental health from n-hexane by following these practices: improving ventilation, implementing engineering controls, using personal protective equipment (PPE), conducting risk assessments and training and awareness programs, engaging in phytoremediation, and complying with regulatory guidelines. By taking a comprehensive and proactive approach to n-hexane chemical toxicity, industries can ensure a future free of harm to both workers and the environment.

Acknowledgments

The research was supported by the National Research, Development, and Innovation Office (NKFIH), NKFIH Identifier: 135854.

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