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(Review Article)

Risks of inorganic chemicals: A comprehensive and current review from an occupational health and safety perspective

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Abstract

Inorganic chemicals are fundamental components of industrial production, playing a critical role in numerous sectors. However, the processes of their production, transport, storage, and use pose serious and multifaceted threats to occupational health and safety (OHS). This review paper provides an in-depth examination of the risks associated not only with heavy metals, acids, bases, and toxic gases but also with other widely used inorganic substances in industry, such as fibrous silicates like asbestos, crystalline silica dust, ammonia, cyanides, and hydrofluoric acid. The paper highlights the relationship between acute hazards, such as poisoning, chemical burns, explosions, and fires, and chronic diseases with long latency periods, including silicosis, asbestosis, manganese, and occupational cancers. National and international legislation, best practice standards, and the risk management hierarchy are discussed in light of current and historical industrial accidents, such as the Beirut Port Explosion, to present a holistic safety perspective. This study posits that working safely with inorganic chemicals is not merely a legal obligation but an ethical responsibility that requires a proactive and knowledge-based risk management culture.

Keywords: Inorganic Chemicals; Occupational Health and Safety; Occupational Diseases; Risk Management; Asbestos; Silica; Chemical Safety

1. Introduction

Globally, millions of employees are exposed to chemical substances in their workplaces, making it one of the leading causes of occupational diseases and accidents. The European Agency for Safety and Health at Work ([EU-OSHA], 2018) reports that approximately 38% of workplaces in Europe involve potentially hazardous chemical or biological substances. Inorganic chemicals, which constitute a significant portion of these substances, are indispensable in key sectors such as metallurgy, mining, construction, the chemical industry, agriculture, and energy production. However, under uncontrolled conditions, they can lead to both sudden industrial accidents and insidiously progressive occupational diseases. The International Labour Organization ([ILO], 2019) confirms that occupational exposure to hazardous chemicals leads to hundreds of thousands of premature deaths and chronic illnesses annually. Therefore, OHS management systems must proactively address not only chemicals with acute toxicity but also substances that cause chronic, irreversible diseases, such as asbestos, silica, and manganese.

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2. Results and Discussion

2.1. Effects on Employee Health: An In-depth Analysis

The health effects of inorganic chemicals exhibit acute or chronic profiles depending on the substance's chemical structure, route of exposure, duration, and concentration.

- **Heavy Metals (Pb, Hg, Cd, Cr (VI), As, Mn):** Classic heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As) lead to systemic poisoning. Additionally, **Hexavalent Chromium (Cr(VI))**, encountered in processes like metal plating and welding, is classified as a Group 1 carcinogen by the International Agency for Research on Cancer ([IARC], 2012) and is a known cause of lung cancer. Exposure to fumes of manganese (Mn), particularly found in welding rods and steel production, can affect the central nervous system, leading to **Manganese**, a condition with symptoms similar to Parkinson's disease (National Institute for Occupational Safety and Health [NIOSH], 2016).
- **Acids and Bases (H_2SO_4, HCl, NaOH, HF):** Substances like sulfuric acid and caustic soda cause severe chemical burns. One of the most dangerous substances in this group is **Hydrofluoric Acid (HF)**. Used in glass etching and the electronics industry, HF, unlike conventional acids, penetrates deep into tissues upon skin contact, can damage bone, and upon entering the bloodstream, can cause fatal cardiac arrhythmias by depleting systemic calcium levels (Centers for Disease Control and Prevention [CDC], 2021).
- **Toxic Gases and Vapors (CO, Cl_2, H_2S, NH_3, NOx):** Alongside well-known toxic gases like CO, Cl_2, H_2S, and NH_3, **Nitrogen Oxides (NOx)** and **Ozone (O_3)**, which are generated during welding and metal cutting, pose an insidious threat. These gases are severe respiratory irritants that can lead to pulmonary edema and chemical pneumonitis upon inhalation.
- **Fibrous Silicates (Asbestos):** Inhalation of asbestos fibers leads to incurable diseases such as asbestosis, lung cancer, and mesothelioma. The global scale of this danger is highlighted by the World Health Organization ([WHO], 2014), which estimates that over 125 million people are exposed to asbestos at work annually and that more than 107,000 die each year from asbestos-related diseases.
- **Crystalline Silica Dust (SiO_2):** Silica dust, a major risk for workers in sectors like mining, construction, and foundries, causes **silicosis**. The difficulties in preventing this disease and its prevalence make it one of the most significant occupational health challenges of the 21st century.
- **Cyanides (NaCN, KCN):** Used in gold mining and metallurgy, cyanides can cause death within minutes by blocking cellular respiration. Accidental contact with acids in these facilities carries the potential for a catastrophic release of hydrogen cyanide (HCN) gas, which could lead to mass fatalities.

2.2. Physical and Chemical Workplace Risks

Beyond reactivity and corrosion, these risks can lead to massive disasters resulting from improper storage and negligence. The storage of oxidizers like ammonium nitrate near incompatible chemicals or heat sources exponentially increases the risk of explosion.

2.3. Historical and Current Industrial Accidents

Inadequate safety measures in industrial activities have historically led to disasters with devastating consequences for both workers and the environment. These cases are tangible proof of how theoretical chemical risks can manifest as real-world tragedies.

- **Texas City Disaster (1947, USA):** Considered the deadliest industrial accident in U.S. history, this event began when approximately 2,300 tons of ammonium nitrate aboard a ship in the port caught fire and subsequently detonated. The explosion triggered a catastrophic chain reaction, igniting another ship carrying ammonium nitrate and nearby chemical facilities, resulting in the deaths of nearly 600 people and injuring thousands. This disaster led to a fundamental overhaul of safety regulations for the storage and transportation of ammonium nitrate in the United States (Kletz, 1994).
- **Hawk's Nest Tunnel Disaster (1930, USA):** The deaths of hundreds of workers from acute silicosis due to intense silica dust exposure under inadequately ventilated conditions demonstrated the devastating industrial scale of this disease.
- **The Global Asbestos Tragedy:** Although not a single event, the widespread use of asbestos throughout the 20th century is considered a slow-moving industrial disaster that has resulted in millions of occupational disease cases.

- **Baia Mare Cyanide Spill (2000, Romania):** The collapse of a tailings dam at a gold mine released approximately 100,000 cubic meters of toxic water contaminated with cyanide and heavy metals into the Tisza and Danube rivers. The spill caused massive fish kills and resulted in one of Europe's worst environmental disasters, affecting Hungary and Serbia as well. The event highlighted the critical importance of waste management and dam safety in mining operations (United Nations Environment Programme [UNEP], 2000).
- **Ajka Alumina Plant Accident (2010, Hungary):** A wall of a waste reservoir at an aluminum plant collapsed, releasing nearly one million cubic meters of "red mud." This highly alkaline (caustic) industrial waste, containing heavy metals, flooded several villages, causing 10 deaths, chemical burns in hundreds of people, and contaminating large agricultural areas and rivers. The accident drew attention to the structural safety risks associated with the storage of large-volume industrial waste (European Commission, 2011).
- **2020 Beirut Port Explosion (Lebanon):** The detonation of approximately 2,750 tons of ammonium nitrate, which had been stored unsafely in a warehouse for years, killed over 200 people, injured thousands, and left a large part of the city in ruins. This event is the most tragic recent evidence of the vital importance of chemical storage safety and regulatory oversight (United Nations Development Programme [UNDP], 2021).

2.4. Legislation and Standards

International frameworks from the ILO, the Occupational Safety and Health Administration ([OSHA]), and the EU (REACH, CLP) form the foundation of chemical safety. These regulations are supported by specific exposure limits. For example, in the United States, OSHA has set the Permissible Exposure Limit (PEL) for respirable crystalline silica at a very low level of 50 micrograms per cubic meter (50μg/m3) as an 8-hour time-weighted average (OSHA, 2016). In Turkey, specific regulations such as the Regulation on Health and Safety Measures in Works with Asbestos (Republic of Turkey Ministry of Family, Labour and Social Services, 2013a) are in force.

2.5. Risk Management and Preventive Approaches

Effective chemical management should be based on the Hierarchy of Controls principle, championed by institutions like NIOSH. This hierarchy ranks interventions from most to least effective:

- **Elimination/Substitution:** The most effective method. For example, using asbestos-free alternatives for brake pads.
- **Engineering Controls:** Isolate the hazard at its source. Examples include closed systems, local exhaust ventilation (LEV), automating hazardous processes, constructing **blast walls** in chemical storage areas, and installing **interlock systems** that prevent machinery from operating if ventilation is off.
- **Administrative Controls:** Include safe work procedures, training, job rotation, and emergency plans.
- **Personal Protective Equipment (PPE):** Should be used as a last resort. Correctly selected and used PPE (e.g., having special calcium gluconate gel available and wearing appropriate gloves for HF) is of vital importance.

3. Conclusion

Inorganic chemicals will remain an integral part of modern industry. However, the risks associated with these substances are not limited to acute and visible dangers. They span a wide spectrum, from devastating explosions like the one in Beirut to the slow progression of manganism in welders or silicosis in miners. The effective management of these risks is possible through a robust legal framework, proactive measures based on the hierarchy of controls, and continuous training and supervision. The lessons from historical and recent accidents clearly show that chemical safety cannot be achieved with a reactive approach but only through a preventive and holistic OHS culture.

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