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COMPREHENSIVE OVERVIEW OF OCCUPATIONAL HEALTH AND SAFETY PRACTICES IN PETROCHEMICAL FACILITIES

PETROKİMYA TESİSLERİNDE İŞ SAĞLIĞI VE GÜVENLİĞİ UYGULAMALARINA KAPSAMLI BİR BAKIŞ

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Review
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Abstract
The petrochemical industry holds critical importance in terms of occupational health and safety (OHS) due to its intensive chemical processes and high-risk working environments. This review comprehensively examines chemical, physical, ergonomic, and psychosocial risk factors specific to the sector; common occupational accidents and diseases; national and international legislative frameworks; OHS management systems such as ISO 45001; training practices; and technological advancements. In addition, successful strategies are evaluated through national and global best practice examples and case studies. While the study identifies current problem areas, it also offers strategic, technological, and cultural-level recommendations to improve the sector's OHS performance. Ultimately, establishing a sustainable safety culture in the petrochemical industry requires not only regulatory compliance but also the integration of digital solutions, behavioral approaches, and governance-based systems.

Keywords: ISO 45001, Occupational health and safety, Occupational diseases, Petrochemical industry, Safety culture

Öz
Petrokimya sektörü, yoğun kimyasal süreçler ve yüksek tehlike sınıfındaki çalışma ortamları nedeniyle iş sağlığı ve güvenliği (İSG) açısından kritik öneme sahiptir. Bu derleme çalışmasında; sektöre özgü kimyasal, fiziksel, ergonomik ve psikososyal risk faktörleri; sık görülen iş kazaları ve meslek hastalıkları; Türkiye ve dünya genelindeki yasal mevzuatlar; ISO 45001 gibi İSG yönetim sistemleri; eğitim uygulamaları ve teknolojik gelişmeler detaylı biçimde incelenmiştir. Ayrıca ulusal ve uluslararası iyi uygulama örneklerine ve vaka analizlerine yer verilerek başarılı stratejiler değerlendirilmiştir. Çalışma, mevcut sorun alanlarını ortaya koymakla birlikte, sektörün İSG performansını artırmaya yönelik stratejik, teknolojik ve kültürel düzeyde öneriler sunmaktadır. Sonuç olarak, petrokimya sektöründe sürdürülebilir bir güvenlik kültürünün inşası için sadece mevzuat uyumu değil, aynı zamanda dijital çözümler, davranışsal yaklaşımlar ve yönetişim temelli sistemler gereklidir.

Anahtar Kelimeler: ISO 45001, İş sağlığı ve güvenliği, Meslek hastalıkları, Petrokimya sektörü, Güvenlik kültürü

1. Introduction

Petrochemical facilities are industrial areas where chemicals with high flammability potential are processed, stored, and transported. By their very nature, this sector simultaneously encompasses numerous chemical, physical, ergonomic, and psychosocial risk factors, making it an extremely critical and multidisciplinary area of intervention in terms of occupational health and safety (OHS). However, a review of the current literature reveals that studies on OHS practices in the petrochemical sector are limited in number; moreover, the existing studies are either confined to technical measures alone or fail to present a comprehensive OHS analysis on a sectoral basis.

This review aims to systematically address OHS risk factors encountered in petrochemical facilities, with the dual goal of providing a thorough assessment of the current situation and filling this significant gap in the literature. By examining topics such as health risks arising from chemical exposures, fire and explosion hazards, confined space operations, the effective use of personal protective equipment, worker training, and the establishment of an OHS culture from an integrated perspective, this review seeks to contribute to the development of a sustainable and proactive OHS approach in the sector.

In addition, this study aims to serve as a reference for both academic circles and practitioner institutions, while also assisting decision-makers in formulating risk-based preventive strategies. In this respect, the review not only summarizes existing knowledge but also offers strategic recommendations aimed at solving practical problems encountered in the field, thereby providing an application-oriented contribution to the literature.

The petrochemical sector is an energy-intensive and high-risk industrial field that converts raw materials derived from petroleum and natural gas into various chemical products. Production processes in these facilities are typically carried out using reactor systems that involve high temperatures, pressure, and volatile chemicals. The complex structure of these plants comprising refineries, cracker units, polymerization plants, and auxiliary support units necessitates intensive occupational safety management both technically and organizationally. Due to these characteristics, the petrochemical industry creates an environment with significant physical, chemical, and psychosocial hazards for workers (Achumie et al., 2022) . Occupational health and safety (OHS) is not only a legal obligation in this sector but also a strategic necessity in terms of production continuity and human resource protection. Petrochemical workers are frequently exposed to toxic substances such as benzene, toluene, and ethylene, which can lead to respiratory diseases, skin disorders, and even cancers (Fassio et al., 2022). Furthermore, the likelihood of high-impact incidents such as gas leaks, fires, and explosions is considerably high in this sector (Cheng et al., 2013). It has also been shown that there is a direct correlation between workers' awareness and knowledge of OHS and the frequency of accidents. A study conducted at a petrochemical facility in Iraq revealed that experienced and trained workers possessed a higher level of OHS awareness, which was effective in preventing accidents (Yaas & Al-Jammas, 2018). Similarly, a study in Malaysia identified a positive correlation between knowledge level and safe attitudes (Mukhtar et al., 2020). The purpose of this review article is to comprehensively address occupational health and safety issues in the petrochemical sector by examining current risk factors, accidents, legislation, technological developments, and best practice examples through the lens of academic literature. Additionally, the study will touch upon topics such as the development of safety culture, effectiveness of training, and future research needs to provide a well-rounded assessment for the sector.

2. Risk Factors in Petrochemical Facilities

Workers in this sector are exposed to toxic chemicals, flammable materials, intense physical conditions, repetitive motions, and psychosocial stressors. Accurately identifying and managing these risks plays a critical role in preventing occupational accidents and diseases (Jahangiri et al., 2018).

2.1. Chemical risks

Employees at petrochemical plants are exposed to many volatile organic compounds, especially benzene, toluene, xylene, ethylene, and propylene. These substances can enter the body via inhalation, leading to acute poisoning, or through skin contact, causing dermatitis. Long-term exposure significantly increases the risk of hematological cancers such as leukemia (Jephcote et al., 2020). Additionally, the accumulation of evaporated chemicals in enclosed spaces dramatically increases the risk of fire and explosion (Lu et al., 2016).

2.2. Physical risks

Physical hazards include noise, high temperatures, vibration, and radiation. High-decibel noise from equipment such as compressors, piping systems, and reactor units can lead to hearing loss (Jahangiri et al., 2018). Moreover, heat stress, resulting in symptoms like fainting and headaches, is common among workers in open-air areas during summer. Elevated temperatures have also been linked to sleep disorders. Workers who are on rotating shifts for more than 40 hours per week frequently report high stress and sleep deprivation (Wu et al., 2024).

2.3. Ergonomic risks

Ergonomic strain from lifting heavy loads, working in confined spaces, and performing repetitive hand-arm movements can cause musculoskeletal disorders such as herniated discs in the back and neck. A study reported that the most common ergonomic complaints were lower back pain and muscle spasms (Majidi et al., 2022).

2.4. Psychosocial risks

Shift work, long hours, high responsibility, and hazardous working environments contribute to chronic stress, sleep disorders, and job dissatisfaction among workers. These psychosocial factors are considered contributors to both mental health issues and accident risks (Ren et al., 2018). Stress has also been associated with cardiovascular diseases, and higher rates of hypertension and heart disease have been reported in certain occupational groups (Gimaeva et al., 2020).

Table 1. Key Risk Factors in Petrochemical Facilities

Risk Factor	Description	Examples / Potential Effects
Chemical Hazards	Exposure to hazardous or toxic chemicals during processing, storage, transfer, or maintenance activities.	Solvent vapors; acid/base splashes; carcinogens (e.g., benzene); hydrogen sulfide (H_2S); corrosive mists.
Fire & Explosion Hazards	Presence of flammable/combustible materials and process conditions that can lead to ignition, flash fire, or vapor cloud explosion.	Gas or vapor leaks; static discharge; overpressure events; improper hot work.
Physical Hazards	Harmful physical agents or environmental conditions in the workplace.	Excessive noise; vibration; heat or cold stress; radiation; high-pressure releases.
Ergonomic Hazards	Work design, tools, and manual handling tasks that strain the body.	Manual lifting; awkward postures; repetitive tasks; control room workstation layout issues; fatigue-related musculoskeletal disorders.
Psychosocial Hazards	Work-related stressors affecting mental health, decision-making, and safety behavior.	Shift work/rotating schedules; high workload; emergency response pressure; fatigue; burnout.
Confined Space Entry	Restricted entry/exit areas that may contain oxygen-deficient or toxic atmospheres and other hidden hazards.	Storage tanks; reactors; pits; asphyxiation; toxic gas exposure; engulfment.
Working at Heights	Tasks performed on elevated structures without adequate fall protection.	Platform or scaffold falls; ladder incidents; dropped objects causing injury.
Electrical Hazards	Unsafe electrical systems, equipment faults, or contact with energized parts.	Shock; arc flash; short circuits; fire from faulty wiring or poor grounding.
Machinery & Equipment	Mechanical hazards from moving parts, stored energy, or inadequate guarding/maintenance.	Caught-in/between injuries; crush points; rotating shafts; pinch points; unexpected startup.

3. Occupational Accidents and Diseases

The petrochemical sector is one of the industries with the highest risk in terms of occupational accidents and diseases. Handling flammable, explosive, and toxic substances, using complex machinery, and working in confined spaces pose numerous threats to occupational health and safety. Most accidents in this sector involve high impact incidents such as explosions, fires, poisonings, and mechanical injuries (Cheng et al., 2013). According to data, accidents in refineries and petrochemical complexes are largely caused by equipment failures, leaks, human errors, and inadequate maintenance activities.

3.1. Occupational diseases

In terms of occupational diseases, workers in petrochemical plants are primarily affected by respiratory illnesses, skin conditions, and certain types of cancer resulting from prolonged chemical exposure. A study conducted in Italy reported the most common occupational diseases in this sector as hearing loss (25.3%), musculoskeletal disorders (22.9%), and malignant tumors (19%) (Campo, 2013). Workers exposed to asbestos, in particular,

showed significantly higher rates of pleural diseases and lung cancer (Innocenzi et al., 2013).
Another large-scale analysis emphasized that acute poisonings remain a serious issue in the sector. Exposure to substances such as ammonia, hydrogen sulfide, and aromatic hydrocarbons continues to result in cases of acute poisoning, with some incidents affecting large groups of workers simultaneously (Muldasheva et al., 2024). These situations jeopardize both worker health and the operational safety of the facilities.

3.2 Occupational accidents

The frequency and severity of accidents are also linked to individual characteristics of workers. A study conducted in Iran found that young, less educated, and inexperienced workers were more likely to be involved in accidents. Furthermore, factors such as smoking, sleep disorders, and a high body mass index were associated with increased accident risk (Jafari et al., 2018).
Another study conducted in Italy between 2002 and 2011 showed that although the overall rate of occupational accidents had declined, the proportion of accidents resulting in death or permanent disability had remained unchanged. This indicates that while safety measures may be effective in reducing minor incidents, they are still insufficient in preventing serious accidents (Giacobbe, 2013).

3.2.1. Engineering controls

- Use of explosion-proof equipment (Ex-proof systems)
- Installation of gas and smoke detectors, as well as fire alarm systems
- Removal of toxic gases through adequate ventilation systems
- Regular inspection and maintenance of pressurized systems
- Implementation of grounding and lightning protection systems to prevent static electricity buildup

3.2.2. Use of personal protective equipment (PPE)

- Flame-retardant work clothing
- Chemical-resistant gloves and safety goggles
- Respiratory protection (gas masks, filter masks)
- Steel-toe safety shoes and helmets
- Hearing protectors in high-noise environments

3.2.3. Continuous monitoring and inspection

- Continuous gas monitoring in work areas
- Automated monitoring of process parameters and alarm systems
- Occupational health and safety inspections and internal audits
- Root cause analysis of incidents to support continuous improvement

4. OHS Management Systems and Legislation

The complex and high-risk structure of the petrochemical industry necessitates systematic and sustainable management of occupational health and safety (OHS). In this context, OHS management systems are not only a legal obligation but also strategic tools that enhance productivity, reduce accident rates, and strengthen corporate reputation. One of the most widely used systems in this field today is the ISO 45001:2018 Occupational Health and Safety Management System Standard. This standard replaced OHSAS 18001 and offers a more integrated and holistic framework (Lyashenko et al., 2024).

4.1. ISO 45001:2018 standard

The ISO 45001 standard provides organizations with a systematic approach to help prevent occupational accidents and diseases. Based on the Plan–Do–Check–Act (PDCA) cycle, it enables the identification, evaluation, prevention, and continuous improvement of risks (Palačić, 2019).
Thanks to its risk-based thinking approach, the standard facilitates proactive management not only of existing hazards but also of potential future risks. Core elements of the standard include leadership, worker participation, management of risks and opportunities, performance evaluation, internal audits, and continual improvement processes. ISO 45001 is also compatible with other standards like ISO 9001 (quality management) and ISO 14001 (environmental management), allowing for the creation of integrated management systems (Heras-Saizarbitoria et al., 2020).
As seen in real-world applications, companies that implement ISO 45001 often experience significant reductions in occupational accidents and workforce losses. Especially in high-risk industries, successful implementation of this system requires strong leadership from management and active worker involvement (Šolc et al., 2022).

4.2. Occupational health and safety legislation in Turkey

The main legal regulation governing occupational health and safety in Turkey is Law No. 6331 on Occupational Health and Safety, which aims to ensure that all employees work in safe and healthy environments. In addition, sector-specific regulations detail employer responsibilities and safety measures according to hazard classes.
Enterprises classified as 'very hazardous,' such as those in the petrochemical sector, are legally required to prepare risk assessment reports, create emergency plans, provide periodic health

surveillance, and employ OHS professionals. Failure to comply with these obligations can result in severe legal penalties and social security liabilities. Studies conducted in the chemical and petrochemical sector, particularly the case of Petkim, indicate that risk matrix analyses have been applied to all integrated facilities to comprehensively evaluate the potential environmental, human health, and economic impacts of possible accidents. Due to the storage of highly flammable, explosive, and toxic chemical substances in the sector, the risks of fire, explosion, and chemical leakage are frequently highlighted. A comparison of Petkim's practices with international standards has revealed certain deficiencies in its risk management processes (Çelebi, 2010).

Emergency Management and Fire Safety: Due to the presence of flammable and explosive materials in petrochemical facilities, comprehensive emergency response plans are mandatory. These include fire drills, gas leak scenarios, evacuation plans, and first aid coordination. ISO 45001 emphasizes not only the development of such plans but also their regular testing and review (Brykalov et al., 2022).

5. OHS Culture and Training Practices

Occupational health and safety (OHS) culture reflects the value an organization places on safety, as evidenced by employee behavior, attitudes, and institutional norms. In high-hazard industries such as petrochemicals, a strong safety culture not only reduces workplace accidents but also directly enhances operational sustainability and productivity (Sepehr et al., 2020). Therefore, safety culture should be viewed as a multidimensional concept that considers human factors as well as technical measures.

5.1. Building and sustaining an OHS culture

The foundation of a strong OHS culture lies in management commitment, employee involvement, and open communication. A study conducted in Japan found a positive correlation between employees' perceptions of safety and their motivation. In particular, managerial attitudes toward safety were shown to influence the entire organizational structure (Çakıt et al., 2019). A study in Brazil demonstrated that safety culture varies according to institutional maturity; facilities with a higher level of maturity had significantly lower accident rates (Boughaba et al., 2014).

5.2. Training programs and their impact:

OHS training is a critical component that enables workers to recognize hazards, assess risks, and develop appropriate safety behaviors. Training programs must be regular, targeted, and measurable. The content of training should not only cover legal regulations but also include hands-on knowledge about behavioral safety, emergency response, and the use of personal protective equipment (PPE) (Hong et al., 2004).

A study conducted in Iran revealed that safety training positively influenced workers' attitudes and perceptions and had an inverse relationship with accident experience (Rad et al., 2016). The long-term effectiveness of training can be monitored through periodic evaluations, feedback loops, and applied scenarios.

5.3. Enhancing risk perception

Another important dimension of OHS culture is improving employees' risk perception. Near-miss incidents should be actively reported, and feedback should be provided to workers. A 2020 study showed that adopting a "learning organization" structure was effective in developing safety culture (Zwetsloot et al., 2020). This approach enables workplaces to proactively address not only actual accidents but also potential hazards.

6. Technological Developments and Digital Solutions

The industry 4.0 revolution has brought fundamental changes to occupational health and safety (OHS) practices through digital technologies. In high-risk sectors such as the petrochemical industry, the opportunities provided by digitalization have facilitated the development of preventive safety strategies and the widespread use of real-time monitoring and intervention systems. Solutions such as automation, artificial intelligence, the Internet of Things (IoT), digital twin technology, and wearable devices are enhancing both worker safety and the efficiency of production processes.

6.1 Automation and real-time monitoring systems

Automation systems in petrochemical plants help reduce occupational accidents by removing workers from dangerous tasks, minimizing human error, and increasing process safety. Advanced control systems (DCS), safety instrumented systems (SIS), and enterprise resource planning (ERP) integrations enable the rapid detection and elimination of potential risks (Jun-lin, 2014).

6.2. Wearable technologies and smart PPE

Wearable gas detectors, heat sensors, and vibration monitors allow for real-time tracking of workers' physical exposure. These devices can alert individuals to hazardous conditions and play a significant role in accident prevention. Smart personal protective equipment (PPE) can also collect user-specific risk data, enabling personalized health monitoring (Mutiara, 2024).

6.3. Digital twin technology:

A digital twin is a virtual simulation that mirrors a physical facility, allowing real-time data modeling. This technology helps analyze potential hazards, optimize maintenance schedules, and test risk scenarios in advance (Park et al., 2023). The use of digital twins in the petrochemical industry allows for integrated management of both process and occupational safety parameters (Jia et al., 2024).

6.4. Artificial intelligence and data analytics

Artificial intelligence (AI) algorithms and big data analytics can predict future risks based on historical accident records and equipment data. This enables more rational planning for preventive maintenance and safety interventions. For example, IoT-integrated systems can detect gas leaks, and AI algorithms can automatically identify the source and shut down the related unit (Krainiuk et al., 2020).

7. Best Practices and Case Studies

Leading companies in the petrochemical industry have adopted various strategies to enhance occupational health and safety (OHS), which can serve as models for others in the sector. Most of these practices are built on proactive safety management, use of technology, employee participation, and behavioral safety approaches.

7.1. Implementation examples from shell, BASF, and sinopec

Shell has adopted the “Goal Zero” approach, aiming for zero workplace accidents. This strategy includes leadership-driven safety culture, active management involvement, daily site inspections, and employee feedback mechanisms (Wu, 2021).

BASF integrates technical measures, digital solutions, and behavior-oriented leadership and cultural initiatives to enhance process safety performance. According to the company’s global report, the rate of high-severity process safety incidents decreased from 0.05 per 200,000 working hours in 2023 to 0.03 in 2024, indicating an improvement within the defined metric framework. The same report highlights that digital tools, training programs, and behavior-based practices such as ‘Safety Moment’ are employed to strengthen risk awareness.

Sinopec has implemented visual safety management systems and RFID-supported monitoring mechanisms, which have shortened emergency response times by 40% (Yong et al., 2011).

7.2. Case study: WD petrochemical

WD Petrochemical, a company based in China, faced high accident rates due to a weak safety culture, underdeveloped systems, and behavioral issues. By implementing the “1-2-4 Model,” which included employee training, system improvements, and cultural transformation, the company achieved significant improvements in its safety performance (Wu, 2021).

7.3. Safety performance simulation via system dynamics

A case study in South Korea used a system dynamics model to simulate OHS management performance. The model clearly demonstrated the decisive impact of top management involvement on safety performance (Park & Park, 2024).

HAZOP-Based OHS Risk Analysis: Another case study used a HAZOP-based model to comprehensively assess technical and managerial risk factors, contributing to the prevention of potential accidents. Compared to traditional HAZOP analysis, this method offered a more strategic, preventive approach (Jing et al., 2014).

8. Challenges and Recommendations for Improvement

Although occupational health and safety (OHS) practices in the petrochemical sector are generally guided by institutional and legal frameworks, various systemic, behavioral, and technological challenges remain. These issues often stem from a superficial adoption of safety culture, ineffective implementation of management systems, inadequate integration of technology, and poor management of worker behavior.

8.1. Behavioral challenges

Employee motivation and attitudes toward safety are key factors contributing to accidents. A study in Malaysia found that personal traits, motivation, and safety commitment significantly influenced safe behavior (Azir, 2010). However, the absence of reward systems and comprehensive training programs to boost safety motivation limits the effectiveness of these influences.

8.2. Gaps in technological transformation

The limited use of data-driven systems, artificial intelligence, and digital monitoring technologies is a significant area for improvement in managing emerging risks. Advanced models for industrial hygiene, exposure analytics, and behavioral risk prediction are still found only in a small number of companies (Achumie et al., 2022).

8.3. Inadequacies in legislation

Current legal regulations tend to be general and lack sector-specific detail, leaving room for broad interpretation and reducing the effectiveness of inspections. Another common issue is the inadequate monitoring and integration of subcontractors (Wells et al., 1991).

8.4. Recommendations for improvement

- Strong leadership and participatory management
- Behavioral safety programs
- Digital integration
- Sector-specific legislation
- Independent auditing and continuous improvement

9. Recommendations

This review has examined the key risk factors, patterns of occupational accidents and diseases, legal and administrative systems, technological solutions, and best practices in occupational health and safety (OHS) within the petrochemical sector from a multidimensional perspective. The findings indicate that due to the complex structure of the industry, it poses a high level of hazard, and as such, OHS practices must be implemented not only for regulatory compliance but also as part of a strategic management approach.

Notably, chemical exposures, fire and explosion hazards, musculoskeletal disorders, and psychosocial stressors are prevalent in this sector. Systematic management models such as ISO 45001 and integrated digital solutions play vital roles in managing these hazards. However, several challenges still hinder the effectiveness of OHS systems in the field. These include behavioral safety gaps, a lack of technological transformation, discrepancies between management and legislation, and problems integrating subcontractor labor into safety systems.

9.1. Academic recommendations

- More local and comparative field studies on safety culture and digital risk analyses
- Use of data-based methods (machine learning, system dynamics) to analyze accident causes
- Encouraging interdisciplinary research on Industry 4.0 technologies in OHS

9.2. Sectoral and policy recommendations

- Building a strong safety culture with managerial ownership and employee participation
- Promoting the adoption of digital twins, wearable sensors, and real-time monitoring systems
- Revising legislation to reflect sector-specific risks and improve subcontractor oversight
- Increasing the presence and capacity of occupational health professionals, with an emphasis on behavioral safety

In conclusion, sustainable and effective OHS in the petrochemical sector can only be achieved through human-centered, data-driven, and strategically planned approaches that combine both technical and social dimensions.

10. Conclusion

This review aims to systematically address OHS risk factors encountered in petrochemical facilities, with the dual goal of providing a thorough assessment of the current situation and filling this significant gap in the literature. By examining topics such as health risks arising from chemical exposures, fire and explosion hazards, confined space operations, the effective use of personal protective equipment, worker training, and the establishment of an OHS culture from an integrated perspective, this review seeks to contribute to the development of a sustainable and proactive OHS approach in the sector.

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