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Advancing chemical safety protocols in small and medium enterprises: A comprehensive guide

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Abstract

Small and Medium Enterprises (SMEs) face significant challenges in managing chemical safety, often due to limited resources, inadequate infrastructure, and a lack of awareness about regulatory requirements. As chemical safety becomes increasingly critical for protecting workers, communities, and the environment, it is essential to develop tailored safety protocols for SMEs that address their unique needs. This review presents a comprehensive guide on advancing chemical safety protocols in SMEs, focusing on risk assessment, proper storage and handling of chemicals, personal protective equipment (PPE), spill prevention, and waste management. The integration of modern technologies, such as digital risk management tools, Internet of Things (IoT) sensors, and AI-driven predictive analytics, offers SMEs cost-effective solutions to enhance chemical safety. These technologies enable real-time monitoring, early warning systems for chemical hazards, and the automation of safety audits, which can significantly reduce risks and improve compliance. Additionally, fostering a strong chemical safety culture within SMEs is vital, requiring leadership commitment, employee training, and effective hazard reporting systems. Navigating regulatory frameworks and achieving compliance with limited resources presents another key challenge for SMEs. This guide highlights practical strategies for meeting safety standards, including leveraging external resources and simplifying documentation processes. Case studies showcase successful implementations of safety protocols and technologies in various SME sectors, providing insights into best practices and lessons learned. As technological advancements continue to evolve, SMEs must stay ahead by adopting innovations such as robotics, wearable safety technologies, and digital twins for chemical safety planning. This review emphasizes that a holistic approach—combining technology, policy, and workplace culture is essential for advancing chemical safety in SMEs, ensuring long-term sustainability, and safeguarding the health and well-being of workers.

Keywords: Chemical Safety; SMEs; Protocols; Comprehensive Guide

1 Introduction

Chemical safety is a critical concern for small and medium enterprises (SMEs) operating across various industries (Adejogbe, 2022). SMEs, which constitute a substantial portion of the global economy, often handle chemicals in their operations, whether in manufacturing, processing, or research and development. Despite their vital role in economic growth and innovation, SMEs frequently face unique challenges in maintaining robust chemical safety protocols due to limited resources and specialized knowledge (Iyede *et al.*, 2023).

In SMEs, chemical safety encompasses a range of practices designed to protect workers, the environment, and public health from the hazards associated with chemical substances (Bello *et al.*, 2022). These practices include proper storage, handling, and disposal of chemicals, as well as the implementation of safety measures to prevent accidents and

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exposures. SMEs, due to their scale and scope, may not have the same resources or expertise as larger organizations to implement comprehensive chemical safety programs (Adejugbe, 2022). This can make them more vulnerable to chemical incidents and regulatory non-compliance. SMEs often struggle with the complexity of chemical safety regulations, which can vary significantly by region and industry. The lack of dedicated safety personnel and limited budgets for training and safety equipment further exacerbate these challenges (Udegbe *et al.*, 2024). As a result, SMEs may face difficulties in adhering to stringent safety standards and effectively managing chemical risks.

The implementation of robust chemical safety protocols is crucial for several reasons (Oyeniran *et al.*, 2023). First and foremost, effective chemical safety measures protect employees from health risks such as respiratory issues, skin irritations, and long-term diseases associated with chemical exposure. Additionally, well-established safety protocols help prevent accidents such as spills, fires, and explosions, which can have severe consequences for both workers and the surrounding community (Toromade *et al.*, 2024). Beyond the immediate safety of employees and the workplace, chemical safety protocols also play a significant role in ensuring environmental protection. Proper management of chemical waste and emissions helps prevent contamination of soil, water, and air, thereby safeguarding ecosystems and public health. Furthermore, adherence to chemical safety regulations and standards is essential for maintaining compliance with legal requirements. Non-compliance can result in significant financial penalties, legal liabilities, and reputational damage (Joseph *et al.*, 2022). For SMEs, which may have fewer resources to absorb these costs, the stakes are particularly high.

This guide aims to address the specific challenges that SMEs face in implementing effective chemical safety protocols. Recognizing that SMEs often operate under constraints such as limited financial resources, smaller teams, and less access to specialized expertise, the guide provides practical strategies and solutions tailored to their needs (Adejugbe, 2021). The guide will cover essential aspects of chemical safety, including risk assessment, safety training, regulatory compliance, and emergency preparedness. It will offer actionable recommendations for developing and maintaining chemical safety programs that are both cost-effective and comprehensive (Bello *et al.*, 2022). By focusing on the unique context of SMEs, the guide seeks to empower these organizations to enhance their chemical safety practices, reduce risks, and achieve compliance with regulatory requirements. Chemical safety is a vital concern for SMEs, with significant implications for worker health, environmental protection, and regulatory compliance. This guide aims to address the specific challenges faced by SMEs in implementing effective chemical safety protocols, providing practical solutions to enhance safety and ensure adherence to standards. Through targeted strategies and recommendations, SMEs can better manage chemical risks and contribute to a safer, more sustainable industrial landscape.

2 Current Challenges in Chemical Safety for SMEs

Small and medium enterprises (SMEs) face a distinct set of challenges in maintaining chemical safety protocols due to their scale and resource limitations (Udegbe *et al.*, 2024). The effective management of chemical safety within SMEs is crucial for protecting workers, the environment, and public health. However, several barriers hinder the implementation of robust chemical safety practices in these organizations. This explores five key challenges: lack of awareness and training, limited resources for safety implementation, inadequate infrastructure and equipment, regulatory compliance difficulties, and the high risk of chemical accidents.

A fundamental challenge in chemical safety for SMEs is the lack of awareness and training among employees and management (Oyeniran *et al.*, 2022). Many SMEs operate with limited safety expertise and may not fully recognize the risks associated with handling chemicals. This knowledge gap can lead to improper handling, storage, and disposal of hazardous substances, increasing the likelihood of accidents and health issues. Training programs are essential for educating employees about chemical hazards, safe handling practices, and emergency response procedures. However, SMEs often lack the resources to invest in comprehensive training programs. As a result, employees may not receive adequate education on chemical safety, which can lead to unsafe practices and non-compliance with regulations (Agupugo *et al.*, 2024).

SMEs frequently face constraints in terms of financial and human resources, which can impede their ability to implement effective chemical safety measures (Joseph *et al.*, 2020). Budget limitations may restrict the acquisition of safety equipment, the hiring of dedicated safety personnel, and the development of safety programs. This scarcity of resources can result in inadequate safety measures and an increased risk of chemical incidents. For instance, purchasing high-quality personal protective equipment (PPE), implementing safety management systems, and conducting regular safety audits all require significant investment. SMEs may struggle to allocate funds for these essential safety components, leading to potential gaps in their chemical safety protocols (Adejugbe, 2020).

The infrastructure and equipment available to SMEs are often insufficient for managing chemical safety effectively. Proper storage facilities, ventilation systems, and emergency response equipment are critical for handling hazardous chemicals safely (Olatunji *et al.*, 2022). However, many SMEs operate in older facilities that may lack the necessary infrastructure to support safe chemical handling. Inadequate storage solutions can lead to improper segregation of chemicals, increasing the risk of reactions and spills (Toromade *et al.*, 2024). Similarly, insufficient ventilation systems can result in the accumulation of harmful vapors, posing health risks to employees. The absence of well-maintained emergency response equipment, such as spill containment kits and fire suppression systems, further exacerbates the risk of chemical accidents.

Regulatory compliance is a significant challenge for SMEs, as they often face complex and evolving chemical safety regulations (Bello *et al.*, 2022). Compliance with regulations such as the Occupational Safety and Health Administration (OSHA) standards or the European Union's REACH (Registration, Evaluation, Authorisation, and Restriction of Chemicals) requires a thorough understanding of legal requirements and the ability to implement them effectively. SMEs may struggle with navigating the regulatory landscape due to limited access to legal and regulatory expertise. Additionally, the dynamic nature of regulations can make it challenging for SMEs to stay up-to-date with new requirements. Failure to comply with chemical safety regulations can lead to legal penalties, fines, and damage to the organization's reputation (Udegbe *et al.*, 2024).

The combination of inadequate training, limited resources, and insufficient infrastructure increases the risk of chemical accidents in SMEs (Oyeniran *et al.*, 2022). Chemical accidents, such as spills, leaks, fires, and explosions, can have severe consequences for workers, the environment, and the surrounding community. In SMEs, the impact of such incidents can be particularly detrimental due to their limited capacity to absorb the financial and operational repercussions. For example, a chemical spill in an SME without proper containment measures can result in contamination of the workplace and surrounding areas. The lack of adequate emergency response protocols can exacerbate the severity of accidents, leading to extended downtime, costly cleanup efforts, and potential health hazards.

The challenges faced by SMEs in chemical safety are multifaceted and stem from various factors, including a lack of awareness and training, limited resources, inadequate infrastructure, regulatory compliance difficulties, and a high risk of chemical accidents (Adejugbe, 2020). Addressing these challenges requires a comprehensive approach that includes enhanced training programs, financial support for safety measures, investment in infrastructure, and improved regulatory guidance. By overcoming these barriers, SMEs can better manage chemical risks, ensure compliance with safety standards, and create a safer working environment for their employees.

2.1 Essential Chemical Safety Protocols for SMEs

Ensuring chemical safety is paramount for small and medium enterprises (SMEs) that handle hazardous substances (Olatunji *et al.*, 2022). Due to their scale and resource limitations, SMEs must adopt effective chemical safety protocols to protect workers, the environment, and comply with regulatory requirements. This outlines essential chemical safety protocols for SMEs, including risk assessment and hazard identification, chemical storage and handling guidelines, personal protective equipment (PPE) requirements, spill prevention and response, and waste management and disposal.

Effective chemical safety begins with a thorough understanding of potential hazards. Risk assessment and hazard identification are crucial steps in developing a robust safety protocol (Bello *et al.*, 2022). Identifying chemical hazards involves evaluating the properties of chemicals used in the workplace. This can be achieved through reviewing Safety Data Sheets (SDS), which provide detailed information on chemical properties, hazards, and safety measures. Additionally, conducting workplace inspections and consulting with employees who handle chemicals can help identify potential risks. Regular risk assessments are essential for identifying new hazards and evaluating the effectiveness of existing safety measures. Risk assessments should be conducted periodically and whenever there are changes in processes, materials, or equipment. This involves evaluating the likelihood and potential impact of chemical incidents and implementing control measures to mitigate these risks.

Proper storage and handling of chemicals are critical to preventing accidents and ensuring safety in the workplace (Agupugo *et al.*, 2024). All chemical containers should be clearly labeled with the chemical name, hazards, and handling instructions. Labels should be legible and updated to reflect any changes in the chemical's properties or regulations. Chemicals should be stored according to their compatibility. Incompatible chemicals should be kept in separate areas to prevent dangerous reactions. For example, oxidizers should be stored away from flammable materials. Some chemicals require specific temperature conditions to remain stable. Storage areas should be equipped with temperature controls and monitored regularly to ensure compliance with these requirements. Employees should be trained in safe

handling procedures, including the use of proper techniques and equipment (Adejuge, 2019). For instance, when transferring chemicals, use appropriate containers and avoid using mouth suction. Adequate ventilation should be provided in areas where chemicals are handled to prevent the accumulation of hazardous fumes or vapors.

PPE is crucial for protecting employees from chemical exposure. Ensuring the proper use, maintenance, and disposal of PPE is essential for effective chemical safety. Chemical-resistant gloves should be selected based on the type of chemical being handled (Olatunji *et al.*, 2022). Gloves should be inspected regularly for damage and replaced as needed. Eye protection is necessary when there is a risk of splashes or spills. Face shields may be required for processes involving higher risks of exposure. Lab coats, aprons, or other protective clothing should be worn to shield skin from chemical contact. Clothing should be made of materials resistant to the chemicals used. PPE should be used according to manufacturer instructions and replaced when damaged. Maintenance includes regular cleaning and inspection. Disposable PPE must be disposed of in accordance with hazardous waste regulations to prevent contamination (Oyeniran *et al.*, 2023).

Preparing for and managing chemical spills is crucial to minimizing their impact and ensuring safety. Spill prevention plans should include strategies for minimizing the likelihood of spills, such as proper storage and handling practices (Toromade *et al.*, 2024). Regular training on spill prevention and emergency procedures should be conducted to ensure all employees are aware of their roles in preventing and responding to spills. Emergency response protocols should be established to address chemical spills quickly and effectively. These protocols should include procedures for containment, cleanup, and reporting. Employees should be trained in the use of spill kits and other response equipment, and an emergency response plan should be developed and regularly reviewed.

Proper management and disposal of chemical waste are essential to prevent environmental contamination and comply with regulations (Bello *et al.*, 2022). Chemical waste should be segregated according to its type and managed in designated areas. Containers for chemical waste should be labeled and sealed to prevent leaks. Waste should be disposed of through licensed hazardous waste disposal services that comply with local and national regulations. Compliance with legal requirements for hazardous waste management is crucial. Regulations vary by country and region but generally include requirements for waste labeling, storage, and documentation. SMEs should stay informed about applicable regulations and ensure their waste management practices align with legal standards.

Implementing essential chemical safety protocols is vital for SMEs to ensure a safe working environment and comply with regulatory requirements (Udegbe *et al.*, 2024). By focusing on risk assessment and hazard identification, proper storage and handling, appropriate PPE use, effective spill prevention and response, and safe waste management, SMEs can mitigate chemical risks and enhance overall safety. Adopting these protocols not only protects employees and the environment but also supports compliance and operational efficiency.

2.2 Technology Integration for Enhancing Chemical Safety

Advancing chemical safety protocols in small and medium enterprises (SMEs) can be significantly enhanced through the integration of modern technologies. The application of digital risk management tools, IoT sensors, artificial intelligence (AI), and automation can improve the efficiency, accuracy, and effectiveness of chemical safety practices (Adejuge, 2019). This explores how these technologies contribute to enhancing chemical safety by addressing digital risk management, real-time monitoring, predictive analytics, and automated safety audits.

Digital risk management tools offer robust solutions for tracking and managing chemical inventories and ensuring compliance with safety regulations. Advanced software systems allow SMEs to maintain comprehensive databases of their chemical inventories. These systems enable real-time tracking of chemical quantities, storage locations, and expiration dates (Olatunji *et al.*, 2022). By centralizing this information, businesses can better manage their chemical supplies, ensure proper storage conditions, and prevent overstocking or understocking issues. Software tools can automate risk assessments by analyzing chemical inventory data and generating risk profiles based on various factors such as chemical properties, quantities, and storage conditions. These tools can also track compliance with regulatory requirements, alerting users to upcoming deadlines for safety audits or regulatory submissions. This automation reduces the administrative burden on SMEs and enhances their ability to stay compliant with safety regulations (Udegbe *et al.*, 2024).

The Internet of Things (IoT) has revolutionized real-time monitoring and management of hazardous materials, providing critical insights into chemical safety (Adewusi *et al.*, 2022). IoT sensors can be deployed to monitor environmental conditions within chemical storage areas, including temperature, humidity, and pressure. These sensors provide continuous data that can be analyzed to ensure that chemicals are stored under optimal conditions, reducing

the risk of degradation or hazardous reactions. Alerts can be set up to notify personnel immediately if environmental conditions deviate from safe ranges. IoT sensors can also detect leaks or spills of hazardous chemicals in real-time. These sensors use technologies such as gas detectors and leak detection systems to identify potential hazards before they escalate. Early warning systems can trigger automatic shutoffs or activate containment measures to minimize the impact of spills and prevent environmental contamination.

Artificial intelligence (AI) and predictive analytics are powerful tools for enhancing chemical safety by forecasting potential incidents and optimizing safety protocols (Adejuge, 2018). AI algorithms can analyze historical and real-time data to predict potential chemical accidents. By examining patterns and correlations in operational data, AI systems can identify conditions that may lead to accidents, such as equipment malfunctions or unsafe handling practices. This predictive capability allows SMEs to implement proactive measures to prevent accidents before they occur. AI can also optimize chemical handling and storage protocols by analyzing data on chemical usage, storage conditions, and safety incidents. AI-driven systems can recommend best practices for handling and storage based on the specific characteristics of the chemicals used. This optimization helps reduce risks associated with improper handling and storage and ensures compliance with safety standards.

Automation in safety audits and inspections can significantly enhance the reliability and efficiency of compliance checks. Automated tools can streamline the process of conducting compliance audits and safety inspections. These tools can schedule and track inspections, generate checklists, and compile inspection reports. By automating these processes, SMEs can ensure that audits are conducted regularly and that all safety protocols are adhered to. Human error is a common factor in routine inspections, which can lead to missed hazards or incomplete assessments. Automated inspection tools reduce the likelihood of such errors by providing standardized procedures and consistent data collection (Olatunji *et al.*, 2022). This ensures a more accurate and reliable assessment of chemical safety practices.

Integrating advanced technologies such as digital risk management tools, IoT sensors, AI, and automation into chemical safety protocols offers significant benefits for SMEs. These technologies enhance the ability to track and manage chemical inventories, monitor storage conditions in real-time, predict and prevent accidents, and streamline safety audits and inspections. By leveraging these technological advancements, SMEs can improve their chemical safety practices, ensure regulatory compliance, and protect their employees and the environment from chemical hazards (Agupugo *et al.*, 2024). The ongoing evolution of technology continues to offer new opportunities for enhancing chemical safety, making it crucial for SMEs to stay informed and adopt these innovations.

2.3 Developing a Chemical Safety Culture in SMEs

Creating a robust chemical safety culture within small and medium enterprises (SMEs) is crucial for mitigating risks associated with chemical handling and ensuring the well-being of employees and the environment (Adejuge, 2016). Developing such a culture requires a comprehensive approach that includes management commitment, employee training, effective reporting systems, and continuous improvement. This explores these key components and their role in fostering a strong chemical safety culture in SMEs.

Management commitment is fundamental to establishing and maintaining a strong chemical safety culture. Leaders set the tone for safety practices by prioritizing safety in organizational policies and demonstrating a commitment to compliance with regulations. Leadership involvement in safety initiatives ensures that chemical safety protocols are integrated into everyday operations and that safety is viewed as a core value rather than an ancillary concern. By actively participating in safety meetings, endorsing safety training programs, and championing safety improvements, management reinforces the importance of a safety-first approach (Adewusi *et al.*, 2024). Effective chemical safety requires adequate resources, including financial investment and personnel. Management should allocate resources to implement and maintain safety measures such as upgrading safety equipment, conducting regular safety audits, and investing in training programs. By committing resources to safety, management not only supports the development of a safety culture but also demonstrates its commitment to protecting employees and mitigating chemical risks.

Regular training is essential for equipping employees with the knowledge and skills necessary to handle chemicals safely (Adejuge, 2015). Training programs should cover a range of topics, including the properties of chemicals, safe handling practices, emergency response procedures, and the use of personal protective equipment (PPE). By providing ongoing education, SMEs can ensure that employees are up-to-date with current safety practices and regulatory requirements, reducing the likelihood of accidents and enhancing overall safety performance. Raising awareness about chemical hazards and safe practices is a critical component of training. Employees should be educated about the specific risks associated with the chemicals they work with and the procedures for minimizing these risks. Effective training programs use a combination of theoretical knowledge and practical exercises to reinforce safe practices (Okoli *et al.*,

2024). Additionally, visual aids, such as posters and labels, can serve as constant reminders of safety protocols, further embedding safety awareness into the workplace culture.

A culture of safety relies on open communication and proactive identification of hazards. SMEs should encourage employees to report unsafe conditions or near-misses without fear of retaliation. Creating an environment where employees feel comfortable reporting concerns helps identify and address potential safety issues before they lead to incidents. Management should actively promote the importance of reporting and provide clear channels for employees to communicate their concerns (Abiona *et al.*, 2024). An anonymous reporting mechanism can further support a culture of safety by allowing employees to report hazards or unsafe practices without revealing their identities. This approach can be particularly effective in addressing issues that employees may be hesitant to report openly due to fear of reprisal or embarrassment. Anonymous reporting systems should be easy to access and use, ensuring that all employees have a means to contribute to safety improvements.

Continuous improvement is essential for maintaining and enhancing chemical safety. SMEs should establish systems for regularly evaluating safety protocols and practices to ensure their effectiveness and relevance (Oyeniran *et al.*, 2024). This includes conducting routine safety audits, reviewing incident reports, and assessing the outcomes of safety training programs. By systematically evaluating safety measures, organizations can identify areas for improvement and implement necessary changes to address emerging risks or deficiencies. Feedback from employees and the results of safety audits provide valuable insights into the effectiveness of safety practices. SMEs should actively seek input from employees on safety issues and involve them in the process of improving safety protocols. Incorporating feedback helps ensure that safety measures are practical and address real-world challenges faced by employees. Additionally, lessons learned from safety audits should be used to refine and enhance safety practices continuously.

Developing a chemical safety culture in SMEs involves a multifaceted approach that includes strong management commitment, comprehensive employee training, effective reporting systems, and a focus on continuous improvement (Sonko *et al.*, 2024). By fostering an environment where safety is prioritized and actively supported, SMEs can mitigate chemical risks, enhance compliance, and protect both employees and the environment. Building a safety culture is an ongoing process that requires dedication, resources, and a willingness to adapt and improve. As SMEs continue to evolve, maintaining a strong focus on chemical safety will be crucial for their long-term success and sustainability.

2.4 Regulatory Frameworks and Compliance for SMEs

Navigating regulatory frameworks and ensuring compliance with chemical safety regulations is a critical challenge for small and medium enterprises (SMEs) (Modupe *et al.*, 2024). These regulations, which vary significantly across regions and industries, are designed to protect workers, the environment, and public health. This explores key aspects of chemical safety regulations, strategies for achieving compliance with limited resources, and the importance of thorough record-keeping and documentation.

Several key regulations govern chemical safety and impact SMEs globally. Notable among these are the Occupational Safety and Health Administration (OSHA) regulations in the United States, the Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH) in the European Union, and the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) adopted internationally. OSHA mandates comprehensive safety measures, including hazard communication, employee training, and proper chemical handling protocols. OSHA's regulations are designed to ensure that workplaces are safe and that employees are informed about the chemicals they may encounter (Adewusi *et al.*, 2024). REACH focuses on the safety of chemicals used in the EU. It requires businesses to register chemicals, evaluate their risks, and authorize their use only if they meet stringent safety standards. REACH emphasizes the responsibility of companies to manage risks associated with their chemicals. GHS provides a global standard for classifying and labeling chemicals. It aims to improve safety through standardized labeling and safety data sheets, which convey information about the hazards of chemicals and the measures to protect against them.

Regulations can vary widely based on geographic location and industry sector. For instance, while OSHA regulations are specific to the United States, other countries have their own regulatory frameworks with different requirements. Additionally, industries such as pharmaceuticals, agriculture, and manufacturing each face unique regulatory challenges based on the types of chemicals they handle and the specific risks involved. Understanding these differences is crucial for SMEs operating internationally or in multiple sectors. SMEs often face challenges in complying with regulations due to limited resources. However, several strategies can help manage compliance costs effectively (Komolafe *et al.*, 2024). Focus on critical areas of compliance that have the most significant impact on safety and regulatory requirements. By addressing these key areas first, SMEs can make substantial progress without overwhelming their resources. Implementing software solutions for tracking chemical inventories, managing safety data sheets, and automating

compliance checks can streamline processes and reduce manual labor. These tools often offer cost-effective solutions compared to manual methods. Regular internal audits can help identify compliance gaps and areas for improvement before external inspections or audits. This proactive approach allows SMEs to address issues early and avoid costly penalties. Many governments offer programs and grants to assist SMEs with compliance costs (Adewusi *et al.*, 2023). These resources can provide financial support, training, and access to expert advice. Engaging with safety consultants can provide SMEs with specialized knowledge and guidance on regulatory compliance. Consultants can help develop compliance strategies, conduct risk assessments, and ensure that safety protocols meet regulatory standards.

Accurate record-keeping and documentation are essential for demonstrating compliance with regulations and managing chemical safety effectively (Adejugbe, 2014). Comprehensive records provide evidence of compliance with safety protocols, facilitate audits, and support investigations in case of incidents. Regulations often require detailed documentation of safety data sheets, training records, hazard assessments, and incident reports. Maintaining these records helps ensure that all safety measures are properly documented and can be reviewed when needed. Utilizing digital tools and software for record-keeping simplifies the documentation process and improves accuracy. These systems can automate data entry, generate reports, and store records securely, reducing the administrative burden on SMEs. Cloud-based platforms allow for easy access to safety records from any location, facilitating better management of documentation. These solutions also provide backup and disaster recovery options, ensuring that records are preserved even in the event of data loss (Adewusi *et al.*, 2023).

Understanding and complying with chemical safety regulations is a complex but crucial task for SMEs. By familiarizing themselves with local and international regulations, employing practical strategies for cost-effective compliance, and maintaining thorough records, SMEs can navigate the regulatory landscape more effectively. Leveraging external resources and utilizing technology can further enhance compliance efforts, ensuring that chemical safety protocols are met and risks are managed efficiently (Babayehu *et al.*, 2024). Through a commitment to regulatory adherence and continuous improvement, SMEs can achieve a high standard of chemical safety while optimizing their resources and operations.

2.5 Case Studies: Successful Implementation of Chemical Safety Protocols in SMEs

The successful implementation of chemical safety protocols is critical for minimizing risks and ensuring compliance in small and medium enterprises (SMEs). Examining real-world examples of SMEs that have effectively integrated advanced safety measures provides valuable insights into best practices and innovative solutions. This *review* explores three case studies highlighting successful chemical safety protocols: the adoption of AI-based safety systems, enhancements in employee safety training, and the use of IoT for real-time monitoring of hazardous chemicals.

A notable example of integrating advanced technology into chemical safety is the adoption of AI-based safety systems by a mid-sized manufacturing SME specializing in chemical processing (Ajiga *et al.*, 2024). This company faced challenges related to monitoring and managing chemical hazards, leading to a decision to implement AI-driven safety systems. The SME adopted an AI-based system designed to analyze operational data and predict potential safety risks. The AI system utilized machine learning algorithms to assess patterns and detect anomalies in chemical handling processes. By integrating this technology, the company could proactively identify risks and implement preventive measures before incidents occurred. The AI system improved the company's ability to foresee potential chemical accidents based on historical data and real-time monitoring. The system provided actionable insights that enabled the company to refine safety protocols, reduce accidents, and improve overall safety performance. Early detection of issues helped the company avoid costly incidents and regulatory fines, demonstrating the economic advantages of investing in advanced safety technology (Adejugbe, 2018).

Another successful case study involves a chemical handling SME that focused on enhancing employee safety training to address gaps in chemical safety knowledge and practices. This company, which dealt with a wide range of hazardous chemicals, recognized the need for a more comprehensive training program to improve workplace safety. The company developed an enhanced training program that included interactive workshops, hands-on training sessions, and regular safety drills. The program covered topics such as proper chemical handling techniques, emergency response procedures, and the use of personal protective equipment (PPE). Employees gained a deeper understanding of chemical hazards and best practices for mitigating risks, leading to a safer work environment (Oyeniran *et al.*, 2023). The company experienced a noticeable decrease in chemical-related accidents and incidents, attributed to the improved knowledge and skills of its workforce. Enhanced training helped the company meet regulatory requirements more effectively, reducing the risk of compliance issues and penalties.

The third case study features an SME in the pharmaceutical industry that implemented Internet of Things (IoT) technology for real-time monitoring of hazardous chemicals. The company needed a solution to continuously track the conditions under which chemicals were stored and handled to prevent accidents and ensure regulatory compliance. The SME installed IoT sensors throughout its chemical storage and handling areas. These sensors monitored critical parameters such as temperature, humidity, and chemical concentrations, providing real-time data to a central control system. The IoT system allowed for continuous monitoring of chemical storage conditions, enabling prompt responses to any deviations from safe operating conditions. The sensors detected potential issues such as leaks or improper storage conditions, triggering automatic alerts to prevent accidents. The real-time monitoring data facilitated better documentation and reporting, helping the company meet regulatory requirements and improve safety practices (Toromade *et al.*, 2024).

These case studies illustrate the effectiveness of various chemical safety protocols implemented by SMEs. The adoption of AI-based safety systems, enhancements in employee safety training, and the use of IoT for real-time monitoring all demonstrate how innovative approaches can significantly improve chemical safety outcomes. By leveraging advanced technologies and focusing on comprehensive training, SMEs can enhance their safety practices, reduce risks, and achieve better compliance with regulatory standards (Porlles *et al.*, 2023). These examples serve as valuable models for other SMEs seeking to advance their chemical safety protocols and foster a safer work environment.

2.6 Future Trends in Chemical Safety for SMEs

The landscape of chemical safety is evolving rapidly, driven by technological advancements and shifting regulatory frameworks (Moones *et al.*, 2023). For small and medium enterprises (SMEs), staying ahead of these trends is crucial for maintaining a safe work environment and ensuring compliance with emerging regulations. This explores four significant future trends in chemical safety: the growth of automation and robotics, the increasing role of digital twins, advancements in wearable technologies, and the evolution of policies and regulatory requirements.

Automation and robotics are transforming chemical management in SMEs by enhancing precision and efficiency in handling hazardous materials. The integration of robotic systems in chemical processes allows for the automation of routine tasks such as mixing, transferring, and packaging chemicals, which reduces human exposure to dangerous substances (Emmanuel *et al.*, 2023). Automated systems minimize human error by performing repetitive tasks with high accuracy, leading to improved safety and consistency in chemical processes. Robotics reduce the need for manual handling of hazardous chemicals, thereby lowering the risk of accidents and exposure. While initial investments in automation can be high, the long-term benefits include reduced labor costs and fewer safety incidents, making it a cost-effective solution for SMEs.

Digital twins are becoming a vital tool for chemical safety planning, offering a virtual representation of physical systems that can simulate and analyze chemical processes in real-time. By creating digital replicas of chemical operations, SMEs can gain valuable insights into system performance and potential safety risks (Ajiga *et al.*, 2024). Digital twins enable SMEs to run simulations and predict how changes in processes or conditions could affect safety. This proactive approach helps in identifying potential issues before they manifest in the real world. Virtual simulations provided by digital twins can be used for training employees, allowing them to experience and respond to emergency scenarios in a controlled environment. Data from digital twins can inform decision-making, helping SMEs optimize chemical management practices and enhance overall safety.

Wearable technologies are increasingly being integrated into chemical safety protocols to provide real-time monitoring and protection for employees. These devices, including smart helmets, gloves, and vests equipped with sensors, are designed to detect hazardous conditions and provide immediate alerts. Wearable devices can monitor exposure levels to chemicals, environmental conditions, and physiological responses, alerting workers to unsafe conditions before they reach dangerous levels (Okeleke *et al.*, 2024). Wearables collect valuable data on worker exposure and environmental conditions, which can be used to improve safety practices and compliance with regulations. Advanced wearables offer features such as built-in communication systems and emergency alerts, improving worker safety and response capabilities.

As chemical safety technologies advance, so too must regulatory frameworks evolve to address new challenges and opportunities. Future regulatory requirements are likely to focus on integrating new technologies into safety standards and addressing emerging risks. Regulations will need to adapt to incorporate new technologies such as automation, digital twins, and wearables. This will require updates to existing standards and the development of new guidelines to ensure that these technologies are used effectively and safely. Future policies may mandate more rigorous reporting and compliance measures related to new technologies, including requirements for real-time data reporting and

verification of digital safety systems. As technology and regulatory practices evolve, there will be a push for greater harmonization of safety standards across borders to facilitate international trade and ensure consistent safety practices (Babayehu *et al.*, 2024).

The future of chemical safety for SMEs is marked by significant advancements in automation, digital technology, and wearable devices. These trends offer the potential to greatly enhance safety, efficiency, and compliance in chemical management. As regulatory frameworks continue to evolve, SMEs will need to adapt to new requirements and leverage emerging technologies to maintain high safety standards. By staying abreast of these developments and integrating innovative solutions into their safety protocols, SMEs can improve their chemical safety practices and better protect their employees and operations (Agupugo and Tochukwu, 2022).

2.7 Challenges and Barriers to Enhancing Chemical Safety in SMEs

Enhancing chemical safety in small and medium enterprises (SMEs) presents a unique set of challenges and barriers (Chien *et al.*, 2021). Addressing these issues is crucial for improving workplace safety and regulatory compliance. This examines four major challenges: financial constraints and budgeting for safety improvements, resistance to change in SME workplaces, lack of access to advanced technologies, and ensuring consistent compliance in dynamic environments.

One of the most significant barriers to enhancing chemical safety in SMEs is financial constraint. Many SMEs operate with tight budgets, and allocating funds for safety improvements can be challenging. Investments in new safety technologies, equipment, and training programs require significant financial outlays, which can be difficult for smaller enterprises to afford. Advanced safety technologies, such as automated systems and real-time monitoring equipment, often come with high upfront costs. SMEs may struggle to justify these expenses given their limited budgets. Maintaining and updating safety systems incurs ongoing costs, including maintenance, calibration, and training, which can strain financial resources (Bittencourt *et al.*, 2021). SMEs may face difficulties in assessing the return on investment for safety improvements, potentially leading to reluctance in making necessary expenditures. Leveraging government programs and subsidies designed to support safety improvements can help alleviate financial burdens. Implementing safety measures in phases can spread out costs and make it easier for SMEs to manage budget constraints.

Resistance to change is a common challenge in many SME workplaces, particularly when it comes to implementing new safety protocols and technologies. This resistance can stem from various sources, including entrenched practices, skepticism about new methods, and reluctance to adopt unfamiliar technologies (Cappuccio *et al.*, 2023). Employees and management may be accustomed to existing practices and may perceive new safety protocols as unnecessary or disruptive. Inadequate training can lead to misunderstandings and resistance, particularly if employees are not adequately prepared for new safety measures. There is often a fear that new technologies or processes will disrupt workflow and productivity. Involving leadership in promoting and championing safety changes can help overcome resistance and foster a culture of safety. Clearly communicating the benefits of new safety measures and providing comprehensive training can help address concerns and facilitate smoother transitions.

Access to advanced safety technologies is another significant barrier for SMEs. Many SMEs operate in environments where cutting-edge technologies, such as real-time monitoring systems and automated safety equipment, are either cost-prohibitive or unavailable. SMEs may lack the infrastructure needed to support advanced safety technologies, such as high-speed internet or specialized equipment. The cost of acquiring and implementing advanced technologies can be prohibitive, particularly for SMEs with limited financial resources. SMEs may also face challenges in understanding and selecting the appropriate technologies for their specific safety needs. Partnering with technology providers or joining industry networks can help SMEs gain access to advanced technologies and resources. Government and industry-sponsored programs that offer technological support and subsidies can facilitate access to necessary safety innovations (Haeussler and Assmus, 2021).

Maintaining consistent compliance with safety regulations can be challenging in dynamic environments where operational conditions frequently change. SMEs often face difficulties in keeping up with evolving regulations and ensuring that safety protocols remain effective under varying conditions. Navigating complex and frequently changing regulations can be overwhelming for SMEs, leading to inadvertent non-compliance. Changes in production processes, materials, or equipment can impact safety protocols, requiring continuous updates and adjustments. Ensuring accurate and up-to-date documentation for compliance purposes can be challenging in fast-paced environments. Conducting regular internal audits and safety reviews can help SMEs stay compliant and adapt to changes in regulations and operations (Chidukwani *et al.*, 2022). Implementing integrated compliance management systems can streamline documentation and ensure that safety protocols are consistently followed.

Enhancing chemical safety in SMEs involves overcoming significant challenges related to financial constraints, resistance to change, lack of access to advanced technologies, and ensuring consistent compliance. By addressing these barriers through strategic planning, effective communication, and leveraging available resources, SMEs can improve their chemical safety practices and better protect their workforce and operations.

3 Conclusion

Advancing chemical safety in small and medium enterprises (SMEs) necessitates a multi-faceted approach that integrates technology, training, and regulatory compliance. Key steps for improving chemical safety include adopting advanced technologies, implementing robust safety protocols, and ensuring ongoing employee training. Each of these elements plays a crucial role in creating a safer work environment and mitigating risks associated with hazardous chemicals. Embracing innovations such as automated systems, IoT sensors, and wearable technologies can significantly enhance safety by improving monitoring and reducing human error. Automation and real-time data can provide actionable insights that preemptively address potential hazards. Regular and comprehensive training programs are essential for educating employees about chemical hazards, safe handling practices, and emergency procedures. Effective training helps ensure that employees are well-prepared to manage risks and respond to incidents. Adhering to local and international chemical safety regulations is critical for legal compliance and maintaining a safe workplace. SMEs should focus on understanding regulatory requirements and implementing necessary measures to achieve and sustain compliance.

A holistic approach that combines technology, training, and compliance is essential for advancing chemical safety. Technology provides the tools for better monitoring and risk management, while training equips employees with the knowledge and skills needed to handle chemicals safely. Compliance ensures that safety measures are aligned with legal standards and best practices. Together, these components create a robust framework for mitigating risks and protecting workers. To achieve chemical safety goals, greater support and collaboration from the industry are vital. Industry associations, government agencies, and technology providers should work together to offer resources, guidance, and financial assistance to SMEs. By fostering partnerships and sharing knowledge, the industry can help SMEs overcome barriers and implement effective safety measures. Collaborative efforts will enhance safety standards across the sector and contribute to a safer working environment for all.

In summary, advancing chemical safety in SMEs requires a concerted effort that integrates cutting-edge technology, thorough training, and stringent regulatory compliance. By supporting SMEs through industry collaboration and providing the necessary resources, the goal of achieving comprehensive chemical safety can be realized.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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