International Journal of Scientific Research and Management (IJSRM)
||Volume||13||Issue||12||Pages||307-312||2025||
Website: https://ijsrm.net ISSN (e): 2321-3418
DOI: 10.18535/ijsrm/v13i12.c01

Hazard Analysis and Safety Management Measures for Chemical Experiment Center

Shi Xiaoming, Huang He*, Li Zaigao, Zhang Xu

College of Chemistry and Environmental Engineering, Yangtze University, Jingzhou, Hubei,434023, China

Abstract

The chemical experiment center, which integrates both undergraduate teaching laboratories and scientific research laboratories, involves diverse personnel and varied research activities, presenting numerous potential safety risks. This study analyzed the hazard sources in chemical experiment centers from three aspects: unsafe chemical factors, unsafe physical factors, and unsafe human behavior. Corresponding hazard management measures are proposed, including strengthening safety education and awareness, constructing standardized laboratories, ensuring scientific and standardized operations, mastering first aid methods for experimental injuries and accident response measures, and improving the management system. This research provided a theoretical basis for safety management and safety construction in experimental centers.

Keyword: Chemical experiment center; Hazard identification; Safety management

Laboratories are essential for cultivating students' experimental and innovative abilities, as well as being a core platform for scientific research. Chemical experiment centers span multiple disciplines, involve a wide range of activities, accommodate many students, and have complex personnel structures. They undertake substantial teaching and research tasks, house precise and valuable instruments and equipment, and manage numerous chemicals, all of which contribute to significant potential safety hazards and risks. In recent years, laboratory safety accidents have occurred almost annually, making laboratory safety a topic of widespread concern. To effectively reduce the occurrence of such accidents, it is imperative to explore effective safety management systems and strategies for addressing laboratory hazards.

1 Analysis of Hazard Sources in Chemical Experiment Center

According to “the Occupational Health and Safety Management Systems-Requirements GB/T28001-2011”, a hazard source is defined as the source, state, or behavior, or a combination thereof, that may cause personal injury and/or health damage. In other words, it refers to parts, areas, places, spaces, positions, equipment, or their locations within a system that possess potential energy or material release hazards, can cause personal injury, and may transform into accidents under certain triggering conditions. Based on Li Zhihong's statistical analysis of 100 laboratory accidents from 2001 to 2013, explosions accounted for 44% of the accidents, fires 42%, poisoning 6%, electric shock 1%, and other types 7% [1]. This indicates that explosions and fires are the primary safety accidents in laboratories, likely closely related to the unique environmental conditions of laboratories. In such environments, poor management or careless operation can lead to explosions, fires, poisoning, leaks, cuts, and other safety incidents. According to Heinrich's Domino Theory, chemical laboratory accidents often stem from unsafe human behavior and/or unsafe conditions of objects. Generally, accident causation involves three factors: people, objects, and the environment. Unsafe human behavior refers to nonstandard, erroneous, or misoperations by personnel in chemical laboratories, including both internal teaching and research staff and external personnel. Unsafe conditions of objects refer to abnormal states of instruments, equipment, water, and electricity in the laboratory. Unsafe environmental conditions refer to factors that trigger dangers such as combustion, explosion, or falling objects.

1.1 Unsafe chemical environment factors

Unsafe chemical environmental factors primarily refer to situations where improper management of hazardous chemicals may reduce laboratory safety. According to " General Rules for Classification and Hazard Notification of Chemicals GB13690-2009", chemicals are broadly categorized into 16 classes: explosives; flammable gases; flammable aerosols; oxidizing gases; gases under pressure; flammable liquids; flammable solids; self-reactive substances or mixtures; pyrophoric liquids; pyrophoric solids; self-heating substances and mixtures; substances which, in contact with water, emit flammable gases; oxidizing liquids; oxidizing solids; organic peroxides; and substances corrosive to metals. During the transportation, storage, and use of these chemicals, improper handling or management may lead to leaks, causing accidents such as fires, explosions, poisoning, or corrosion. For these chemicals, their transportation, storage, and usage methods should be determined based on their Material Safety Data Sheets (MSDS), i.e., Chemical Safety Technical Specifications. Users must be familiar with their health hazards, fire-fighting measures, and first-aid emergency procedures. Each chemical should have an accessible MSDS for reference.

1.2 Unsafe Physical Environment Factors

Unsafe physical environmental factors refer to unreasonable layout of the experimental site, non-standard installation of experimental instruments and special equipment; and poor use, installation, or management of water, electricity, heat, and other utilities, resulting in reduced safety.

① **unreasonable spatial layout.** In recent years, Chinese universities have developed rapidly. Each year, a number of young doctors join the teaching staff, becoming main forces in scientific research. Limited by existing laboratory space, many teachers often have to share laboratories to conduct scientific experiments, leading to disruption of the overall laboratory layout, breakdown of functional zoning, lack of necessary buffer zones, and increased safety risks.

②**Poor equipment management.** Accidents involving experimental equipment are generally caused by operator misoperation, unsafe installation or placement of equipment, obsolete equipment lacking protective measures, or overload use.

③**Pressure vessel management defects.** Chemical experiment centers often store and use various gases, such as asphyxiating gases (N_2, CO_2, He, Ar), toxic gases (H_2S, Cl_2) , and explosive gases (H_2). These gases are typically stored in high-pressure cylinders. Improper management can lead to cylinder tipping injuries, or in severe cases, explosions or asphyxiation incidents. Various high-pressure reactors, vacuum devices, and vacuum distillation apparatus used in synthesizing new materials and substances may cause safety accidents due to sudden changes in test conditions or misoperation.

④**Inadequate management of high and low temperature environment.** Chemical experiments often use heating devices or liquid nitrogen quick-freezing materials, which may encounter the risk of high temperature scald and low temperature frostbite.

⑤**Unreasonable line planning and electrical fire.** Due to the unclear or confused division of the laboratory, the confusion of computers, instruments and equipment in the laboratory, and the mixed connection of wiring boards, wires and network cables, it often leads to electric shock, or line overload, short circuit, and even electrical fire in serious cases.

⑥**Insufficient fire and explosion prevention conditions.** There is no effective ventilation in the laboratory with flammable and explosive gas, no gas alarm device, no explosion-proof equipment installed in the electrical appliances, and the equipment is easy to produce static electricity and sparks during operation, thus causing safety accidents.

⑦**Improper storage of chemicals.** There are many kinds of chemicals and reagents in the chemical experiment center. If they are not stored in different categories according to their nature, those drugs and reagents with opposite nature will easily leak and cause safety accidents. If the storage environment temperature of dangerous chemicals with low flash point and low boiling point is not well controlled, it is very easy to cause explosion accidents.

1.3 Unsafe human behavior factors

A hazard source comprises three elements: inherent hazard, existing conditions, and triggering factors. The inherent hazard of a hazard source refers to the potential injury or loss that may result from moving machinery, radioactivity, or energy sources if an accident is triggered. The existing conditions of a hazard source refer to its physical, chemical, biological state, and constrained state, such as confined working spaces, elevated platforms, environmental pressure, high and low temperatures, chemical stability, pressure vessel strength, and environmental obstacles. Triggering factors are the causes or conditions that transform potential hazards into accidents—the external causes that turn hazards into actual incidents. Each type of hazard has a corresponding sensitive trigger. For example, for flammable and explosive materials, heat energy is the trigger for combustion and explosion; for pressure vessels, pressure increase is the trigger for explosion; chemical leakage is the trigger for poisoning. Therefore, controlling triggering factors can prevent hazard sources from becoming hazardous states, thereby reducing accident occurrence. Among various triggering factors, unsafe human behavior is the most significant. Laboratory personnel mainly include teachers, students, visiting scholars, and visitors. Key potential safety hazards include the following:

①**Weak safety awareness.** This is mainly manifested in turning a blind eye to laboratory safety hazards, insufficient understanding of the danger and severity of experimental accidents, or taking chances. Chemical experiment safety accidents range from minor incidents such as skin corrosion by acids/alkalis or cuts from broken beakers and test tubes, to major accidents like toxic gas leaks, fires, and explosions. Behind every major safety accident, there are typically multiple minor incidents and numerous potential hazards.

②**Lack of safety knowledge.** Few Chinese universities include chemical experiment safety in their curricula, whereas developed countries in Europe and America treat "Laboratory Safety for Chemistry Students" as a compulsory course [2]. This leads many teachers and students to prioritize technology over safety, lacking systematic learning and training in safety knowledge.

③**Lack of safety management.** Although many colleges and universities have relatively comprehensive management systems, implementation is often difficult, resulting in de facto management gaps. The responsible person of each laboratory plays a decisive role in experimental safety management. The head of a teaching laboratory is typically the experimenter, while the head of a research laboratory is a professor or PhD. Especially in research laboratories, where multiple people and projects operate simultaneously, the absence of a coordination mechanism makes safety accidents inevitable.

④**Insufficient safety measures.** Due to years of enrollment expansion, many colleges and universities, particularly local institutions, face serious resource shortages. Limited resources are often invested in capital construction and purchasing high-grade instruments, while investment in safety measures that do not yield direct benefits is clearly insufficient.

2 Countermeasures for Safety Management of University Chemical Laboratories

2.1 Strengthening Safety Education and Awareness as the Prerequisite for Laboratory Safety.

Safety education includes cultivating safety awareness, training safety knowledge, and providing safety countermeasures, enabling teachers and students not only to possess awareness for accident prevention but also the ability to identify safety risks and the skills to handle accidents.

The content of chemical laboratory safety education is extensive [3,4], including: ① national safety regulations and institutional safety management systems; ② management of hazardous chemicals; ③ emergency response and safety rescue for experimental accidents, and the use of safety protection equipment; ④ knowledge of safe use of water, electricity, and fire and explosion prevention; ⑤ safe use of instruments and equipment; ⑥ synthesis, thin-layer chromatography, rotary evaporation, collection and treatment of hazardous wastes, etc. To enhance the sense of safety responsibility, safety responsibility agreements should be signed with laboratory users and responsible persons. Laboratories in developed countries such as the United States and Europe have implemented safety access systems, requiring relevant personnel to pass safety examinations before entering laboratories for research or study. Regular laboratory safety drills, safety knowledge contests, examinations, lectures, and safety accident analyses should be conducted to foster a safety culture, cultivate safety awareness, and prevent accidents.

2.2 Laboratory standardization construction is the foundation of safety

The main environmental factors triggering safety accidents are non-standard or unreasonable laboratory construction. In the renovation of old laboratories and the construction of new ones, the "Chemical Experiment Teaching Center" must engage qualified companies to design with disciplines as the core, health and safety as the focus, rationally arrange laboratories according to relevant design specifications, increase investment in occupational health, safety, and environmental protection facilities, and ensure the construction of safe laboratory environmental conditions. Ventilation systems should be installed in environments where toxic and harmful gases are generated; electrical appliances and switches should have explosion-proof functions in environments with combustion and explosion hazards. Reasonable zoning is key—separating hazardous areas from valuable instruments, experimental areas from office areas, and flammable/explosive areas within experimental zones from ignition sources. Scientific zoning can effectively reduce the occurrence of dangers and minimize losses if accidents occur. Chemicals and reagents should be stored in dedicated cabinets according to their properties, classified for storage, with attention to ventilation, leak prevention, and corrosion prevention. For example, inorganic and organic substances should be separated, acids and alkalis separated, strong oxidants and strong reducing agents separated, and moisture-proof and waterproof measures must be emphasized for substances that react with water. Additionally, the amount of chemicals stored in laboratories should be minimized. Highly toxic drugs and hazardous chemicals should be stored in dedicated hazardous chemical warehouses or cabinets as regulated, with clear labeling and proper inventory management. Experimental wastes are hazardous during collection and storage. Corresponding specifications should be established for experimental waste collection, and collected wastes should be promptly transferred to standardized laboratory hazardous waste temporary storage facilities. Large precision instrument rooms should be equipped with safety devices or automatic fire extinguishing systems. The ideal storage method for flammable and explosive high-pressure gas cylinders is to place them outside the usage site and connect them via dedicated pipelines. If conditions require storage within the laboratory, cylinders must be secured in gas cylinder cabinets equipped with exhaust facilities and alarm devices at the top.

2.3 Scientific and Standardized Operation as the Guarantee of Experimental Safety.

To a great extent, experimental safety accidents occur due to non-compliance with operational norms. To avoid accidents caused by non-standard operations, the following must be ensured: (1) Teaching experiments must establish safety operation rules, which should be printed or posted on walls for easy access by teachers and students. Before experiments, the project leader or supervisor must assess potential safety issues and formulate corresponding safety plans. (2) Experiments involving toxicity and flammability must be conducted within ventilation facilities; adjust air doors to prevent diffusion of toxic gases, and open windows and doors and activate exhaust equipment to ensure normal air circulation. (3) Use minimal amounts preferable. Do not use unlabeled or unidentified reagents. Prepare chemicals as needed and avoid long-term storage. (4) Wear gloves when weighing and using toxic substances, and wash hands immediately after operation. (5) Empty containers and toxic residues after use must be properly disposed of, not discarded or poured into sewers. Waste generated in experiments should be collected by classification, registered, and safely disposed of by qualified environmental protection companies.

2.4 Familiarity with Accident Handling Measures and Injury First Aid Methods as Necessary for Experimental Safety.

The management principle for experimental accidents is prevention first, which can be divided into physical prevention, technical prevention, and human prevention. Physical and technical prevention are the foundation, and human prevention is the key. Personnel must not only be familiar with using physical and technical prevention measures but also with accident handling measures and injury first aid methods, which are important for reducing accident losses. Experimental accidents can be categorized as: poisoning, corrosion, cuts from glassware, mechanical rolling injuries, fire burns, scalds, frostbite, and electric shock. Therefore, it is essential to understand the causes of accidents and be able to take appropriate emergency rescue methods and disposal measures based on the accident nature. Laboratories must be equipped with first aid kits, eye washers, emergency showers, fire blankets, fire extinguishers, sandboxes, ventilation systems, and other necessary equipment, and personnel must be skilled in their operation and use.

2.5 Improving the Management System

Safety management is generally divided into four levels based on responsibility: university, college, department, and laboratory responsible person [5,6,7]. The university president and party secretary are the first responsible persons at the university level; deans and party secretaries at the college level; department heads at the department level; and laboratory users are the direct responsible persons. The university should establish a dedicated functional department responsible for laboratory safety to uniformly manage laboratory safety across the institution. Its responsibilities include: ① Formulating university-level safety management systems, such as the safety post responsibility system, safety inspection and rectification system, large-scale instrument usage management system, electrical safety code, special equipment management regulations, hazardous chemicals management system, waste and waste liquid treatment system, experimental teaching staff responsibilities, laboratory safety rules, and laboratory contingency plans. When formulating management systems, clear responsibilities and authorities, reasonable division of labor, elimination of blind spots, and prevention of future troubles should be ensured to guarantee the implementation of various safety measures. System formulation is the foundation, and system implementation is the key. Laboratory safety management must implement the principle of level-by-level responsibility and layer-by-layer implementation, requiring each level to have a safety responsible person, each laboratory to have a safety manager, clear accountability for safety errors, and thorough accident responsibility tracing. Supervision and inspection are effective methods and means for implementing laboratory safety systems. Inspections can be conducted in various ways, either regularly or irregularly. Regular inspections can check laboratory environment safety, instrument and equipment safety, and the implementation of rules and regulations; irregular inspections mainly target major hazardous places and can also verify hazard rectification without prior notice. Potential safety hazards identified during inspections should be rectified promptly within a set time limit. ② Being responsible for the safety management of special equipment, supervision of radioactive substances and hazardous chemicals, and collection and disposal of experimental wastes; safety training and inspections, etc. ③ Formulating the university laboratory safety plan and allocating construction funds according to the plan. Management at the college level primarily involves implementing university-level management systems, formulating corresponding management regulations based on the college's specific situation, and executing daily inspection and rectification measures.

2.6 Safety management mode

Yangtze University has proposed a safety management model of “0142412” and applied it in practice. The “0142412” model: “0”: zero safety accidents as the work objective; “1”: the unit head as the first responsible person, ensuring safety work is valued; “4”: the four-level safety responsibility system (university, college, department/center, and individual) ensures no gaps in safety responsibility and that everything is someone's responsibility; “2”: safety scope divided into two major categories： teaching laboratories and research laboratories each managed and guided by dedicated personnel, ensuring everything is managed and supervised; “4”: establishing four systems：“laboratory access system”, “laboratory safety management system”, “laboratory precursor explosives and hazardous chemicals management system”, and “laboratory safety inspection system”; “1”: focusing on a key aspect “hazard management”, which is crucial for preventing safety accidents; “2”: two types of capacity building: laboratory safety drills and emergency capacity building, and laboratory safety facilities and personal protection capacity building which guarantee the reduction of accident hazards.

3. Conclusion

Due to their inherent particularity and complexity, chemical laboratories harbor numerous potential hazards. To effectively manage risks, it is first necessary to conduct a thorough analysis of hazard sources, followed by the implementation of targeted preventive measures against risk factors. Safety education is the premise, safety technology is the foundation, and safety management is the guarantee. These three aspects complement each other. Strengthening the construction of a safety culture, striving to create a safe, harmonious, and environmentally friendly environment, and providing assurance for the development of teaching and scientific research in colleges and universities are essential.

References

1. Li Zhihong. Statistical analysis of 100 laboratory safety accidents and countermeasures [J]. Experimental Technology and Management, 2014, 31 (4): 210-2165.
2. Cheng Jingli. Management and Enlightenment of Chemistry Laboratories in American Universities [J]. Experimental Technology and Management, 2012, 29 (7): 176; -178.
3. Gao Wenhong, Sun Huan, Han Xiaomin, et al. Improving laboratory safety management level with "five key points" [J]. Laboratory Science, 2020, 23 (6): 211-214.
4. Qin Chuanli, Fan Naiying, Wu Huayang, et al.Preliminary study on teaching mode of chemical experiment safety knowledge [J].Laboratory Research and Exploration, 2020,39 (10): 291-295.
5. Liu Xianfeng, Zhang Dongping, Zhang Fang, et al. Construction of safety system of chemical

laboratory in engineering colleges and universities [J]. Shandong Chemical Industry, 2020, 49 (17): 193-194.

6. Lu Xianyong.Enlightenment of laboratory safety management in American universities to the construction of safe "double first-class initiative" laboratories in China — — a case study of University of Michigan at Ann Arbor [J].Laboratory Technology and Management, 2020,37 (9): 306-310.
7. Xiong Shunzi, Peng Huasong, Liu Jinsheng, et al. Research on Laboratory Safety Education and Exercise System in Colleges and Universities [J]. Laboratory Research and Exploration, 2018, 37 (12): 296-299.

Foundation Project: Experimental Work Research Project of Universities in Hubei Province (HBSY2017-13).

First Author: Shi Xiaoming (born 1976), male, Hubei Province. Associate Professor. Research interests: environmental science, laboratory safety management.

*Corresponding Author: Huang He (born 1969), male, Hubei Province.Ph. D., associate professor, research interests: environmental ecology, laboratory safety management.

E-mail:huanghe@yangtzeu.edu.cn