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Advancing Safety in University Chemistry and Materials Labs

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Abstract: The challenges in and the strategies for enhancing laboratory safety within university chemical and material science labs are explored in this paper. Key issues such as insufficient safety awareness, inadequate management systems, and the absence of effective reward and punishment mechanisms are identified. Focusing on practical solutions, the study advocates for a robust safety control system, regular safety inspections, proper hazardous material handling, and targeted safety education and training. The findings emphasize the critical need for a holistic approach to safety management in academic laboratories, highlighting the importance of a balanced integration of awareness, regulation, and proactive risk management in ensuring a safe academic research environment.

Keywords: Laboratory safety; Chemical hazards; Safety management; University laboratories; Hazard control

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1. Introduction

Chemical experiments that involve gases, flammable and explosive reagents, and toxic and harmful drugs, have seen frequent occurrences of accidents such as fires, explosions, and poisonings in recent years [1]. Laboratory safety is closely related to the personal safety, property, and health of teachers and students. Safety accidents, once occurred, can cause immeasurable losses to students, teachers, schools, and society. These incidents can significantly impact the academic reputation of schools, their "Double First-Class" initiative, and enrollment, and also adversely affect the research progress and personal reputation of the teachers. Therefore, strengthening the management of laboratory safety is a safeguard for the "Double First-Class" academic initiative, a necessity for the high-quality development of higher education institutions, and represents a win-win situation for families, schools, and society. On the other hand, laboratory safety education, safe operation, and safety management are indispensable parts of the comprehensive quality education for all students. Enhancing students' awareness of safety and management skills also has significant practical significance.

The current state of laboratory safety largely reflects the maturity of a nation or region's research and teaching levels. With the rapid development of technology and diversification of experimental methods, laboratory safety is facing increasingly complex challenges. In various fields such as chemistry, biology, and

physics, lab safety issues encompass chemical management, biosafety, radiation protection, and the safety of instruments and equipment. Regrettably, despite increased awareness of safety, accident reports and data show that safety incidents still frequently occur in many laboratories, often due to negligence, poor management, or lack of safety education.

In terms of teaching, laboratory safety education is an important part of cultivating students' experimental skills and scientific literacy. A safe laboratory environment not only protects students and teachers from harm but also creates a conducive environment for learning and exploration. The continuous strengthening of safety education and strict implementation of practical operations help in cultivating students' safety awareness and a responsible attitude towards scientific research.

In the research field, laboratory safety directly affects the progress and quality of scientific research projects. A safe experimental environment not only reduces the risk of accidental incidents but also ensures the reliability of experimental data and the continuity of research. Moreover, good safety management also involves research ethics and compliance, which are crucial for maintaining scientific integrity and institutional reputation.

2. Challenges faced in laboratory safety

There is often insufficient emphasis on chemical laboratory safety in universities. Besides, there is a lack of safety awareness among teachers and students. Laboratories also suffer from poor management and safety education is usually conducted for the sake of formality. According to statistics, the frequency of accidents in chemical laboratories in universities and research institutes in China is much higher than that in research-oriented enterprises. This is attributed to the strict safety requirements and reward and punishment systems in enterprises, contrasting with the emphasis and challenges of laboratory safety education in universities.

2.1. Strengthening safety awareness among teachers and students

In recent years, the Ministry of Education has placed high importance on laboratory safety in universities and conducted special inspections for laboratory safety across universities. Most universities have made laboratory safety a key focus, but some local engineering colleges have neglected laboratory safety as they focus on the school's development research outcomes. This is evident in the lack of emphasis on laboratory safety at the departmental level and the neglect of laboratory safety management by teachers and research teams. During laboratory lessons, some teachers lack a sense of responsibility, focusing only on teaching the content of experiments and neglecting the cultivating of safety awareness, failing to provide full-time supervision and guidance during laboratory operations. Furthermore, some research teams only pursue work efficiency and convenience even at the cost of violating rules, completely ignoring laboratory safety regulations and underestimating potential dangers.

2.2. Imperfections in laboratory management systems

The laboratory management team is an essential component of university laboratory management and is key to ensuring the safety of the daily operations of university laboratories. Currently, local engineering colleges generally face challenges such as insufficient professional technical staff in laboratories and difficulties in implementing detailed safety management. On one hand, local engineering colleges often pursue research outcomes and focus on attracting and training teaching and research talents, neglecting support staff such as laboratory managers. This leads to issues like unreasonable laboratory management positions, unclear assessment and reward-punishment mechanisms, marginalization of laboratory management roles, and low

recognition, leading to a lack of enthusiasm for their work. On the other hand, the laboratory management systems of secondary colleges should also be improved. There are too few full-time laboratory management staff, leading to high pressure and heavy workloads. Consequently, staff members of the teaching and research faculty are required to assist in laboratory management part-time. However, the part-time staff are already burdened with teaching and research tasks, so they struggle to manage the laboratories effectively and be constantly available. Additionally, there is a lack of laboratory management funding, and professional skill training for laboratory management staff is often overlooked, so the safety management concepts applied are often outdated. The lack of practical skills for emergency handling hampers proper safety supervision and the ability to respond to emergencies.

2.3. Lack of reward and punishment mechanisms in laboratory management

University laboratory safety inspections are the most direct and effective way of understanding a university's laboratory management conditions, eliminating safety hazards, and preventing safety accidents. Laboratory safety inspections mainly include random checks by higher authorities, regular and special inspections at the university level, routine inspections by relevant departments, and daily self-inspections by the laboratory staff. However, oftentimes, laboratory safety inspections are only taken seriously at the higher levels but regarded lightly at the middle and lower levels, particularly at the level of daily self-inspections. There are two reasons for this phenomenon: firstly, safety inspection work is extensive and should be done frequently, but the laboratory management personnel are insufficient, leading to superficial inspections. Secondly, management personnel lack systematic training and vary in professional competence, resulting in incomplete checks for hidden risks in laboratories. Laboratory safety inspections also tend to focus more on the immediate situation and less on follow-up. For example, a hazard rectification report is made on the safety hazards discovered, but on-site rectification and re-inspection are not carried out. A strict supervision and feedback mechanism is a powerful means to ensure timely rectification of safety hazards. However, most university laboratories lack a reward and punishment mechanism, leading to insufficient attention by some laboratories to safety inspection rectifications. Common issues like poor laboratory environments and improper storage of chemicals are recurrent, and there is no long-term follow-up for hazards that cannot be rectified immediately, eventually leading to unresolved issues [2].

2.4. Problems in chemical and material laboratories

2.4.1. Safety hazards with hazardous chemicals

Material and chemical engineering laboratories store a diverse and large quantity of hazardous chemicals, making them the most problematic type of laboratories. The safety management of hazardous chemicals is crucial. Safety hazards of hazardous chemicals can occur in various phases such as procurement, usage, storage, and disposal. Therefore, the management of hazardous chemicals involves the entire chain. In the procurement phase, if regulations in the "Management Regulations of Precursor Chemicals" and "Public Security Management Measures for Explosive Precursor Chemicals" are not strictly implemented for chemicals that can be used for drug or explosive manufacturing, it can pose a significant risk to public safety. Material and chemical experiments often involve the use of corrosive and volatile reagents. In the high temperatures and humidity during summer, improper storage can lead to high concentrations of volatile reagents in enclosed spaces, creating significant safety hazards. Additionally, chemical reagents can deteriorate if not used for a long time.

2.4.2. Hazards related to instrument and equipment usage

Electrical equipment is often used in material processing laboratories, so they are prone to instrument- and equipment-related accidents. Laboratory wiring is generally embedded in walls, making it difficult to detect aging wires, and it also makes daily inspections and maintenance difficult. There are many small devices such as stirrers and ovens in the laboratories, which, if placed improperly, can lead to disorganized wiring and improper connections. Power strips are often placed on the ground or near sinks, posing a risk of leakage when wet. In material processing laboratories, improper operation and insufficient protection of large equipment and specialized instruments can lead to accidents such as crushing, squeezing, bumping, radiation exposure, or burns. Besides, the improper operation, use, and maintenance of high-pressure gas cylinders can cause explosions, which may injure the people near the explosion.

2.4.3. Fire safety hazards

There are many causes of fires, such as aging of electrical wires, water contact with power strips, circuit overloading, or long-term use. Additionally, improper handling of reagents, experimental operations, and management can also cause fires. For example, when disposing of old reagents, when the labels of the reagent bottles fall off, the content of the bottles becomes unknown, and accidents might occur when these reagents are mixed carelessly with water. Furthermore, water baths that are not refilled in time can dry out and cause a fire. A malfunction in the temperature control components of ovens can also lead to overheating and smoking of items inside, potentially leading to fire accidents [3].

3. Suggestions for laboratory safety

3.1. Strengthening safety culture construction, focusing on safety education and training

The responsible entities for safety education should first be defined, with the persons responsible for implementing safety education at the school and college levels clearly identified. Besides, indicators such as the frequency, number of participants, and content of safety education should be quantified for each semester. This is to ensure the effective implementation of safety education. Secondly, the relevance and practicality of safety education should be enhanced by introducing compulsory laboratory safety education courses. General safety knowledge, laboratory safety management rules and regulations, and relevant policies and laws should be taught during the first year to enhance the awareness of laboratory safety of freshmen. In the second and third years, safety education should be more specific to the students' programs like biology, chemistry, physics, and computer laboratories, and targeted in-class safety education should be given for each type of experiment. Thirdly, a good laboratory safety culture should be created and safety education models should be continuously improved. On the basis of offering compulsory safety education courses, laboratory safety culture workshops should be organized. Besides, various laboratory safety culture competitions can also be held to promote safety knowledge. Moreover, micro-courses and Massive Open Online Courses can also be introduced. Online courses related to laboratory safety, virtual experiments, and other interactive teaching methods can also be adopted to help students establish safety awareness and enhance their understanding of hazardous experimental materials and operations, and strengthen personal protection capabilities.

3.2. Establishing a safety control system

Combining the functional characteristics of science and engineering laboratories and the theory of hazard source classification, laboratory hazards can be categorized into three types: The first type includes material hazards such as mechanical equipment, chemicals that can be used for drug or explosive manufacturing,

pathogenic microorganisms and waste, compressed combustible gases, and radioactive substances. The second type consists of energy hazards like electrical, sound, and light energy; high temperature and pressure internal energy, and potential energy. The third type includes factors that trigger the risk of the first two types, such as safety management decisions, experimental environmental conditions, and unsafe human behaviors. Universities should comprehensively and accurately identify the types and characteristics of laboratory hazards according to the classification and grading standards of laboratory hazards, and compile a list of laboratory hazards to provide a basis for risk assessment. Secondly, corresponding control measures should be formulated. Classified and graded management of laboratories should be implemented, the monitoring and management of hazards within laboratories should be strengthened, and laboratory safety management measures in terms of risk control responsibilities, protective measures, entry training, safety inspections, and emergency plans and drills should be implemented. For experimental projects with different risk levels, the principles of eliminating risks, replacing risks, and reducing exposure should be followed. Subsequently, targeted, operable, and economically reasonable control measures should be implemented to ensure that the risks are reduced to an acceptable range.

3.3. Establishing a reasonable laboratory reward and punishment mechanism

A safety reward and punishment mechanism is crucial to prevent laboratory safety accidents. The punishment measures should be determined based on the severity of safety incidents or accidents. Safety can be considered an important indicator in annual assessments, linked with comprehensive awards, teacher title evaluations, and student excellence evaluations. Teachers, students, and laboratories that perform excellently should be awarded while laboratories that repeatedly experience dangers or fail to implement rectifications properly should be suspended for comprehensive rectification [4].

3.4. Strengthening safety management in chemical and material laboratories

The storage of hazardous chemicals should comply with relevant national regulations, and ventilation devices must be installed in the storage areas. Incompatible chemicals must be stored separately and strictly categorized. Flammable, explosive, highly toxic, pathogenic microorganisms, narcotics, and radioactive materials must be stored in dedicated storerooms with specialized cabinets, and be managed by designated personnel with a dual-lock system for secure storage. Automatic monitoring and fire alarm systems should be installed according to the storage warehouse conditions. The storage areas should also be equipped with fire-fighting and anti-theft devices. Expired and ineffective hazardous chemical wastes should not be disposed of or buried arbitrarily, but rather be centrally stored and regularly disposed of properly. Residues and leftovers of highly toxic substances must be rendered harmless. The destruction and disposal of hazardous chemical wastes that pose risks of burning, explosion, poisoning, or other dangers should be conducted by qualified entities after obtaining approval from safety and environmental protection departments [5].

Regular electrical safety inspections to ensure the safety of wires, plugs, and power strips, and should be inspected, and aging or damaged wires and electrical components should be replaced promptly. Laboratory equipment and power lines should be arranged rationally to avoid disorganized wiring and ensure that there is enough space for the operation of large equipment. Lastly, training should be given to the staff to ensure proper handling of the equipment.

Chemical reagents should be categorized and labeled properly to prevent arbitrary mixing or incorrect handling. In addition, it is crucial to ensure the correct use and regular maintenance of equipment such as ovens and water baths to prevent overheating and fires. Fire awareness among laboratory personnel should be enhanced and fire emergency drills should be conducted regularly. Lastly, laboratories should be equipped with

sufficient fire-fighting facilities, such as fire extinguishers and fire blankets, and the relevant personnel should be proficient in using them.

Disclosure statement

The author declares no conflict of interest

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