Design and Planning of Physicochemical Laboratories for Food Enterprises

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Abstract Rational laboratory layout design and scientific management systems are key to improving overall laboratory efficiency and safety, providing a solid foundation and guarantee for the smooth progress of scientific research. This article addresses a series of issues such as low testing efficiency caused by unreasonable laboratory layouts, incomplete or outdated equipment configurations affecting testing accuracy, and safety hazards arising from the lack of effective laboratory management systems. It conducts an in-depth exploration of the design and planning strategies for physicochemical laboratories. By proposing specific designs and guidelines for the location selection, functional zoning, and layout requirements of physicochemical laboratories, the aim is to optimize laboratory space utilization, enhance testing efficiency, and ensure the advancement of equipment configurations and the accuracy of testing precision. Simultaneously, it emphasizes the establishment of an effective laboratory management system to prevent and control safety hazards, safeguarding the lives of laboratory personnel and ensuring stable laboratory operations.

Key words Physicochemical laboratory, Design, Planning, Food enterprises

0 Introduction

Food safety has become a global focus, making the design and planning of physicochemical laboratories in food enterprises critically important[1]. With technological advancements and rising consumer demands, food enterprises must rely on advanced physicochemical testing methods to monitor product quality and prevent safety risks[2]. Efficient, precise, and internationally compliant physicochemical laboratories serve as the backbone for technological innovation in enterprises and are key to enhancing brand reputation and safeguarding consumer health[3]. However, some food enterprises face challenges in laboratory construction and operation, such as irrational layouts, equipment configuration issues, and lack of management systems, which constrain enterprise development and threaten food supply chain safety. In light of this, this article aims to explore the design and planning of physicochemical laboratories for food enterprises. By integrating advanced domestic and international concepts and technological trends, it proposes laboratory construction solutions that comply with regulations and ensure efficient operations, focusing on aspects such as location selection, functional zoning, and construction layout.

1 Laboratory location selection

When designing a physicochemical laboratory in a food factory, location and layout are crucial as they not only affect operational efficiency but also involve safety, hygiene, and process fluidity.

1.1 Building location Physicochemical laboratories should be located in specific areas of the factory or laboratory building, generally not suitable for placement near densely populated areas or critical production processes. A relatively independent area should be selected to avoid contamination from laboratory-generated waste and gases affecting other work areas. Physicochemical laboratories should be kept away from food processing areas and raw material storage zones. This reduces the risk of cross-contamination and prevents potential chemical substances or gases from affecting the production environment during experiments. Food factories typically have dedicated zoning, and laboratories should be situated in areas not directly interfacing with production processes.

1.2 Isolation requirements Laboratories should be located away from storage areas for flammable, explosive, or other hazardous materials to avoid potential dangers. Additionally, laboratories should avoid placement in areas with significant noise or vibration to minimize external interference with experiments.

Buildings with adequate load-bearing capacity should be selected to ensure that the weight load of laboratory equipment does not exceed standards. Floors should be flat and stable to prevent groundwater or humidity from affecting the experimental environment.

1.3 Transportation and logistics The laboratory location should facilitate the transportation of materials and waste disposal. Especially for large chemical laboratories, logistics pathways should be spacious to avoid overlap between transport vehicles and personnel activity zones.

1.4 Waste treatment The laboratory waste discharge system should be located as far away as possible from residential areas and crowd gathering zones, complying with environmental protec-

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tion requirements. Hazardous waste should be regularly transported to dedicated waste treatment facilities.

1.5 Energy supply The laboratory should be connected to stable infrastructure such as electricity, gas, steam, and water supply to ensure long-term stable operation and avoid interruptions or insufficient supply. Special equipment in physicochemical laboratories, such as fume hoods and drainage pipes, requires convenient access to the factory's ventilation and drainage systems. Therefore, physicochemical laboratories should be located near these infrastructure areas to facilitate installation and maintenance.

2 Functional zoning of laboratories

Physicochemical laboratories are typically divided into multiple functional zones, with each area rationally planned and laid out based on experimental requirements, frequency, and safety considerations. The main functional zones include the following sections.

2.1 Receiving area This area receives samples from the factory production line or external sources and performs preliminary processing (*e.g.*, labeling, registration, and classification). The receiving area is typically located at the entrance of the laboratory.

The receiving area must have sufficient space for sample storage and initial classification while preventing contamination of other zones. This area should include appropriate temperature control equipment (*e.g.*, refrigerators or cold storage) for storing perishable samples[4].

2.2 Preparation area The preparation area is used for sample pretreatment, chemical reagent preparation, solution formulation, and instrument calibration. This is a critical step in the pre-experimental phase. The preparation area should be equipped with appropriate workbenches, storage cabinets, and kept isolated from other areas to avoid cross-contamination. This area requires good lighting and accessible power outlets to support various experimental operations[5].

2.3 Experimental area This is the core area of the laboratory, where actual physical and chemical analyses and testing are conducted. The layout of the experimental area may vary depending on the type of experiments (*e.g.*, chemical analysis, physical testing, microbial detection).

The experimental area should have sufficient workbench space and be equipped with essential instruments such as balances, reagent bottles, glassware, and gas analyzers. Additionally, ventilation equipment such as fume hoods and exhaust systems must be considered in this area[6].

2.4 Weighing area The balance room should be an independent space to prevent external vibration interference. It should also be located near the basic chemistry laboratory for operational convenience.

The balance room should be kept away from vibration-generating equipment or areas (*e.g.*, machinery, traffic routes) to minimize the impact of vibrations on measurement accuracy. It is preferable to place the balance room on the ground floor or lower levels to reduce vibrations from the building structure and human activity. The balance room should ideally face north to minimize direct sunlight and temperature-induced vibrations. The walls, floor, and ceiling of the balance room must be robust and stable to withstand vibration loads without deformation or damage. The balance table inside the room should be made of vibration-damping materials such as marble or granite. The balance room should include three-level vibration isolation devices, such as thick granite countertops, vibration-damping rubber pads, and soft rubber feet, to absorb most environmental vibrations.

The balance room must be kept away from strong electromagnetic interference sources (*e.g.*, large electrical equipment, high-voltage power lines) to reduce measurement errors. A buffer door is recommended in the balance room to prevent airflows from affecting weighing accuracy.

2.5 Analysis area The analysis area is used for data analysis and result documentation. In physicochemical laboratories, data analysis is a critical step, typically requiring computers, data acquisition devices, and analytical software. This area should provide a comfortable working environment with ergonomic seating, workstations, and display equipment to ensure focused data processing. Data should be promptly uploaded to a central database for further analysis and management[7].

2.6 Storage area This area is used to store reagents, chemicals, laboratory equipment, and processed samples. A well-designed storage area prevents leaks or cross-contamination of chemicals and reagents. The storage area should be zoned based on chemical properties: flammable, explosive, and corrosive chemicals should be stored separately with dedicated ventilation systems. Additionally, sample storage must account for temperature and humidity requirements[8].

2.7 Waste disposal area The waste disposal area handles chemical waste, liquid waste, and other hazardous materials generated during experiments. The design of this area must comply with environmental protection and safety regulations. The laboratory's waste, wastewater, and exhaust gas treatment systems should be independent of the main building. Exhaust emission equipment should be located away from personnel activity zones. Exhaust discharge points should be positioned above the laboratory roof to prevent gas backflow.

The laboratory wastewater treatment system should include tailored equipment based on the characteristics of different wastewater types. All wastewater pipelines must have effective isolation measures to prevent cross-contamination with clean water systems. Hazardous waste storage should be kept away from experimental areas to ensure safe handling and transport of waste[9].

2.8 Cleaning area The cleaning area should be equipped with dedicated water sources, washing equipment, and disinfection facilities, and must be separated from other experimental zones to prevent contamination. This area should also include secure storage for detergents and disinfectants[10].

2.9 Water preparation area Water is one of the most commonly used reagents in laboratories. Laboratory water must meet varying purity requirements (*e. g.*, deionized, distilled, ultrapure), as its quality directly impacts the accuracy of experimental results.

The water preparation area is dedicated to water purification and treatment. It should be equipped with deionized water machines, distillation units, ultrapure water systems, and piping networks to ensure timely access to water of required purity across all experimental zones.

The area should be moderately sized to accommodate water treatment equipment and necessary storage facilities. While the water preparation area may be semi-independent from chemical storage zones, it should not be too distant from other experimental areas to ensure efficient water supply. The design should incorporate water quality monitoring systems to ensure compliance with experimental standards. Wastewater treatment is also critical in this area. Properly configured wastewater discharge systems are required to ensure compliant treatment of laboratory wastewater[11].

2.10 Gas storage area Gases are essential reagents in many physicochemical experiments. Examples include industrial and experimental gases such as nitrogen, oxygen, hydrogen, and helium. Proper gas storage design ensures safe usage and prevents accidents such as leaks or explosions.

This area stores bottled gases, including high-pressure cylinders and liquefied gases, while ensuring their safety. The gas storage area must be kept away from ignition sources and heat, with dedicated ventilation to prevent fires or poisoning due to gas leaks. It is typically located on the building's periphery for quick evacuation in emergencies.

A robust ventilation system is mandatory to maintain gas concentrations within safe limits. Ventilation equipment should be inspected regularly to ensure unobstructed airflow. Fireproof and explosion-proof measures, such as explosion-resistant lighting and automatic fire suppression systems, must be installed. Gas cylinders should be secured in dedicated racks or cabinets to prevent leaks or explosions caused by vibration or impact[12]. For laboratories with high gas usage, dedicated gas piping systems should be designed to deliver gases directly to workstations, minimizing cylinder handling.

2.11 Reserved experimental area The reserved experimental area refers to space allocated for potential future experimental needs or equipment. As experimental technology advances or requirements evolve, laboratories may need new functionalities or equipment. Thus, reserving space during initial design avoids future renovation costs[13].

This area is typically not used immediately but should provide sufficient space for future expansion. The design must account for potential future needs, leaving adequate unused space. These areas should have pre-installed utilities such as power outlets, water supply, and gas pipeline interfaces to facilitate future equipment installation.

2.12 Laboratory safety facilities Emergency eyewash stations and safety showers must be placed in visible locations at a safe distance from experimental zones, ensuring quick access during accidents. Appropriate fire extinguishers must be installed in all areas, especially where flammable chemicals are stored, and must be easily accessible. Safety exits and evacuation routes should be designed to meet emergency evacuation needs, ensuring unobstructed access to exits to prevent congestion during crises.

3 Layout requirements

3.1 Passage design and area isolation The laboratory layout should fully account for personnel flow paths to avoid contamination caused by cross-movement. Distances between functional zones should be minimized to reduce material transport time and improve efficiency.

Passages within the laboratory must be spacious, with a minimum width of 1.2 m to allow two people to walk side by side. Additionally, all passages should remain unobstructed, free from clutter. Clear physical isolation should exist between different zones, especially between experimental areas and hazardous material storage or waste disposal areas. Safety doors, ventilation systems, and warning signs must be installed. The laboratory should have multiple safety exits to ensure rapid evacuation during emergencies. Emergency exits should lead directly outdoors, avoiding enclosed spaces[14].

3.2 Electrical and gas supply layout

3.2.1 Electrical layout. Power capacity and outlet planning must estimate total laboratory electricity demand to ensure sufficient supply. Outlet locations and types should align with equipment layout. Appropriate voltage levels (*e. g.*, 220 V and 380 V) must be selected, with current capacity calculated to prevent overload. Safety voltage and grounding protection should be configured. Laboratory lighting must be uniform and sufficient, using explosion-proof and dust-resistant fixtures, with emergency lighting installed. Power outlets and accessories must be high-quality with multi-protection features to ensure the convenient and safe access of electrical equipment[15].

Cable routing should be planned to avoid tangling, ensuring neat and aesthetic organization. Power lines should be zoned according to laboratory functional areas for easier maintenance.

A certain amount of electricity is reserved in power planning to meet the increase of laboratory equipment and electricity demand in the future. The electrical layout should be flexible to adapt to functional or equipment changes.

3.2.2 Gas pipeline layout. Gas pipeline design must consider equipment layout, gas usage frequency, routing, and space utilization, ensuring short and smooth paths for easy installation and maintenance. It is necessary to classify gases by properties and implement safety measures, including dedicated pipelines, explosion-resistant materials, and leak detection devices.

Pipeline materials (*e. g.*, stainless steel, copper, galvanized pipes) must align with gas properties, pressure, temperature, and environment. Explosion-proof materials are required for flammable gases. Safety devices (*e. g.*, leak detectors, pressure regulators, relief valves) are essential for safe operation. Gas pipelines must be clearly labeled with gas name, pressure, and flow direction for efficient management and maintenance[16].

In order to improve laboratory safety, it should be managed in zoning according to gas properties, and fire isolation belts and leakage alarm devices should be set up. Emergency shutdown and alarm systems should be integrated to address gas leaks.

3.2.3 Exhaust system layout. Exhaust systems must efficiently remove hazardous gases, vapors, and particulates while preventing backflow. Local exhaust hoods or fume hoods with adequate airflow should be installed near hazardous gas sources. General exhaust systems should maintain air circulation, with airflow volume designed based on lab size, occupancy, and experimental intensity[16]. Exhaust ducts should be straight and easy to maintain, with smart controls for airflow adjustment and alarms. It is necessary to install safety valves and fire dampers; exhaust outlets must be placed away from crowded or flammable areas.

4 Requirements for doors, windows, floors and walls

4.1 Floor requirements Laboratory floors must resist chemical corrosion. Epoxy resin flooring or PVC anti-static flooring is recommended. Acid/alkali-resistant ceramic tiles are suitable for highly corrosive areas. The ground should have anti-slip properties to prevent staff from slipping during the experiment. Floor materials should be easy to clean to maintain cleanliness and hygiene in the laboratory[17].

4.2 Door and window requirements Doors and windows must use fire-resistant, anti-theft, and explosion-proof materials for safety. Their placement should align with evacuation needs to ensure rapid exit during emergencies. Door openings should be ≥1 200 mm wide, with observation windows on doors and optional light/ventilation windows above frames. Window sills should be 900 mm to 1 000 mm high, with wall widths between windows ≤1 200 mm. Open doors/windows must not obstruct indoor space usage or corridor safety[18]. Passages must be unobstructed, avoiding dead ends to facilitate evacuation and equipment transport. Main passage widths depend on workstations: ≥1 500 mm for dual-sided central workstations. Side workstation passages should be ≥1 200 mm. Dual-sided fume hoods require ≥1 500 mm spacing.

4.3 Wall requirements Walls must resist acid/alkali corrosion. Epoxy resin coatings or corrosion-resistant tiles are recommended. Wall materials should have certain fire resistance to increase the safety factor of the laboratory. Wall materials should be easy to clean. Right angles should be avoided when designing the wall. Rounded corners should be selected to facilitate cleaning and prevent dirt from accumulating.

There are often high-temperature experiments in the laboratory, and the wall should have good thermal insulation performance to ensure the stability of laboratory temperature. Walls should include cavities for installing wires, pipes, and other utilities, ensuring easy maintenance. Connections between walls, floors, ceilings, and doors/windows must be secure to prevent cracks or loosening[19].

The bottom and surface of the wall should be waterproofed to prevent moisture from entering the interior of the wall, causing structural damage to the wall or problems such as mildew. Ventilation equipment must be integrated into walls for air circulation and gas exhaust. An exhaust pipe should be installed in the wall to facilitate the discharge of harmful gases produced in the laboratory[20].

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4.6 Exploring the implementation path of comprehensive "discipline-competition-innovation" integration In agricultural and related disciplines at higher vocational colleges, the implementation path of comprehensive integration of "discipline-competition-innovation" is being explored. Leveraging the competition platform, this approach deeply integrates professional education with innovation practices, aiming to holistically enhance students' comprehensive competencies and employability, thereby precisely aligning with industrial development needs. Concurrently, policy support and institutional reforms from governments and higher vocational colleges provide robust guarantees for the sustained development of the competition.

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