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HYGIENIC DESIGN OF MEAT PROCESSING FACILITIES

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Abstract. The article addresses current issues related to the hygienic design of meat processing facilities as a foundation for effec-tive microbiological risk management and food safety assurance. In the context of increasing sanitary requirements imposed by regulatory authorities and consumer expectations, hygienic design is recognized as a key preventive tool against product contamination and a means of implementing the principles of international standards. The study presents a systematic analysis of the theoretical foundations, regulatory requirements, and practical aspects of hygienic design, covering all levels – from site selection and architectural zoning to the choice of construction materials and the organization of internal flows. Particular attention is given to the importance of sanitary protection zones and the zoning principle, which entails dividing the enterprise's premises into functional areas according to the level of microbiological risk. The necessity of establishing sanitary barriers, airlocks, s

anitation checkpoints, and systems with positive air pressure in «clean» zones is substantiated. A separate section is devoted to the analysis of construction materials and design solutions. The article provides a detailed description of hygienic equipment design requirements, including core principles recommended by international organizations. The article also summarizes international best practices in organizing personnel, raw material, finished product, and waste flows. It is demonstrated that key principles include physical and organizational segregation of flows, unidirectional movement, prevention of route intersections, and the establishment of barriers between zones with different hygiene statuses. Based on the conducted analysis, a number of practical recommendations are formulated to enhance the hygienic design of meat processing facilities. The proposed approach is particularly relevant for enterprises striving to meet international standards, enter foreign markets, improve brand reputation, and build consumer trust. The implementation of systematic hygienic design also contributes to the sustainable development of the food industry as a whole, promoting public health and enhancing the competitiveness of domestic producers.

Keywords: design, meat processing facilities, food safety, sanitary and hygiene standards.

Introduction. Formulation of the problem

Ensuring food safety is one of the most pressing issues of the modern era, with a direct impact on public health, economic stability, and international trade. In this context, the quality and safety of meat and meat products are of particular importance, as they constitute a major component of the diet for a significant portion of the global popula-tion. Meat serves not only as a vital source of high-quality protein, iron, zinc, and B vitamins, but also as a potential carrier of microbiological and chemical hazards [1].

According to the World Health Organization (WHO), millions of people worldwide suffer from foodborne illnesses each year, with a significant proportion linked specifically to meat products [2]. Pathogenic microorganisms such as Salmonella spp., Listeria monocytogenes, Escherichia coli O157:H7, and Clostridium perfringens can cause serious outbreaks of foodborne infections [3]. In countries with well-developed food safety monitoring systems, meat products are subject to continuous control; however, even under these conditions, cases of contamination are still reported. In countries with less efficient control infrastructure, these risks are substantially higher [4].

Despite advancements in meat processing, transportation, and storage technologies, the sanitary and hygienic condition of production facilities remains the key determinant of the safety of the final products. This issue is further complicated by the fact that meat processing enterprises often represent complex facilities with multi-stage technologi-cal cycles, including slaughtering, deboning, trimming, grinding, thermal processing, packaging, and storage. At each of these stages, there exists a risk of secondary contamination with microorganisms, chemical residues, or foreign matter [5].

One of the most effective approaches to mitigating such risks is the implementation of hygienic design principles at all stages of the development and operation of meat processing facilities. Hygienic design refers to a system of archi-tectural, engineering, and technological solutions aimed at minimizing the risk of product contamination by ensuring optimal conditions for sanitation procedures, preventing cross-contamination, and facilitating effective monitoring and control of production zones [6].

The relevance of hygienic design is growing in the context of increasing demands for food quality and safety, both from government regulations and from consumers. In the European Union, the United States, Canada, and other coun-tries, strict standards for food facility design are in place, based on the principles of HACCP (Hazard Analysis and Crit-ical Control Points), sanitary design, GMP (Good Manufacturing Practice), and other food safety management sys-tems. These principles include strict zoning of production areas, the use of appropriate construction materials, the crea-tion of barrier-free environments for cleaning, effective ventilation, water supply and wastewater systems, and the as-surance of personnel hygiene [7].

At the same time, in Ukraine and many other countries, problems related to outdated designs of legacy meat pro-cessing plants, worn-out infrastructure, and insufficient automation remain pressing issues. These factors significantly hinder compliance with hygienic requirements [8]. Under such circumstances, the modernization of meat processing enterprises in line with hygienic standards becomes not only a necessity but also a competitive advantage in the mar-ket.

Modern approaches to the design of food processing facilities emphasize the integration of hygienic requirements at the earliest planning stages. This proactive strategy helps to prevent numerous issues in the future: it reduces sanita-tion costs, minimizes cleaning time, lowers the risk of production downtime due to microbiological non-compliance, and—most importantly – ensures consistent quality and safety of meat products [9]. In this regard, hygienic design serves not only as a critical component of sanitary control but also as an essential element of a company's overall sus-tainable development strategy.

Therefore, the study of hygienic design principles in meat processing facilities is highly relevant in the context of food security, consumer health protection, and enhancing the competitiveness of the industry. This paper explores the theoretical foundations, practical approaches, and international experience related to hygienic design in meat pro-cessing enterprises, analyzes common challenges, and proposes solutions adapted to current global and industry-specific demands.

Analysis of recent research and publications

The issue of meat and meat product contamination is one of the central topics in food safety research. Animal-derived products, particularly meat, provide a favorable environment for the growth of pathogenic microorganisms due to their chemical composition, high moisture content, and abundance of nutrients. As demonstrated by numerous recent studies, the greatest threats are posed by bacteria of the genera Listeria, Salmonella, Escherichia, Campylobacter, and Clostridium, as well as certain viruses and parasites [2–4,10–14].

In study [1], Listeria monocytogenes was detected in 17.14% of cooked, 36.84% of dry-cured smoked, and 24.32% of air-dried meat products. Additionally, 22.72% of surface samples from food-contact areas were also found to be contaminated. These findings indicate a high level of persistence and the ability of the pathogen to survive in food processing environments, even under existing sanitation measures [10].

According to a study conducted in China, L. monocytogenes was identified not only in finished meat products but also on equipment surfaces, where it formed resilient biofilms. These biofilms protect the bacteria from the effects of disinfectants, making thorough cleaning of equipment significantly more difficult. As a result, even minor deficiencies in cleaning and disinfection procedures can create a persistent reservoir of pathogens [11].

In countries with low levels of HACCP system implementation, the situation is even more challenging. For instance, a study conducted in Pakistan on meat contamination at markets and retail outlets revealed that over 84% of samples contained pathogenic or opportunistic microorganisms, with Enterobacter spp., Staphylococcus aureus, Pseudomonas aeruginosa, Bacillus subtilis, and Salmonella spp. being the most prevalent. The sources of contamination were linked to unsanitary conditions and the use of equipment unsuitable for food processing purposes [12].

In the European Union, according to the European Food Safety Authority (EFSA) report (2022), Salmonella remains one of the leading causes of foodborne illnesses, with more than 87,000 cases reported in 2021, a significant portion of which were associated with meat products. The report also noted that up to 20% of ground pork samples in Eastern European countries contained Salmonella spp., indicating substantial deficiencies in food control systems [13].

Researchers have also paid particular attention to microbial contamination resulting from airborne transmission. In a study conducted in Ireland, Prendergast, D. M., and colleagues found that facilities with complex spatial layouts (e.g., two-story structures with reverse flows) exhibited significantly higher levels of aerosol contamination compared to plants with linear configurations, where material, personnel, and airflows are clearly segregated [14].

Several studies also emphasize the role of the human factor in contamination processes. For example, a study conducted in Uganda revealed that poor personal hygiene among workers, inadequate enforcement of protective clothing use, and untimely cleaning of work areas significantly contributed to increased microbial loads in meat products [15]. Similar findings were reported in study [16], where the implementation of mandatory control measures—including HACCP—resulted in a reduction of samples exceeding hygienic limits by more than 40%.

In Ukraine, a number of studies have been conducted to assess the microbiological status of meat processing facilities. Notably, a study carried out at a meat processing plant in the Vinnytsia region identified biological hazards at the raw material reception stage. Four control points were established to effectively monitor biological, chemical, and physical hazards during the receipt, procurement, and processing of raw materials [17].

Another study conducted in the Dnipropetrovsk region demonstrated a significant presence of Listeria species in poultry meat products. Out of 8,172 analyzed samples, 36.7% tested positive for Listeria spp., with L. monocytogenes specifically identified in 6% of the samples [18].

A study [19] conducted at a meat processing facility in Ukraine demonstrated that the sanitary and hygienic condition of the facility directly affects the safety of the produced beef and pork. It was established that non-compliance with sanitary regulations leads to an increased microbiological load on the final product.

Another study revealed that recontamination of vacuum-packed meat products can occur after thermal processing during slicing, preparation for packaging, and the packaging process itself. To mitigate this risk, the authors proposed reapplying thermal treatment to the finished product in order to inhibit surface microbiota [20].

Sanitary and hygienic design of food facilities, particularly meat processing plants, is a critical component of the overall food safety management system. Effective sanitary design significantly reduces the risk of food contamination and supports compliance with HACCP, GMP, ISO 22000, and EHEDG (European Hygienic Engineering & Design Group) standards.

Study [21] highlights the importance of structural cleanliness and ease of equipment cleaning. The authors emphasize that complex surfaces, crevices, enclosed spaces, lack of drainage, or the presence of dead zones can contribute to the accumulation of product residues, moisture, and microorganisms. A systematic approach to hygienic design should include risk assessment related to contamination at the levels of equipment, facility layout, and overall infrastructure.

Article [22] discusses the fundamental principles of sanitary design for food processing facilities. The researchers emphasize the importance of selecting materials resistant to moisture, corrosion, chemicals, and thermal impact, as well as planning production areas based on the barrier concept. This includes the clear separation of clean and dirty zones, the isolation of raw material and finished product flows, and the creation of conditions that facilitate cleaning and disinfection.

Study [23] also deserves attention, as it examines microbial biofilms as a consequence of suboptimal equipment design. The authors demonstrate that applying hygienic design principles – such as avoiding horizontal surfaces, sharp angles, hidden cavities, and unhygienic weld seams – reduces biofilm formation and facilitates cleaning.

Synthesizing existing scientific data, it can be concluded that the issue of microbiological contamination of meat is multifactorial, encompassing not only raw material processing stages but also aspects such as facility layout, equipment design, employee behavior, and the effectiveness of sanitation control systems. In this context, hygienic design of meat processing enterprises plays a critical preventive role in minimizing contamination risks at all stages of the production process.

In the context of Ukrainian realities, an analysis of professional literature reveals a lack of a systematic approach to hygienic design at many facilities. Hygienic requirements are often considered retrospectively—during modernization or reconstruction—which leads to additional costs, the need for reconfiguration, and increased risk of non-compliance with international standards. Therefore, the integration of hygienic design principles at the initial planning stage is a key factor in ensuring the sustainable development of the meat processing industry in Ukraine.

The purpose of the study is to summarize and systematize modern principles and practical approaches to the hygienic design of meat processing enterprises, taking into account food safety requirements , as well as to identify the key factors influencing the sanitary and hygienic conditions of production and the level of product contamination, in order to develop recommendations for optimizing architectural, planning, and engineering solutions. To achieve this goal, the following **tasks** were set:

- to summarize contemporary scientific approaches to the hygienic design of meat processing enterprises as a preventive tool for ensuring the microbiological safety of food products;
- to analyze architectural, planning, and infrastructural solutions, including the layout of production areas, the selection of building materials, and the organization of internal flows, in terms of their impact on the sanitary and hygienic conditions at the enterprise;
- to identify the main challenges associated with the implementation of hygienic design principles;
- to formulate recommendations for optimizing the sanitary and hygienic conditions of production in accordance with international standards.

Results of the research and their discussion

A generalized review of current research indicates that hygienic design forms the foundation of a preventive control system aimed at preventing contamination rather than eliminating its consequences [10]. Standards developed by international organizations such as the EHEDG, Codex Alimentarius, ISO 22000, and GFSI (Global Food Safety Initiative) explicitly emphasize the importance of incorporating hygiene requirements at the enterprise design stage [24, 25].

Most instances of microbiological contamination at meat processing plants are associated with flawed equipment design, including cracks, crevices, or surfaces that are difficult to clean [21]. These areas can foster the formation of biofilms, which hinder effective cleaning and may serve as persistent sources of product recontamination [23].

Hygienic design enables the creation of an environment in which contaminants are less likely to accumulate and easier to remove, which is particularly important in the context of gentle or minimal processing technologies. The implementation of hygienically sound design solutions not only reduces contamination risks but also lowers the costs of cleaning, sanitation, and equipment maintenance.

Hygienic design should be regarded not as a purely architectural task, but as a comprehensive, system-based approach to ensuring product safety, covering all structural and functional elements of the facility.

Design of Production Infrastructure

The hygienic design of a meat processing facility begins with the appropriate selection and development of the site. The location must comply with sanitary requirements, as potential sources of contamination—such as dust, insects, rodents, polluted air, or water—can already be present at this stage. International guidelines emphasize the importance of considering microbiological risks during the initial zoning of the construction site [26].

Site Selection and Zoning for the Facility

The proper selection of a location for a meat processing enterprise is a fundamental prerequisite for ensuring sanitary safety. According to EHEDG recommendations, the site must be situated in a way that allows for the establishment of a sanitary protection zone, effectively separating production areas from external sources of contamination [26].

Ideally, the facility should be located at a considerable distance from potential pollution sources, including industrial areas emitting harmful substances, high-traffic highways, solid waste landfills, sewage treatment plants, and potentially contaminated water bodies. The distance from such sources must be sufficient to allow for the creation of a sanitary protection buffer in accordance with applicable norms and standards (e.g., a minimum of 300–500 meters, depending on the nature of the surrounding objects) [25, 26].

The facility should be situated on level or elevated terrain to prevent the accumulation of rainwater or industrial effluents and to eliminate the risk of flooding. Submerging buildings below the level of nearby roads or water bodies increases the risk of infiltration by contaminated water, which can adversely affect sanitary conditions. To mitigate this risk, it is recommended that the foundation be elevated above the surrounding ground level.

Location selection must also consider environmental factors such as wind direction and speed, airborne dust levels, humidity, and temperature, all of which influence the dispersion of aerosols, pathogens, and extraneous odors. Preference is given to areas with stable airflows and low dust concentration [22].

Effective logistical support is essential, necessitating convenient access roads that do not intersect with domestic or other traffic flows. It is crucial to enable the separation of transport routes for raw materials and finished products. The installation of separate access routes and loading/unloading ramps, isolated from personnel service areas, is strongly recommended.

Proper site zoning ensures a logically structured and hygienically safe production process by preventing the intersection of clean and contaminated flows.

Site zoning involves the establishment of clearly defined areas with varying levels of hygienic requirements, thereby minimizing contact between raw materials, finished products, and potential contaminants. A practical aspect of this approach is the provision of a hard-surfaced perimeter around the facility, extending at least 3 meters and free from vegetation. This reduces the risk of bacterial growth in the soil and facilitates easier cleaning of the surrounding area [21].

Key Functional Zones:

– Raw Material Reception Area. Located on a separate site, this zone is equipped to enable rapid disinfection of transport vehicles and quality control of incoming raw materials. It includes facilities for washing, cooling, sorting, and temporary storage of raw inputs.

– Production Areas. These are divided into “clean” and “contaminated” zones based on the principle of minimizing cross-contamination. Contaminated zones include raw material processing, while clean zones are designated for packaging, sealing, and storage of finished products.

– Waste Management Zone. An isolated area designated for the temporary storage and removal of waste, with barrier systems in place to prevent the spread of odors and pathogens.

– Personnel Service Area. Toilets, locker rooms, and staff rest areas must be physically separated from the production spaces to maintain hygiene integrity.

– Transport Routes. Separate pathways for raw material and finished product transport are established, with regulated vehicle movement and mandatory disinfection procedures [22].

Establishment of a Sanitary Protection Zone and Zonal Barrier Principle

A sanitary protection zone is a buffer area surrounding a production facility, designed to minimize the impact of external contaminants on manufacturing processes. It acts as the first line of defense against dust, vehicle emissions, chemical pollutants, pests, and other potential sources of contamination. The size of the sanitary protection zone is regulated by national legislation and international standards (for example, the Codex Alimentarius recommends a minimum of 30 meters, while EHEDG suggests distances starting from 100 meters depending on the level of risk) [25].

Components of the Sanitary Protection Zone:

– Paved Surfaces and Landscaping. Grass cover is excluded within the sanitary protection zone to reduce the spread of dust and rodents. The area is surfaced with asphalt or concrete, featuring gradients for effective water drainage.

– Access Restrictions. Sanitary barriers are implemented to restrict access by unauthorized personnel, vehicles, and animals, all of which may act as contamination vectors.

- Greenery. Vegetation may be used as a dust control measure; however, plant species must be carefully selected to avoid creating habitats for pests.

- Environmental Monitoring. Regular assessments of air, soil, and water contamination levels are conducted within the sanitary protection zone, enabling early detection and elimination of potential hazards [27].

The Zonal Barrier Principle involves dividing the enterprise's territory into multiple zones with progressively stricter hygienic requirements from the outer perimeter toward the inner production areas. This layered approach ensures the isolation of the most sensitive technological processes from potential sources of contamination [28]. A typical zoning structure is presented in Table 1.

Each zone must be separated using structural barriers such as walls and doors (sealed to prevent the ingress of dust and pests); airlocks (sanitary airlocks with clothing control and hand disinfection for personnel); ventilation systems (zones with higher hygiene requirements must maintain positive air pressure to prevent contaminated air from entering from adjacent areas) [29].

Organizational control within the framework of hygienic design of meat processing facilities involves a set of measures aimed at ensuring biological safety in production zones. One of the key elements is regulated access for personnel and transport in accordance with predefined clearance levels, which minimizes the risk of uncontrolled movement between areas with varying degrees of hygiene strictness.

An essential principle is the unidirectional flow of personnel, raw materials, and finished products, implemented according to the "clean-to-dirty" concept. This approach prevents cross-contamination and reduces the risk of secondary microbial contamination [30].

At the interface between zones, sanitary procedures are mandatory, including hand disinfection, changing or treatment of protective clothing, and decontamination of tools and auxiliary equipment.

Additionally, systematic documentation and control of hygiene measures are implemented through the maintenance of relevant records: entry/exit logs, sanitation reports, and inspection protocols. This ensures traceability and enhances staff accountability [26].

Construction Materials and Structural Solutions

Construction materials and structural elements used in food processing facilities, particularly in meat processing plants, play a critically important role in preventing product contamination. Non-compliance of materials with hygienic standards can result in the formation of microbial harborage sites, biofilm development, and pest intrusion. Therefore, materials used for floors, walls, ceilings, pipelines, ventilation systems, and lighting must be selected based on hygienic design principles, ease of cleaning, durability, and resistance to chemical exposure.

Floors in meat processing facilities must be impermeable, resistant to aggressive substances, non-slip, mechanically durable, and easy to clean and disinfect. According to recommendations [31], the floor should have an appropriate slope for drainage, and be constructed from seamless, chemically inert materials such as epoxy resin or acid-resistant ceramic tiles.

Table 1 – Typical Zoning Structure

Zone	Description	Hygienic Requirements
B0 – External surroundings	General area surrounding the facility	Minimum requirements, environmental monitoring
B1 – Sanitary protection zone	Buffer zone isolating production from external factors	Restricted access for unauthorized personnel, regular cleaning, continuous monitoring
B2 – Service/support zone	Technical premises, storage areas, raw material receiving zone	Enhanced access control, sanitary procedures
H1 – Production zone	Areas for primary processing of raw materials	High hygiene standards, personnel flow control
H2 – Open product handling zone	Zones with exposed products requiring a high level of cleanliness	Maximum isolation measures, air flow control

Walls must be smooth, free from cracks, pores, and joints, easily washable, and resistant to moisture and disinfectants. The most suitable materials for walls include high-density concrete blocks with epoxy coating or gel-coated fiberglass-reinforced panels. The latter provide a continuous, hard, waterproof surface with excellent wear resistance [22].

Ceilings must also be constructed from smooth, durable materials that are resistant to condensation and particle shedding. In high-humidity areas, the use of suspended metal or wooden ceilings is not recommended, as these surfaces are difficult to clean and prone to dust accumulation and mold growth [31].

It is also important to follow the principle of coving at the junctions between floors and walls to facilitate cleaning and prevent dirt accumulation.

For piping systems (water, steam, ventilation), corrosion-resistant materials are preferred – particularly stainless steel grades AISI 304 or 316. All piping must be designed to allow for cleaning access or enclosed within a false ceiling that provides maintenance access. Ventilation systems must be designed based on pressure gradients – from "clean" to "dirty" zones – to prevent recirculation of contaminated air.

Lighting fixtures must be moisture-resistant, impact-protected, and installed in a manner that avoids dust and microbial accumulation on their surfaces. The use of smooth-surfaced luminaires with protective casings is recommended to prevent contamination in case of lamp breakage.

Common errors in material selection for hygienic design are often associated with the use of materials that do not meet sanitary standards and contribute to contamination risks. For example, the use of wood or particleboard panels for wall or ceiling finishes is inadvisable due to their porous structure and the inability to achieve complete surface sealing [32]. Similarly, the use of uncoated concrete or asphalt floors is problematic, as these surfaces readily absorb moisture, creating favorable conditions for microbial growth.

Another issue is the use of galvanized metal, which can undergo zinc delamination over time, increasing the risk of food product contamination. Likewise, porous or uneven tiles are difficult to clean effectively, and grout joints between tiles often become sites of microbial contamination [33]. The use of uninsulated ventilation ducts is also considered a design flaw, as condensation may form and drip onto working surfaces, posing an additional contamination risk.

Equipment and Its Integration into a Hygienic Environment

Hygienic equipment design is a key factor in ensuring product safety at meat processing facilities. The primary objective of integrating equipment into a hygienic environment is to minimize the risk of product contamination by pathogenic microorganisms, chemical residues, and physical hazards [1]. The concept of hygienic design implies the creation of conditions in which equipment is fully accessible for cleaning and disinfection, contains no "niches" – hard-to-reach areas where contaminants may accumulate and ensures safe contact with food products.

One of the most important modern standards is the "10 Principles of Hygienic Equipment Design" proposed by the American Meat Institute. These principles serve as a foundation for the development and evaluation of equipment intended for use in the food industry, particularly in meat processing. They are aimed at ensuring sanitary control and minimizing contamination risks under high-intensity production conditions. The principles include: cleanability to a microbiological level, use of compatible materials, full accessibility for inspection and maintenance, absence of liquid collection points, sealed hollow areas, elimination of crevices and dead spaces, hygienic operational performance, hygienic integration with other plant systems and the availability of validated cleaning procedures [34].

Cleanability to a microbiological level – the design of equipment must ensure effective cleaning of all product-contact surfaces in such a way that no microorganisms or residual contaminants remain after washing and disinfection.

Use of compatible materials – all materials used in the construction of equipment must be chemically and biologically inert, and must not interact with cleaning agents, food products, or the surrounding environment.

Full accessibility for inspection, maintenance, and cleaning – equipment must be designed so that all components are easily accessible for visual inspection, cleaning, and, when necessary, disassembly without the use of specialized tools. Enclosed or sealed parts must be accessible via inspection hatches or other sanitary openings.

Absence of liquid collection areas – equipment surfaces should be properly sloped to allow complete drainage of liquids, avoiding stagnant zones where microorganisms may develop or cleaning solutions may accumulate. The presence of such zones poses a serious hygienic risk.

Sealing of hollow bodies – all internal cavities, piping, and joints must either be fully sealed or made accessible for cleaning. Hollow areas that are not cleanable or ventilated may become sources of secondary contamination.

Avoidance of crevices and dead spaces – equipment must be designed to eliminate crevices, gaps, or narrow spaces where contaminants can accumulate. For example, welds should be smooth and crack-free, and joints should avoid sharp internal angles.

Ensuring sanitary operational functionality – equipment must not only comply with hygienic standards but also be operationally reliable, safe for personnel, and easy to operate. Its use must not pose a risk of cross-contamination during normal processing.

Hygienic integration with other plant systems – equipment must be properly integrated with facility infrastructure, including ventilation, drainage, water and steam supply, to prevent backflow or reintroduction of contaminants into the processing environment.

Contamination protection during normal operation – equipment must be designed to minimize the risk of foreign matter (e.g., lubricants, particles, or fragments) entering the product during standard operation, maintenance, or component replacement.

Availability of validated and effective cleaning procedures – for each type of equipment, a cleaning procedure must be developed, validated, and approved, taking into account its specific design and the materials used. These procedures must be documented and readily available to personnel [34].

The integration of equipment into a hygienic environment also requires a carefully considered spatial layout and organization of the production process. According to integrated design principles, all functional zones must be arranged to prevent the crossing of clean and contaminated flows, and the equipment itself must not only meet hygiene standards but also align with the overarching concept of "global design safety" [35].

An essential stage of integration involves logistical planning of material and personnel flows. For instance, equipment should be positioned to prevent any backflow of raw materials into finished product areas, which is especially critical in thermal processing and packaging departments. Additionally, provisions must be made for easy disassembly of components for sanitation, use of color-coded markings for service zones, and zoning based on levels of microbiological risk.

During the design phase, ergonomics and occupational safety must be taken into account when integrating equipment. This includes the availability of easily accessible control elements, the absence of protruding parts, the use of noise-absorbing materials, and protection against electrical hazards [35]. Reducing physical strain on workers through optimized working surface heights, automation of manual operations, and the creation of safe service zones lowers the risk of workplace injuries and minimizes human error.

The effectiveness of equipment integration is closely related to the planning of cleaning zones, ventilation systems, proper pipeline installation, and the isolation of high-risk areas such as locations with high humidity or temperature fluctuations. For example, drainage systems must be installed in such a way as to prevent the formation of stagnant zones, while ventilation should ensure airflow from clean areas to less critical ones, in accordance with the principles of an air barrier.

In addition to technical aspects, equipment integration must comply with international standards—such as ISO 14159, EHEDG, and HACCP plans, which consider critical control points at every stage of the production process. Compliance with these standards is not only a requirement for product export but also a crucial condition for maintaining consumer trust.

Successful implementation of hygienic design principles requires collaboration among equipment manufacturers, engineers, facility architects, and food technologists. Interaction between these parties allows for consideration of all technical, hygienic, economic, and practical aspects of operation. Equipment that meets modern hygienic standards ensures not only food safety but also improves the overall efficiency, durability, and energy efficiency of production processes.

Hygienic Zoning of Production Areas as a Strategy for Microbiological Risk Management

Zoning of production areas according to the level of microbiological risk is one of the leading strategies for ensuring food safety at meat processing facilities. According to the approaches recommended by EHEDG and the Codex Alimentarius, production space should be organized as a set of interconnected zones with graduated hygiene requirements, appropriate labeling, and architectural isolation [25].

The main types of hygienic zones are considered to be Zone B (Basic – basic level of hygiene), Zone M (Medium – medium level of hygiene), and Zone H (High – high level of hygiene). This classification allows for a logical sequence of the technological process, preventing cross-contamination between raw materials, semi-finished products, and final products [21].

Zone B includes areas with a low risk of microbiological contamination, where no open handling of food products occurs or where products are already packaged. These include packaged product warehouses, office spaces, technical areas, locker rooms, and logistics corridors. Hygiene requirements in these areas are minimal; however, basic cleaning, ventilation, pest control, and restricted access for unauthorized personnel are ensured.

Zone M includes areas where open raw materials or semi-finished products are processed, which are subsequently subjected to thermal or other treatment that ensures microbial inactivation. Such areas include primary meat processing departments, salting, and minced meat preparation. Sanitary and hygienic requirements here are enhanced: personnel must wear designated protective clothing, follow strictly defined movement routes, and regular disinfection of equipment and surfaces is required. Filtered ventilation (minimum F7) must be installed, and cross-flow movement is restricted [33].

Particular attention is paid to maintaining air balance – negative pressure must not be created in Zone M, as it may contribute to the ingress of aerosol contaminants from Zone B. It is also recommended to avoid open passages and to ensure physical separation from other zones.

Zone H includes processing areas where open food products are handled that are ready for consumption or will not undergo further thermal treatment. These include packaging departments, slicing areas, packaging and cooling zones for delicatessen products, and the production of food for infants or medical nutrition purposes [31].

In Zone H, the most stringent requirements are applied:

– maintenance of positive air pressure using HEPA filtration;

– access control through fully equipped sanitary checkpoints with showers, hand disinfection, clothing and footwear change;

– complete physical separation by means of sealed doors, airlocks, and tight partitions;

– exclusive use of equipment compliant with hygienic design principles;

– implementation of automated personnel entry/exit tracking systems.

Compliance with zoning must be ensured both administratively and through the implementation of integrated monitoring systems (access control, video surveillance, digital auditing). The architectural design of the facility itself must ensure that the movement of personnel, products, and waste does not violate the hygienic hierarchy, and that transitions between zones are only possible after completing the appropriate sanitary procedures.

Planning of Raw Material, Finished Product, and Personnel Flows

Effective planning of raw material, finished product, and personnel flows is a key element in maintaining hygiene at food processing facilities. Improper layout or intersection of these flows can lead to cross-contamination, posing a serious threat to food safety.

Separation of Physical Flows to Prevent Cross-Contamination

One of the fundamental principles widely applied in modern facilities is the unified one-way flow ("linear flow") – from raw material reception to storage or dispatch of finished products without reverse movement or route crossing. As stated in the Codex Alimentarius, violation of this sequence increases the likelihood of microbiological contamination, which is a critical risk for meat and meat products [25].

According to research [21], the most vulnerable areas for secondary contamination are those where raw material, finished product, and personnel flows intersect – for example, during the return of containers, re-entry of staff without complete sanitary treatment, or in situations where there is a lack of architectural separation between zones.

Practical approaches to the separation of physical flows include:

– creation of separate entry and exit points for raw materials, finished products, and personnel, which must not intersect;

– implementation of barrier zones (sanitary checkpoints), where personnel change clothing and disinfect hands and footwear before moving between areas with different hygiene requirements;

– use of color-coded markings for equipment, containers, and tools according to the zone or type of product being handled (e.g., red for raw materials, blue for clean zones);

– division of production space into zones according to risk level (Zone B0 – external area, B1 – auxiliary zone, M – medium hygiene zone, H – high hygiene zone), which enables the establishment of movement rules for personnel and products [36];

– installation of physical barriers (walls, partitions, airlocks) between processing areas, as well as implementation of access control systems (key cards, fingerprint scanners) to ensure regulated personnel movement [37].

In addition, personnel must be informed and trained regarding the importance of adhering to the direction of movement, using designated routes, as well as following entry and exit procedures for zones with different hygienic statuses. As shown by data [38], neglecting these aspects is often the primary cause of contamination incidents at meat processing facilities.

To reduce the risk of contamination during the transportation of raw materials or products, internal logistical routes must be designed with spatial separation in mind (for example, the use of overhead monorails or conveyors that do not pass through "clean" zones), and must also include designated areas for handling containers and returnable packaging to avoid contact between "clean" and "dirty" material flows.

The planning of physical flows should be integrated with the architectural and layout design of the facility at the project stage, allowing these requirements to be addressed systematically, without the need for costly future reconstruction.

Installation of Air and Physical Barriers

The use of air and physical barriers in the design of meat processing facilities is one of the key components that enables effective implementation of hygienic zoning principles and prevention of cross-contamination. These barriers facilitate spatial and technological separation of processes, reducing the risk of transfer of pathogenic microorganisms, dust particles, aerosols, and microdroplets from areas with lower sanitary standards to zones with higher hygienic requirements [39].

Air barriers, including air curtains, pressure gradients, and air filtration, are employed to restrict air movement from potentially contaminated areas into product processing zones. According to the study [40], air curtains can reduce the transfer of aerosol particles and microorganisms by 40–60%, provided that they are properly configured in terms of temperature, velocity, and flow stability.

Maintaining pressure gradients is another effective tool widely used in high-hygiene zones (H-zones). The principle involves creating positive pressure in "clean" rooms, which prevents air from adjacent areas from entering. In this case, contaminated air from neighboring sections cannot penetrate the zone where the product undergoes final processing or packaging [21].

An effective ventilation system with filtration of at least HEPA or F7 class significantly reduces the microbial load in the air, especially under conditions of open product handling. Additionally, turbulent airflow must be avoided, as it can lift particles from the floor or equipment surfaces [26].

Physical barriers are implemented in the form of stationary partitions, airlocks, separating walls, and hermetically sealed doors. Their primary function is to prevent the physical transfer of contaminants (particles, aerosols, insects, dust), and to restrict the movement of personnel and equipment between zones with different hygienic statuses.

Modern facilities employ airlock systems where hand disinfection, clothing changes, or air showers (personnel airflow decontamination) are carried out before entering high-hygiene zones. Rotating turnstiles or automated doors with access control are also commonly installed to minimize unauthorized movement [41].

In meat processing facility designs, physical partitions are constructed from stainless steel or polymer panels that are easy to clean and free of joints capable of accumulating dirt. Access control systems can be integrated with infrared scanners, touch panels, or access cards for personnel identification [21].

In modern hygienic design practice, the combination of air and physical barriers provides the highest level of effectiveness. For example, installing an air curtain in front of automatic hermetically sealed doors with pressure control creates multi-level protection against external contaminants. This is especially relevant in areas where direct contact with exposed food products occurs, such as during slicing, packaging, or cooling of finished products [41].

The principle of multi-level protection is also implemented through zones with varying levels of air cleanliness (zones B, M, H), where each subsequent level imposes stricter requirements for air management, pressure, filtration, and air exchange frequency. This approach not only reduces microbial load but also ensures a stable microclimatic environment in each production zone.

Waste Flows and Their Isolation

The organization of waste flows at food industry facilities is one of the key factors in ensuring production hygiene and preventing cross-microbiological contamination. Improper management of these flows, particularly the lack of adequate isolation and routing, can lead to the spread of contaminants, including pathogenic microorganisms, significantly increasing the risk of compromising food safety.

To minimize such risks, the principle of material flow separation is implemented, whereby waste flows must be clearly isolated from the flows of raw materials, finished products, and personnel. This approach involves both physical and functional zoning of the production space, with the allocation of dedicated waste routes that do not intersect with other logistical pathways of the facility. One of the effective methods for implementing this principle is the construction of separate corridors or airlock vestibules for transporting waste containers, as well as the introduction of automated removal systems [21].

Special attention must be paid to waste classification by type (organic, chemical, mixed), which enables the implementation of a differentiated system for collection, storage, and disposal. Organic waste, which poses the highest biological risk, must be removed as quickly as possible, with strict adherence to temperature control and container sealing. Containers should be labeled according to the waste type, made of corrosion-resistant materials, and suitable for frequent washing and disinfection [42].

Waste collection and accumulation areas must be physically isolated from primary production areas. They should be equipped with ventilation systems operating under negative pressure to prevent the spread of airborne contaminants, as well as washing stations for the sanitary treatment of containers. The use of antimicrobial surface materials, automated UV disinfection systems, and air ozonation are examples of effective engineering solutions that enhance the level of biosecurity [43].

Sanitary control in waste accumulation zones involves regular disinfection of surfaces, equipment, and containers, as well as maintaining cleaning logs. Failure to comply with established sanitary protocols contributes to the formation of biofilms on surfaces, which significantly complicates cleaning and creates conditions for the prolonged survival of pathogens [44].

An additional hazard is posed by the attractiveness of waste areas to insects, rodents, and other pests, which can act as vectors for disease-causing agents. Therefore, specific biosecurity measures are implemented, including container sealing, physical isolation of collection sites, installation of insecticidal traps, and regular monitoring of pest activity involving pest control specialists.

The introduction of digital technologies, such as RFID identification of container movement or access control systems for waste zones, allows for the automation of waste management within the hygienic chain and enables real-time analytical monitoring [45].

Proper planning of waste flows, their classification, isolation, and control constitutes an integral part of an effective food safety management system based on the principles of HACCP, hygienic design, and biosecurity.

Analysis of Hygienic Design Deficiencies in the Practice of Ukrainian Enterprises

In the process of implementing hygienic design at meat processing enterprises in Ukraine, numerous obstacles are observed at the practical, technical, and educational levels. Despite the recognition of hygienic design as one of the key elements in the food safety assurance system, its practical implementation – especially in the context of Ukrainian meat processing enterprises – faces a number of significant challenges. These barriers are multi-layered and encompass not only engineering and technological aspects but also economic, organizational, and behavioral factors. An analysis of industry practices indicates that even when food safety management systems (in particular HACCP) are formally in place, most enterprises do not comply with critically important provisions regarding the hygienic layout of premises, flows, infrastructure, and engineering solutions.

Under current conditions in Ukraine, there is a significant disparity in the level of implementation of hygienic practices between large enterprises focused on exports to the European Union and small to medium-sized production structures serving only the domestic consumer market. While the former generally possess sufficient material and technical resources to implement the principles of hygienic design, the latter largely ignore even basic requirements, implementing only selected elements of HACCP, GMP, or GHP systems. As a result, the main problem remains the incomplete and unsystematic integration of food safety assurance approaches. As research results show [46], comprehensive functioning of the HACCP system is mainly characteristic of enterprises with access to international markets [47].

Another important problem is the technical unpreparedness of infrastructure to meet hygienic requirements. A significant portion of meat processing enterprises in Ukraine was built in the second half of the 20th century and does not comply with modern sanitary and hygienic standards. Typical violations include: lack of clear zoning of premises according to the level of contamination risk (from "dirty" to "clean" zones), intersection of movement routes for raw materials, finished products, and personnel, and installation of engineering communications (ventilation ducts, pipelines, cable channels) above open technological lines. Such structural features constitute a source of systemic microbiological hazards in food production environments [48].

The absence of effective sanitary airlocks, incomplete separation of “dirty” and “clean” zones, as well as the use of unsuitable construction materials – such as painted surfaces in wet areas or porous floor tiles – create favorable conditions for the proliferation of microbiological contaminants. As emphasized by Cherednichenko (2020), in many projects the principles of hygienic design are ignored, which is particularly characteristic of renovated facilities adapted for the needs of the meat processing industry without proper redesign [49].

An additional barrier to the implementation of hygienic design is the use of construction materials that do not comply with regulatory documentation requirements. In premises where regular wet cleaning and disinfection are expected, materials with porous or abrasive surfaces are often used: painted concrete walls, tiles with damaged joints, wooden structures that cannot be properly sterilized, or non-weldable drainage channels. This contributes to the accumulation of organic contaminants, moisture penetration into substructural spaces, and the formation of biofilms with high microbial activity.

Another systemic deficiency is the lack of qualified personnel for implementing hygienic design. Most meat processing enterprises do not employ sanitary audit specialists, hygiene engineers, or internal EHEDG design experts. The absence of specialized training for designers and operational staff leads to situations where, even when technically sound solutions are available, they are implemented incorrectly, partially, or entirely neglected during operation. As noted by Oshchypok (2019), in practice only 40–45% of enterprises that have formally declared HACCP implementation actually operate in accordance with its requirements [47].

Furthermore, state supervision and regulatory control in this area are fragmented and inconsistent. Even after the legislative establishment of mandatory HACCP implementation for all food business operators (in accordance with the requirements of the Law of Ukraine “On Basic Principles and Requirements for Food Safety and Quality”), actual compliance with hygienic design provisions is not always verified during audits. In many cases, inspections focus on documentation, while infrastructural deficiencies remain overlooked.

Practical Recommendations Based on International Standards for Successful Hygienic Design

Effective hygienic design of meat processing enterprises is a multifactorial process based on a systematic approach, integration of HACCP principles, international standards (EHEDG, ISO, Codex Alimentarius), and consideration of both technological and sanitary-hygienic aspects of food industry operations.

According to EHEDG guidelines, the key determining factor is the implementation of the “hygienic design” principle, which involves the architectural and engineering layout of production areas in a way that eliminates the formation of microbiologically hazardous zones, facilitates effective cleaning of surfaces, and prevents cross-contamination. In accordance with EHEDG requirements, facility design should include physical separation of areas according to the level of microbiological risk, the use of constructions made from smooth, waterproof, and disinfectant-resistant materials, as well as proper control of raw material, personnel, air, and water flows [50].

For its part, ISO 22000:2018 standards, which establish general requirements for food safety management systems, integrate hygienic design into the structure of prerequisite programs (PRP), which define the basic sanitary and technical conditions for safe production operations. According to these standards, a crucial requirement is the presence of documented and verified procedures for cleaning, sanitation, pest control, water supply and wastewater management, separation of areas with different technological functions and risk levels, as well as ensuring proper personnel training [51].

Significant attention is also devoted to aspects of hygienic design in the Codex Alimentarius, particularly in the document General Principles of Food Hygiene (CXC 1-1969, 2022 revision). This document emphasizes the need to establish a production environment that ensures the logical sequence of operations, spatial separation of raw material processing and finished product handling stages, provision of adequate ventilation and drainage, pest control, and the use of building materials that are safe for food environments. Additionally, the Codex calls for the implementation of Good Manufacturing Practice (GMP) procedures and hazard analysis with the identification of critical control points (HACCP) already at the design stage of the facility [25].

All the aforementioned standards are aligned in their fundamental provision concerning the necessity of implementing multi-level barriers to protect food products from potential sources of contamination. According to the zoning concept described in EHEDG and Codex Alimentarius, production premises should be organized as a sequence of functional zones – from the external environment to areas with high levels of hygienic control. This model includes:

External barrier – location of the facility in an environmentally safe area, physical protection of the territory (fencing, access control, sanitary buffer zones);

Structural barrier – building elements that prevent contaminants from entering production zones (tightly fitted doors, air filtration, sealing of joints);

Internal barrier – separation of functional zones according to the level of microbiological risk, taking into account the flow of products, personnel, and air;

Technological barrier – use of equipment and production lines that comply with hygienic design principles and prevent contact between raw and finished products [28, 50].

Recommendations for Primary Meat Processing Enterprises

Primary meat processing, encompassing slaughter, bleeding, hide removal, evisceration, and carcass deboning, represents one of the most critical stages in ensuring product safety. At this stage, the risk of microbiological contamination is particularly high, which necessitates special attention to the hygienic design of production areas. International regulatory frameworks, including EHEDG (2018) and Regulation (EC) No. 853/2004, emphasize the need for clear separation of «dirty» and «clean» zones. In practice, this means that operations associated with contamination (stunning, hide removal, evisceration) must be physically segregated from subsequent stages where the carcass is considered clean and ready for further processing. The flows of raw materials, by-products, and finished half-carcasses must not intersect, while personnel movement between zones should occur exclusively through sanitary checkpoints.

Water supply and wastewater disposal systems are of particular importance. All technological operations must be carried out using potable water only, and equipment in contact with carcasses must be equipped with high-temperature tool sterilizers (82 °C), as required by the Codex Alimentarius (CXC 1-1969, Rev. 2022). Wastewater networks must be designed to ensure rapid drainage, equipped with floor traps containing backflow valves, and constructed with adequate floor slope to prevent stagnation.

Materials used for equipment and production facility finishing should be resistant to corrosion and repeated sanitary treatment. Special attention should be given to avoiding open joints and crevices capable of accumulating organic residues. Cooling rooms must be equipped with systems capable of rapidly reducing the internal muscle temperature of carcasses to 7 °C, in line with ISO 22000:2018 requirements and confirmed by research findings [52].

Microbiological safety management also relies heavily on the control of airflow. In clean zones, forced ventilation systems with multistage filtration are applied, maintaining pressure differentials that prevent air transfer from contaminated areas. For deboning facilities, maintaining a temperature regime of 10…12 °C is recommended, as this significantly reduces microbial growth rates.

Another essential element of hygienic design is waste management. By-products and technical waste must be removed from production areas through separate airlocks. Their collection should be carried out in sealed containers made of materials that are easy to wash and disinfect.

Research findings [52, 53] demonstrate that compliance with hygienic design principles in primary processing facilities reduces microbial contamination of carcass surfaces by a factor of 2-3 compared with enterprises that rely solely on basic sanitary measures.

Recommendations for Secondary Meat Processing Enterprises

Secondary meat processing encompasses the production of sausages, smoked products, semi-finished goods, and ready-to-eat items; therefore, this stage presents the widest range of microbiological and technological risks. Unlike primary carcass processing, where the principal objective is the prevention of initial contamination, the key challenge in secondary processing facilities is the prevention of cross-contamination between raw and heat-treated products, as well as the maintenance of stable conditions for storage and packaging.

According to EHEDG (2018), Codex Alimentarius (CXC 1-1969, Rev. 2022), and international food safety management systems (ISO 22000:2018), the correct architectural and engineering zoning of production facilities is of critical importance. Raw ingredients must be delivered into designated areas, strictly separated from zones where thermal processing or packaging takes place. Any potential contact between raw and finished products – including personnel, containers, or airflows – must be completely eliminated.

Microbiological safety control relies heavily on the management of airflows. In packaging zones for cooked or smoked products, maintaining positive air pressure through the use of HEPA-filtered air is recommended to prevent contaminants from entering from adjacent areas. Research demonstrates that the implementation of laminar airflow systems in “clean” rooms significantly reduces the risk of contamination in finished sausages [54].

The hygienic design of equipment is another critical aspect. All technological lines for grinding, mixing, and stuffing must be made of stainless steel, with a minimal number of joints and connections, and designed for easy disassembly during cleaning. The use of automated clean-in-place (CIP) systems in the production of pâtés and sausages substantially facilitates routine equipment disinfection while reducing labor intensity [55].

Special attention must also be given to the cooling and storage of finished products. In accordance with European regulations (Regulation (EC) № 853/2004), ready-to-eat meat products must be stored at temperatures not exceeding 4 °C, and cooling after thermal treatment should be as rapid as possible to prevent the growth of psychrotrophic microflora. For products packaged under vacuum or in modified atmosphere, multi-stage temperature monitoring is considered highly effective, as confirmed by studies in food microbiology [56].

Waste management in secondary processing facilities is equally important. Unlike slaughterhouses, these enterprises generate considerable quantities of organic residues (trimmings, minced leftovers, skin, adipose tissues) that, if handled improperly, may become an additional source of contamination. Consequently, waste must be removed in sealed containers through separate technological airlocks, without re-entering the production cycle.

For secondary meat processing enterprises, the central strategy of hygienic design is the establishment of a multi-level barrier against cross-contamination, while simultaneously ensuring the stability of technological processes and preserving the quality of finished products.

The practical implementation of the recommendations set out in international standards involves not only compliance with technical requirements but also the establishment of an integrated system for hygienic management of space and processes at all levels — from the facility concept to its operation. Incorporating such approaches at the design stage of meat processing enterprises is a crucial factor in ensuring a consistent level of food safety.

Conclusion

The article examines the issue of hygienic design of meat processing facilities as an important element of the food safety management system.

The main principles of a systematic approach are analyzed, including architectural, engineering, sanitary, and organizational factors, as well as their impact on the prevention of microbiological contamination at various stages of the technological process.

The synthesis of international experience has made it possible to develop practical recommendations for the application of HACCP, GMP, ISO 22000, and EHEDG standards in facility design. For primary processing enterprises, the implementation of hygienic design principles ensures clear zoning of «dirty» and «clean» areas, control over carcass, waste, and personnel flows, as well as efficient cooling and equipment disinfection. Practical studies demonstrate that such measures reduce microbial contamination of carcasses by a factor of 2-3 compared with enterprises that adhere only to basic sanitary requirements.

In secondary processing enterprises, hygienic design contributes to the prevention of cross-contamination between raw and heat-treated products, control of airflows and temperature regimes, automation of equipment cleaning and disinfection, and the maintenance of stable storage conditions for finished products. These measures reduce the risk of product spoilage, enhance the effectiveness of HACCP systems, and facilitate international certification (BRC, IFS).

It has been established that the integration of hygienic design at the early stages of planning meat processing facilities provides multi-level protection of products against microbiological contamination, improves food safety and product quality, and increases the competitiveness of enterprises in both domestic and international markets.

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ГІГІЄНІЧНЕ ПРОЄКТУВАННЯ М'ЯСОПЕРЕРОБНИХ ВИРОБНИЦТВ

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Анотація . У статті розглянуто актуальні питання гігієнічного проєктування м'ясопереробних виробництв як основи для ефективного управління мікробіологічними ризиками та забезпечення безпечності харчових продуктів. На тлі зростання вимог до санітарного стану харчових підприємств з боку регуляторних органів і споживачів, гігієнічне проєктування виступає важливим інструментом профілактики контамінації продукції та реалізації принципів міжнародних стандартів. Стаття містить системний аналіз теоретичних засад, нормативно-правових вимог та практичних аспектів гігієнічного проєктування, охоплюючи всі рівні – від вибору земельної ділянки і архітектурного зонування до вибору матеріалів і організації внутрішніх потоків. Особливу увагу приділено важливості санітарно-захисної зони та зонального принципу проєктування, що передбачає розмежування території підприємства на функціональні зони відповідно до рівня мікробіологічного ризику. Обґрунтовано доцільність створення санітарних бар'єрів, шлюзів, санпропускників та систем з позитивним тиском повітря в «чистих» зонах. Окремий розділ статті присвячено аналізу будівельних матеріалів і конструктивних рішень. Детально охарактеризовано вимоги до гігієнічного проєктування обладнання, включно з основними принципами, рекомендованими міжнародними організаціями. У статті узагальнено міжнародний досвід з організації потоків персоналу, сировини, готової продукції та відходів. Показано, що основними принципами є фізичне та організаційне розмежування потоків, односторонній напрям руху, запобігання перетину маршрутів і організація бар'єрів між зонами з різним гігієнічним статусом. На підставі проведеного аналізу сформульовано низку практичних рекомендацій щодо вдосконалення гігієнічного проєктування м'ясопереробних виробництв. Запропонований у статті підхід є особливо актуальним для підприємств, що прагнуть відповідати міжнародним стандартам, виходити на зовнішні ринки, підвищувати репутацію бренду та формувати довіру споживачів. Впровадження системного гігієнічного проєктування сприяє також сталому розвитку харчової галузі в цілому, забезпечуючи збереження здоров'я населення та конкурентоспроможність національного виробника.

Ключові слова: проєктування, м'ясопереробне підприємство, харчова безпека, санітарно-гігієнічні вимоги