Technical White Paper on Industrial Cleanroom Purification System Total Solution

In fields such as environmental protection equipment manufacturing, precision machining, new material production, laboratory testing, and waste gas treatment equipment assembly,the cleanliness, temperature and humidity, pressure differential, and air flow organization of the production environment directly affect product quality, equipment operational stability, andproduction compliance. Traditional workshops commonly face problems such as uncontrolled dust diffusion, VOCs accumulation, large temperature and humidity fluctuations, pressure imbalance, andcross-contamination, which not only affect the overall performance of environmental protection equipment but also easily cause secondary pollution, making it difficult to meet modernhigh-standard production and environmental protection regulatory requirements.

The Industrial Cleanroom Purification System, with air purification, environmental control, pollution treatment, and intelligent operation and maintenance as its core, constructs a clean production environmentthat meets production needs through systematic design, modular construction, and refined operation and maintenance, achieving effective control of dust, particulate matter, harmful gases, and microorganisms,while ensuring that key indicators such as workshop temperature and humidity, pressure differential, air exchange rate, and noise levels meet standards.

This white paper comprehensively expounds on the technical system, core components, design principles, key equipment,construction specifications, operation and maintenance management, and typical applications of the industrial cleanroom purification system. Combining relevant national standards and industry specifications,it provides enterprises with a complete, implementable, and replicable cleanroom construction and operation technical solution, helping enterprises achieve production environmentupgrades, product quality improvement, and environmentally compliant operations.

I. System Definition and Application Value

The Industrial Cleanroom Purification System is a comprehensive environmental control engineering designed for industrial production scenarios. Through technical means such as air filtration,air flow organization optimization, temperature and humidity regulation, pressure differential control, fresh air supply, waste gas and dust treatment, and intelligent monitoring,it controls environmental parameters such as suspended particulate matter, harmful gases, temperature and humidity, and static pressure differential within specified ranges,creating a stable, clean, and safe production space.

Different from civil purification and medical cleanrooms, industrial cleanrooms focus more on production applicability, durability, pollution resistance, and energy efficiency,adapting to industrial conditions with high dust, high humidity, and VOCs release, balancing both production process requirements and environmental protection treatment needs.

Its core application value is mainly reflected in the following aspects. First, improving product and equipment quality. Especially in links such as core component processing of environmental protection equipment,filter media assembly, sensor assembly, and catalytic unit production, a clean environment can effectively prevent dust adhesion and impurity contamination, enhancing equipment reliability and service life. Second, achievingenvironmental compliance in the production process. Through closed purification, centralized dust removal, and waste gas collection and treatment, dust and VOCs emissions are controlled at the source, meeting fugitive emissioncontrol requirements and reducing environmental inspection risks. Third, improving the working environment and protecting occupational health, reducing hazards to operators from dust, odors, and harmful gases, lowering occupational disease risks and improving production safety and employee satisfaction. Fourth, optimizing production processes and achieving standardized, refined production. A clean environment can reducecleaning frequency, lower rework rates, and improve material turnover efficiency, providing a stable operating foundation for automated production lines and intelligent assembly lines. Fifth, extending the service life of purification and environmental protectionequipment. A clean environment reduces

external dust entering core components such as fans, filters, catalytic modules, and activated carbon devices,lowering blockage, wear, and maintenance costs.

II. Total Solution Technical System

The Industrial Cleanroom Purification System total solution adopts an integrated technical approach of "Design - Equipment - Construction - Commissioning - Operation &Maintenance", covering the entire lifecycle from early-stage survey to later operation and maintenance, ensuring stable, efficient, and energy-saving operation.

The total solution is guided by environmental parameters. Based on production processes, it determines core indicators such as cleanliness class, temperature and humidity range, pressure differentialrequirements, fresh air volume, and noise limits. On this basis, it conducts air flow organization design, purification process configuration, equipment selection matching, and layout optimization.The system takes high-efficiency filtration as the core purification method, coordinated with fresh air purification, circulating purification, local dust removal, and waste gas treatment modules to form a multi-stagepurification system. Simultaneously, it achieves precise temperature and humidity regulation through air conditioning units, reasonable pressure differentials through supply and exhaust systems, and real-time monitoringand automatic adjustment of all parameters through intelligent control systems.

The solution has high adaptability, can be flexibly adjusted based on workshop area, ceiling height, production equipment layout, pollution source distribution, and cleanliness class requirements,supporting various scenarios such as new cleanroom workshop planning, existing workshop renovation and upgrading, and local ultra-clean workstation construction, balancing purification effects, construction costs, and operating energy consumptionto achieve optimal comprehensive benefits.

III. Core System Components and Functions

The Industrial Cleanroom Purification System consists of seven modules: enclosure structure system, air purification system, air conditioning temperature and humidity system,air flow and pressure differential system, fresh air exhaust system,

pollution collaborative treatment system, and intelligent monitoring system. All modules operate in coordination to constitute a complete clean environment control system.

The enclosure structure is the basic carrier of the cleanroom, typically using color steel sandwich panels, clean doors and windows, and epoxy or PVC clean flooring. It features dust prevention, easy cleaning,corrosion resistance, and good air tightness, effectively blocking external dust intrusion, preventing internal pollutant accumulation and cross-contamination, while meeting industrial safety requirements such as fire prevention, sound insulation, and load bearing.

The air purification system is the core for achieving cleanliness. It mainly consists of primary, medium, and high-efficiency filters forming a multi-stage filtrationsystem, coordinated with FFU fan filter units, laminar flow hoods, and clean tents to continuously purify circulating air.effectively removing suspended particulate matter from the air to meet different cleanliness class requirements. For industrial scenarios with high dust, pre-filtration and pulse dust removal devices can be added to extend the service life of high-efficiency filters.

The air conditioning temperature and humidity system is responsible for stabilizing the workshop environment. Through combined air conditioning units, heating and cooling source systems, and humidification and dehumidificationdevices, it achieves precise control of temperature and relative humidity, avoiding problems such as material deformation, condensation, rust, and microbial growth due to temperature and humidity fluctuations,especially suitable for precision component production and testing environments of environmental protection equipment.

The air flow and pressure differential system forms unidirectional or turbulent air flow organizations through reasonable arrangement of supply, return, and exhaust vents,quickly removing pollutants and preventing diffusion. Simultaneously, through supply and return air volume ratio, it forms a stable pressure differential, ensuring that clean area air pressure is higher than non-clean areas,preventing external unclean air backflow and achieving zone control and graded purification.

The fresh air exhaust system provides continuous fresh air for the workshop, exhausting stale air and excess heat and humidity. Fresh air undergoes multi-stage

filtration and temperature and humidity pretreatmentbefore being supplied indoors, ensuring indoor air quality and operator respiratory health. For process links with VOCs, odors, and dust, independent exhaust systems are set up to achieve centralized waste gas collection and subsequent treatment.

The pollution collaborative treatment system is an important feature that distinguishes industrial cleanrooms from ordinary cleanrooms. It can link with existing enterprise environmental protection equipment to collect and purify dustand organic waste gas generated from grinding, spraying, welding, and assembly processes, achieving integrated clean control and environmental protection treatment and preventing pollutant accumulation in the clean space.

The intelligent monitoring system conducts 24/7 real-time monitoring and automatic regulation of key cleanroom parameters, including temperature and humidity, pressure differential, cleanliness, PM values,VOCs concentration, filter resistance, and fan operating status. It features abnormal alarms, data recording, remote monitoring, and automatic variable frequency energy saving, achieving intelligent, visualized, and unattended operation and maintenance.

IV. Design Principles and Key Technical Points

The industrial cleanroom purification system follows five major principles during the design phase: practicality, safety, energy efficiency, expandability, and compliance, avoiding over-design or functional deficienciesand ensuring the solution fits actual production conditions.

Practicality requires centering on production processes without blindly pursuing high cleanliness classes. Indicators are determined based on actual conditions, balancing effectiveness and investment costs. Safety focuses on fire prevention, explosion prevention,static prevention, leakage prevention, emergency exhaust, and other designs, complying with industrial safety specifications. Especially for conditions involving VOCs and dust, explosion prevention and pressure relief designs are strengthened. Energy efficiency reduces air conditioningand purification system operating energy consumption through optimizing air flow organization, reducing air leakage, using variable frequency control, heat recovery devices, and high-efficiency

fans. Expandability reserves interfaces and space for equipment replacement, system expansion,and process upgrades for later renovation. Compliance strictly follows relevant national regulations and industry standards while meeting local environmental protection, fire safety, and safety acceptance requirements.

Key technical points mainly include air flow organization design, pressure differential control, filter configuration, fresh air ratio, noise control, and energy optimization. Reasonable air flow organization can avoid dead zones and turbulence,quickly removing pollutants; pressure differential control ensures no cross-contamination between different clean zones; multi-stage filter configuration balances purification efficiency and operating costs; sufficient fresh air volume ensures air qualityand operational safety; noise control avoids affecting production and operating environments; the overall system achieves long-term energy savings through variable frequency, heat recovery, and optimized duct layout.

V. Main Equipment Selection and Configuration Requirements

The selection of core system equipment directly determines cleanroom performance and stability, requiring matching based on working condition indicators.

Among air filtration equipment, primary filters are used for fresh air pretreatment to block large dust particles; medium-efficiency filters protect downstream high-efficiency filters;high-efficiency filters are used for terminal fine filtration to ensure cleanliness. FFU laminar flow units are suitable for high-cleanliness areas, offering flexible arrangement and easy maintenance.

Air conditioning and temperature and humidity equipment use industrial-grade combined air conditioning units with functions such as cooling, heating, humidification, dehumidification, and filtration,configured with variable frequency control systems to adapt to load changes. Humidification and dehumidification equipment are selected based on regional climate and production needs to ensure stable year-round operation.

Fan and air valve equipment select low-noise, high-efficiency, energy-saving centrifugal or axial fans, coordinated with electric air valves and check valves for air

volume adjustment and backflow prevention.Key parts use sealed air valves to improve air tightness.

Pollution treatment supporting equipment can be configured with mobile dust collectors, welding fume purifiers, activated carbon adsorption devices, and photocatalytic devices based on workshop pollution sources,operating in coordination with the clean system to achieve simultaneous purification and treatment.

Intelligent monitoring equipment includes various sensors, touch screens, PLC controllers, and background management software, supporting data storage, remote viewing, historical traceability, and automatic adjustment,meeting digital management needs of modern factories.

VI. Construction Installation and Commissioning Acceptance Specifications

Cleanroom engineering construction must follow standardized procedures to ensure airtightness, cleanliness, and safety. Before construction, the site is cleaned, dust removed, and moisture-proofed;enclosure structure installation focuses on sealing joints and eliminating air leakage; flooring construction ensures flatness, wear resistance, and easy cleaning; duct manufacturing and installation focus on airtightness and smooth inner walls to reduce dust accumulation and resistance.

Purification equipment, air conditioning units, FFU, filters, monitoring systems, etc. are accurately positioned and installed with standardized wiring and reasonable pipe layout, avoiding affecting production flow lines.After installation, system commissioning is conducted, including air volume balance, pressure differential adjustment, temperature and humidity calibration, air flow uniformity testing, filter leak detection, noise testing, and automatic control system integration.

During the acceptance phase, design indicators are verified item by item, including key parameters such as cleanliness, temperature and humidity, pressure differential, air exchange rate, fresh air volume,noise, and settling bacteria. Simultaneously, environmental protection treatment effects are verified to ensure the system meets design requirements and usage standards before delivery and operation.

VII. Operation, Maintenance, and Long-term Management

The long-term stable operation of the cleanroom depends on standardized operation and maintenance management. Daily maintenance focuses on filter replacement, equipment servicing,cleaning management, parameter monitoring, and energy consumption management.

Regularly inspect filter resistance and cleanliness, promptly replace primary, medium, and high-efficiency filters to avoid reduced air volume and purification failure due to blockage. Air conditioning units, fans, water pumps,and humidification/dehumidification equipment require regular servicing to ensure stable operation. The workshop implements standardized cleaning procedures using cleanroom-specific tools to avoid secondary contamination.

Continuously track key parameters through the intelligent monitoring system, promptly discover and address anomalies, establish operation and maintenance records documenting maintenance content, replacement cycles, and energy consumption datato achieve preventive maintenance. Simultaneously optimize operating modes based on production load and seasonal changes to reduce energy consumption under the premise of ensuring cleanliness effectiveness and extend equipment service life.

VIII. Typical Application Scenarios

This total solution is widely applicable in environmental protection equipment and related industrial fields. In environmental protection equipment manufacturing workshops, it can be used for production and assembly of high-precision componentssuch as filter media, filter cartridges, catalysts, activated carbon modules, sensors, and control units, improving product consistency and reliability. In waste gas treatment supporting clean workstations, local clean environments can be constructedfor catalytic combustion equipment, zeolite rotors, and activated carbon adsorption equipment core component assembly. In new material and filter media production workshops, it controls dust and fiber fly, improving product quality and production environment safety.In laboratories and testing centers, clean testing environments are constructed to ensure accurate and reliable data for environmental protection equipment performance testing, filter media efficiency testing, and catalytic

performance analysis.In precision machining and sheet metal assembly workshops, it controls dust and oil contamination, improving the surface quality of environmental protection equipment housings and structural components, and reducing subsequent grinding and cleaning pressure.

IX. Technical Development Trends

Future industrial cleanroom purification systems will continue to upgrade in the direction of energy efficiency, integration, intelligence, and low carbon. Technologies such as high-efficiency low-resistance filtration, heat pipe heat recovery,photovoltaic power supply, and variable frequency adaptive control will be continuously applied to further reduce operating energy consumption. Purification systems will deeply integrate with dust removal, waste gas treatment, and intelligent production lines to achieveintegrated environmental control, production processes, and environmental protection treatment. Internet of Things, big data, and digital twin technologies will enable full-lifecycle management of cleanrooms.

Remote operation and maintenance, intelligent early warning, and automatic optimization will become standard. Low-carbon building materials, recyclable materials, and modular rapid disassembly and assembly technologies will make cleanroom constructionmore environmentally friendly, efficient, and flexible.

X. Conclusion

The Industrial Cleanroom Purification System total solution is an important foundation project for modern industrial enterprises to achieve high-quality production, green manufacturing, and compliant operations.It can not only significantly improve product quality, improve working environments, and protect occupational health, but also deeply integrate with enterprise environmental protection treatment systems to achieve synergistic benefits in production processes and pollution control.

This white paper systematically organizes the technical system, component modules, design points, construction specifications, and operation and maintenance management of industrial cleanrooms, providing enterpriseswith a complete, scientific, and implementable total solution.