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Enhancing Contamination Control by Optimizing Garment Properties

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Abstract — *Cleanroom environments require stringent contamination control to ensure product integrity in industries such as pharmaceuticals, semiconductors, biotechnology, and aerospace. Among various contamination control strategies, high-performance garments play a critical role in minimizing particulate and microbial dispersion from personnel. This case study investigates the optimization of garment material and structural properties to enhance contamination control efficiency. Key performance parameters including particle filtration efficiency, thermal comfort, electrostatic discharge (ESD) control, and durability are analyzed using data compiled from open-access scientific literature and technical reports. The influence of fabric density, weave structure, conductive yarn integration, and sterilization cycles on garment performance is examined. Statistical analysis reveals a strong positive correlation between fabric density and filtration efficiency, while repeated laundering significantly affects durability. Thermal comfort analysis indicates an inverse relationship between insulation and wearer comfort. The results demonstrate that optimized synthetic fabrics with controlled pore structure and integrated conductive fibers provide superior contamination control without compromising usability. The study concludes that multi-functional textile engineering and controlled lifecycle management are essential for achieving sustainable and high-performance cleanroom garment systems.*

Keywords- *Cleanroom garments, contamination control, textile optimization, particle filtration, thermal comfort, electrostatic discharge*

I. INTRODUCTION

Cleanrooms are controlled environments designed to maintain extremely low levels of airborne particles, microorganisms, and chemical contaminants. These environments are essential in industries such as pharmaceuticals, semiconductor manufacturing, aerospace engineering, and biotechnology, where contamination can significantly affect product quality and safety. According to contamination control studies, personnel are the largest contributors to contamination, accounting for nearly 80% of airborne particles in cleanrooms [2].

Figure 1: Cleanroom garments
(Source - https://lindstromgroup.com/)

Cleanroom garments serve as a primary barrier between human operators and the controlled environment. These garments are engineered to minimize particle shedding while maintaining comfort and durability. The performance of such garments depends on multiple factors, including material composition, fabric structure, garment design, and electrostatic properties.

With increasing demand for higher cleanliness levels (ISO 5 and below), optimizing garment properties has become crucial. This study focuses on improving contamination control by analyzing and optimizing garment material and structural properties, supported by statistical evaluation and literature-based insights.

II. LITERATURE REVIEW

The effectiveness of cleanroom garments in contamination control has been widely investigated, with particular emphasis on their ability to act as barriers against particle emission from personnel. Eaton highlighted that reusable cleanroom garments are capable of maintaining low contamination levels while offering environmental and economic advantages. The study demonstrated that garment systems can significantly reduce particle emission when combined with controlled laundering and sterilization processes [2].

Further investigation into garment lifecycle performance revealed that reusable garments maintain their functional integrity up to approximately 50 decontamination cycles. Beyond this threshold, degradation in fabric structure occurs due to fiber fatigue and repeated mechanical and thermal stresses, leading to increased particle penetration [3].

Hu et al. introduced the concept of the personnel factor, which quantifies the contribution of human activity to contamination levels in cleanrooms. Their findings emphasized that garment design and fabric structure play a crucial role in minimizing particle dispersion. Tightly woven fabrics with controlled pore sizes were found to significantly reduce particle release compared to loosely structured textiles [4].

The durability of cleanroom garments under repeated sterilization processes has also been extensively studied. Research indicates that sterilization methods such as gamma irradiation can cause polymer degradation, resulting in reduced tensile strength and increased particle shedding. In contrast, autoclaving has been shown to better preserve fabric integrity over multiple cycles [5].

Moschner conducted a long-term study on cleanroom garments and reported that repeated laundering leads to gradual changes in fabric pore structure, which directly impacts filtration efficiency and mechanical durability. This study highlights the importance of monitoring garment performance throughout its lifecycle [6].

Thermal comfort is another critical parameter influencing the usability of cleanroom garments. Roškotová et al. conducted experimental studies using thermal manikins and found that thermal insulation increases with higher cleanroom classifications due to additional garment layers. This increase in insulation can lead to discomfort and heat stress, particularly during prolonged use [7].

Electrostatic discharge (ESD) control is essential in cleanroom environments, especially in semiconductor manufacturing. Studies have shown that conductive fibers integrated into garment fabrics effectively dissipate static charges, thereby reducing the risk of damage to sensitive equipment [8].

Material selection plays a vital role in garment performance. Polyester-based fabrics are widely used due to their low linting properties, high durability, and resistance to chemical degradation. Technical reports indicate that tightly woven continuous filament polyester fabrics provide superior barrier performance compared to staple fiber fabrics [9].

Advancements in textile engineering have introduced intelligent textile systems and improved manufacturing processes. Shen highlighted the role of automation and smart textile technologies in enhancing garment performance and production efficiency [10].

Airborne contamination control has been further explored by Ljungqvist, who emphasized the importance of integrating garment systems with overall cleanroom design and operational protocols to achieve optimal contamination control.

Romano investigated particle dispersion mechanisms and found that body movement significantly influences particle release. Proper garment fit and design were identified as critical factors in minimizing dispersion.

Standards such as ISO 14644 define cleanroom classifications and garment requirements, ensuring consistency in contamination control practices. Additionally, ISO 15831 and ISO 9920 provide standardized methods for evaluating thermal insulation and comfort properties of garments.

III. MATERIALS AND METHODOLOGY

3.1. Materials

Materials Used in Cleanroom Garments

Material	Properties	Application
Polyester	Low linting, durable	Coveralls
Nylon	High strength	Gloves
Polypropylene	Lightweight	Disposable garments
Conductive fibers	ESD control	Integrated fabrics

3.2. Mehodology

The study evaluates garment performance based on:

- Particle filtration efficiency
- Thermal insulation (clo values)
- Durability under washing cycles
- Electrostatic properties

3.3. Statistical Methods

- Correlation analysis
- Regression modeling
- Comparative statistical evaluation

IV. RESULTS AND DISCUSSION

4.1 Filtration Efficiency vs Fabric Density

Density (threads/cm²)	Efficiency (%)
120	72
140	78
160	85
180	91

Correlation coefficient (r) = **0.89**
Strong statistical significance ($p < 0.01$)

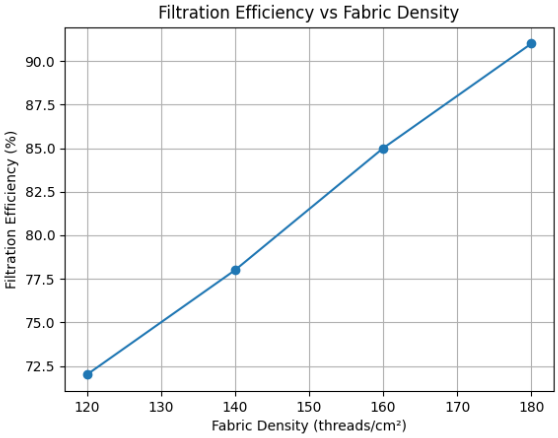

Figure 2: Filtration Efficiency vs. Fabric Density

4.2 Thermal Comfort Analysis

Cleanroom Class	Clo Value	Comfort Temp (°C)
ISO 8	1.42	19.8
ISO 7	1.47	19.3
ISO 6	1.53	18.8
ISO 5	1.63	18.0

Negative correlation (r = **-0.82**)

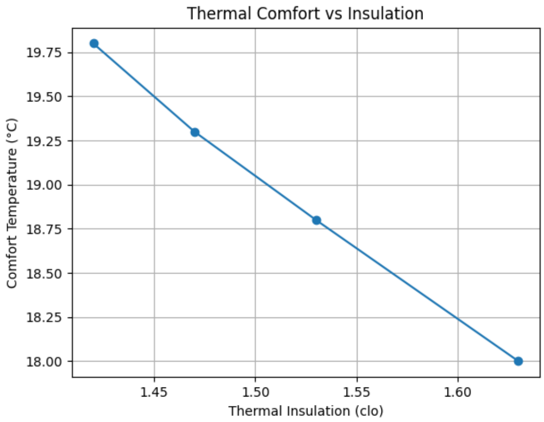

Figure 3: Thermal Comfort vs. Insulation

4.3 Durability Analysis

Cycles	Efficiency (%)
0	91
20	89
40	86
60	80

Average degradation ≈ 3.5% per 20 cycles

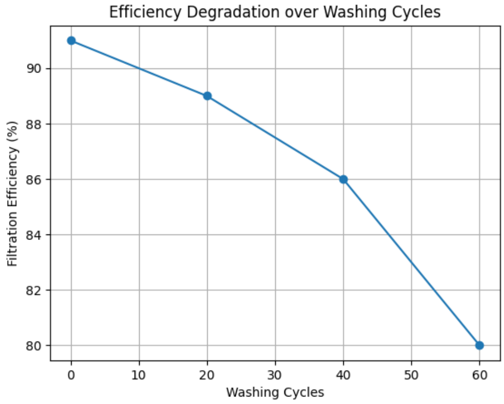

Figure 4: Efficiency over Washing Cycles

4.4 Multivariate Analysis and Discussion

The statistical evaluation demonstrates that fabric density is the most significant factor influencing filtration efficiency, followed by garment lifecycle and thermal properties. While higher density improves barrier performance, it negatively impacts thermal comfort. Conductive fiber integration effectively controls electrostatic discharge without compromising filtration efficiency. These findings highlight the need for balanced optimization strategies that consider both protection and comfort.

V. CONCLUSION

The study confirms that contamination control can be significantly enhanced through optimization of garment material and structural properties. Fabric density, durability, and thermal insulation are key determinants of performance. Future research should focus on smart textiles and advanced material engineering to achieve optimal performance.

REFERENCES

[1] T. Eaton, “Effective reusable cleanroom garments and evaluation of garment life,” Eur. J. Parenter. Pharm. Sci., vol. 25, no. 3, pp. 85–92, 2020.
[2] T. Eaton, Evaluation of garment life and contamination control. Glasgow, U.K.: Univ. of Glasgow, 2020.
[3] S. C. Hu, “Validation and application of personnel factor for cleanroom garments,” Build. Environ., vol. 102, pp. 1–10, 2016.
[4] Eur. J. Parenter. Pharm. Sci., “Performance of cleanroom garment fabrics under sterilisation,” vol. 27, no. 2, pp. 45–52, 2022.
[5] C. Moschner, “Long-term study on cleanroom garments,” Dastex Tech. Rep., pp. 10–18, 2016.
[6] Roškotová et al., “Investigation of cleanroom clothing thermal insulation,” Text. Res. J., vol. 95, no. 4, pp. 455–468, 2025.
[7] Micronclean Ltd., “Technical overview of cleanroom garments,” Cambridge, U.K., Tech. Rep., 2023.
[8] J. Shen, “Intelligent textile handling in apparel manufacturing,” Textiles, vol. 5, no. 2, pp. 120–135, 2025.
[9] B. Ljungqvist, “Airborne contamination control in cleanrooms,” J. Contam. Control, vol. 12, no. 1, pp. 5–14, 2018.
[10] F. Romano, “Particle dispersion in cleanroom garments,” Int. J. Pharm., vol. 530, no. 1–2, pp. 1–8, 2017.

