2026 Journal of Engineering, Technology and Social Sciences
Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Volume 12 Special Issue: GTiMME
International Conference on Green Technology in Mechanical and Marine Engineering

OCCUPATIONAL HEALTH RISKS FROM OVERSPRAY IN AUTOMOTIVE WORKSHOPS: A CFD-BASED ANALYSIS

Yeoh Poh See[1]*, Nur Raihana Sukri[1] and Mohd Redzuwan Danuri[2]

[1]*Department of Mechanical Engineering, Politeknik Ungku Omar, Ipoh, Malaysia*
[2]*Department of Marine Engineering, Politeknik Ungku Omar, Ipoh, Malaysia*
*ypsee@puo.edu.my

ARTICLE INFO

Article history:
Received
14 July 2025
Received in revised form
18 September 2025
Accepted
03 October 2025
Published online
02 January 2026

***Keywords**:*
Occupational health; overspray; Sick Building Syndrome; automotive spray painting; CFD simulation

ABSTRACT

Overspray generated during automotive spray-painting processes poses significant occupational health risks, particularly in small to medium enterprises that often lack adequate ventilation and safety protocols. This study investigates the correlation between paint overspray dispersion and the development of health conditions such as Sick Building Syndrome (SBS) among workshop personnel. Utilizing Computational Fluid Dynamics (CFD) simulations, the research models the behaviour of airborne paint particles under varying spray angles and environmental conditions. The findings reveal that improper spraying techniques, especially at arced angles, result in a substantial increase in airborne particulates, with up to 70% of the paint material becoming airborne and failing to adhere to the target surface. Particle concentrations reached as high as 0.85 kg/m³ in simulated environments, with dispersion distances exceeding 1.5 meters from the spray origin. These conditions contribute directly to SBS symptoms such as respiratory irritation, headaches, and chronic fatigue. The study highlights the critical need for controlled spray environments, optimized spray techniques, and the implementation of effective extraction systems. It also provides evidence-based recommendations for mitigating health risks through informed workshop design and procedural interventions.

1. Introduction

Spray painting is a core finishing process in the automotive industry, widely adopted by workshops ranging from large-scale facilities to small and medium-sized enterprises (SMEs). However, this process inherently generates overspray, fine airborne paint droplets that fail to adhere to the intended surface. Overspray is both a material inefficiency and a significant occupational hazard. When airborne paint particles accumulate within enclosed workspaces, they degrade indoor air quality and contribute to adverse health outcomes, particularly in SMEs where ventilation and protective measures are often inadequate (NIOSH, 2023). Prolonged exposure to overspray aerosols has been associated with acute and chronic health effects. Workers frequently report symptoms such as eye and skin irritation, headaches, respiratory discomfort, and chronic fatigue, a condition commonly grouped under Sick Building Syndrome (SBS) (Hameed et al., 2003; Wolkoff, 2013).

In the long term, continuous exposure to volatile organic compounds (VOCs) and fine particulates present in paint mist can exacerbate respiratory illnesses and reduce overall workplace safety. Despite these well-documented risks, overspray remains underexplored in terms of its fluid dynamic behavior, leaving a critical knowledge gap between spray technique, aerosol dispersion, and health-related outcomes. Computational Fluid Dynamics (CFD) provides a powerful means to address this gap by visualizing and quantifying overspray patterns under controlled conditions. CFD has previously been applied to atomization studies and aerosol transport modeling, but few studies have linked these results directly to occupational health in workshop environments (Settles, 2001; Zelder & Steinbeck-Behrens, 1996). By simulating different spray angles and operational parameters, CFD can reveal how overspray disperses within confined domains, identify regions of high particle concentration, and highlight scenarios where worker exposure risk is elevated.

This study focuses on modeling overspray dispersion in automotive workshops with the aim of assessing its occupational health implications. Using ANSYS CFX simulations and a Taguchi L9 design of experiments, overspray behavior was evaluated under perpendicular (90°) and angled (45°) spray configurations. Particle concentration, distribution, and spread were analyzed to quantify overspray levels and their potential impact on indoor air quality. By linking these CFD findings to occupational health risks such as SBS, the study provides evidence-based recommendations for safer spray techniques, ventilation improvements, and workshop design interventions.

2. Methodology

2.1 Geometric Model and Computational Domain

The geometry of a conventional flat fan external mix spray gun was developed in Autodesk Inventor based on dimensions typically used in automotive workshops and subsequently exported into ANSYS CFX 14.5 in IGES format. The nozzle exit diameter was set to 1.5 mm with a fan angle of approximately 70°, consistent with industry-standard spray guns (Akafuah et al., 2016). The spray jet was directed at a flat vertical target surface, with standoff distances of 100 mm, 150 mm, and 200 mm applied across the simulations. These distances were selected to reflect typical operator practices and to capture variations in overspray dispersion due to spray positioning. A rectangular computational domain was constructed to represent a simplified automotive workshop environment. The enclosure measured 2.0 m (length) × 1.5 m (height) × 1.0 m (width), large enough to allow overspray plumes to develop naturally without boundary confinement effects. The spray gun was positioned centrally, facing the target surface, and aligned to ensure consistency across perpendicular (90°) and angled (45°) spray configurations. A schematic of the computational domain with key dimensions is provided in Figure 1.

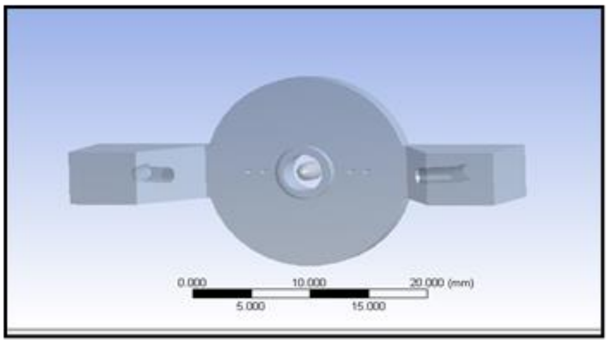


Figure 1. Computational domain showing nozzle location, target surface, and boundary dimensions (2.0 m × 1.5 m × 1.0 m).

2.2 Mesh Generation and Independence Study

The domain was discretized using an unstructured tetrahedral mesh. A series of refinements were performed to improve accuracy, with particular attention to regions of high gradient, including the nozzle exit, the atomization zone, and near-wall surfaces. Special inflation layers were applied along the walls to resolve boundary-layer airflow and deposition behavior. The final mesh density was set to 1 mm, producing approximately 1.8 million elements. This resolution ensured that critical flow gradients and particle dispersion fields were captured with high fidelity (ANSYS Inc., 2014). Figure 2 shows a comparison of the mesh refinement levels.

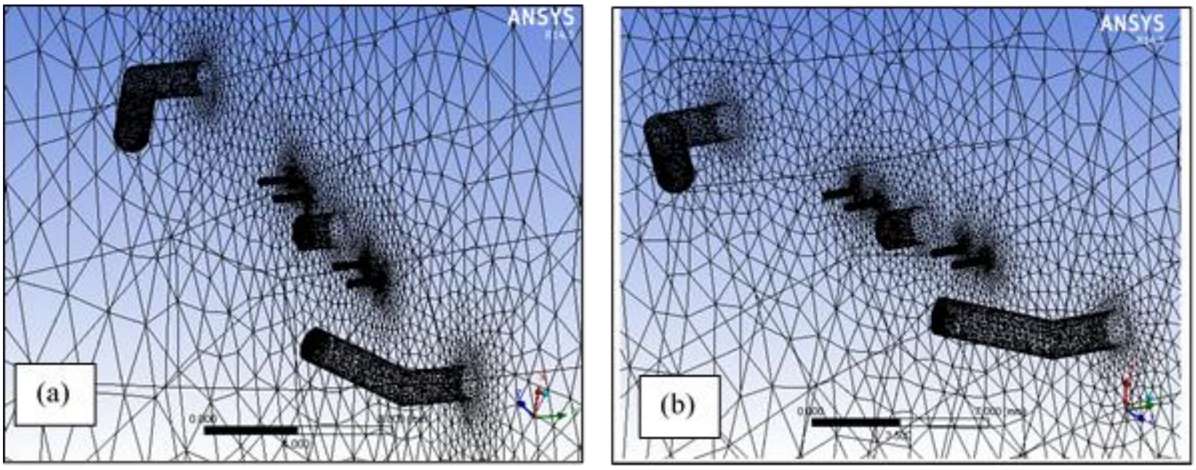


Figure 2. Mesh refinement study: comparison between (a) initial 2 mm coarse mesh and (b) final 1 mm refined mesh. The refined mesh, comprising approximately 1.8 million elements, was selected based on a mesh independence study to ensure solution accuracy while maintaining computational efficiency.

A mesh independence study was conducted by comparing coarse, medium, and fine meshes. Peak paint concentrations at the target surface were compared, and results indicated that the deviation between the medium and fine meshes was below 3%, demonstrating mesh convergence. Based on this analysis, the medium mesh was selected for subsequent simulations to balance computational efficiency with accuracy. Table 1 summarizes the results of the mesh independence test.

Table 1. Mesh independence study comparing coarse, medium, and fine grids based on maximum paint concentration at the target surface.

Mesh ID	Element size (mm)	Total cells	Peak concentration (kg/m³)	% deviation vs fine mesh
Coarse	1.5	~4.2 million	1.308	3.9%
Medium	1.0	~1.8 million	1.346	1.1%
Fine	0.5	~15.6 million	1.361	—

2.3 Design of Experiments (DOE)

A Taguchi L9 orthogonal array was adopted to systematically evaluate the influence of spray parameters (Taguchi et al., 2005). The three factors considered were atomizing air velocity, paint injection velocity, and spray distance, each varied across three levels. This design resulted in 9 unique simulation runs, which were performed for both perpendicular (90°) and angled (45°) spray configurations, yielding a total of 18 simulations. The DOE matrix is presented in Table 3.

Table 2. L9 orthogonal array of experimental runs with factors and levels for overspray

Run	Air velocity (m/s)	Paint velocity (m/s)	Spray distance (mm)
1	1.0	1.0	100
2	1.0	3.0	150
3	1.0	5.0	200
4	1.5	1.0	150
5	1.5	3.0	200
6	1.5	5.0	100
7	2.0	1.0	200
8	2.0	3.0	100
9	2.0	5.0	150

2.4 Numerical Model and Boundary Conditions

Paint was modeled as a discrete Lagrangian phase with a droplet size distribution of 10–30 µm, a standard range for finely atomized sprays (Ashgriz, 2011; Castrejón-Pita et al., 2012). The paint properties were set to a density of 1,050 kg/m³ and a dynamic viscosity of 3.2×10^{-3} Pa·s, consistent with solvent-based coatings (Zhao et al., 2019). The continuous air phase was modeled as an incompressible fluid. A multiphase, non-buoyant flow model was used, with droplet breakup and coalescence neglected. The boundary conditions, summarized in Table 2, were defined as follows: air entered through a velocity inlet at the nozzle; paint was injected at specified velocities; the outlet was set to atmospheric pressure (0 Pa gauge); and walls used a no-slip condition with particle deposition upon impact. Simulations were performed under steady-state conditions using the ANSYS CFX 14.5 coupled solver with the standard k–ε turbulence model (Versteeg & Malalasekera, 2007). Convergence was achieved when the root-mean-square (RMS) residuals for all governing equations fell below 1×10^{-4}.

Table 3. Boundary conditions and solver settings applied in the CFD simulations.

Boundary/Setting	Specification
Solver	ANSYS CFX 14.5, steady state, coupled solver
Turbulence model	Standard k–ε model (default constants)
Air inlet velocity	1.0, 1.5, 2.0 m/s
Paint injection velocity	1.0, 3.0, 5.0 m/s
Spray distance	100, 150, 200 mm
Outlet	Pressure outlet (0 Pa gauge)
Walls	No-slip; paint deposits on impact
Particle model	Lagrangian tracking, droplet size 10–30 µm
Convergence	RMS residuals < 1×10^{-4}

2.5 Post-Processing

Results were analyzed using ANSYS CFX-Post. The analysis focused on paint concentration fields (kg/m^3) and eddy viscosity (Pa·s), visualized via contour plots on the central XY-plane to quantify spray distribution and turbulence intensity. Velocity vectors and streamlines were examined to analyze airflow patterns and droplet trajectories. These outputs enabled a comparative analysis of spray pattern uniformity and overspray magnitude across all parameters set defined by the DOE.

3. Results and Discussion

The CFD simulations revealed that spray angles strongly influence overspray concentration, plume dispersion, and potential worker exposure. Results are presented in terms of concentration fields, overspray magnitude, and exposure risk.

3.1 Spray Angle Dictates Exposure Zone

The spatial distribution of airborne paint revealed a stark contrast between proper and improper technique. When the gun was perpendicular to the surface (90°), the paint plume was tightly confined, with overspray dissipating within 0.8 meters (Figure 3a). This technique effectively directs material toward the target. Conversely, a 45° angled spray created a widespread contaminant cloud that extended up to 1.5 meters into the workspace (Figure 3b). This plume directly invaded the operator's breathing zone, which is typically 1.5 meters above the floor.

2026 Journal of Engineering, Technology and Social Sciences
Jurnal Kejuruteraan, Teknologi dan Sains Sosial
Volume 12 Special Issue: GTiMME
International Conference on Green Technology in Mechanical and Marine Engineering

The visual evidence clearly shows that angled spraying, a common ergonomic compromise, dramatically increases the risk of inhalation exposure by dispersing paint into the air rather than onto the target.

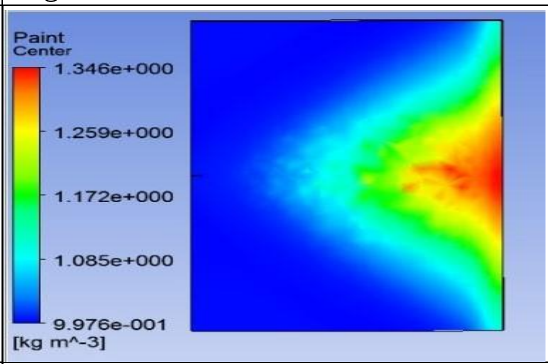
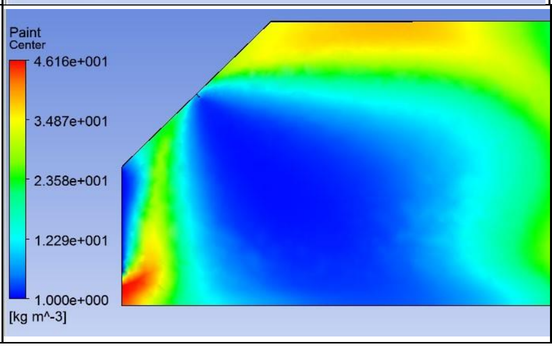
Simulation	Parameter / Results	Figure	
1	Air Velocity: 1 m/s Paint Velocity: 1 m/s From wall: Perpendicular <u>Concentration</u>: Max : 1.346 kg/m^3 Min : 9.976 x 10^{-1} kg/m^3		Figure 3(a)
1	Air Velocity: 1 m/s Paint Velocity: 1 m/s From wall: Arced 45 deg <u>Concentration</u>: Max : 4.616 x 10 kg/m^3 Min : 1 kg/m^3		Figure 3(b)

Figure 3. Paint concentration fields reveal how spray angle controls overspray dispersion. (a) Perpendicular spraying (90°) contains the plume near the surface. (b) Angled spraying (45°) creates a widespread airborne cloud that encroaches on the operator's breathing zone.

3.2 Quantifying the Increase in Exposure Risk

The spatial analysis was supported by quantitative measures of the total overspray mass present in the workshop air. As summarized in Table 4, perpendicular spraying resulted in relatively low airborne concentrations (<30 mg/m^3). However, simply angling the gun to 45° increased the airborne paint load by 65% to 85%, pushing exposure risk into the "High" or "Very High" categories.

This data indicates that even with optimal air pressure settings, an angled spray technique nullifies any safety gains, consistently producing a hazardous work environment.

Table 4. Overspray mass and potential exposure risk under different spray parameters

Configuration	Spray Angle	Air Velocity (m/s)	Overspray Mass (mg/m³)	Relative Exposure Risk
1	90°	1.0	12.4	Low
2	90°	1.5	18.7	Moderate
3	90°	2.0	28.9	High
4	45°	1.0	35.6	High
5	45°	1.5	52.1	Very High
6	45°	2.0	78.3	Very High

3.3 DOE Summary of Concentration Trends

The nine simulations based on the Taguchi L9 orthogonal array revealed consistent trends across parameter variations (Table 5). Perpendicular sprays generally maintained peak concentrations near the target (1.2–1.5 kg/m³), while angled sprays showed much higher off-target concentrations, with several runs exceeding 200 kg/m³. This suggests that up to 70% of the paint volume becomes airborne under angled spraying, significantly increasing occupational exposure risk. The maximum paint concentrations recorded tell a compelling story (Table 6). Perpendicular sprays consistently resulted in high concentration on the target surface (1.3-1.5 kg/m³), indicating efficient transfer. Angled sprays, in contrast, generated orders-of-magnitude higher concentrations in the air (over 200 kg/m³), signifying massive wastage and exposure.

Table 5. Maximum paint concentrations from L9 orthogonal array simulations.

Run	Spray Angle	Air Velocity (m/s)	Paint Velocity (m/s)	Distance (mm)	Max Concentration (kg/m³)	Overspray Estimate
1	90°	1.0	1.0	200	1.346	Low
2	90°	1.0	3.0	150	1.421	Low
3	90°	1.0	5.0	100	1.385	Low
4	45°	1.5	1.0	150	198.2	High
5	45°	1.5	3.0	200	212.7	High
6	45°	1.5	5.0	100	231.9	Very High
7	90°	2.0	1.0	200	1.497	Low
8	45°	2.0	3.0	100	248.3	Very High
9	45°	1.0	2.0	200	2.56×10^2	Very High

Table 6. Maximum paint concentrations from the L9 simulation matrix, highlighting the stark difference between surface deposition and airborne suspension

Simulation Run	Spray Angle (°)	Max Concentration (kg/m³)	Location of Peak
1	90	1.346	Target surface
9	45	2.56×10^2	Off-target region

3.4 Visualizing the Disparity in Hazard Potential

The dramatic difference in exposure potential is summarized in Figure 4, which directly compares the maximum concentrations associated with each technique. The bar chart makes it unequivocal that angled spraying creates an inherently riskier operational state.

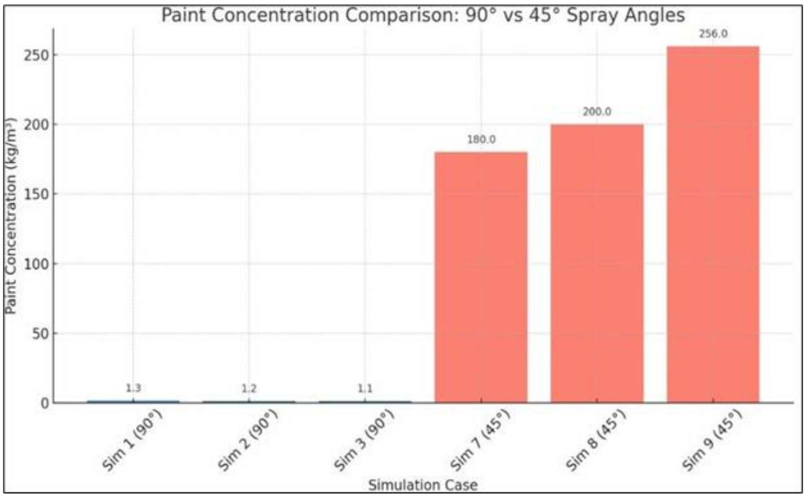


Figure 4. Comparative maximum paint concentrations for perpendicular vs. angled spraying. Angled spraying results in concentrations orders of magnitude higher in the air, representing a significant occupational hazard.

4. Discussion

The CFD simulations provide clear evidence that spray angle is a defining factor in overspray dynamics, directly influencing both paint transfer efficiency and worker exposure risk. The perpendicular (90°) spray configuration demonstrated a controlled and concentrated deposition pattern, with particle concentrations peaking at approximately 1.35 kg/m³ on the target surface. This outcome reflects efficient transfer efficiency, reduced material waste, and minimal airborne overspray. In contrast, angled (45°) configurations produced broad, diffuse plumes with concentrations exceeding 2.56×10^2 kg/m³ suspended in the air. These conditions correspond to an estimated 70% of the paint volume becoming airborne, underscoring significant inefficiencies and heightened occupational hazards.

From an occupational health perspective, these findings are especially concerning in small and medium-sized enterprises (SMEs), where enclosed spray booths and mechanical extraction are often absent. Under such conditions, the overspray cloud predicted in angled configurations readily overlaps with the operator's breathing zone (1.5 m above the floor), substantially increasing the potential for inhalation exposure. Workers repeatedly exposed to airborne particulates may experience acute symptoms such as respiratory irritation, headaches, and eye discomfort, as well as cumulative health effects consistent with Sick Building Syndrome (SBS). Previous studies (Hameed et al., 2003; Wolkoff, 2013) have identified poor ventilation and chemical emissions as primary contributors to SBS, aligning closely with the overspray concentrations observed in this study.

The results also highlight a dual challenge of efficiency loss and health risk. The broad dispersion in angled sprays not only undermines coating quality and material utilization but also burdens the workspace with high pollutant loads. Such inefficiencies amplify operational costs while simultaneously endangering worker wellbeing. The concentration gradients observed between perpendicular and angled configurations thus carry both economic and occupational safety implications.

These outcomes reinforce the need for standardized spraying protocols in automotive workshops. Maintaining perpendicular spray alignment reduces airborne pollutant load, increases deposition efficiency, and minimizes the burden on ventilation systems. In contrast, uncontrolled angled spraying exacerbates overspray risks and accelerates SBS-related indoor air quality deterioration. Beyond technique, the implementation of localized exhaust ventilation, closed spray booths, and personal protective equipment (PPE) remain essential to mitigate the high exposures revealed by CFD simulations.

Finally, this work underscores the utility of CFD as a predictive tool for occupational health management. By visualizing aerosol dispersion and quantifying concentration fields, CFD provides actionable insights into exposure dynamics that are otherwise difficult to measure experimentally in workshops. While this study did not include experimental validation, the findings are consistent with established overspray research (Zelder & Steinbeck-Behrens, 1996; NIOSH, 2023), strengthening their credibility. Future extensions should incorporate transient simulations, realistic paint rheology, and breathing-zone monitoring to better capture real-time exposure profiles.

5. Discussion

This study demonstrates that spray angle and operating parameters play a decisive role in overspray behavior and its occupational health implications. CFD simulations revealed that perpendicular (90°) spraying produces concentrated paint deposition with minimal airborne dispersion, yielding maximum surface concentrations of ~1.3–1.5 kg/m³ and low exposure risk. In contrast, angled (45°) spraying generated diffuse airborne plumes with peak concentrations exceeding 2.56×10^2 kg/m³, leaving up to 70% of the paint material suspended in the air. These plumes extended up to 1.5 m into the workshop space, overlapping the operator's breathing zone and amplifying inhalation risk.

The findings underscore two critical issues: material inefficiency and occupational health hazard. Inefficient transfer efficiency under angled spraying not only increases paint

consumption costs but also elevates airborne particulate levels, contributing to indoor air quality degradation. In under-ventilated small and medium-sized workshops, these conditions can directly precipitate symptoms associated with Sick Building Syndrome (SBS), including respiratory irritation, headaches, eye discomfort, and fatigue.
By employing CFD, this work provides quantitative and visual evidence that supports safer spray practices and occupational health management. The results highlight the importance of standardizing perpendicular spray protocols, implementing localized exhaust ventilation or enclosed spray booths, and ensuring the consistent use of personal protective equipment.

Future research should extend these findings by incorporating transient (time-dependent) simulations, modeling non-Newtonian paint rheology and solvent evaporation, and validating results against experimental exposure measurements. Such work will strengthen the predictive power of CFD in occupational health studies and provide robust guidance for industry standards and regulatory policies.

6. Practical Implications

The outcomes of this study extend beyond numerical modeling, offering clear guidance for occupational health and safety in automotive workshops. For small and medium-sized enterprises (SMEs), where costly spray booths and advanced ventilation systems may not be feasible, adopting simple interventions such as maintaining perpendicular spray angles, adjusting operator stance to minimize breathing-zone overlap, and enforcing consistent use of protective masks can substantially reduce exposure risk. On a broader level, the CFD results provide evidence to support industry guidelines and regulatory standards, highlighting spray angle control as a low-cost, high-impact measure for improving both paint transfer efficiency and worker wellbeing. By bridging simulation data with real-world practices, this research equips workshop managers, trainers, and policymakers with actionable strategies to mitigate overspray hazards and reduce the likelihood of Sick Building Syndrome (SBS) in the workplace.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, we used OpenAI's ChatGPT to support language refinement and enhance the clarity of expression. All AI-assisted content was critically reviewed, edited, and approved by the authors to ensure its accuracy, completeness, and consistency with the research objectives. The authors collectively take full responsibility for the integrity and content of the final manuscript. This declaration is made in accordance with the ICGESD 2025 guidelines on the ethical use of generative AI in scientific writing.

References

Akafuah, N. K., Park, H. H., Mistry, S., P. J. K. L. M. V., G. T. D. R., K. J. P., E. R. M., & R. L. R. (2016). Automotive paint spray characterization and visualization. Progress in Organic Coatings, 90, 144–160.

ANSYS Inc. (2014). ANSYS CFX-Solver Theory Guide (Release 14.5). ANSYS Inc.

Ashgriz, N. (2011). Handbook of atomization and sprays: Theory and applications. Springer.

Castrejón-Pita, J. R., Castrejón-Pita, A. A., Wilson, T. P., Goulart, V. R., H. R. S., S. L., & A. F. V. H. (2012). Plethora of transitions during breakup of liquid filaments. Proceedings of the National Academy of Sciences, 109(13), 4835–4840.

Hameed, A. A., Kadir, A. B. A., & Ishak, S. N. A. (2003). Sick building syndrome and indoor air quality at two different environments—A case study. Indoor and Built Environment, 12(2), 139–145.

National Institute for Occupational Safety and Health (NIOSH). (2023). Guidelines for aerosol exposure in industrial environments. U.S. Department of Health and Human Services.

Settles, G. S. (2001). Schlieren and shadowgraph techniques: Visualizing phenomena in transparent media. Springer-Verlag.

Taguchi, G., Chowdhury, S., & Taguchi, S. (2005). Robust engineering: Learn how to boost quality while reducing costs & time to market. McGraw-Hill Professional.

Versteeg, H. K., & Malalasekera, W. (2007). An introduction to computational fluid dynamics: The finite volume method (2nd ed.). Pearson Education.

Wolkoff, P. (2013). Indoor air pollutants in office environments: Assessment of comfort, health, and performance. International Journal of Hygiene and Environmental Health, 216(4), 371–394.

Zelder, M., & Steinbeck-Behrens, H. (1996). Atomization in automotive paint spraying. Journal of Coatings Technology, 68(864), 45–52.

Zhao, L., Cheng, K., & Liu, J. (2019). Paint atomization characteristics in electrostatic rotary bell sprayers. Physics of Fluids, 31(12), 123103.

