Proceedings of the ASME 2024
Fluids Engineering Division Summer Meeting
FEDSM2024
July 15-17, 2024, Anaheim, California

FEDSM2024-121354

AN INVESTIGATION INTO THE IMPACT OF SIMPLIFIED LUNG AIRWAY MODELS ON RESPIRABLE DUST PARTICLE DEPOSITION USING CFD AND WIND TUNNEL TESTING

Ahmed Aboelezz[1], Mostafa Hassanalian[1], Pedram Roghanchi[2]

[1]Department of Mechanical Engineering, New Mexico Institute of Mining and Technology, Socorro, NM 87801, USA
[2]Department of Mining Engineering, University of Kentucky, Lexington, KY 40506-0107, USA

ABSTRACT

This study investigates the impact of simplified lung airway models on the deposition of dust particles. It uses Computational Fluid Dynamics and wind tunnel testing to assess the accuracy and reliability of these models in predicting dust behavior in the respiratory system, particularly in coal mining. Through CFD simulations, we analyzed it in a simplified lung model. These results were compared with those from more complex models. The simulations focused on key factors influencing particle deposition. Wind tunnel experiments were conducted to validate the simulation results and observe dust behavior. These experiments provided insights into the limitations of simplified lung models in capturing the deposition of fine dust particles.

The study found significant differences in air velocities between simplified and complex lung models, leading to potential underestimation or overestimation of dust deposition. This research enhances understanding of dust particle deposition in the lungs, contributing to respiratory health and safety. It highlights the need for more sophisticated modeling techniques in occupational health studies and improves safety standards in industries with dust exposure.

Keywords: Respirable Dust Deposition; Computational Fluid Dynamics (CFD); Lung Airway Models; Wind Tunnel Testing; Occupational Health Hazards

1. INTRODUCTION

The examination of the deposition of dust particles that can be inhaled into the human respiratory system holds great significance due to its considerable implications for the preservation of health and safety. The act of breathing in fine particles of dust presents a grave hazard, leading to various respiratory ailments and adversely affecting the overall well-being of the general public. The comprehension of the manner in which these particles interact with and settle within the air passages of the lungs is of utmost importance in the development of effective protective measures and health guidelines.

The inhalation of coal dust within mining environments presents notable risks to respiratory health, a concern that has been substantiated by numerous studies. Rahimi et al. (2023) conducted an extensive investigation into the inhalation of respirable coal mine dust (RCMD) and respirable crystalline silica (RCS) within United States coal mines, identifying pivotal factors that contribute to the high prevalence of respiratory diseases among miners. Their research underscores the cumulative effects of inhaling RCMD and RCS, which result in obstructive lung diseases despite efforts to minimize exposure to dust (Rahimi et al., 2023). Similarly, Wilk, Garland, and Falk (2021) discuss occupational lung diseases, including coal workers' pneumoconiosis (CWP), emphasizing the significance of occupational history in the diagnosis of these conditions caused by the inhalation of dust and fumes (Wilk et al., 2021). Shekarian et al. (2023) provide a systematic review of occupational exposure to RCMD, shedding light on the resurgence of CWP cases among coal workers and identifying contributing factors such as mining practices and measures taken to control dust (Shekarian et al., 2023). Furthermore, Long, Stansbury, and Petsonk (2015) delve into the involvement of small airways in coal mine dust lung disease, connecting the deposition of mineral dust within these airways to respiratory symptoms and declines in lung function, thus highlighting the intricate nature of lung injuries caused by dust (Long et al., 2015). Collectively, these studies underscore the multifaceted health risks associated with the inhalation of coal dust within mining environments, necessitating comprehensive health monitoring and the implementation of protective measures for miners.

Recent advancements in the utilization of Computational Fluid Dynamics (CFD) have markedly augmented our comprehension of the deposition of dust particles within the respiratory system, specifically in the realm of occupational health within coal mining environments. Madureira et al. (2023)

conducted an exhaustive evaluation on the deposition of Respirable Coal Mine Dust (RCMD) in the lungs, emphasizing the role of CFD in simulating the behavior of particles within the respiratory tract and pulmonary organs. Their investigation underscores the intricate interplay between particle characteristics and breathing patterns in the determination of lung deposition, thereby highlighting the significance of accurate CFD modeling in the prediction of dust particle behavior (Madureira et al., 2023). Likewise, Arya's investigation into the efficacy of a flooded-bed dust scrubber on a longwall shearer, employing both laboratory testing and CFD simulation, exemplifies the practical applications of CFD in enhancing safety measures against dust exposure in occupational settings. Additionally, the investigation conducted by Geng et al. (2023) with regards to the suspension characteristics of coal-quartz dust mixtures during the mining process provides valuable insights into the behavior of dust particles within mining environments. This further demonstrates the usefulness of Computational Fluid Dynamics (CFD) in the field of occupational health research. Furthermore, the research carried out by Gołębiowski et al. (2022) on a coal miner suffering from silicosis explores the potential association between exposure to silica dust and the deposition of amyloid. This indicates the broader health consequences of dust exposure in mining environments and highlights the necessity for comprehensive CFD modeling to comprehend these effects. Collectively, these studies underscore the crucial role played by CFD in advancing our understanding of dust deposition in the lungs, particularly in the context of coal mining and the accompanying health hazards.

Recent studies have brought attention to the complexities involved in accurately modeling the deposition of coal dust in the lungs, particularly emphasizing the challenges posed by simplifications in lung models. Madureira et al. (2023) delve into the realm of respiratory health, specifically focusing on the deposition of Respirable Coal Mine Dust (RCMD) within the respiratory tract and lungs. Their comprehensive review highlights the critical role of Computational Fluid Dynamics (CFD) in simulating particle behavior and points out the significant challenges in predicting dust particle behavior due to simplifications in the models. Similarly, the work of Tripathi et al. (2020), which centers on the impact of coal dust deposition on solar photovoltaic panels, provides insights into the effects of dust mass deposition. This study's approach to understanding the relationship between dust deposition and performance degradation can serve as analogies for how simplifications in lung models may affect the accuracy of coal dust deposition studies. Additionally, Raja et al. (2015) address the broader environmental impact of coal dust deposition, primarily focusing on soil health. Although their study is not directly related to lung models, it offers valuable context for understanding the behavior and deposition of coal dust. Furthermore, Miller et al. (2013) investigate the uniformity of coal dust deposition on filters and its implications for the accuracy of analyses. This study emphasizes the importance of considering deposition uniformity in lung models, as simplifications may lead to inaccuracies in understanding dust deposition patterns, especially in occupational health scenarios.

These collective studies place significant emphasis on the necessity for comprehensive and accurate modeling in the examination of dust deposition within the pulmonary system, particularly in the context of coal mining and the associated health hazards. The simplification of lung models can have a substantial impact on the comprehension of dust behavior and deposition, underscoring the significance of detailed and realistic modeling approaches. Recent experimental inquiries have offered valuable insights into the deposition of coal dust in the lungs, which is a critical concern for occupational health in mining environments. Negishi's investigation involving golden hamsters exposed to coal fly ash has unveiled crucial aspects of lung clearance mechanisms subsequent to excessive dust deposition. This research, which focuses on the role of alveolar macrophages in the ingestion and elimination of particles, illuminates the physiological responses to high concentrations of coal dust (Negishi, 1995). While Zhang et al. (2023) primarily scrutinize dust deposition on solar photovoltaic modules, their findings regarding dust composition and size characteristics are relevant to the comprehension of similar deposition processes in the lungs, specifically in relation to particle size and its impact on respiratory health (Zhang et al., 2023). Additionally, Qingtao Zhang et al. (2020) delve into the wetting mechanisms of coal dust, exploring how varying degrees of coal metamorphism influence dust wettability. Their utilization of infrared spectrum and NMR techniques provides a detailed understanding of the microstructure of coal dust, which is crucial for comprehending its behavior within lung tissues (Qingtao Zhang et al., 2020). Moreover, the study conducted by Gang Zhou et al. (2022) on the micro wettability of coal dust, taking into account its physical and chemical characteristics, contributes to a more profound comprehension of the factors that influence coal dust deposition within the lungs, thereby highlighting the intricate interplay of various properties of coal dust (Gang Zhou et al., 2022). These experimental studies collectively augment our understanding of the behavior of coal dust and its implications for the health of miners, thereby providing essential data for the development of effective occupational health strategies.

The application of wind tunnel experiments has greatly advanced our comprehension of coal dust deposition, particularly in relation to the lung health of miners. Chang et al. (2021) conducted a crucial investigation employing wind tunnels to assess the effectiveness of surfactants in suppressing coal dust. Their research, which integrated Computational Fluid Dynamics (CFD) modeling with experimental data, furnished vital insights into the movement characteristics of coal dust particles and the efficacy of different surfactants in dust suppression (Chang et al., 2021). Similarly, Madureira et al. (2023) provided a comprehensive review of lung deposition of respirable coal mine dust, emphasizing the role of CFD in simulating particle behavior within the respiratory system. This study underscores the complexities involved in predicting dust particle behavior and the potential of wind tunnel experiments in enhancing our comprehension of these dynamics (Madureira et al., 2023).

Additionally, Zhao et al. (2023) utilized CFD modeling to examine the influence of air inlet distance on coal dust pollution characteristics during tunneling, highlighting the impact of air flow redistribution on dust deposition, a critical factor for lung health in mining environments (Zhao et al., 2023). Moreover, the work of Richards-Thomas and Neuman on volcaniclastic dust emission, while not directly related to coal dust, imparts valuable insights into the physical processes of dust mobilization and dispersion, which are applicable to understanding coal dust behavior (Richards-Thomas & Neuman, 2023). Collectively, these studies demonstrate the significance of wind tunnel experiments in enhancing our understanding of coal dust deposition and its implications for miner health.

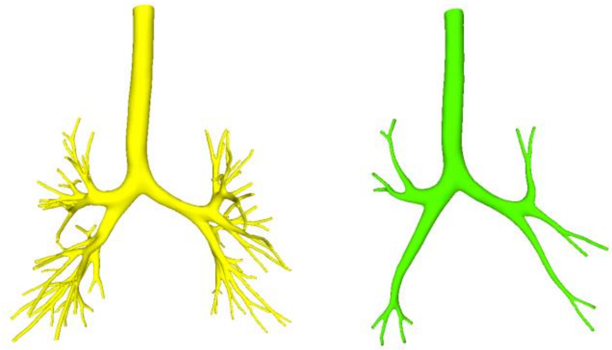
Based on the existing literature, it is imperative to examine how the selection of lung airways mode influences the outcomes of coal dust deposition. While employing a simplified model can offer advantages in terms of reduced computational time, it is crucial to ascertain the accuracy of the results obtained from these models. Hence, the primary objective of the present study is to investigate methods for rectifying the outcomes derived from simplified models. The methodology involves utilizing two lung airways models, one of which is simplified, and subsequently comparing the obtained results with those from the standard model. Finally, these results will be utilized to establish correlations.

2. Lung airway models in the current study.

In this investigation two distinct models of lung airways, were employed, reconstructed from high-resolution scans of a 60-year-old female participant, to enhance our understanding of airway dynamics. The first model maintains anatomical detail to provide a precise representation of lung airway structures, while the second underwent a strategic simplification process. This simplification aimed to reduce geometric complexity, thereby increasing computational efficiency without significantly compromising the model's ability to reflect key physiological phenomena. Such an approach facilitates the examination of a broader range of scenarios, enhancing the robustness and applicability of our findings.

The rationale behind employing both a detailed and a simplified model lies in the need to balance between the accuracy provided by detailed anatomical features and the computational practicality offered by simplified representations. This dual-model strategy enables a comprehensive analysis, allowing for the assessment of how variations in model complexity affect airflow patterns and particle deposition. Furthermore, it provides insights into which anatomical details are crucial for accurate simulations, guiding future model development and research.

Both models are depicted in Figure 1 for visual comparison, and Table 1 systematically presents their dimensions and geometric attributes. This detailed presentation not only underscores the modifications made during the simplification process but also facilitates a deeper understanding of the impact of these changes on the study's outcomes.



(a) (b)

FIGURE 1: Lung airways used in the current study. (a) complect lung airways, (b) simplified lung airways

Complect lung airways	Size 199.9 103.2 231 (mm) Volume 41625 (mm^3) Surface Area 28363 (mm^2)
Simplified lung airways	Size 170.7 77.8 230.5 (mm) Volume 31251 (mm^3) Surface Area 14788 (mm^2)

Table 1: Lung airways geometry used in the current study.

3. DUST WIND TUNNEL TESTING

A dust wind tunnel was constructed to explore the deposition of dust particles in the respiratory passages, and this particular wind tunnel was employed in the present study. The identical pair of respiratory airways models were manufactured and employed in conjunction with this wind tunnel, as illustrated in figure 2. The primary objective of this experimentation is to authenticate the results obtained through computational fluid dynamics (CFD). An aerosol generator was utilized in conjunction with the wind tunnel to introduce dust particles into the airflow within the wind tunnel.

A hot wire was employed to quantify the velocity of the airflow and the degree of turbulence in the respiratory tract's intake region. Additionally, a device for assessing particle size and concentration was utilized to determine the dimensions and quantity of dust particles entering the respiratory tract. This information is presented visually in figure 3.

FIGURE 2: Experimental setup showcasing a custom-built dust wind tunnel with an integrated aerosol generator used to simulate the deposition of dust particles in the respiratory system.

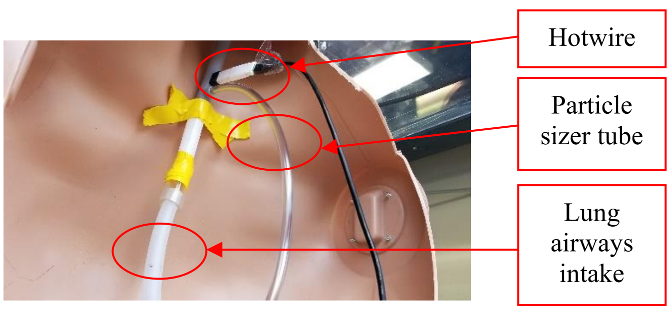


FIGURE 3: Close-up view of the respiratory tract model with measurement instruments, highlighting a hot wire anemometer for determining airflow velocity and turbulence at the lung airways intake.

4. CHARACTERIZATION OF THE DUST SAMPLE

The characterization of dust samples utilized in the present study is of paramount importance. A detailed understanding of these characteristics is essential to accurately replicate real mining conditions within the experimental framework. This ensures that the experimental outcomes are both relevant and reliable. Moreover, this detailed characterization addresses critical factors influencing lung deposition and disease risk, aligning with the overarching goals related to occupational health and safety.

In an effort to closely simulate the conditions encountered in underground coal mines, a coal sample was procured from a Pennsylvanian coal mine. This sample was subsequently processed to generate the coal dust used in the study. A series of tests were conducted to thoroughly characterize this dust.

The initial test was designed to ascertain the sizes of particles present within the sample. To achieve this, a scanning electron microscope provided by the Center of Integrated Nanotechnologies (CINT) was employed. The findings from this analysis indicated that the majority of the particles were smaller than 10µm (super-micron), with only a marginal 7% of the particles exceeding 10 µm (sub-micron) in size.

Furthermore, a TSI aerosol sizer was utilized to analyze the dust sample. The resultant data, illustrating the relationship between particle diameters and their respective concentrations for 8 times measurements, is depicted in Figure 4 with the average value curve in blue.

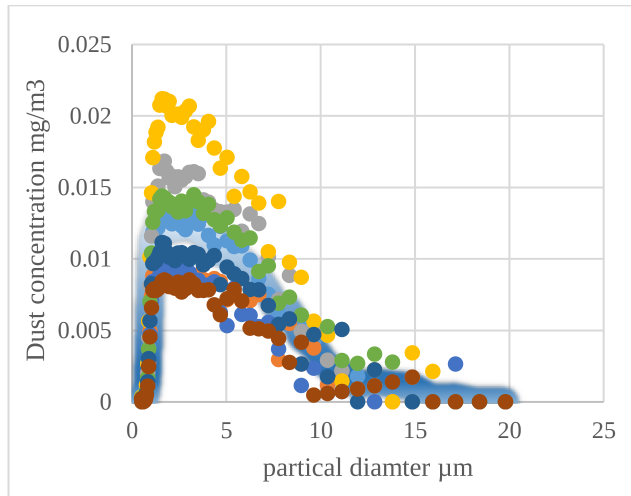


FIGURE 4: **R**elationship between particle diameters and their respective concentrations in the coal dust sample.

5. COMPUTATIONAL FLUID DYNAMICS (CFD)

CFD (Computational Fluid Dynamics) was also applied to investigate coal particle deposition. The same two models of airways were utilized. Due to the model's complexity, a hybrid hexahedral-tetrahedral mesh was employed for discretization, as depicted in Figure 5. To ensure accurate CFD results, a mesh dependency study was conducted, which balanced precision with computational efficiency. The selected mesh size achieved this balance, and the specific results from the mesh dependency study are illustrated in Figure 6. For turbulence modeling, a k-epsilon model with enhanced wall treatment was chosen for its stability in the solution. However, further validation of this turbulence model is necessary.

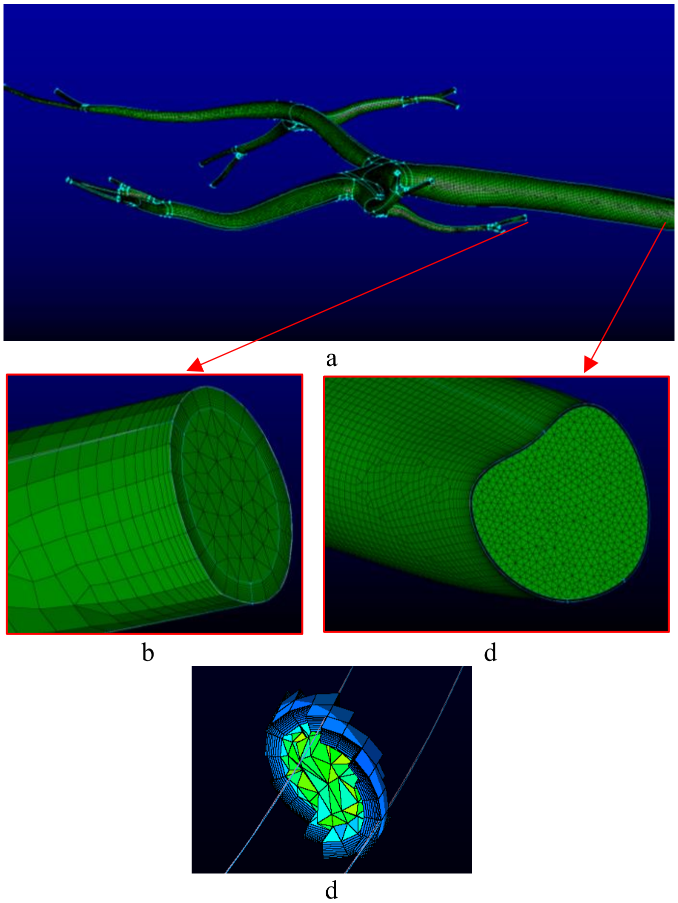


FIGURE 5: Visualization of the CFD meshing strategy for the respiratory airway models using a hybrid hexahedral-tetrahedral approach.

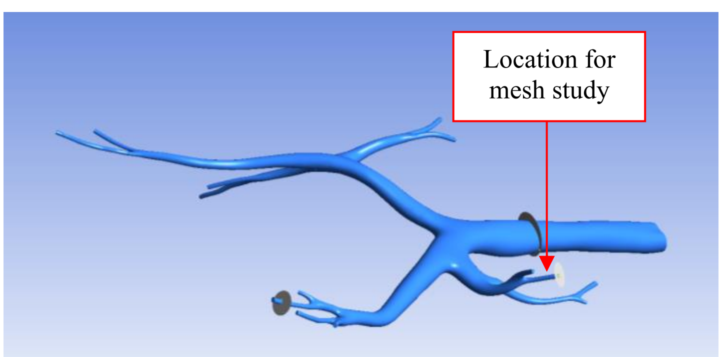


FIGURE 6: Illustration of the selected location on the 3D model of the respiratory airways for conducting the mesh dependency study within the computational fluid dynamics (CFD) analysis.

6. RESULTS AND DISCUSSION

This section presents the outcomes of the experimental procedures designed to investigate the deposition of coal dust particles within the respiratory airways. The results are derived from a series of tests conducted using a custom-built dust wind tunnel and the Computational Fluid Dynamics (CFD) simulations initial results. Due to the limited time only the simplified lung mode was experimentally tested and only the flow simulation in CFD was conducted.

6.1 Experiment results and discussion

The experiments were meticulously planned to measure the variables critical to understanding particle behavior in the respiratory system. The data collected includes airflow velocity, particle size distribution, and deposition patterns within the airway models. Utilizing advanced instrumentation such as hot wire anemometers and particle sizer tubes, the experiments aimed to replicate the complex conditions that occur in human respiratory tracts.

The results depicted in Figure 7 illustrate a direct and proportional relationship between the flow rate of the suction pump and the airspeed in the intake of the respiratory airway model. This is an expected outcome as the increase in flow rate would naturally cause an increase in the speed of air being drawn through the airways, mimicking the process of inhalation.

The graph suggests a roughly linear progression, with no apparent signs of plateauing within the tested range, implying that the airway model can handle increasing flow rates without significant resistance or turbulence that would otherwise disrupt the linear trend.

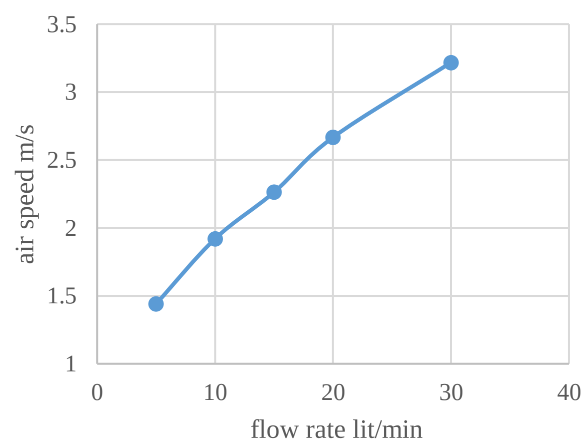


FIGURE 7: Graphical representation of the relationship between the airspeed at the intake of the airway model and the flow rate set on the suction pump used to simulate inhalation.

Figure 8 presents a time series analysis of airspeed data collected from the hot wire anemometer during the experiment.

The plot reveals the fluctuations in airspeed at the airway intake over a substantial period.

The average airspeed, depicted by the red line, is a crucial point of reference as it demonstrates the central tendency around which the airspeed varies. The consistency of the average airspeed at approximately 3.08 m/s suggests that the experimental setup provided a stable simulation of respiratory air flow over time.

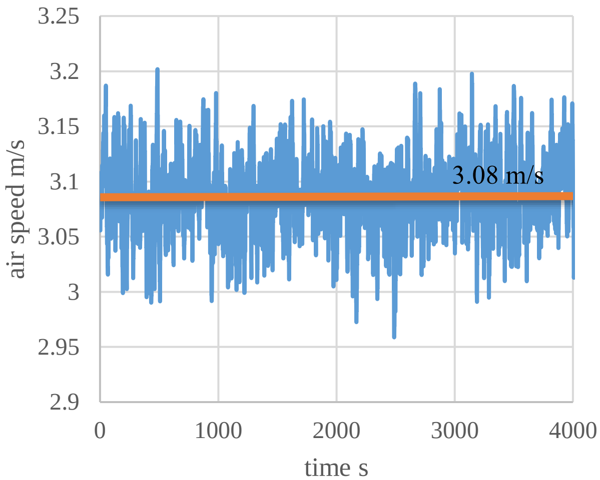


FIGURE 8: Time series plot of airspeed measured by the hot wire anemometer over the duration of the experiment.

The data presented in Figure 9 illustrates the change in dust concentration within the wind tunnel over the course of the experiment, measured for four different particle sizes. Initially, all particle sizes show high concentration levels, which is expected immediately after the introduction of dust into the system. Over time, a decline in concentration is evident for all particle sizes, which could be indicative of dust settling or adherence to the surfaces within the tunnel.

The rate of decline in concentration appears to be more rapid for larger particles (10 µm), as seen by the steep initial slope, which is consistent with the greater mass and gravitational settling velocity of these particles. Conversely, the smaller particles (1 µm and 2.5 µm) exhibit a slower rate of decline, suggesting that they remain suspended in the air for longer periods due to lower settling velocities and possibly higher Brownian motion.

This temporal profile of dust concentration is critical for understanding the exposure dynamics within the tunnel and for simulating respiratory dust exposure. It also provides insights into the efficiency of the wind tunnel's ventilation system in removing particles of various sizes from the air.

The overlay of different particle sizes allows for a direct comparison of their behavior under identical airflow conditions. Such data is invaluable for assessing health risks associated with inhaling particles of different sizes and for designing protective measures in occupational settings.

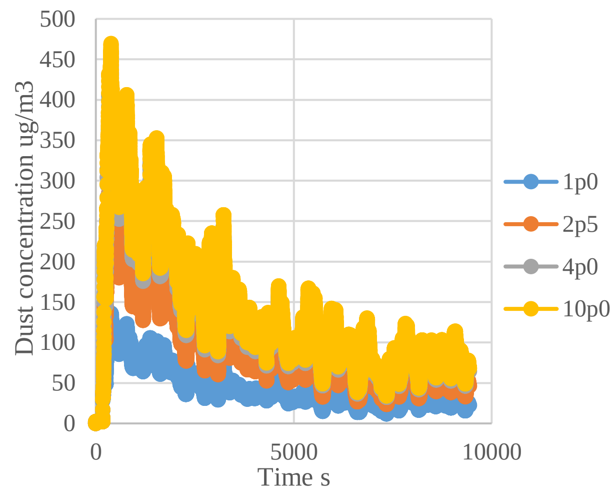


FIGURE 9: Dust concentration levels inside the wind tunnel over time for different particle sizes during the experiment.

Figure 10 presents a trend analysis of particle deposition within the airway models over the experimental duration. The deposition percentage represents the proportion of particles that are captured or deposited within the airways as opposed to those that exit the system. The decreasing trend suggests that the decrease in the dust concentration in the wind tunnel affects the deposition rate inside the lung.

Understanding the time-based behavior of particle deposition can also contribute to insights into the short-term versus long-term exposure risks in environments with particulate matter. For respiratory health assessments and the design of protective equipment, such as masks or ventilation systems, it is crucial to know how deposition rates change over time.

Further experiments could explore different airflow rates, particle sizes, and humidity levels to see how these factors might alter the deposition rates and patterns observed in this experiment. This would help in creating a more comprehensive model of particle behavior in the respiratory system under various conditions.

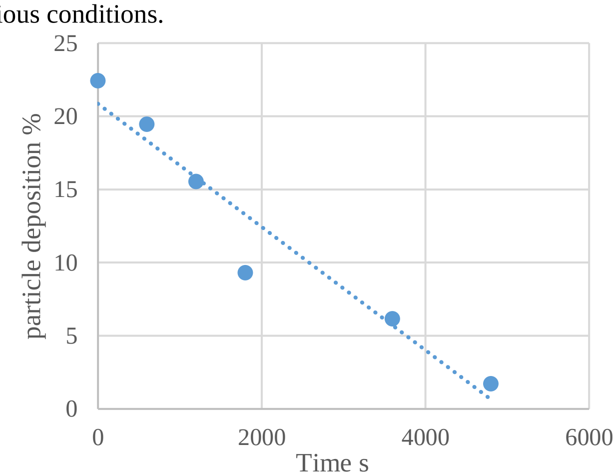


FIGURE 10: Scatter plot depicting the percentage of particle deposition over time within the airways during the experiment.

6.2 CFD results and discussion.

In this subsection, we explore the outcomes of the Computational Fluid Dynamics (CFD) flow simulations performed to investigate the airflow through the respiratory airway models. Due to time constraints, our focus was exclusively on the behavior of the airflow rather than on particle deposition. These simulations provide valuable insights into the complex flow patterns that occur within the airways, which are fundamental to understanding particle transport and deposition, despite the latter not being directly simulated in this phase of the study. The inlet speed was 2 m/s and k-epsilon turbulence model with 4% turbulence level were used.

Figure 11 illustrates a clear exponential relationship between the complexity of the mesh, indicated by the number of cells, and the computational time required to run the CFD simulations. The graph shows that as the mesh becomes more refined, with an increase in the number of cells, the time needed for computations increases disproportionately.

This trend is expected in CFD simulations; higher mesh resolutions typically lead to more accurate results but require greater computational resources and time. The exponential nature of the curve suggests that there is a point beyond which increasing the mesh resolution will yield diminishing returns in terms of the balance between computational cost and solution accuracy.

The steep curve progression as cell numbers reach into the millions highlights the practical limitations encountered during mesh refinement. It emphasizes the need for careful mesh optimization strategies where the mesh is refined selectively in regions of interest to capture critical flow details without unnecessarily increasing the overall cell count.

Understanding this relationship is crucial for CFD practitioners to make informed decisions about mesh density, ensuring efficient use of computational resources while maintaining the desired level of accuracy in the simulations. Future work in CFD could explore advanced meshing techniques such as adaptive mesh refinement, which could potentially offer a compromise between computational expense and simulation precision.

Figure 12 displays the results of a mesh dependency study conducted to identify the optimal mesh size for the CFD simulations. Each line represents the airspeed profile for a different mesh refinement, with the characteristic length normalized to facilitate comparison. The goal of such a study is to determine a mesh that is fine enough to capture the critical flow features without being unnecessarily dense, which would lead to excessive computational costs.

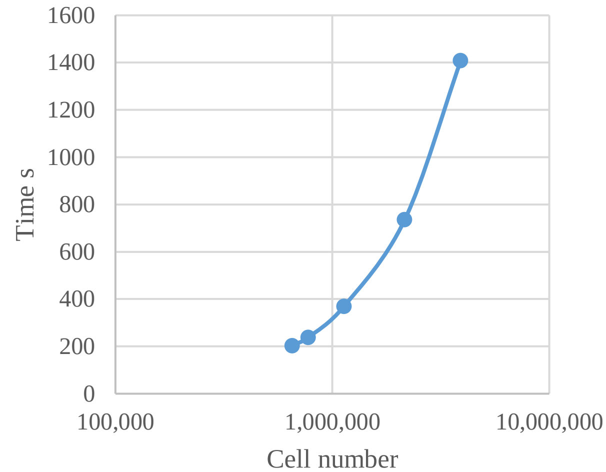


FIGURE 11: Graph demonstrating the relationship between the number of cells in the computational mesh and the computational time required for CFD simulations.

The results in figure 12 show that the airspeed profile for mesh 1 is distinctly different from the others, suggesting that this level of mesh is too coarse to accurately simulate the flow. As the mesh is refined from mesh 1 to mesh 2, there is a notable change in the airspeed profile, indicating an improvement in the solution's accuracy.

The transition from mesh 2 to mesh 3 shows a minor change, and the profile for mesh 3 closely aligns with that of mesh 4. This negligible difference between mesh 3 and mesh 4 suggests that the solution has reached a point of convergence, where further refinement does not significantly affect the outcome. Therefore, mesh 3 with about 2000000 cell was selected as the appropriate mesh for these simulations, balancing accuracy with computational efficiency.

The selected mesh ensures that the CFD model is reliable for simulating the airspeed within the airway models, which is crucial for any subsequent analyses, such as particle deposition studies. This mesh dependency study demonstrates the importance of validating the CFD model against physical phenomena and establishes a solid foundation for future work that could extend these simulations to include more complex factors.

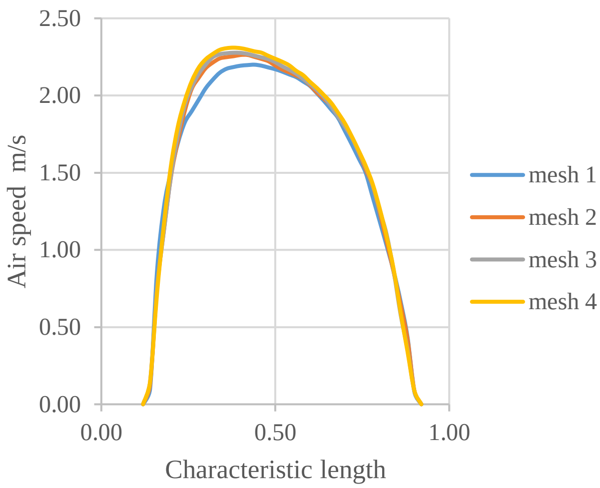


FIGURE 12: Velocity profile for different mesh elements

Figure 13 provides a side-by-side comparison of airflow within two different respiratory airway models, as analyzed through CFD simulations. The models are color-coded to represent airflow velocities, with streamlines illustrating the direction and behavior of the flow through the branching airways.

The visualization in Figure 13 is a powerful tool for identifying areas within the airway models that require more detailed investigation and may benefit from further mesh refinement or targeted experimental validation. This comparative analysis is essential for developing more accurate and reliable CFD models of respiratory airflow.

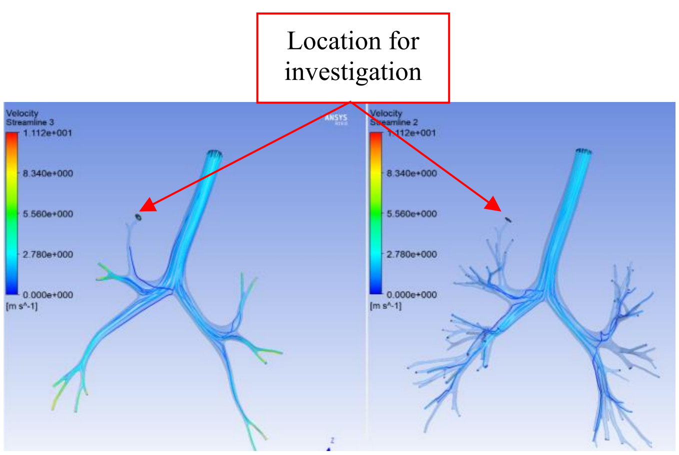


FIGURE 13: CFD visualization comparing airflow velocity and streamlines through two distinct respiratory airway models. The image highlights a specific location for further investigation.

The investigation at the specified location within the respiratory airway models has yielded intriguing results, as depicted in Figures 14 and 15. In Figure 14, the cross-sectional velocity profiles demonstrate the variations in airspeed across the diameter of the airways, with the center regions experiencing higher velocities.

Figure 15 provides a comparative analysis of airspeed along the characteristic length of the airways for both a simplified lung model and a more anatomically accurate lung model. Notably, the simplified model shows a much higher peak in airspeed. This substantial increase in airspeed within the simplified model could be attributed to its reduced surface area and lack of geometric complexities, which would otherwise disrupt and slow down the airflow in a more realistic model.

The correlation suggested between the change in surface area and the increase in airspeed has important implications for particle deposition. Generally, higher airspeeds can lead to decreased deposition due to increased inertial forces carrying particles past the deposition surfaces. Therefore, when using simplified models, it is critical to consider how these geometrical alterations might lead to discrepancies in predicting particle deposition. This information is vital for CFD model validation and for understanding the limitations of simplified models. It is also crucial for researchers and engineers who rely on these simulations to inform the design of respiratory devices or to assess inhalation risks in occupational health. The findings underscore the need for careful consideration of model geometry when predicting particle behavior in respiratory airway simulations.

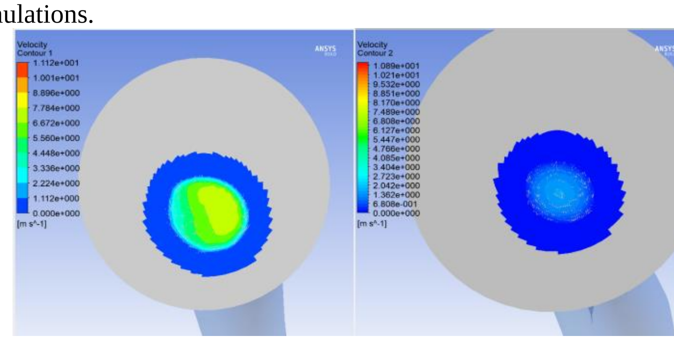


FIGURE 14: Cross-sectional CFD velocity profiles at the investigation location within the respiratory airway models, illustrating the velocity distribution across the diameter.

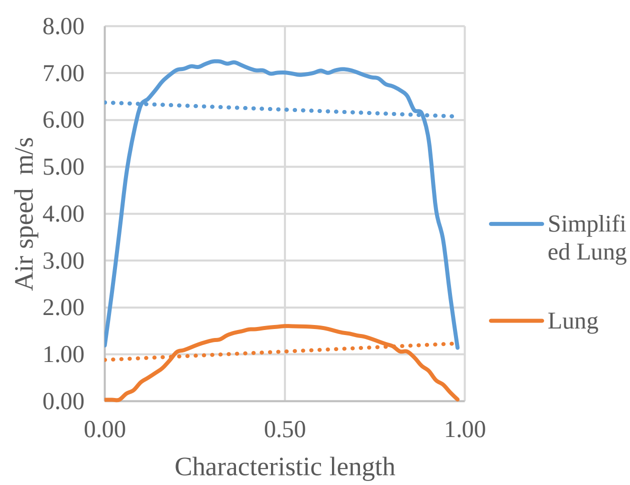


FIGURE 15: Graph depicting the airspeed profiles along the characteristic length of the respiratory models: a simplified lung model and a more anatomically accurate lung model.

7. CONCLUSION

In conclusion, the experimental and computational studies presented herein provide valuable insights into the dynamics of airflow and particle deposition within respiratory airways. The careful balance between computational efficiency and accuracy has been underscored, emphasizing the importance of mesh optimization in CFD simulations. The findings highlight the significant influence of airway geometry on flow patterns and particle behavior, suggesting a need for precise modeling in predicting respiratory exposure and health risks. This work lays a foundation for future research to refine simulation techniques and enhance our understanding of inhalation mechanics.

Funding

This research is funded by the National Institute for Occupational Safety and Health (NIOSH) [Contract #: 75D30119C06390]. The views, opinions, and recommendations expressed herein are solely those of the authors and do not imply any endorsement by NIOSH.

REFERENCES

[1] Rahimi, E., Shekarian, Y., Shekarian, N., & Roghanchi, P. (2023). Investigation of respirable coal mine dust (RCMD) and respirable crystalline silica (RCS) in the U.S. underground and surface coal mines. Scientific Reports, 12, 20745. DOI: 10.1038/s41598-022-24745-x.

[2] Wilk, A., Garland, S. G., & Falk, N. P. (2021). Less Common Respiratory Conditions: Occupational Lung Diseases. American Family Physician, 103(5), 287-294.

[3] Shekarian, Y., Rahimi, E., Rezaee, M., & Roghanchi, P. (2023). A systematic review of occupational exposure to respirable coal mine dust (RCMD) in the U.S. mining industry. Current Environmental Health Reports. DOI: 10.1007/s40789-023-00586-5.

[4] Long, J. L., Stansbury, R., & Petsonk, E. (2015). Small Airways Involvement in Coal Mine Dust Lung Disease. Seminars in Respiratory and Critical Care Medicine, 36(3), 373-380. DOI: 10.1055/s-0035-1549451.

[5] Madureira, E., Aboelezz, A., Su, W.-C., & Roghanchi, P. (2023). From Dust to Disease: A Review of Respirable Coal Mine Dust Lung Deposition and Advances in CFD Modeling. Minerals, 13(10), 1311. DOI: 10.3390/min13101311.

[6] Arya, S. (n.d.). Investigation of the Effectiveness of an Integrated Flooded-Bed Dust Scrubber on a Longwall Shearer Through Laboratory Testing and CFD Simulation. DOI: 10.13023/ETD.2018.074.

[7] Geng, F., An, J., Wang, Y., Gui, C., Guo, H., & Wen, T. (2023). Suspension Characteristics of the Coal-Quartz Dust Mixture in the Working Environment During the Fully Mechanized Mining Process. DOI: 10.1007/s11356-023-28911-0.

[8] Gołębiowski, T., Kuźniar, J., Porażko, T., Wojtala, R., Konieczny, A., Krajewska, M., & Klinger, M. (2022). Multisystem Amyloidosis in a Coal Miner with Silicosis: Is Exposure to Silica Dust a Cause of Amyloid Deposition? International Journal of Environmental Research and Public Health, 19(4), 2297. DOI: 10.3390/ijerph19042297.

[10] Tripathi, A., Prasad, S., & Ray, S. (2020). Laboratory Investigation on the Impact of Coal Dust Deposition on PV Panel Performance. IOP Conference Series: Materials Science and Engineering, 993(1), 012088. DOI: 10.1088/1757-899X/993/1/012088.

[11] Raja, R., Nayak, A., Shukla, A., Rao, K., Gautam, P., Lal, B., Tripathi, R., Shahid, M., Panda, B., Kumar, A., Bhattacharyya, P., Bardhan, G., Gupta, S., & Patra, D. (2015). Impairment of Soil Health Due to Fly Ash-Fugitive Dust Deposition from Coal-Fired Thermal Power Plants. Environmental Monitoring and Assessment, 187(10), 4902. DOI: 10.1007/s10661-015-4902-y.

[12] Miller, A. L., Drake, P., Murphy, N. C., Cauda, E., LeBouf, R., & Markevicius, G. (2013). Deposition Uniformity of Coal Dust on Filters and Its Effect on the Accuracy of FTIR Analyses for Silica. Aerosol Science and Technology, 47(6), 634-643. DOI: 10.1080/02786826.2013.787157.

[14] Negishi, T. (1995). Lung clearance of particles following excessive deposition of fly ash in golden hamsters. Experimental Animals, 44(2), 131-138. DOI: 10.1538/EXPANIM.44.131.

[15] Zhang, Z., Gao, R., Li, Z., Wu, J., Yang, W., Liu, X., & Ma, K. (2023). Experimental investigation of a monitoring model for dust deposition on solar photovoltaic modules. DOI: 10.1080/15435075.2023.2202739.

[16] Zhang, Q., Zhou, G., Hu, Y., & Wang, W. (2020). Experimental investigation on wetting mechanism for coal dust with different metamorphic degree based on infrared spectrum and 13C-NMR. Surface and Interface Analysis, 52(3), 123-130. DOI: 10.1002/sia.6757.

[17] Zhou, G., Luan, G., Li, S., Liu, Z., Zhang, Q., & Miao, Y. (2022). Experimental investigation on the micro wettability of coal dust: considering the comprehensive effects of physical chemistry characteristics. Arabian Journal of Geosciences, 15(12), 10352. DOI: 10.1007/s12517-022-10352-7.

[18] Chang, P., Chen, Y., Xu, G., Huang, J., Ghosh, A., & Liu, W. (2021). Numerical study of coal dust behaviors and experimental investigation on coal dust suppression efficiency of surfactant solution by using wind tunnel tests. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. DOI: 10.1080/15567036.2019.1639855.

[20] Zhao, B., Li, S., Lin, H., & Liu, X. (2023). Influence of air inlet distance on coal dust pollution characteristics in working environment during tunneling based on CFD method. DOI: 10.1080/02726351.2023.2200372.

[21] Richards-Thomas, T., & McKenna Neuman, C. (2023). Wind Tunnel Experiments on Volcaniclastic Dust Emission and

Dispersion Initiated by Water Droplet Impact. DOI: 10.1029/2022JD038149.

Proceedings of ASME 2024 Fluids Engineering Division Summer Meeting

(FEDSM2024)

Volume 2

July 15-17, 2024
Anaheim, California

Conference Sponsor
Fluids Engineering
Division

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

ISBN: 978-0-7918-8813-1