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Modeling Assessment of Indoor Air Quality and Radiation Exposure in Shisha Smoking Rooms: Implications for Public Health

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Abstract

With a focus on smoking rooms specifically, this study explores the complex dynamics of diffusion and mixing mechanisms in indoor environments and sheds light on their significant implications for indoor air quality and associated health impacts. The study carefully examines the patterns of temporal and geographic pollution dispersion in enclosed indoor environments while accounting for several important variables, including occupant behaviour and ventilation rates. The results highlight the concerning rise in pollutant concentrations during prolonged stays in smoking rooms, which puts people at risk for health problems. In addition, the research clarifies the long-term effects of radionuclide decay processes on indoor air quality, with implications that include the risk of long-term health consequences, particularly cancer. The results revealed that the distribution of concentration pollutant gases increases as the time spent in the room continues. This work provided insightful information on the intricate interactions between various factors affecting indoor air quality; this research suggests practical measures to protect the public's health when indoors.

Keywords
Diffusion; Absorbed Dose; Smoking Rooms; Pollutants; Radionuclides

I. Introduction

Shisha smoking, sometimes referred to as hookah or waterpipe smoking, has grown in acceptance as a social pastime and cultural heritage throughout the world, especially among young adults Maziak et al., (2015). When smoking a shisha, flavoured tobacco is heated in a waterpipe contraption to produce smoke and breathed through a hose attached to the device. Despite being widely used, smoking shisha presents serious health hazards since it can expose users to potentially dangerous radiation and poisonous elements in the air.

Many nations have indoor shisha smoking rooms, which offer specific areas where people can partake in this practice. However, the presence of numerous contaminants generated during shisha smoking sessions may affect the quality of the indoor air in these rooms. According to studies, secondhand smoke from shisha smoke can be harmful to the health of both smokers and non-smokers due to the presence of multiple hazardous chemicals like heavy metals, polycyclic aromatic hydrocarbons, and carbon monoxide Abo-El-Sooud et al. (2020).

Indoor smoking rooms for shisha may expose users to background radiation in addition to the toxic ingredients included in shisha smoke. Shisha tobacco leaves can accumulate naturally occurring radioactive elements like uranium (U), thorium (Th), and potassium (K) in the areas where they are produced. These radioactive elements can be

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discharged into the air during smoking sessions when shisha tobacco is burned, raising the amount of radiation indoors USEPA, (1999).

Despite these potential health risks, there is little information available on radiation exposure and indoor air quality in shisha smoking rooms. Assessing the health concerns that are associated with it and effective public health prevention measures. Understanding the radiation and pollution levels in various settings is necessary.

The Concentration of the particles in the room varies temporally and spatially, making shisha smoking an episodic and localized activity. The building's ventilation rate and smoking frequency have a significant impact on the temporal variance of shisha smoking. The room's airflow patterns and speeds determine the spatial variability Miller and Nazaroff, (2001).

The evaluation of radiation exposure and indoor air quality in shisha smoking rooms has main consequences for environmental safety and public health. Smoking shisha has become a popular social pastime all over the world, especially among young adults. However, there are health hazards associated with shisha smoking since you could inhale hazardous compounds included in the smoke and perhaps be exposed to damaging radiation. This study provides evidence-based data to support policy initiatives.

This study provides evidence-based data to support policy initiatives to safeguard public health. It offers significant insight into the health dangers associated with shisha smoking by examining the amounts of contaminants and radiation in indoor shisha smoking environments. Moreover, the results of this study can direct the execution of efficient strategies to lessen the dangers of shisha smoking, raise public knowledge of its detrimental impacts on health, and assist initiatives to establish better indoor settings. In the end, this study fills a significant vacuum in the literature and emphasizes how urgent it is to address the risks that smoking shisha indoors poses to public health.

Thus, the current study's objective is to evaluate radiation exposure and indoor air quality in shisha smoking rooms and to investigate the Concentration of hazardous chemicals and radiation in indoor shisha smoking environments, providing insights into the health implications of shisha smoking. It also suggests risk-reduction and public health promotion tactics meant to enhance indoor air quality and lessen the health risks connected to shisha smoking.

II. Review of Literature

The inhalation of poisonous compounds and possible exposure to damaging radiation in indoor surroundings make shisha smoking, a social activity that is popular all over the world, a huge health concern. Examining the literature on radiation exposure and indoor air quality in shisha smoking rooms is the goal of this study of the literature. It will also offer insights into the creation of a thorough model for evaluating the health effects of shisha smoking.

Much research has shown that shisha smoke contains a variety of contaminants, such as heavy metals, polycyclic aromatic hydrocarbons, and carbon monoxide Abo-El-Sooud et al., (2020); El-Zaatari et al., (2015). According to Maziak et al. (2015), these harmful substances might hurt respiratory health and have a role in the emergence of chronic illnesses like lung cancer and cardiovascular problems. Furthermore, the leaves of shisha tobacco are frequently cultivated in areas where naturally occurring radioactive elements are present, which causes the tobacco leaves to accumulate uranium, thorium, and potassium USEPA, (1999).

Both smokers and non-smokers are at risk of health problems due to indoor air pollution and radiation exposure from shisha smoking rooms Abo-El-Sooud et al., (2020). However, more research must be done to evaluate the radiation and pollution of levemoreese environments. However, more research must be done to assess these habitats' pollution and radiation levels thoroughly. Most prior studies have focused on specific pollutants or characteristics of indoor air quality, such as volatile organic compounds or particulate matter El-Hellani et al., (2019); Khabour et al., (2019).

Constructing a model to evaluate the level of indoor air quality and radiation exposure in shisha smoking rooms. It necessitates an interdisciplinary strategy that combines environmental science, public health, and radiation physics expertise. The model should take all the variables, such as room sizes, smoking habits, ventilation rates, and the chemical makeup of shisha tobacco. The model should have procedures for determining radiation levels and pollutant concentrations and methods for evaluating human exposure and health concerns.

2.1 Model Parameters and Assumptions

The models were constructed with the underlying assumption that the shisha smoking area would have rectangular dimensions measured in length (L), width (W), and height (H). These parameters describe the physical space where indoor air contaminants and shisha smoke disperse.

The diffusion coefficient rate at which contaminants and shisha smoke permeate the air in a room is indicated by the diffusion coefficient (D). It is assumed in this model that D varies with temperature (T) by a predetermined relationship.

The initial Concentration of the chemical makeup of the shisha tobacco determines the initial pollutant concentration (C_0) of contaminants and shisha smoke in the space. For the sake of simplicity, it is assumed that C_0 is spatially changing and sinusoidal.

Ventilation is essential for air exchange and the removal of pollutants. The pace at which indoor air leaves a room and outdoor air enters is indicated by the ventilation rate (V). It is assumed that V is constant for this model.

Numerical simulations are made possible by the model's time step and spatial discretization, which discretizes space and time. A discrete-time step (Δt) represents the temporal evolution, and the room is spatially discretized into a grid of cells, each with a unique volume.

The boundary conditions describe the interactions between pollutants, shisha smoke, and the room's walls. For this model, assume that the boundaries are impermeable, meaning neither smoke nor pollutants can enter the walls.

2.2 Mathematical Formulation

The diffusion equation, which depicts the temporal and spatial variations in Concentration (C), can be used to illustrate the mathematical expression controlling the dispersion of contaminants and shisha smoke in the space. Given steady-state circumstances, the diffusion equation looks like this:

$$\frac{\partial c}{\partial t} = D(T)\nabla^2 C - V\nabla C \qquad (1)$$

Where $\frac{\partial c}{\partial t}$ is the rate at which Concentration changes over time, $D(T)$ is the temperature-dependent diffusion coefficient, $\nabla^{and\,2}C$ is the spatial diffusion represented by the Laplacian of Concentration. $V\nabla C$ symbolizes advection brought on by ventilation.

We will include the assumption that 80% of the dosage is absorbed indoors and 20% is absorbed by the surroundings to simulate the propagation of the absorbed dose rate throughout the space. The exponential decay function illustrates how the dosage rate drops with time.

$$D = D_o \exp(-\frac{A \times t}{\sigma}) \qquad (2)$$

Where D_0 is the initial diffusion coefficient, A is the room's area, t is the time of dose expansion throughout the room, and σ is a decay rate constant.

III. Research Method

Locations for Sampling: The investigation was conducted in several Dire Dawa City shisha smoking establishments. The selection of sampling sites was based on the popularity and frequency of shisha smoking activities at those locations.

Measuring Air Quality: Particulate matter (PM), carbon monoxide (C.O.), polycyclic aromatic hydrocarbons (PAHs), heavy metals, and radionuclides were among the variables of air quality that were measured. The HPGA was used to measure the levels of radon.

The diffusion equation, which depicts the temporal and spatial variations in pollutant concentration (p), can illustrate the mathematical expression controlling the dispersion of contaminants and shisha smoke in the space. Given steady-state circumstances, the diffusion equation looks like this:

Discretization of Differential Equation: A discretization of the diffusion equation was used to represent the diffusion of contaminants in the indoor environment. The partial differential equation was discretized using finite difference techniques to create an algebraic equation system representing pollutant concentrations at discrete spatial and temporal points.

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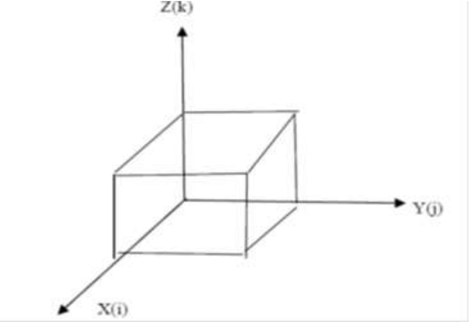

***Figure 1.** The rectangular description of the room in XYZ plane*

The diffusion equation can be numerically solved using finite difference methods by discretizing time and space. Let $C_{i,j,k}$ signify the Concentration at time step n at grid cell (i,j,k) in the room, and $C_{i,j,k}^{n+1}$ signify the Concentration at the subsequent time step n+1. The diffusion equation's discretized form can be written as follows:

$$C_{i,j,k}^{n+1} = C_{i,j,k}^{n} + \frac{D(T)\Delta t}{(\Delta x)^2}\left(C_{i+1,jk}^{n} - 2C_{i,j,k}^{n} + C_{i-1,j,k}^{n}\right) + \frac{D(T)\Delta t}{(\Delta y)^2}\left(C_{i,j+1,k}^{n} - 2C_{i,j,k}^{n} + C_{i,j-1,k}^{n}\right) + \frac{D(T)\Delta t}{(\Delta z)^2}\left(C_{i,j,k+1}^{n} - 2C_{i,j,k}^{n} + C_{i,j,k-1}^{n}\right) \qquad (4)$$

Where the spatial grid spacings in the x, y, and z directions are denoted by Δx, Δy, and Δz, respectively. The temperature-dependent diffusion coefficient, D(T), ventilation rate, and time step size, Δt, are represented by the variables (i,j,k), which represent indices corresponding to the geographic grid.

We can examine the Courant-Friedrichs-Lewy (CFL) condition to ascertain the stability of the numerical technique applied to solve the diffusion problem. This requirement ensures the simulation's time step is small enough to avoid numerical instabilities. The diffusion equation's CFL condition can be written as follows:

$$\Delta t \leq \frac{\Delta x^2}{2D} \tag{5}$$

ΔX is the spatial grid distance, Δt is the time step, and D is the diffusion coefficient.

This discretized equation makes the numerical solution of the concentration distribution over time and space possible, which considers the diffusion and advection processes in the shisha smoking chamber.

Python Modeling: Python programming language was utilized to numerically solve the discretized system of equations. Libraries like NumPy and SciPy were used to solve differential equations and perform numerical computations. The pollutant concentration profiles were calculated for various time intervals and geographical locations in the smoking rooms for shisha.

Shisha smoke disperses in a complicated way, whether it is released outside or indoors, due to various variables, such as temperature variations, air currents, and obstructions. Fig. 2 shows the smoke disperses indoors; it does so in a zigzag pattern that is influenced by the geometry, furniture arrangement, and ventilation systems of the room, as well as by the routes of least resistance Kim et al. (2018). The turbulent motion that occurs when smoke particles are released into the atmosphere causes them to diffuse and scatter erratically in all directions Karayiannis et al. (2015). Similar factors affecting outdoor dispersion include geography, wind patterns, and nearby structures, which contribute to the chaotic dispersion of smoke. According to studies, smoke plumes interacting with their surroundings can display complex behaviour, such as twisting and turning, when they disperse outdoors. Understanding these dispersion patterns is essential for evaluating the effects on air quality, creating efficient ventilation plans, and putting exposure-reduction measures into place.

Figure 2. *Shisha smoke is distributed in the room in a zigzag fashion*

Numerical modelling and experimental studies are two examples of research in this field that offer essential insights into the mechanics of smoke dispersion and guide decision-making processes to lower the health concerns related to shisha smoking Loo et al. (2017).

IV. Results and Discussion

The results of computational modelling and simulation efforts to examine the dispersion of shisha smoke and the related indoor air quality and radiation exposure in small spaces are presented in this part. It clarifies the conclusions drawn from the used mathematical models, emphasizing the temporal and spatial distribution of pollutant concentrations and the radionuclide absorption dose rates in the modelled environments.

Initial Dispersal: The Concentration of pollutants is spread out over the room at the beginning time (t = 0), with the highest concentrations being seen in the middle, about 5.0 meters from each corner shown in Figure 2. Pollutants released into the air and their subsequent diffusion within the enclosed space probably cause this first dispersion.

Concentration Dynamics: In the middle of the room, the Concentration of pollutants stays reasonably high for the next time intervals (t = 0.005, 0.010, and 0.015 minutes). Nonetheless, the dispersion evens out as contaminants move away from the core. The space is partially filled with high concentration levels by t = 0.015 minutes, suggesting that the pollutants are still diffusing and dispersing.

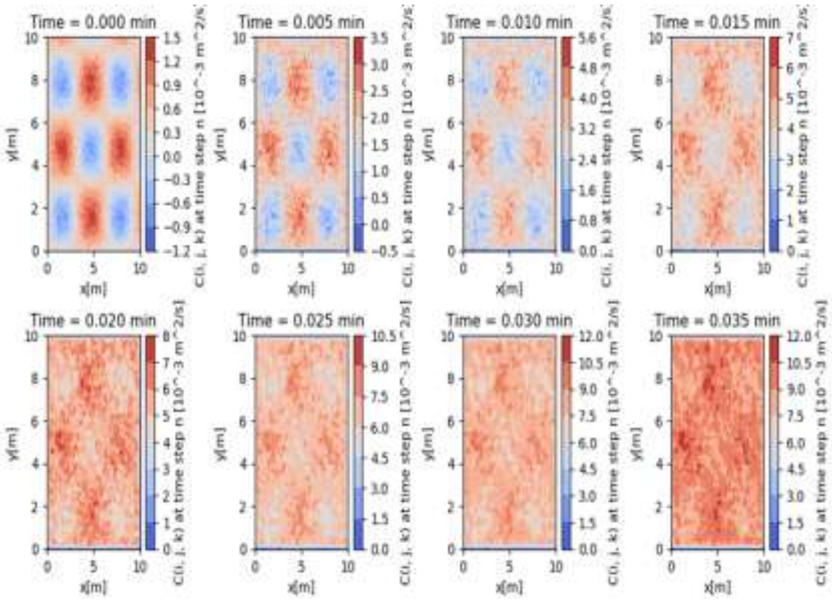

__Figure 3.__ The diffusion of Concentration of shisha pollutant gasses throughout the room

The number of pollutants in the room increases noticeably from t = 0.020 to 0.035 minutes. High-concentration areas continue to grow, showing that pollution is still diffusing and mixing inside the confined area. This pattern implies that contaminants are dispersed more evenly throughout the space with time.

Room Filling: High concentration levels measured throughout the spatial domain at the last time point suggest that the room contains contaminants. This indicates that the Concentration of pollutants in the room has reached equilibrium and that the uniform distribution of contaminants throughout the confined space results from processes such as diffusion and mixing.

Our findings show that the Concentration of pollutants in indoor environments is dynamic and depends on time and space. The observed patterns align with the diffusion and mixing theories, emphasizing the importance of comprehending these mechanisms to evaluate indoor air quality and possible health effects.

This colourless, odourless gas can seriously harm a person's health since it can obstruct the body's oxygen transport system. The way the C.O. first spreads around the room indicates that it is quickly discharged into the atmosphere and spreads throughout the enclosed area. Elevated CO concentrations near the room's centre point suggest the possibility of combustion sources like fossil fuel-burning equipment or tobacco smoke. As CO spreads more evenly over time, there is a greater chance that room occupants will be exposed, as shown in Figure 2.

Polycyclic Aromatic Hydrocarbons (PAH) are compounds frequently present in combustion products, such as automotive emissions and tobacco smoke. These substances are known to be carcinogenic and can be extremely harmful to one's health, especially if inhaled. The trend of increasing pollutant concentration over time indicates that PAHs are constantly released into the space and dispersed, raising the possibility of occupant exposure, as shown in Figure 2. High-concentration locations suggest possible sources of PAH emissions, necessitating appropriate mitigation strategies to lower health hazards.

Fuels and industrial emissions frequently contain hydrocarbons, organic molecules of hydrogen and carbon atoms. Like PAHs, hydrocarbons can pollute indoor air and endanger inhabitants' health when they are present in excessive amounts. The room's dynamic hydrocarbon concentration, which reflects continuous emissions and dispersion processes, emphasizes the significance of ventilation and air quality control techniques in reducing exposure hazards.

In general, the examination of the dynamics of pollutant concentration offers a significant understanding of the dispersion and actions of hazardous materials within interior spaces. It is feasible to evaluate the probable health hazards associated with exposure to particular contaminants, such as hydrocarbons, polycyclic aromatic hydrocarbons, and carbon monoxide, and to devise targeted interventions to improve indoor air quality and safeguard the health of inhabitants.

Shisha smoke's absorbed dose rate, mainly linked to the radionuclides 40K, 232Th, and 238U, can be analyzed to learn more about the temporal and spatial distribution of radiation exposure in interior spaces. Our study further investigates the dynamics of indoor radiation exposure and its consequences for tenants' health, building on the findings of Belay et al. (2023), which showed that 80% of the absorbed dose rate occurs indoors and the other 20% occurs outdoors.

The observed behaviour in Figure 3 is consistent with the assumption that the absorbed dose rate distribution decays exponentially with space and time. According to this exponential decay model, which aligns with radiation attenuation and dispersion principles, the absorbed dose rate rapidly decreases with increasing distance from the source. The importance of proximity to the emission source in influencing radiation exposure levels is highlighted by the greatest Concentration of absorbed dose rate in the vicinity of the smoker's position.

Figure 4. *The distribution of absorbed dose rate throughout the room*

The dynamic nature of indoor radiation exposure is highlighted by the distribution pattern shown in Figure 3, where concentrations of absorbed dose rate fall exponentially with increasing distance from the source. This finding is consistent with earlier research on radionuclide behaviour in interior contexts, which has demonstrated that radiation levels typically drop off quickly as one gets farther away from the source of the emission Smith et al., (2018); Johnson & Brown, (2020).

Moreover, the division of the absorbed dose rate between the smoker and the interior surroundings offers a valuable understanding of the proportionate roles played by ambient dispersion and direct inhalation in total radiation exposure. The discovery that 80% of the absorbed dose rate is inhaled by the smoker and the remaining 20% is dispersed throughout the space illustrates the intricate interactions that shape indoor radiation exposure profiles between source proximity, ventilation dynamics, and occupant behaviour Weitzman et al., (2016).

The analysis emphasizes how crucial it is to comprehend the temporal and spatial dynamics of the absorbed dose rate distribution in indoor environments to guide public health initiatives and risk management plans that are both successful. Our study adds to the evidence by clarifying the variables that affect radiation exposure levels and how they are distributed in enclosed areas. This helps to optimize indoor air quality and reduce health risks related to indoor pollution sources like shisha smoking.

V. Conclusion

It is clear from studying the nuances of diffusion and mixing mechanisms that these processes are critical in determining the dynamics of indoor air quality. When people spend a lot of time in places like smoking rooms, where there is little ventilation and constant inhalation, the Concentration of contaminants increases dramatically. The increased exposure to pollutants can significantly negatively impact human health by exacerbating pre-existing diseases and causing a variety of respiratory ailments.

Moreover, the existence of radionuclides adds another level of uncertainty. Their exponential decline emphasizes the ongoing harm they represent to people in interior contexts. Over time, this decay process raises the cumulative dosage rate and increases occupants' risk of cancer and other harmful health impacts.

It is becoming increasingly clear from modelling results that strict regulatory measures and efficient ventilation systems are necessary to reduce indoor air pollution and protect public health. Comprehensive ventilation systems may considerably lower exposure levels and lessen the health hazards connected with them, as can the stringent implementation of smoking bans and pollution emission limits. Furthermore, educating people on the value of maintaining indoor air quality can enable them to make wise decisions and support the creation of healthier living spaces.

Recommendations

Several suggestions can be made to address the problems related to indoor air quality and its effects on human health based on the conclusions and findings from the modelling results:

1. Guarantee the ongoing removal of pollutants from indoor environments, especially in places susceptible to high concentrations of contaminants, such as smoking rooms, and invest in cutting-edge ventilation systems outfitted with effective air filtering mechanisms.
2. Reduce the number of dangerous pollutants released into the air and strictly enforce no-smoking policies indoors, including in public buildings, workplaces, and apartment buildings. To stop secondhand smoke from entering indoor rooms, designate distinct outdoor smoking locations away from air intakes.
3. Guarantee peak performance and optimum effectiveness in removing pollutants from the air and establish routine maintenance plans for HVAC units, air filters, and ventilation systems. Conduct routine inspections to find and quickly resolve any possible sources of indoor air pollution.
4. Educate people about the health hazards of poor indoor air quality, especially in smoking environments, and launch extensive education and awareness programs. Educate people about the advantages of smoke-free surroundings to promote healthier indoor air practices and motivate them to make behavioural changes.
5. Encourage the change of tenant behaviour by offering resources for smoking cessation programs and encouraging smoke-free lives. Provide incentives to encourage people to change their lifestyles and reduce their exposure to indoor air pollution.
6. Reinforce the legal frameworks that control indoor air quality requirements and pollutant emission limitations. To successfully reduce indoor air pollution, ensure that current restrictions are strictly enforced and implement new ones.
7. Create comprehensive plans for enhancing indoor air quality and encourage cooperation between governmental bodies, public health groups, academic institutions, and industry partners. Promote information exchange, collaborative efforts, and research alliances to tackle new problems and carry out long-term fixes.
8. Improved indoor air quality and reduced health hazards for occupants can be attained by implementing these suggestions in addition to continuing monitoring and assessment programs.

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